



Soil response to long-term projections of extreme temperature and precipitation in the southern La Plata Basin

Vanesa C. Pántano^{1,2} · Olga C. Penalba^{1,2}

Received: 28 March 2017 / Accepted: 27 November 2017
© Springer-Verlag GmbH Austria, part of Springer Nature 2017

Abstract

Projected changes were estimated considering the main variables which take part in soil-atmosphere interaction. The analysis was focused on the potential impact of these changes on soil hydric condition under extreme precipitation and evapotranspiration, using the combination of Global Climate Models (GCMs) and observational data. The region of study is the southern La Plata Basin that covers part of Argentine territory, where rainfed agriculture production is one of the most important economic activities. Monthly precipitation and maximum and minimum temperatures were used from high quality-controlled observed data from 46 meteorological stations and the ensemble of seven CMIP5 GCMs in two periods: 1970–2005 and 2065–2100. Projected changes in monthly effective temperature and precipitation were analysed. These changes were combined with observed series for each probabilistic interval. The result was used as input variables for the water balance model in order to obtain consequent soil hydric condition (deficit or excess). Effective temperature and precipitation are expected to increase according to the projections of GCMs, with few exceptions. The analysis revealed increase (decrease) in the prevalence of evapotranspiration over precipitation, during spring (winter). Projections for autumn months show precipitation higher than potential evapotranspiration more frequently. Under dry extremes, the analysis revealed higher projected deficit conditions, impacting on crop development. On the other hand, under wet extremes, excess would reach higher values only in particular months. During December, projected increase in temperatures reduces the impact of extreme high precipitation but favours deficit conditions, affecting flower-fructification stage of summer crops.

1 Introduction

The increase in greenhouse gas emission, among other factors, has contributed to the observed changes in climatic variables on global and regional scale (IPCC 2007). The climate system will continue to have consequences in the future, even if emissions stabilise at the estimated value of recent years (IPCC 2014). Owing to its impact on agriculture production, assessing soil response to changes in climate system is relevant for regional economy of Argentina.

In this regard, a synthesis of projected changes in mean and extreme values in Argentina was documented based on the Global Climate Models (GCMs) involved in the Phase 5 of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012) through the Third National Communication to the United Nations Framework Convention on Climate Change Project (Barros et al. 2013). This report highlights temperature increases throughout the country and warns about the high range of errors in the projections of increase precipitation, according to the most extreme emission scenario.

For these projections, internal variability, physical processes simulated by GCMs and assumptions over emission scenarios lead to large uncertainties. Hawkins and Sutton (2009) explain that internal variability is responsible for the major part of uncertainty concerning near future projections. Whereas, uncertainty generated by inter-model variability and variability between emission scenarios is more relevant for long-term projections. Blázquez and Nuñez (2012); Blázquez et al. (2012) assess uncertainties of CMIP5 models in South America and find better reliability of temperature projections than precipitation projections. Solman and

✉ Vanesa C. Pántano
vpantano@at.fcen.uba.ar

¹ Departamento de Ciencias de la Atmósfera y los Océanos, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Intendente Güiraldes 2160, Pabellón 2, 2° floor, Ciudad Universitaria, C1428EGA Buenos Aires, Argentina

² Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Av. Rivadavia 1917, C1033AAJ Buenos Aires, Argentina

Pessacg (2012) find similar spatial patterns for different sources of uncertainties.

In general, the studies of projected changes carried out in Argentina based on CMIP5 outputs are mainly concentrated on mean values (Blázquez et al. 2012; Penalba and Rivera 2015, among others). Researches focused on projected extremes are scarce. For example, Carvalho and Jones (2013) show increase in intense rainfall in northeastern Argentina. Penalba and Rivera (2013) find increase in the frequency of short and long-term droughts for Southeastern South America, characterised by shorter durations and greater severity.

In this sense, there is special concern about the impact of the changes in climatic extremes over La Plata Basin (LPB)—second largest river basin in the world after Amazon basin. Approximately 30% of LPB belongs to Argentina, interest region of this research, where rainfed agricultural production is one of the main economic activities. Since it is carried out without irrigation, precipitation is the most important influence to water availability. Apart from this leading variable, a diversity of other factors determines the complexity of the soil–atmosphere system. In this regard, recent studies show that this region is characterised by a strong feedback between soil moisture and precipitation through the role of evapotranspiration (Sörensson and Menéndez 2011; Ruscica et al. 2014). Thus, it is important to take into account the balance between precipitation and evapotranspiration. Additionally, the crops' yield mainly responds to variations in available soil water, as a result of the balance between the contributions and losses of water in the depth of radical water extraction (Pascale and Damario, 2004).

For this reason, a continuous monitoring of the water balance is needed and, therefore, it is carried out by different institutions in the country such as Agricultural Risk Office, National Weather Service and National Institute for Agricultural Technology. However, in spite of the recent studies on projected temperature and precipitation by CMIP5 GCMs, there is lack of knowledge on the future response of the water balance over the southern LPB. In addition to this, climate model simulations, despite providing future projections, exhibit biases in spatial distribution whereas observational datasets provide a more adequate representation of temperature and precipitation in a regional scale. Careful consideration of spatial and temporal distribution in the region of study is crucial to understand the vulnerability of agriculture sector. Therefore, combining high quality-controlled observed data and the outputs of the CMIP5 GCMs projections improves the analysis.

The objective of this research is separated in two steps: (1) to estimate projected changes of precipitation and temperature and (2) to evaluate the potential impact on soil hydric condition under extreme precipitation and evapotranspiration using GCMs outputs combined with observational data at meteorological station locations.

This study attempts to contribute to adaptation actions, given that the influence of climate extremes on soil hydric conditions is related to the occurrence of floods and droughts, which represent economic impacts on the agriculture production in the study region.

2 Data and methodology

The region of study corresponds to the southern LPB, where rainfed agricultural production is carried out. The box 28–38°S and 58–64°W, contained in this region, was defined to compare observed data and outputs from Global Climate Models (Fig. 1).

2.1 Observed data

Daily precipitation and maximum and minimum temperatures data were used from 46 stations, for the period 1970–2010 with less than 10% missing data. The data was obtained from the National Weather Service and the National Institute for Agricultural Technology and has undergone through a consistency analysis. The database construction and quality control analysis are detailed in a previous work, by Penalba et al. (2014).

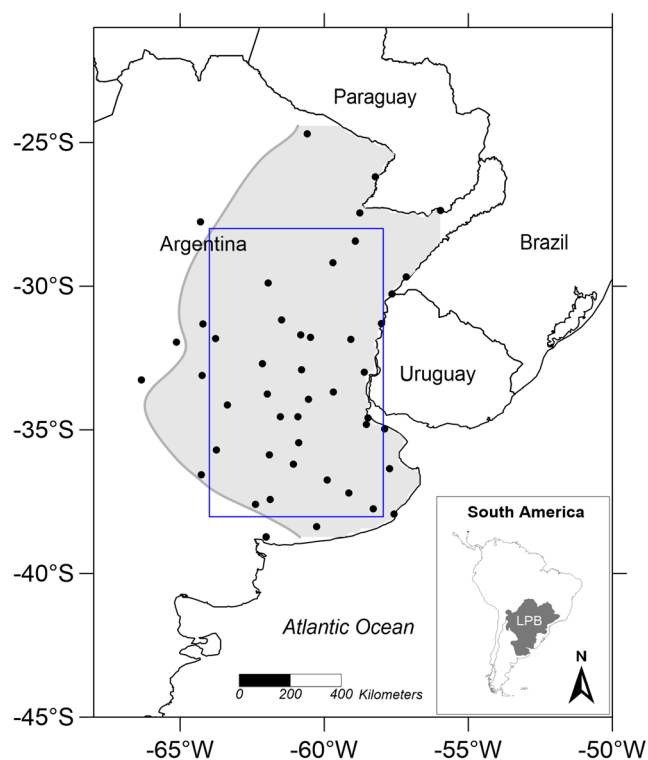


Fig. 1 Spatial distribution of the meteorological stations (black points) used in the study region. Shading indicates the southern La Plata Basin (LPB) region and blue inset delimitates the region considered for the GCMs outputs

2.2 Global Climate Models

Monthly precipitation and maximum and minimum temperatures were obtained from seven Global Climate Models selected from the Phase 5 of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012): ACCESS 1.0, CanESM2, CESM1 (CAM5), EC-EARTH, IPSL-CM5A-MR, MIROC5, MPI-ESM-MR. The selection process was based on Knutti et al. (2013), who show the dependence between models.

