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Assessing how accumulated precipitation and long dry sequences impact the soil water storage

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ABSTRACT: Precipitation or no precipitation persistent over time often became extreme weather conditions with greater regional economic impact. The temporal and spatial variability of these variables, together with the evapotranspiration, is crucial in the east-northeast of Argentina, where rain-fed agricultural production is carried out. In this work, the frequency of precipitation was studied from dry spells and complemented with an analysis of the accumulated precipitation and evapotranspiration. In particular, dry sequences longer than 15 days, return period and severity, were the focus of this study. Finally, the impact of the amount and frequency of precipitation on soil water storage was assessed through a decadal analysis. The region of study is characterized by northeast-southwest gradient in accumulated precipitation and east–west gradient in winter long dry sequences. During summer, higher and more frequent precipitations (lower probability of long dry sequences and lower return period of 15 days and severity) were presented whereas the opposite was found in winter. However, the stations located to the west presented the highest probability of long dry sequences with higher severity and lower accumulated precipitation. This result highlights the vulnerability of the agriculture activity in the western stations. Regarding the impact of long dry sequences over soil water storage, the seasonality of evapotranspiration is also involved. The impact is stronger during austral summer because of higher values of evapotranspiration and it is lower during winter, in spite of the higher probability of long sequences. Decadal analysis suggested that soil water storage responds to precipitation amount or frequency depending on the magnitude of the anomalies. In this sense, the impact of precipitation over soil water storage depends on how it is distributed.

KEY WORDS dry spells; precipitation distribution; soil-atmosphere interaction; return period

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1. Introduction

The excess or deficit of precipitation, persistent over time, may impact regional economy in a rain-fed agriculture production since precipitation is one of the most relevant variables jointly with evapotranspiration and available water in soil for crops. Getting to know climatic variables involved in agricultural production processes helps to establish guidelines for making strategic decisions regarding short, medium and long-term planning in agricultural systems. For example, in maize crop production systems, Bert *et al.* (2006) identified decisions sensitive to climate in the Argentinean Pampas. In particular, they analysed how precipitation variability, associated with ENSO signal, influences on deciding sowing date, maize hybrid choice, maize nitrogen fertilizer management, etc. In a larger scale, Podestá *et al.* (2009) assessed the increase in production income when adaptation is applied based on climate information in the same region.

Precipitation in the region of study is characterized by seasonality, low frequency and inter-annual and decadal variability, described by Rusticucci and Penalba (2000); Penalba and Vargas (2004); Liebmann *et al.* (2004); Doyle *et al.* (2012); Russián *et al.* (2015), among others. Two climate types characterize the region of study, according to Köppen-Geiger climate classification (Peel *et al.*, 2007; Pántano, 2016): warm temperature fully humid in almost all the region and warm temperature with dry winter to the west.

Several studies showed an increase in the inter-annual variability of the precipitation in the central and eastern part of Argentina after the decade 1970 (Minetti *et al.*, 2003; Magrin *et al.*, 2005; Barros *et al.*, 2013; among others), displacing the agriculture border westward (Barros *et al.*, 2005).

An approach to this problem, associated with the extreme monthly and daily precipitation, was made by Penalba and Vargas (2008); Boulanger *et al.* (2005); Penalba and Robledo (2010); Naumann *et al.* (2012); among others. In this regard, extreme daily precipitation is included in the monthly accumulated precipitation. Robledo (2012) found that the daily accumulated precipitation exceeding the 75th percentile, explains more than

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60% of the monthly precipitation, varying spatially and depending on the time of year.

The distribution of precipitation and no precipitation in a given period is also involved in this problem. In this sense, Gattinoni (2008) and Scardilli (2013) analysed daily wet sequences in different stations of the country whereas Llano and Penalba (2010) studied the sequences of days without precipitation (0.1 mm), finding that the probability of occurrence decreases asymptotically with increasing duration. Penalba and Llano (2008) characterized the spatial variability of sequences of precipitation below 2 mm, fitted a Markov chain model and analysed the spatial coherence. For the study of extreme dry spells, Vicente-Serrano and Beguería-Portugués (2003) recommended to take partial series of excedances (values above a selected threshold). Since there could be more than one event per year, this treatment is more adequate than selecting the annual maxima sequence. The generalized Pareto distribution approximates the distribution of a random variable exceeding a certain magnitude (Pickands, 1975). The estimation of the return period of large dry spells and the severity of extreme events through the theoretical distribution is useful in the design of strategies to attenuate their impact, which cause economic losses analysed by Murphy (2010).

The same amount of accumulated precipitation in a given period may produce different responses in the growth of crops, depending on how that precipitation occurs. For example, during March 1990 and 2001, monthly accumulated precipitation was similar in Junín station although the distribution differed. In March 1990, there was an extreme event that lasted for 3 days. In the first 2 days, the precipitation accounted for over 60% of the monthly total, whereas in March 2001 rainfall of lesser magnitude was distributed throughout the month. Therefore, impact over daily soil water storage was different in these two cases, also depending on the initial soil hydric conditions and stage of crops.

Some issues may be explained regarding precipitation such as frequency, amount, intensity, length of rainy period, spatial variability, among others. In the region of study, there is a lack of understanding on the impact of precipitation distribution over the availability of soil water. To address these issues, focused on extreme events, the aim of this work is to analyse seasonal precipitation and dry spells, and their impact on soil water storage. Owing to the relevance of decadal variability, results are compared for different decades.

This article is organized as follows: Section 2 presents the data and the method employed; Sections 3.1, 3.2 and 3.3 provide a description of the climatology of seasonal precipitation and the balance between precipitation and potential evapotranspiration, dry sequences and soil water storage in the study region, respectively; Section 3.4 carries out a decadal analysis of the relationship between the three variables focus of this study and Section 4 presents our conclusions.

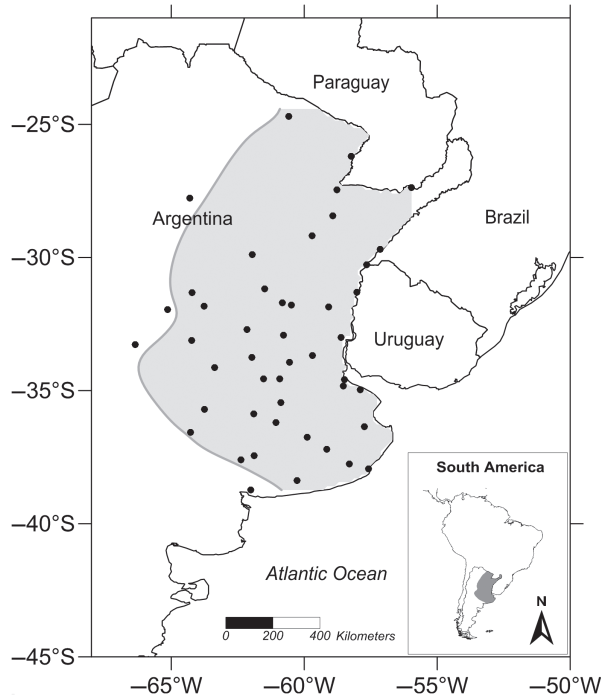

Figure 1. Spatial distribution of the meteorological stations used in the study. Shading indicates region of rain-fed agriculture production.

2. Data and methodology

In this work, daily precipitation and maximum and minimum temperature data were used from 46 stations, for the period 1970–2010 (Figure 1). The region of study corresponds to the east-northeast of Argentina, where rain-fed agricultural production is carried out. The data was obtained from the National Weather Service and the National Institute for Agricultural Technology and has undergone through consistency control analysis of CLARIS LPB database (Penalba *et al.*, 2014) in the framework of the European Community's CLARIS-LPB project 'A Europe-South America Network for climate Change Assessment and Impact Studies in La Plata Basin'. This project derived from the previous CLARIS project (Boulanger *et al.*, 2010).

At monthly scale, 46 stations were used, 30 of them were selected for the daily analysis and 19 were used for soil study in which complete series were required.

For the quantification of dry sequences, the threshold of precipitation below which a rainy day was considered in the dry spell was first defined. Taking into account the crop requirements and water losses from evapotranspiration and run-off, a threshold of 5 mm was established (Dastane, 1978). Additionally, when two consecutive days accumulated more than 5 mm of precipitation, the second day was considered as a rainy day. As a consequence, each dry sequence ends when accumulated precipitation in two consecutive days exceeds 5 mm. Moreover, one day without precipitation in a sequence of rainy days does not cut the wet sequence.

In order to analyse dry sequence events that impact soil water storage, those exceeding a certain length were

Table 1. Scale and shape parameters, according to the generalized Pareto distribution for a location parameter of 15 days.