Two different periods were used: 1970–2005 as climate reference for historical experiment and 2065–2100 for projections under two Representative Concentration Pathways scenarios (RCPs 4.5 and 8.5). Simulations were interpolated to a $2^\circ \times 2^\circ$ standard grid, using bilinear method (Accadia et al. 2003). Following this, multi-model ensemble was calculated, improving the performance owing to the cancellation of off-setting errors in the individual models (Knutti et al. 2010).

Validation process has been carried out comparing GCM historical experiment outputs (including their ensemble) and observational data. The skills to represent mean and extreme values and inter-annual variability were evaluated at monthly scale, more details regarding the validation in Pántano (2016).

2.3 Water balance model

For the implementation of the water balance, the following assumptions were made using homogeneous soil in a single layer. The effects of wind, deep drainage, precipitation intercepted by the canopy and precipitation intensity were not included since the analysis was carried out on monthly basis within a climatological approach. Additionally, lateral flows, solid phase of precipitation and irrigation were not considered because of the characteristics of the study region. For simplification, crop rotation was not taken into account, even though it can modify the water storage in soil (Spescha et al. 2005). In order to allow comparisons between different localities, grassland coverage was assumed in the whole region, active and permanent throughout the year. With these assumptions, soil water storage increases because of precipitation and decreases because of potential evapotranspiration. According to this methodology, results allow analysing soil response to climatic variables, and it is not applicable to study soil water fluxes influence. The water balance was estimated using a revised methodology proposed by Thornthwaite and Mather (1957), described in detail by Pántano et al. (2014). The main adaptations of the methodology were as follows: a different estimation of soil water storages and the inclusion of effective field capacity of the soil for each station (Forte Lay and Spescha 2001).

For the estimation of monthly potential evapotranspiration, several methodologies are compared in the literature. The simplicity of Thornthwaite's method (Thornthwaite 1948) allows

applying it in a wider area on monthly basis. For a better estimation, the daily effective temperature (T_{ef}) was used instead of mean temperature, according to Camargo et al. (1999):

$$T_{ef} = 0.36 * (3 * T_{max} - T_{min})$$

where T_{min} and T_{max} are the daily minimum and maximum temperature, respectively.

Thus, monthly precipitation, monthly potential evapotranspiration and field capacity constitute input information for the water balance model used in this study whereas output variables are soil water storage, excess and deficit.

At a monthly scale, grassland suffers from hydric stress when the precipitation is less than the potential evapotranspiration, computed as deficit conditions. On the other hand, when the precipitation is higher than the potential evapotranspiration and the water storage in the soil reaches the field capacity, the surplus causes excess conditions. In the same case, when field capacity is not reached, equilibrium conditions are observed (Pascale and Damario 1977).

2.4 Projected changes in temperature and precipitation

Projected changes modify the whole probability distribution function. Therefore, changes (C) between historical experiment ($hist$) and future projections (fut) were derived for each probabilistic interval of percentiles (P) of the entire frequency distribution following a quantile-quantile approach. For monthly temperature (T) changes were quantified additively whereas changes in monthly precipitation (PP) were quantified multiplicatively, such that:

$$\begin{aligned} C(T) &= P(T_{fut}) - P(T_{hist}) \\ C(PP) &= P(PP_{fut}) / P(PP_{hist}) \end{aligned}$$

For each station, this method fits the empirical frequency distribution of the future change (projected by GCMs) onto the observed empirical frequency distribution. Thus, observed series of monthly temperature and monthly precipitation were modified using the change projected for the grid cell where it is located. This criterion was applied for each probabilistic interval and modified variables were obtained as:

$$\begin{aligned} T_m &= T_{obs} + C(T) \\ PP_m &= PP_{obs} * C(PP) \end{aligned}$$

where m and obs sub-indices refer to modified and observed variables, respectively. Figure 2 schematizes this methodology. By considering the change between historical and projections outputs and applying to observations, GCM's systematic errors do not interfere to observed spatial and temporal distribution.

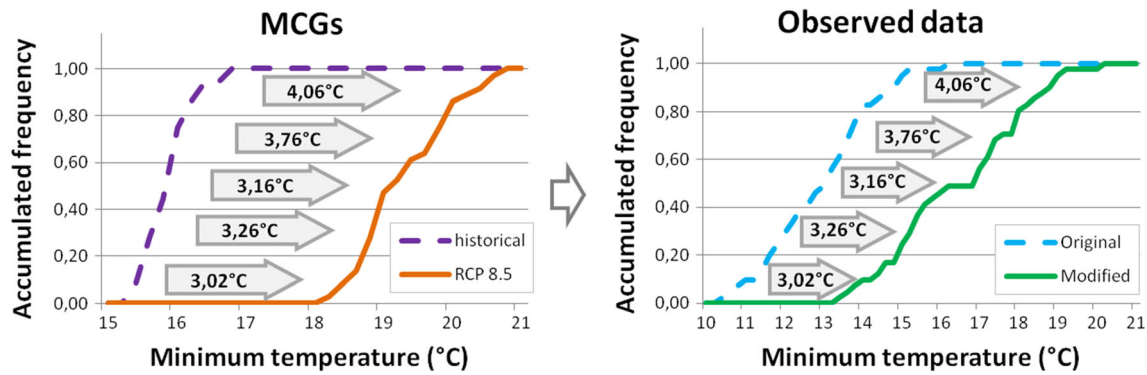


Fig. 2 Scheme of the quantification of projected changes by GCMs (left panel) and subsequent modification of the empirical probabilistic distribution of observations (right panel), for minimum temperature in Mar del Plata station

Accordingly, projected monthly potential evapotranspiration was estimated based on modified temperature.

Inter-model uncertainty was assessed through the ratio between signal (change) and noise (inter-model variability) according to Blázquez et al. (2012). In this case, the change was calculated as the difference between projected value by RCP scenarios and simulated value by historical experiment for both temperature and precipitation, from the ensemble. Agreement in the sign of projected change between the members of the ensemble was also analysed.

The purpose of the quantification and analysis of projected changes was to assess the response of the variables involved in the water balance. Therefore, modified monthly precipitation and potential evapotranspiration were used as input variables for the water balance model in order to obtain consequent soil hydric condition.

3 Results

3.1 Changes in temperature and precipitation

Projected changes in temperature and precipitation were assessed for median values (50th percentile) and for extreme high (90th percentile) and extreme low (10th percentile) values. In order to avoid a large number of very similar figures, results simulated by the multi-model ensemble are shown as follows: spatial distribution for annual scale and the average over the study domain for monthly scale.