Station	Latitude	Longitude	Shape parameter				Scale parameter			
			DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Azul	−36.75	−59.89	0.11	0.32	−0.01	−0.75	3.52	4.87	11.98	13.12
Bahía Blanca	−38.73	−62.02	0.03	−0.03	0.23	0.19	6.23	9.55	10.59	2.97
Bella Vista	−28.43	−58.92	0.01	−0.57	0.05	−0.07	4.40	11.70	12.19	7.33
Buenos Aires	−34.58	−58.48	−0.11	0.05	−0.31	0.02	4.18	6.08	8.58	5.52
Caseros	−30.27	−57.65	−0.33	−0.07	−0.05	−0.14	6.04	4.55	6.48	4.91
Ceres	−29.88	−61.95	−0.07	−0.29	−0.22	0.26	5.14	8.75	24.44	6.71
Concordia	−31.30	−58.02	−0.22	−0.16	0.05	−0.17	6.13	5.22	5.75	4.91
Córdoba	−31.32	−64.22	−0.05	0.32	−0.57	0.04	2.53	5.41	42.97	8.02
Corrientes	−27.45	−58.77	−0.11	−0.17	0.15	−0.06	4.70	6.30	6.93	4.90
Formosa	−26.20	−58.23	0.58	−0.28	0.22	1.47	2.09	5.70	5.60	0.75
General Pico	−35.70	−63.75	−0.01	−0.13	−0.23	−0.15	3.88	8.68	21.49	8.09
Gualeguaychu	−33.00	−58.62	1.11	−0.01	−0.01	−0.23	2.04	4.73	6.35	7.45
Junín	−34.55	−60.92	0.16	0.31	0.06	0.13	2.54	4.45	12.90	4.43
La Plata	−34.97	−57.90	0.33	0.21	−0.19	−0.26	2.26	4.65	6.72	6.69
Laboulaye	−34.13	−63.37	0.41	−0.05	−0.15	0.00	3.30	8.11	21.79	6.60
Marcos Juarez	−32.70	−62.15	0.09	0.05	0.03	0.25	3.55	5.03	13.59	4.79
Mar del Plata	−37.93	−57.58	−0.12	0.00	−0.01	−0.13	4.00	6.78	8.89	5.87
Paraná	−31.78	−60.48	−0.37	0.04	−0.18	−0.40	5.31	4.95	15.74	10.34
Paso de los Libres	−29.68	−57.15	−0.11	0.20	0.09	−0.55	5.41	3.95	6.24	7.27
Pehuajó	−35.87	−61.90	0.67	0.19	0.15	−0.36	1.53	6.24	12.42	9.42
Pergamino	−33.93	−60.55	−0.19	0.31	0.10	−0.25	5.32	4.90	10.80	7.94
Posadas	−27.37	−55.97	−0.21	−0.26	−0.02	−1.06	9.58	5.53	5.11	9.69
Reconquista	−29.18	−59.70	0.11	0.36	−0.02	−1.04	3.08	3.42	9.47	11.55
Río Cuarto	−33.12	−64.23	−1.23	0.40	−0.29	0.12	6.25	4.76	24.92	6.79
Rosario	−32.92	−60.78	0.52	0.57	−0.32	−0.26	2.94	4.00	18.36	8.40
San Luis	−33.27	−66.35	0.34	0.33	−0.68	−0.21	3.14	6.19	35.33	11.83
Sauce Viejo	−31.70	−60.82	−0.01	0.00	−0.24	−0.35	7.43	6.01	16.77	9.93
Santa Rosa	−36.57	−64.27	−0.35	0.12	−0.15	0.11	7.92	6.78	24.00	7.45
Tandil	−37.20	−59.15	−0.12	0.40	0.07	−0.42	5.68	5.40	10.77	10.03
Tres Arroyos	−38.38	−60.27	0.09	0.05	−0.01	0.06	4.63	7.80	11.57	6.20

considered. The threshold has to be low enough to include relevant information, and high enough to be representative of long dry spell. Therefore, dry sequences equal or above 15 days were considered long sequences. This threshold is above percentile 80 for all seasons, except for winter, and it was also defined for this season to allow a comparative analysis. Then, the partial series of excedances was constructed and Generalized Pareto Distribution was fitted (99% confidence level evaluated with a Chi-square distribution). Table 1 displays the parameters for the generalized Pareto distribution obtained for these long sequences. The return period of the 15 days dry sequences was derived and the severity of long sequences was calculated as their average. Empirical probability of long sequences was also estimated.

For the estimation of potential evapotranspiration, several methodologies are found in the literature. The simplicity of Thornthwaite's method (Thornthwaite, 1948) allows applying it in a wider area on a monthly basis. Thus, this method was used to analyse the balance between monthly potential evapotranspiration and precipitation. For a better estimation, the effective temperature (T_{ef}) was used instead of mean temperature, according to Camargo *et al.* (1999):

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

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

On a daily scale, Penman–Monteith's method is strongly recommended by Food and Agriculture Organization (FAO) of the United Nations, where the amount and type of variables involved in their calculation are measured (Allen *et al.*, 1998). This method was applied to estimate daily potential evapotranspiration involved in the daily water balance.

Finally, in order to analyse the impact of dry sequences on soil water storage, daily water balance (Fernández Long *et al.*, 2012) was used. Different categories of soil water storage were defined based on Field Capacity (FC), Conditional Drought Level (CDL) and Permanent Wilting Point (PWP) for each location from Forte Lay and Spescha (2001) and Spescha *et al.* (2006). These hydrological constants define Optimum Moisture (OM: between CDL and FC), Conditional Drought (CD: between PWP and CDL) and Absolute Drought (AD: below PWP).

In the region of study, the main summer crops are maize, soybean and sunflower whereas the main winter crop is wheat. Considering the influence of precipitation and evapotranspiration on these crops in their different phenological stages, results are summarized by December–February (summer), March–May (autumn), June–August (winter) and September–November (spring).

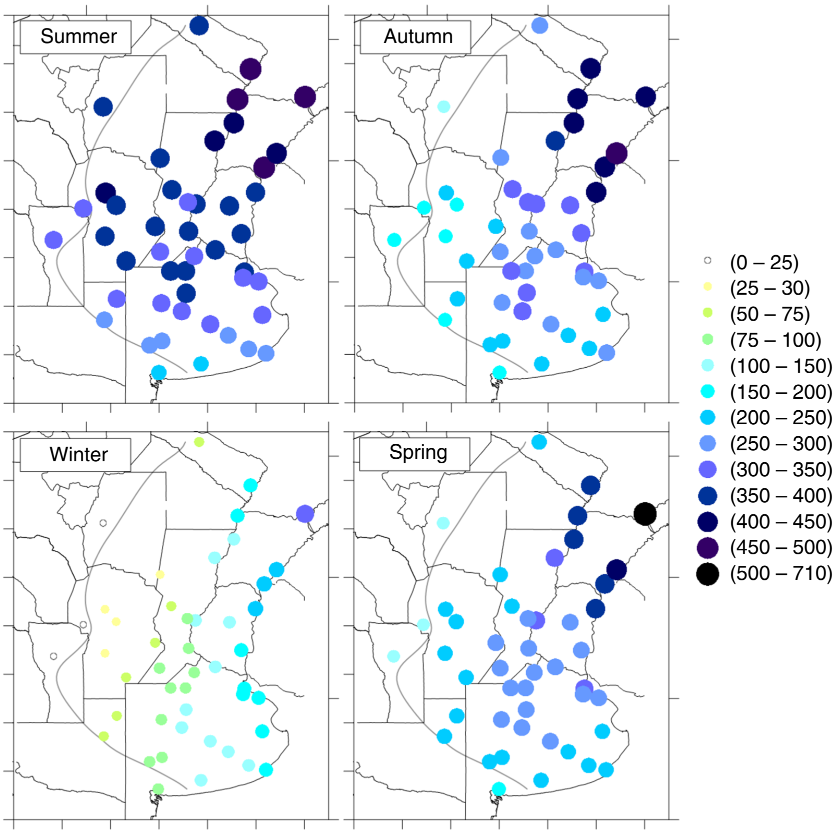

Figure 2. Spatial distribution of seasonal accumulated precipitation (mm) averaged over the period 1970–2010. [Colour figure can be viewed at wileyonlinelibrary.com].