Figure 3 displays projected changes in annual median and extreme values for precipitation and effective temperature. In general terms, there is increase in precipitation in the study region, with very few exceptions. Under RCP4.5 scenario, the multi-model ensemble simulates larger increase in extreme low values than in the median. This result is more noticeable to the northwest where decrease is projected for extreme high values. Projected changes in extreme low values are between 5 and 10% in most of the region under both RCP4.5 and RCP8.5 scenarios. Median and extreme high values are

projected to increase in a higher rate in the southern part of the region and under the most extreme scenario. Agreement in sign between the members of the multi-model ensemble is above 60% in most of the grid cells. It is remarkable that the agreement is lower for the few grid points where the ensemble projects decrease in precipitation. In general, agreement is higher for higher latitudes.

Regarding projected changes in temperature, maximum temperature increases in the same rate or higher than minimum temperature in the study region (not shown) in concordance with Kharin et al. (2013), Barros et al. (2013) and Pántano (2016). As a consequence of their changes, annual effective temperature increases between 1 and 2 °C under RCP4.5 and between 1 and 4 °C under RCP8.5 (Fig. 3). Under this last scenario, changes are higher for higher values in the northern stations of the study region, with 100% agreement in the whole region.

These results (projected changes and agreement) differ in monthly scale (Fig. 4). There is increase in monthly precipitation, except for September and October and for extreme high values during August. Under RCP4.5 scenario, monthly changes are higher in July whereas under RCP8.5 scenario, changes in extreme high (low) values are higher during July (August). As for annual scale, changes are higher under the most extreme scenario of emission. The discrepancies between the members of the ensemble are represented through the heterogeneous agreement throughout the months. Monthly effective temperature changes are lower during austral winter months. A hundred percent agreement was obtained in the sign of change in monthly effective temperature (not shown).

3.2 Inter-model uncertainty

The analysis of the uncertainties was carried out for annual and monthly scale. Signal to noise ratio of annual precipitation (Fig. 5) presents values below 1 indicating that projected changes (signal) based on the ensemble are lower than the inter-model variability (noise) in the whole region. The

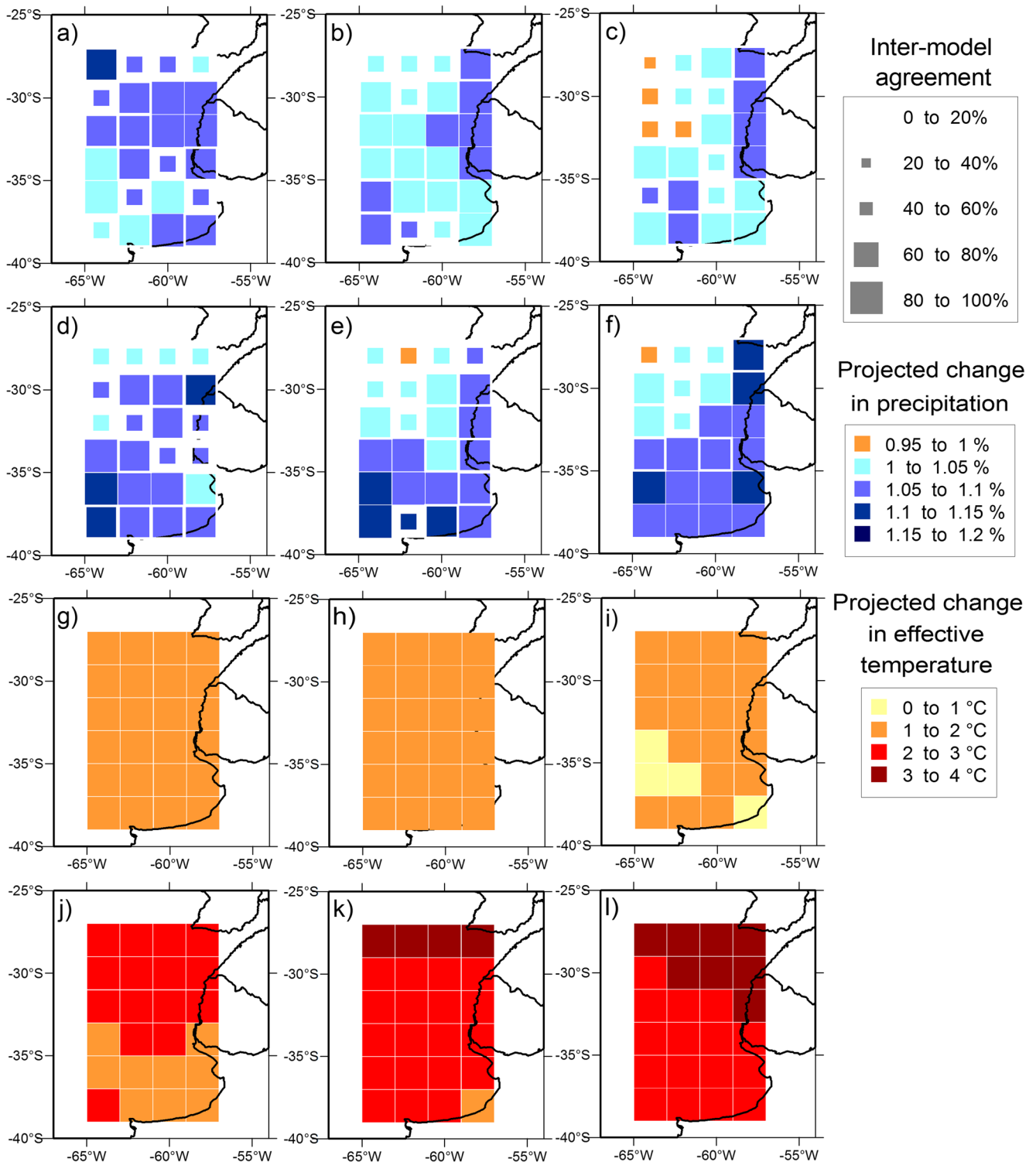


Fig. 3 Projected changes in annual precipitation (panels a to f) and effective temperature (panels g to l) under RCP 4.5 (panels a, b, c, g, h, i) and RCP 8.5 (panels d, e, f, j, k, l) scenarios for extreme low (left

panels), median (middle panels) and extreme high (right panels) values. Inter-model agreement in the sign of change is included in the size of the plots, in percentage

uncertainty of annual precipitation is not following the spatial distribution of projected change but the inter-model variability. It is interesting to highlight that values are also below 1 for annual effective temperature (Fig. 5). Moreover, for mean and

high values, uncertainty is lower under RCP 8.5 scenario (higher values of signal to noise ratio) since the projected change is higher. Then, uncertainty of effective temperature is more dependent on the magnitude of the change. However,