3. Results

3.1. Seasonal precipitation and potential evapotranspiration

Taking into account the seasonal and spatial variability of the precipitation in the study region, seasonal precipitation averaged over the period 1970–2010 was quantified for each station (Figure 2). In general terms, northeast-southwest gradient is observed during autumn and spring whereas longitudinal distribution is presented during winter, showing higher values eastward. In the northeast, values exceed 400 mm during summer and autumn and minimum values are observed during winter. The rest of the region shows maximum precipitation in summer, higher than 250 mm, followed by autumn and spring with values between 150 and 350 mm. Minimum values are observed in winter, in particular, western stations present precipitation below 50 mm, in mean terms. The difference in precipitation between warm and cold semesters results in two different climate types according to Köppen-Geiger's climate classification. While western stations are classified as warm temperature with dry winter, the rest of the region is classified as warm temperature fully humid (Peel *et al.*, 2007; Pántano, 2016). Because of scarce precipitation during cold months, winter crops depend on water recharge generated from autumn precipitation and also influenced by summer conditions. For example, if April is exceptionally extreme dry, conditions may severely impact the winter crops (Cavalcanti *et al.*, 2015). This consideration also applies to summer crops because, despite higher rains, the available water for crops is lesser due to high values of evapotranspiration. Hence, it is also important to take into account the seasonality of the balance between precipitation and evapotranspiration. Therefore, the percentage of cases in which precipitation overcomes potential evapotranspiration is shown in Figure 3, adapted from Pántano *et al.* (2014). In mean terms, the whole region is characterized by high values of evapotranspiration exceeding precipitation during summer. During winter, values of precipitation higher than potential evapotranspiration prevail in a few stations located in the east. For the other seasons, lower values of precipitation prevail in the western zone whereas positive and negative values of the balance between both variables are presented in similar percentages in the rest of the region.

3.2. Dry sequences

In addition to the previous analysis, the probability of dry sequences was calculated for each station. As an example, Figure 4 displays the distribution of empirical probability of dry sequences during autumn for four selected representative stations of the region of study. Lower probability of occurrence is observed for longer sequences, although it does not decrease asymptotically, as shown by Penalba and Llano (2008) and Llano and Penalba (2010), because

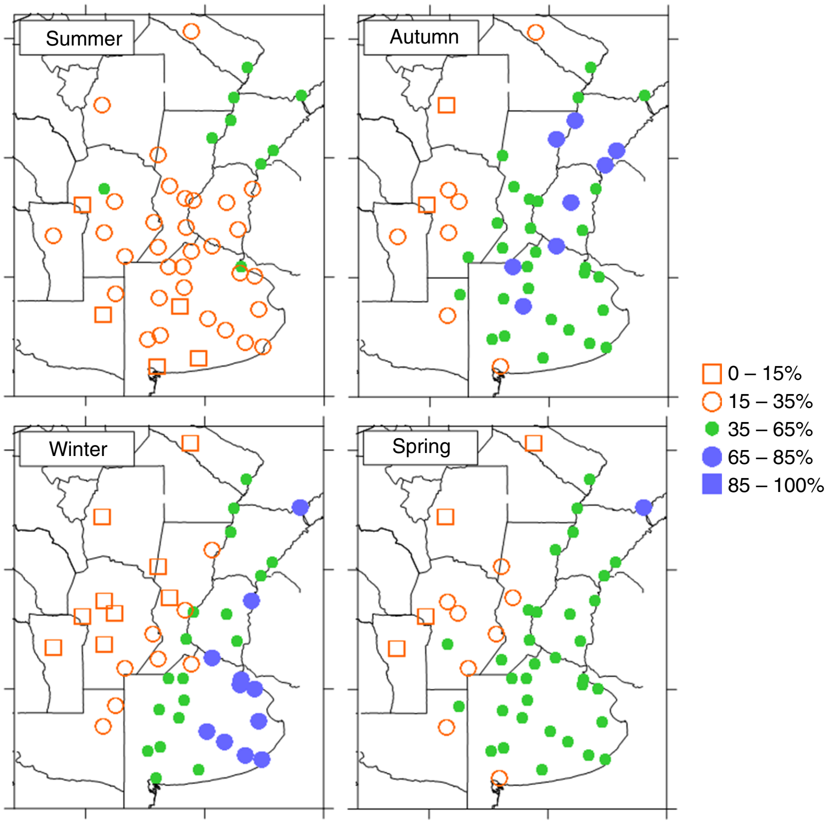

Figure 3. Spatial distribution of the percentage of positive cases of precipitation minus potential evapotranspiration over the period 1970–2010. Adapted from Pántano *et al.* (2014). [Colour figure can be viewed at wileyonlinelibrary.com].

of the threshold applied. For example, General Pico station presents maximum probability of 3–4 day length and secondary maximum of 7–8 day length. Similar results are observed in Ceres station whereas Azul and Gualeguaychú stations show a slight increase around 15 day length. In general, higher probabilities correspond to 2–9 days of dry spells characterized by synoptic scale processes. Extreme dry sequences of more than 15 day length are also observed.

Different lengths of dry sequences have diverse consequences. For example, frequent rains at the beginning of autumn season (short dry sequences) may cause adverse situation for summer crops harvest, whereas they provide required water recharge in soil.