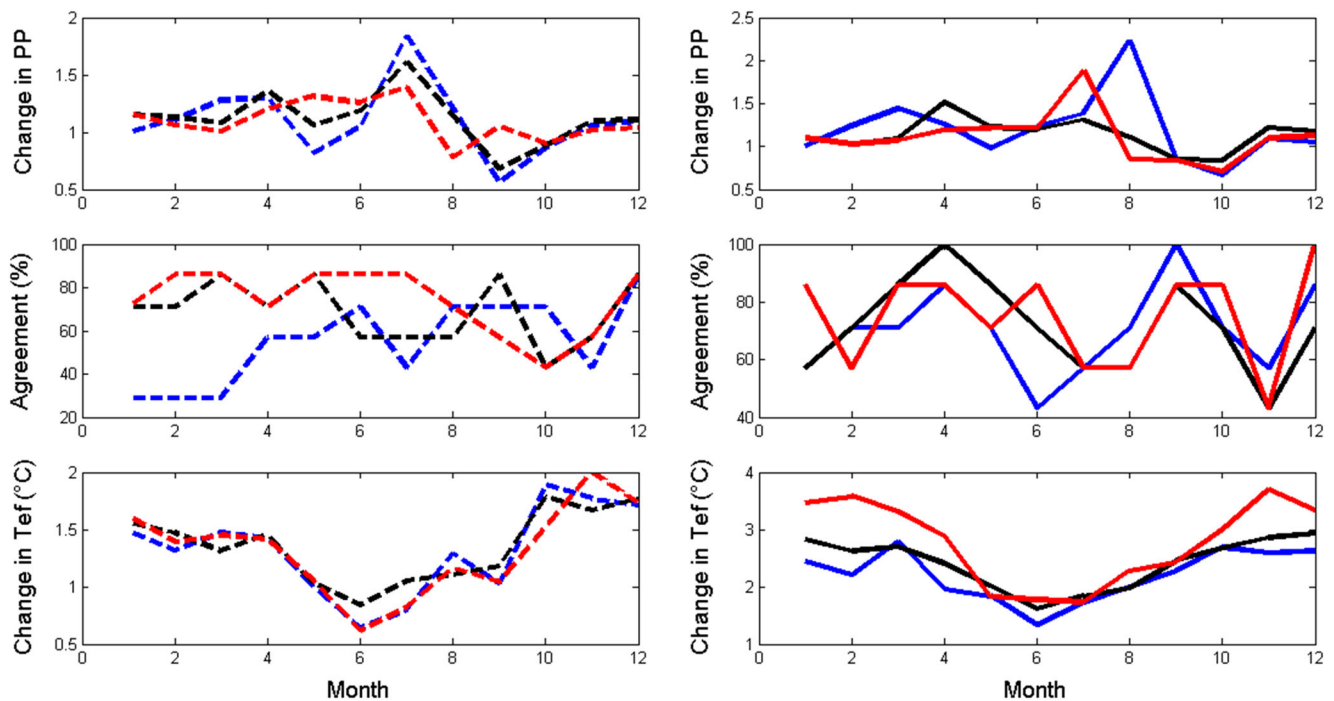


Fig. 4 Projected changes (top panels) and agreement (middle panels) in monthly precipitation (PP) and projected changes (bottom panels) in monthly effective temperature (Tef) under RCP 4.5 (left panels) and

RCP 8.5 (right panels) scenarios for extreme low (blue lines), median (black lines) and extreme high (red lines) values

even though the inter-model variability is higher than the change, the seven models agree on the sign of the change for this variable (Fig. 3).

At monthly scale (Fig. 6), uncertainty in precipitation is lower in April, when the signal to noise ratio is closer to 1, especially under RCP 8.5 scenario. In particular, for extreme low values, the change is higher than inter-model variability. During August and September, the ratio is negative because of negative change projected for precipitation. For effective temperature, the ratio is below 1 with similar values for all the months. Uncertainty in variables in this regional study limits the decision making for managing adaptation to such changes.

3.3 Soil response analysis

Precipitation and potential evapotranspiration were compared as input variables of the water balance. In a previous work, the spatial and seasonal distribution of the percentage of years in which precipitation exceeds potential evapotranspiration was analysed for the observational period 1970–2010 (Pántano et al. 2017). According to the authors, precipitation prevails over potential evapotranspiration in eastern stations during the austral winter and the opposite is observed during austral summer. In western stations, potential evapotranspiration exceeding precipitation predominates all over the year. In the centre of the region, there is a transition zone with similar percentage of years under positive and negative values of the balance

between both variables. This behaviour is also representative at monthly scale.

In this section, the changes projected for the future period (2065–2100) in the relation between monthly precipitation and potential evapotranspiration were assessed at meteorological station locations. The spatial distribution of these results is very similar under both emission scenarios, with higher magnitude of changes under RCP 8.5 scenario. For that reason, Fig. 7 shows the changes in the percentage of years with precipitation exceeding potential evapotranspiration only for RCP8.5 scenario. From April to July, this percentage increases in almost all the region (except for the northeast). From August to December, decrease is extended all over the study domain, meaning increases in the percentage of evapotranspiration exceeding precipitation. From January to March, there is an asymmetric change: negative and positive in the northern and southern stations, respectively. Increase of more than 10% is located in different zones depending on the month, being higher during austral spring months. In general, while increase keeps below 10%, decrease exceeds 10%. These results highlight the importance of including the spatial variability from observational datasets.

Finally, soil response to these changes was assessed under climate extremes. For this purpose, climate conditions favouring wet and dry extremes were defined. On one hand, the months in which precipitation exceeds its 90th percentile and potential evapotranspiration beneath its 10th percentile were selected as wet extremes. On the other hand,