Empirical probability of long sequences is shown in Figure 5 for each station and season. Lower probabilities of long sequences are observed during summer in almost the whole region (less than 15% of dry sequences have a length of more than 15 days). For the other seasons, east–west gradient is observed, with higher probabilities of long sequences westward. During winter, long sequences present more than 20% probability of occurrence. In the north of Córdoba and San Luis, more than 60% of dry sequences are long during this season.

Figure 5 also shows the return period of 15 days dry sequence and the severity of long sequences. For summer, autumn and spring, the return period is between 5 and 10 years for most of the stations distributed all over the region. Among the exceptions, it is noticeable the high return value during summer and spring in Posadas station (located in the extreme north–east of the study region), which is characterized by a different precipitation regime (Reboita *et al.*, 2010). The severity is below 25 days with lower values in summer in almost all the stations while there is lower probability of occurring long sequences. Then, even presenting low return period for 15 days, when long sequences occur they present lower severity than the other seasons. This result means that summer is characterized by shorter dry sequences, which implies more frequent precipitation. The opposite is found during winter and it is characterized by an east–west gradient. Even though the return period of long sequences is higher westward, dry sequences are mainly long (probabilities above 50% in most of them) and present higher severity (above 25 days). Therefore, lower frequency of precipitation is expected.

These results highlight the vulnerability of the agriculture activities in the western stations, where accumulated precipitation is low (Figure 2) and long sequences are more severe and probable (Figure 5) during winter. In this sense, precipitation during autumn is crucial for the development of the crops.

3.3. Daily soil water storage

In order to assess the spatial distribution of soil water storage, Figure 6 displays the percentage of days under Optimum Moisture (OM), Conditional Drought (CD) and Absolute Drought (AD) conditions for each season.

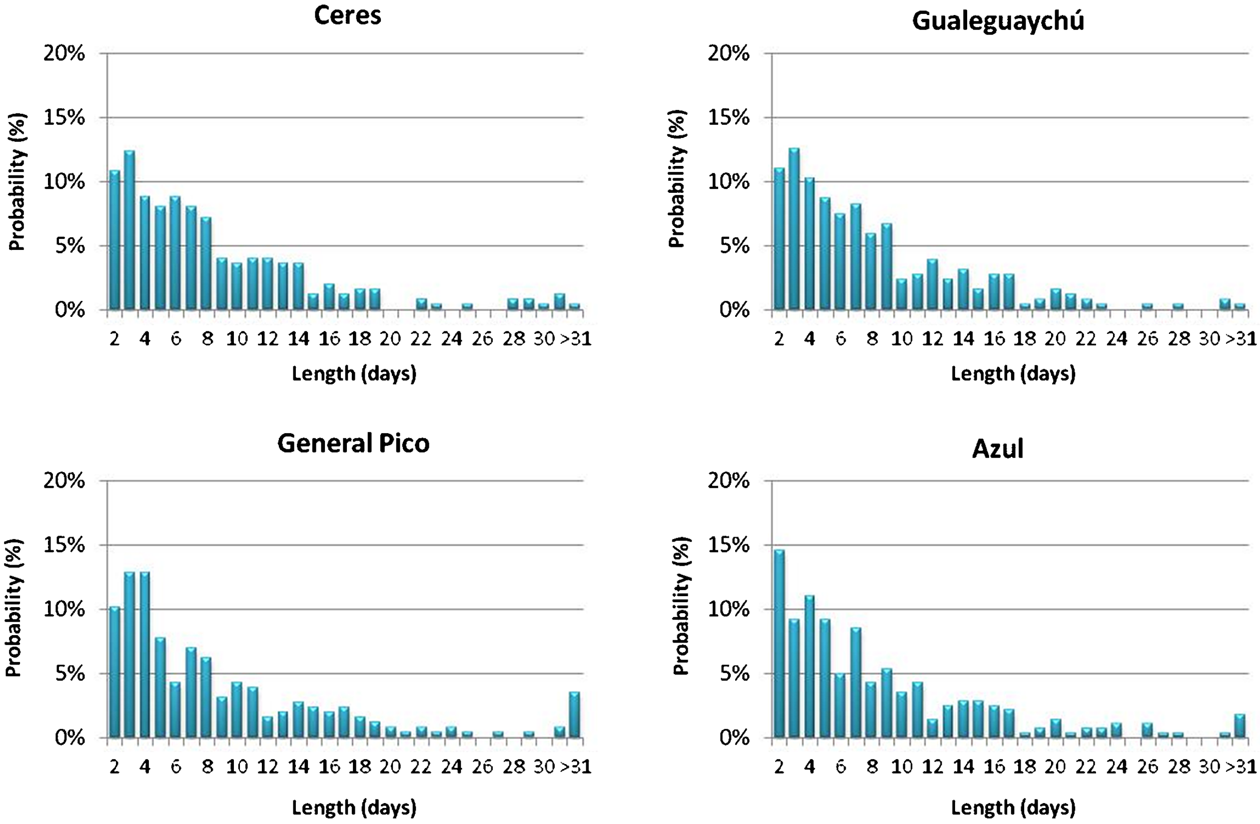

Figure 4. Empirical probability of dry sequences, for autumn season based on the period 1970–2010. [Colour figure can be viewed at wileyonlinelibrary.com].

Although summer precipitation is higher (Figure 2) and more frequent (Figure 5), high evapotranspiration (Figure 3) explains why drier categories of water storage are more probable south and westward. While southern stations present AD conditions over 50% of days, CD predominates only in two stations located in Buenos Aires Province, and no particular category exceeds 50% in the other stations. During autumn, water storage under OM predominates in most of the region with more than 50% occurrence because of higher precipitation and lower evapotranspiration. During winter, as precipitation decreases, so does evapotranspiration resulting in a balance between both variables that satisfies hydric requirements in eastern stations (Figure 3). Thus, OM predominates during this season too, with more than 75% occurrence for eastern stations. During spring, precipitation increases, but it is not high enough to exceed evapotranspiration westward (Figure 3). Therefore, OM storage prevails eastward whereas AD prevails westward. In the centre, the three categories show similar percentage of occurrence.

Depending on the season, the dry sequence ends with a drier soil water storage category or remains in the same one (result not shown). During summer, most of the long sequences end in a drier category, since high evapotranspiration enhance the dry sequence impact.

3.4. Decadal variability

Finally, the impact of the frequency and amount of precipitation on the soil water storage is analysed. Owing to decadal variability in temperature and precipitation observed in the region of study, an integral analysis is carried out for each decade. Starting in 1971, the following three variables were considered: seasonal precipitation anomalies; higher or lower occurrence of long sequences and anomalies of the percentage of days under every water storage category, for each decade compared to the whole period.

During summer, Figure 7(a) highlights that the centre-west zone presents the opposite sign of precipitation anomalies with respect to the surroundings. The 1970s and 1990s show positive precipitation anomalies in most of the stations and negative anomalies in the centre. However, during these decades, soil water storage show stronger response to the frequency of precipitation. In the 1970s, higher percentage of long sequences are observed and, as a consequence, most of the stations show fewer OM cases, whereas in the 1990s the percentage of long sequences is lower, leading to an increase in OM cases at the expense of decrease in AD. Soil type also influences the water recharge response. For example, in the centre of the study region, high quality soil with good storage capacity is presented. In there, increase in OM conditions is observed in the decade of the 1990s because of soil type, in spite of more frequent and lesser accumulated precipitation. In the 1980s and 2000s, negative precipitation anomalies predominate, but storage response is spatially variable since the more/less occurrence of long sequences is also spatially variable.