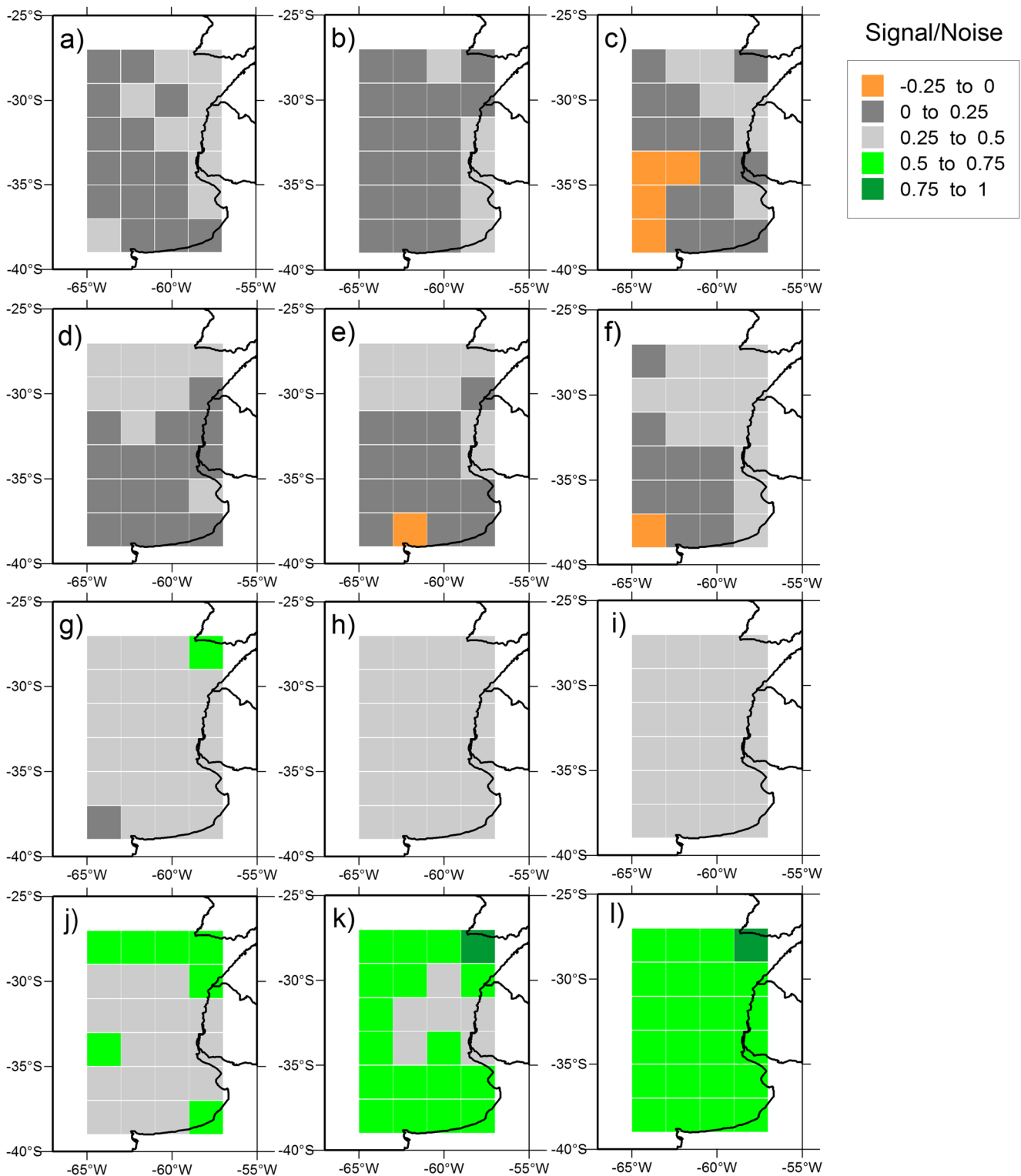


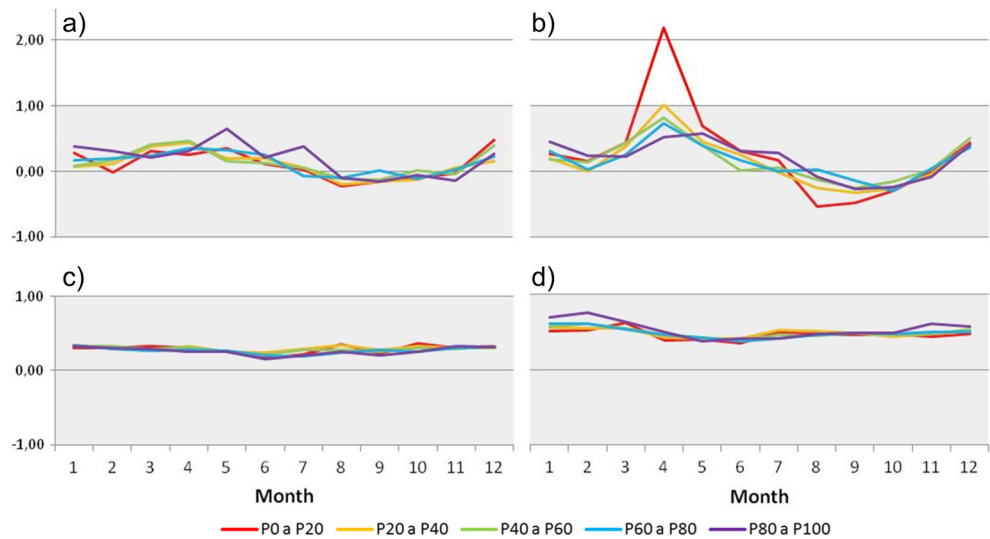
Fig. 5 As Fig. 3, but for signal-to-noise ratio of precipitation (panels a, b, c, d, e, f) and effective temperature (panels g, h, i, j, k, l)

precipitation beneath its 10th percentile and potential evapotranspiration exceeding its 90th percentile were selected as dry extremes. Focused on the impact of these atmospheric conditions, we identified the maximum value of excess and deficit among wet and dry extremes, respectively, for each month and

station. In order to show different aspects of the impact, we selected to show April, July and December (Figs. 8 and 9), as representative of three different soil responses.

For the observed period (Fig. 8), eastern stations reach higher values of excess and lower values of deficit than

Fig. 6 Signal-to-noise ratio for precipitation (top panels) and effective temperature (bottom panels), comparing historical outputs with RCP 4.5 (left panels) and RCP 8.5 (right panels) scenarios for each of the probabilistic interval considered



western stations. Moreover, some western stations do never reach excess conditions. This means that even though precipitation exceeds potential evapotranspiration in certain months, water storage do not reach field capacity to

generate excess conditions. Regarding deficit conditions, higher values are reached during summer (such as it is shown for December) because of high potential evapotranspiration. Even though, under wet extremes, high

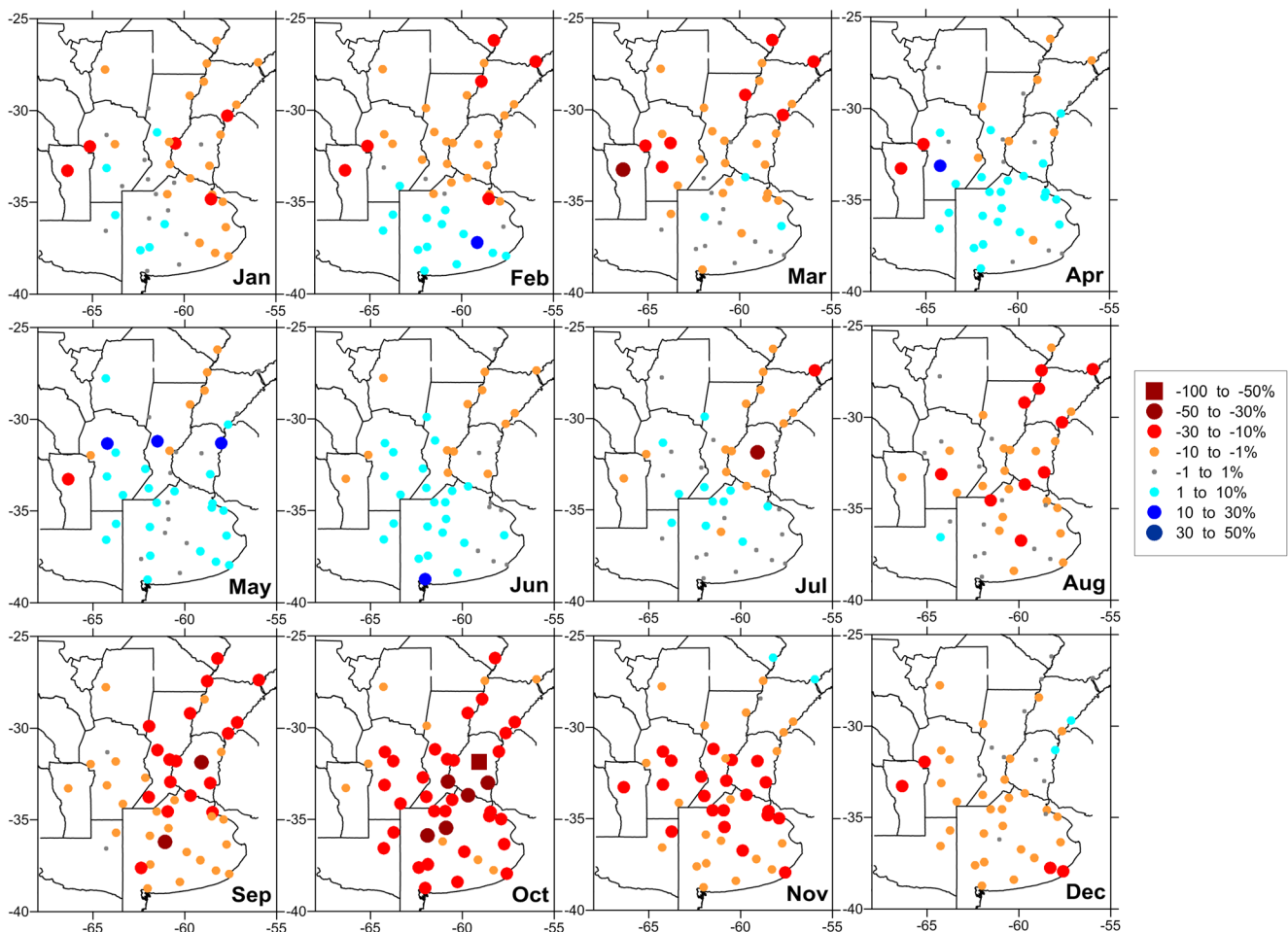


Fig. 7 For each meteorological station, projected changes in the percentage of years under positive difference between precipitation and potential evapotranspiration, according to the multi-model ensemble under the RCP 8.5 scenario relative to observed data

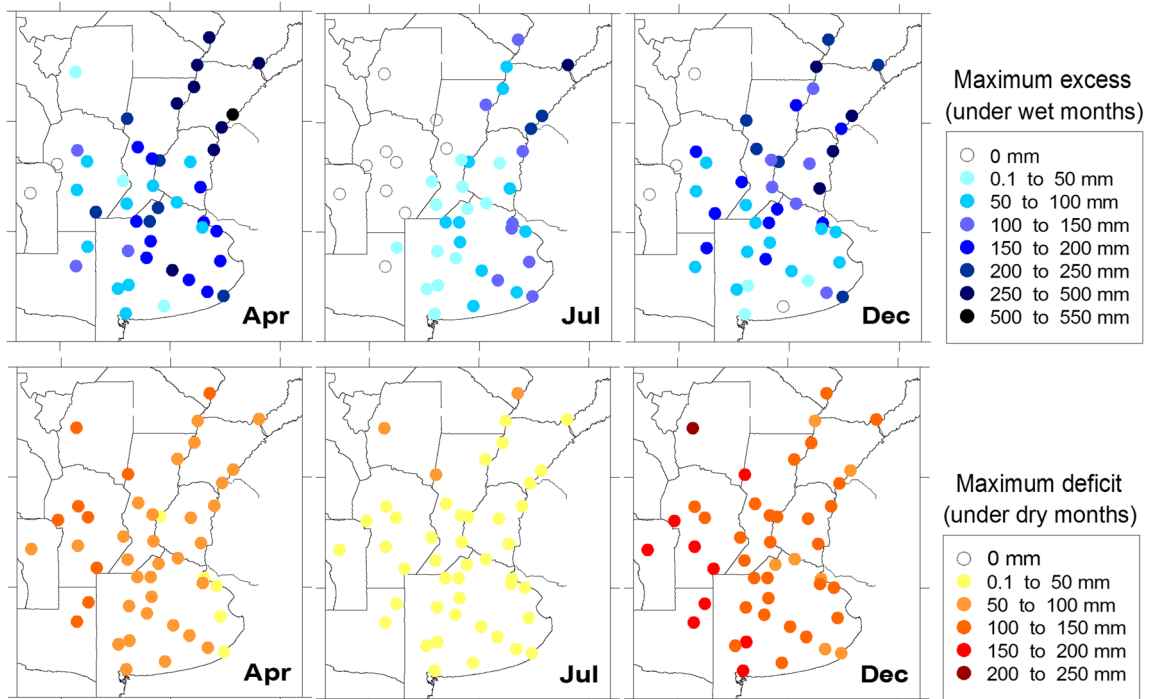


Fig. 8 For each meteorological station, maximum excess under wet extremes (top panels) and maximum deficit under dry extremes (bottom panels) for April, July and December

values of excess are also observed. Similar results are found in April whereas lower values are observed during July because both precipitation and potential evapotranspiration are lower in almost all the region.

Changes in the maximum excess and maximum deficit reached under wet and dry extremes, respectively, are shown under RCP 8.5 (Fig. 9). Multi-model ensemble projections show increase in both maximum deficit and maximum excess

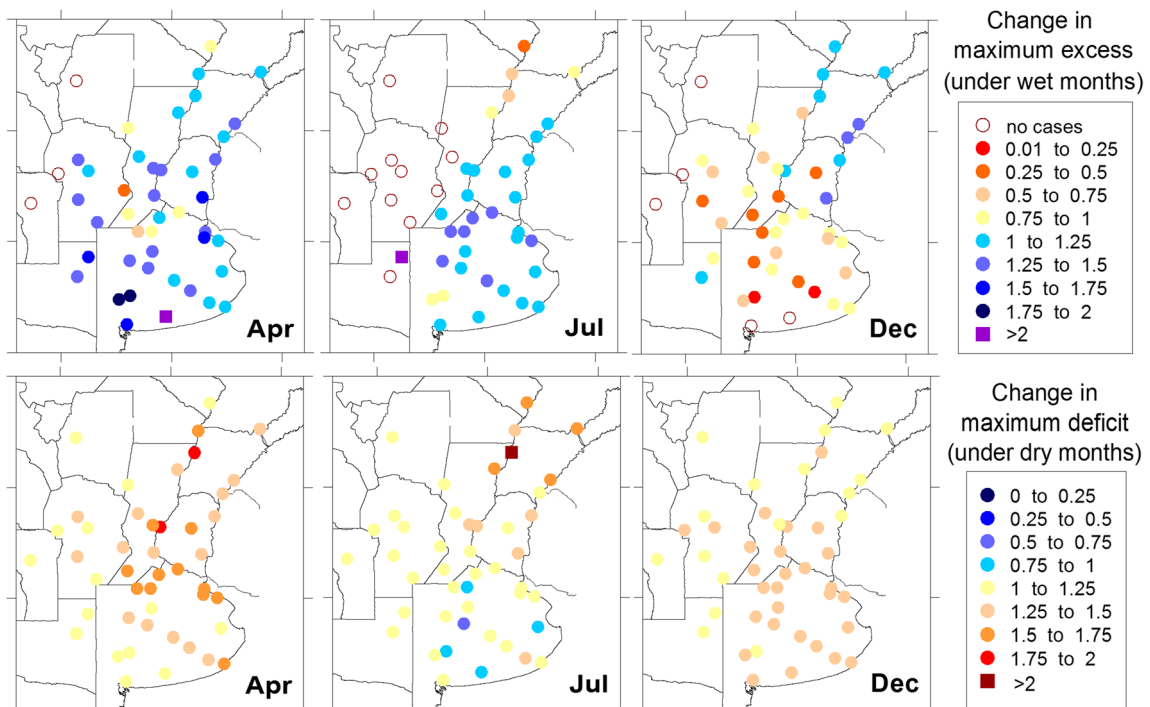


Fig. 9 Ratio between projections under RCP 8.5 scenario and historical experiment simulations, for maximum excess under wet extremes (top panels) and maximum deficit under dry extremes (bottom panels) for April, July and December

for April, under every extreme condition analysed, with few exceptions. Then, if a particular month with scarce precipitation is presented, more extreme deficit conditions are expected because of projected increase in potential evapotranspiration. During July, there is decrease in excess in a few stations located in the northeast whereas there is increase in the rest of the region, except for western stations where no excess conditions occur (see Fig. 8). For this month, there is increase in deficit all over the region. Climatologically, December is characterised by deficit conditions because of high values of potential evapotranspiration. This behaviour is projected to be intensified by increase in deficit and decrease in excess attributed to higher increase in potential evapotranspiration. The increase in precipitation is low, although is high enough to increase excess conditions in the northeast.

4 Discussion and conclusions

Projected changes in mean and extreme temperature and precipitation have a socio-economic impact in the southern La Plata Basin. In order to provide a contribution for adaptation actions, in this research, projections of the main meteorological variables participating in soil-atmosphere interaction and associated impact on soil hydric conditions were assessed. Projected changes were based on the ensemble of seven CMIP5 GCMs under RCP4.5 and RCP8.5 scenarios and were improved by combination with observational data. Then, the results of soil response were obtained at meteorological station locations.

Projections in annual and monthly precipitation indicate increases in almost all the region with a few exceptions. In the north of the study region, these changes may be due to a southward shift of the Atlantic Anticyclone together with an intensification of the Low Level Jet Stream and the Chaco Low, which lead to an increase in the transport of moisture toward these regions (Blazquez et al. 2012).

Projected maximum and minimum temperatures show changes depending on the scenarios (results not shown). As a consequence, annual and monthly projected effective temperature increase. Additionally, projected increase is lower during winter months comparing to summer months.

Greater agreement between models was found in the projected increase of temperature compared to precipitation, in concordance with Orłowsky and Seneviratne (2012).

The analysis of uncertainties showed weak signal of change for precipitation owing to inter-model variability. Other studies showed that temperature is characterised by lower uncertainty than precipitation (i.e. Blázquez and Núñez 2012). However, in this study, the quantification of effective temperature gave also high uncertainty. Given that the selection of models to construct an ensemble is arbitrary, it should be interpreted as the uncertainty of the projections

simulated by the particular ensemble selected for this study (Knutti and Sedláček 2013).

Changes in the balance between precipitation and potential evapotranspiration were analysed at meteorological station locations. The analysis revealed increase of more than 10% in the prevalence of potential evapotranspiration over precipitation, during spring months. By contrast, an increase of 10% in prevalence of precipitation is projected for winter months.

These results should be interpreted in the context of the complex feedback mechanism between temperature, precipitation and evapotranspiration. The role of evapotranspiration in the soil-atmosphere interaction can be studied through two different approaches. As an evaporative demand, increase in temperature leads to a potential increase in evapotranspiration. Eventually, it leads to a decrease in soil moisture provided that there is water available for evapotranspiration (Seneviratne et al. 2010).

Another approach to the analysis is the role of evapotranspiration as a water flux response from soil to atmosphere, made by other researchers. Since projected precipitation increases in the study region, soil moisture increases because of positive feedback between both variables (Eltahir 1998). As a consequence, recent studies based on Regional Climate Models found that the coupling between precipitation and evapotranspiration (Ruscica et al. 2014) and the coupling between temperature and evapotranspiration (Menendez et al. 2016) are projected to weaken in the future; given that soil moisture loses importance as a limiting factor (Seneviratne et al. 2010).

In this study, changes in potential evapotranspiration were analysed as the response to evaporative demand through increases in temperature. In this sense, Rind et al. (1990) explain that increases in potential evaporation, due to higher temperatures, can increase droughts, even in regions where total rainfall also increases.

Finally, soil response was assessed. From the complexity of the soil-atmosphere interaction, this study focused on the atmosphere-leading-soil coupling. Therefore, other effects such as the phreatic level or land use were not taken into account although they are relevant for the soil-leading-atmosphere coupling (Ruscica et al. 2014; Pessacq and Solman 2012).

In a previous study, Pántano et al. (2014) and Penalba et al. (2016) analysed the spatial distribution of hydric conditions in mean terms and in comparison to the Standardized Precipitation Index, respectively. As a step forward, changes in maximum values of deficit and excess conditions under extreme events were analysed in this research, at meteorological station locations. These results revealed another aspect of concern. Although autumn months are expected to present more cases of precipitation over potential evapotranspiration, for particular dry extremes, higher deficit conditions are expected. Given that the water recharge in soil for winter crops is produced

during these months, the impact over the yield of these crops can be enhanced under particular dry autumn months (Cavalcanti et al. 2015). On the other hand, under extreme wet events favouring excess conditions, maximum excess would reach higher values making the harvest of summer crops difficult. Analogously, higher deficit during July would impact on vegetative period of wheat crops because precipitation is scarce in many meteorological stations during winter. Then, these changes may represent disadvantages for the development of winter crops and reinforce the importance of water recharge during autumn.

In December, there is a projected reduction of the impact of extreme high precipitation. This is one of the months in which potential evapotranspiration takes more importance, attributed to radiation forcing. The region with the best summer hydric conditions is currently occupied by water-demanding maize and soybean crops. In the western zone, where potential evapotranspiration is more important, sunflower has better results.

In general, projected temperatures lead to increase deficit conditions in the three analysed months (April, July and December). This result agrees with Costa et al. (2013), who showed lower soil water availability, mainly in spring and summer. In this regard, Murgida et al. (2014) explain that soybean can benefit from this, since this crop is characterised by a better tolerance of temperature increase. However, the authors warn about the hazard of monoculture for soil degradation.

This study explored the influence of temperature and precipitation changes on water balance in soil in a regional scale, with special attention on the response under climate extremes. This analysis contributes to validate GCMs in a particular region and supports the importance of developing downscaling techniques to study regional climate, such as the ongoing initiative coordinated by CORDEX Project (Giorgi et al. 2009). The results help to the design of strategies of adaptation to eventually attenuate the vulnerability of the agriculture production, over which several other factors influence.

Acknowledgements The authors thank the responsible editor and the reviewers for their valuable suggestions that improved the manuscript.

Funding information This research was supported by the projects UBACyT (2014-17) 20020130100263BA from the University of Buenos Aires and CONICET 11220150100137CO (2016-2018) from the National Council of Scientific and Technical Research.

References

- Accadia C, Mariani S, Casaioli M, Lavagnini A, Speranza A (2003) Sensitivity of precipitation forecast skill scores to bilinear interpolation and a simple nearest-neighbor average method on high-resolution verification grids. *Weather Forecast* 18(5):918–932. [https://doi.org/10.1175/1520-0434\(2003\)018<0918:SOPFSS>2.0.CO;2](https://doi.org/10.1175/1520-0434(2003)018<0918:SOPFSS>2.0.CO;2)
- Barros V, Vera C, Agosta E, Araneo D, Camilloni I, Carril A, Doyle M, Frumento O, Nuñez M, Ortiz de Zárate M, Penalba O, Rusticucci M, Saulo C, Solman S (2013) Cambio climático en Argentina, tendencias y proyecciones. Tercera Comunicación de la República Argentina a la Convención Marco de las Naciones Unidas sobre Cambio Climático. Buenos Aires, Argentina, Secretaría de Ambiente y Desarrollo Sustentable de la Nación, p. 341
- Blázquez J, Nuñez MN (2012) Analysis of uncertainties in future climate projections for South America: comparison of WCRP-CMIP3 and WCRP-CMIP5 models. *Clim Dyn* 41(3–4):1039–1056. <https://doi.org/10.1007/s00382-012-1489-7>
- Blázquez J, Nuñez M, Kusunoki S (2012) Climate projections and uncertainties over South America from MRI/JMA global model experiments. *Atmos Clim Sc* 2(04):381–400. <https://doi.org/10.4236/acs.2012.24034>
- Camargo AP, Marin FR, Sentelhas PC, Giarola Piccini A (1999) Ajuste de equação de Thornthwaite para estimar la evapotranspiración en climas arido y superhmedo, com base na amplitude térmica diária. *Rev Bras Agrometeorologia* 7(2):251–257
- Carvalho L, Jones C (2013) Multiannual-to-decadal variability of the American monsoons: present climate and CMIP5 projections. *U.S. Clivar Variations* 11, No. 1
- Cavalcanti IFA, Carril AF, Penalba OC, Grimm AM, Menéndez CG, Sanchez E, Cherchi A, Sörensson A, Robledo F, Rivera J, Pántano V, Bettolli LM, Zaninelli P, Zamboni L, Tedeschi RG, Dominguez M, Ruscica R, Flach R (2015) Precipitation extremes over La Plata Basin—review and new results from observations and climate simulations. *J Hydrol* 523:211–230. <https://doi.org/10.1016/j.jhydrol.2015.01.028>
- Costa A, González MH, Nuñez MN (2013) Cambios esperados en la disponibilidad hídrica del suelo en Argentina. *Meteor-Forschung* 38(1):43–52
- Eltahir EA (1998) A soil moisture–rainfall feedback mechanism: 1. Theory and observations. *Water Resour Res* 34(4):765–776. <https://doi.org/10.1029/97WR03499>
- Forte Lay JA, Spescha L (2001) Método para la estimación de la climatología del agua edáfica en las provincias pampeanas de la Argentina. *Rev Arg Agrometeorologia* 1(1):67–74
- Giorgi F, Jones C, Asrar G (2009) Addressing climate information needs at the regional level: the CORDEX framework. *WMO Bull* 58:175–183
- Hawkins E, Sutton R (2009) The potential to narrow uncertainty in regional climate predictions. *Bull Am Meteorol Soc* 90(8):1095–1107. <https://doi.org/10.1175/2009BAMS2607.1>
- IPCC (2007) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, 2007 (eds: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL) Cambridge University Press, United Kingdom and New York, USA
- IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change (eds: Core Writing Team, Pachauri RK, Meyer LA). Geneva, Switzerland, 151 pp.
- Kharin VV, Zwiers FW, Zhang X, Wehner M (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble. *Clim Chang* 119(2):345–357. <https://doi.org/10.1007/s10584-013-0705-8>
- Knutti R, Furrer R, Tebaldi C, Cernak J, Meehl GA (2010) Challenges in combining projections from multiple climate models. *J Clim* 23(10):2739–2758. <https://doi.org/10.1175/2009JCLI3361.1>
- Knutti R, Masson D, Gettelman A (2013) Climate model genealogy: generation CMIP5 and how we got there. *Geophys Res Lett* 40(6):1194–1199. <https://doi.org/10.1002/grl.50256>
- Knutti R, Sedláček J (2013) Robustness and uncertainties in the new CMIP5 climate model projections. *Nat Clim Chang* 3(4):369–373. <https://doi.org/10.1038/nclimate1716>
- Menendez C, Zaninelli P, Carril A, Sánchez E (2016) Hydrological cycle, temperature, and land surface–atmosphere interaction in the La Plata Basin during summer: response to climate change. *Clim Res* 68(2–3):231–241. <https://doi.org/10.3354/cr01373>

- Murgida A, Travasso M, González S, Rodríguez G (2014) Evaluación de impactos del cambio climático sobre la producción agrícola en la Argentina. *Publicación de las Naciones Unidas*
- Orlowsky B, Seneviratne SI (2012) Global changes in extreme events: regional and seasonal dimension. *Clim Chang* 110(3–4):669–696. <https://doi.org/10.1007/s10584-011-0122-9>
- Pántano V (2016) Sensibilidad de la interacción suelo-atmósfera a los extremos de temperatura y precipitación en el sudeste de Sudamérica. Unpublished doctoral Thesis. University of Buenos Aires, Buenos Aires
- Pántano V, Penalba O, Spescha L, Murphy G (2017) Assessing how accumulated precipitation and long dry sequences impact the soil water storage. *Int J Climatol* 37(12):4316–4326. <https://doi.org/10.1002/joc.5087>
- Pántano V, Spescha L, Penalba O, Murphy G (2014) Influencia de la variabilidad de la temperatura y la precipitación en el agua del suelo, en la región oriental de secano de Argentina. *Meteor-Forschung* 39: 21–36
- Pascale JY, Damario EA (1977) El Balance Hidrológico Seriado y su utilización en estudios agroclimáticos. *Rev. Fac. Agron. La Plata (3a época)* 53 (1–2): 15–34
- Pascale JY, Damario EA (2004) Bioclimatología agrícola y agroclimatología. *FAUBA Pags*:327–360
- Penalba O, Rivera J (2013) Future changes in drought characteristics over southern South America projected by a CMIP5 ensemble. *Am J Clim Chang* 2(3):173–182. <https://doi.org/10.4236/ajcc.2013.23017>
- Penalba O, Rivera J (2015) Comparación de seis índices para el monitoreo de sequías meteorológicas en el sur de Sudamérica. *Meteor-Forschung* 40:33–57
- Penalba OC, Rivera JA, Pántano VC (2014) The CLARIS LPB database: constructing a long-term daily hydrometeorological dataset for La Plata Basin, southern South America. *Geosci Data J* 1(1):20–29–20–29. <https://doi.org/10.1002/gdj3.7>
- Penalba OC, Rivera JA, Pántano VC, Bettolli ML (2016) Extreme rainfall, hydric conditions and associated atmospheric circulation in the southern La Plata Basin. *Clim Res* 68(2-3):215–229. <https://doi.org/10.3354/cr01353>
- Pessacg N, Solman S (2012) Effects of land-use changes on climate in southern South America. *Clim Res* 55(1):33–51. <https://doi.org/10.3354/cr01119>
- Rind D, Goldberg R, Hansen J, Rosenzweig C, Ruedy R (1990) Potential evapotranspiration and the likelihood of future drought. *J Geophys Res: Atmos* 95(D7):9983–10004. <https://doi.org/10.1029/JD095iD07p09983>
- Ruscica RC, Sörensson AA, Menéndez CG (2014) Hydrological links in southeastern South America: soil moisture memory and coupling within a hot spot. *Int J Climatol* 34(14):3641–3653. <https://doi.org/10.1002/joc.3930>
- Seneviratne SI, Corti T, Davin EL, Hirschi M, Jaeger EB, Lehner I, Orlowsky B, Teuling A (2010) Investigating soil moisture–climate interactions in a changing climate: a review. *Earth Sci Rev* 99(3): 125–161. <https://doi.org/10.1016/j.earscirev.2010.02.004>
- Solman S, Pessacg N (2012) Evaluating uncertainties in regional climate simulations over South America at the seasonal scale. *Clim Dyn* 39(1–2):59–76. <https://doi.org/10.1007/s00382-011-1219-6>
- Sörensson AA, Menéndez CG (2011) Summer soil–precipitation coupling in South America. *Tellus A* 63(1):56–68. <https://doi.org/10.1111/j.1600-0870.2010.00468.x>
- Spescha LB, Murphy GM, Forte Lay JA, Hurtado RH, Scarpati OE (2005) Riesgo de sequía en la Región Pampeana. *Rev. Arg. de Agrometeorología* (5-6): 53-61
- Taylor KE, Stouffer RJ, Meehl GA (2012) An overview of CMIP5 and the experiment design. *Bull Amer Meteor Soc* 93(4):485–498. <https://doi.org/10.1175/BAMS-D-11-00094.1>
- Thornthwaite CW (1948) An approach toward a rational classification of climate. *Geog Review* 38(1):55–94. <https://doi.org/10.2307/210739>
- Thornthwaite CW, Mather JR (1957) Instructions and tables for computing potential evapotranspiration and water balance. Drexel Institute of technology. *Publications in Climatology*. Vol. X (3): 185-311