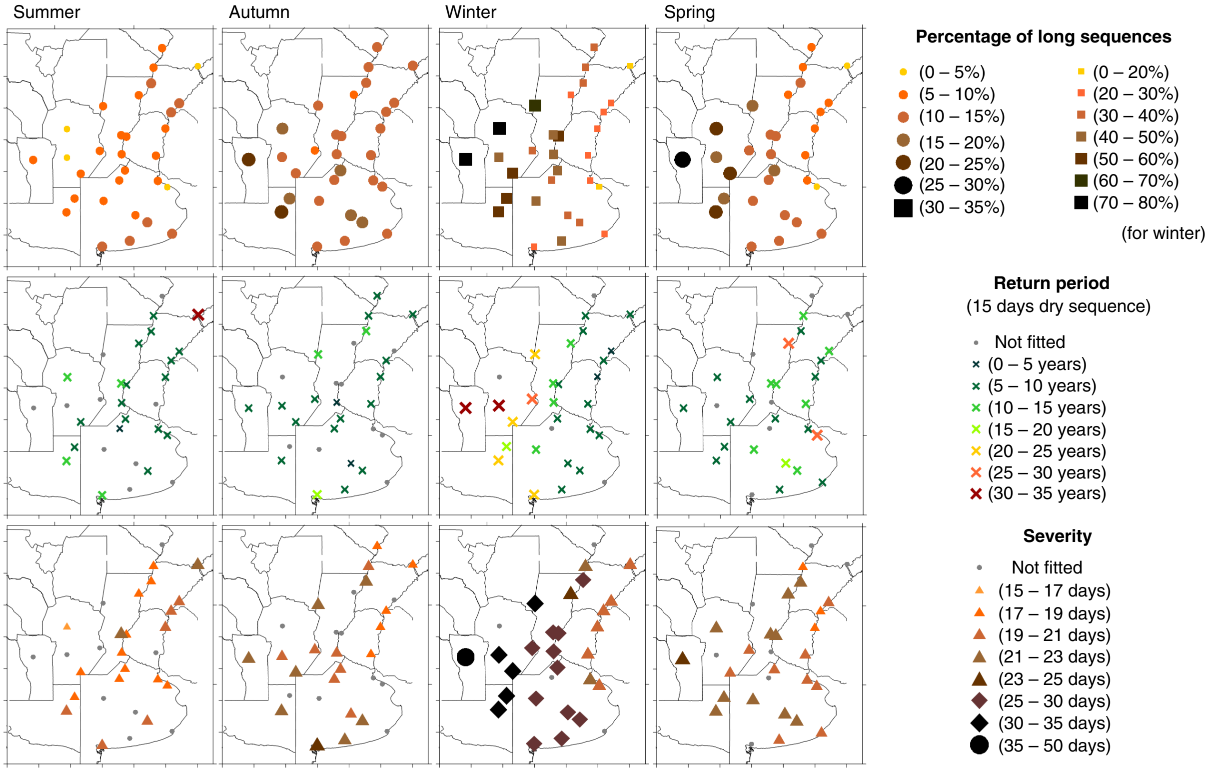

Figure 5. For each season, in the period 1970–2010: Percentage of long sequences –longer than 15 days-(top panel); return period for 15 days dry sequence (middle panel); severity of long sequences (bottom panel). For middle and bottom panel: Grey dots indicate that empirical distribution did not fit theoretical distribution. [Colour figure can be viewed at wileyonlinelibrary.com].

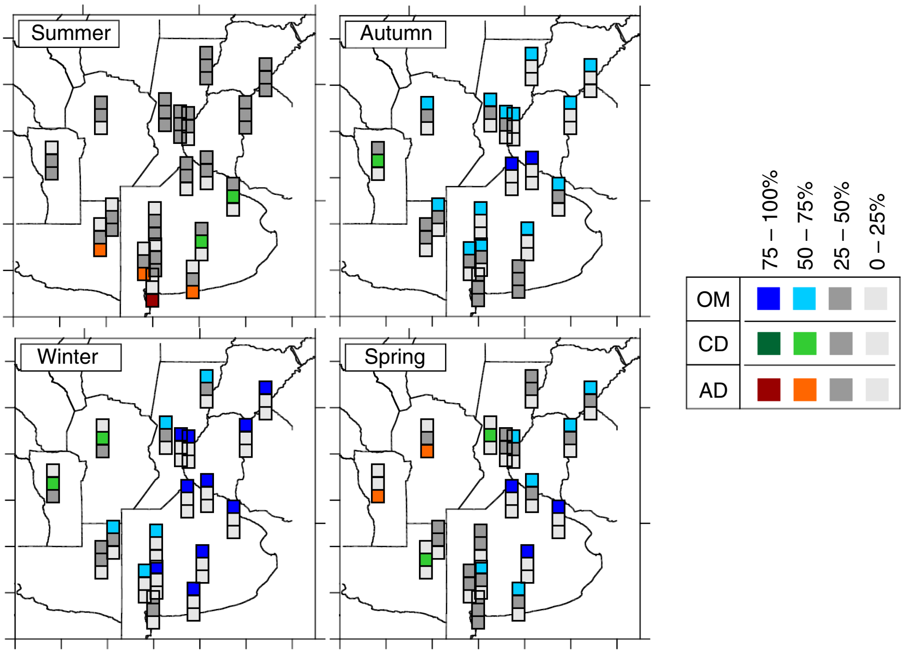

Figure 6. Percentage of days with soil water storage under Optimum Moisture conditions (OM), Conditional Drought conditions (CD) and Absolute Drought conditions (AD), for each season, for the period 1970–2010. [Colour figure can be viewed at wileyonlinelibrary.com].

During autumn (Figure 7(b)), the opposite is observed. In the decade of the 2000s, spatial homogeneity in long sequences allows to identify that water storage is influenced by anomalies in the amount of precipitation observed. In this decade long sequences are higher in the central and eastern stations. However, there is concordance between OM anomalies and precipitation anomalies: negative in the northeast and southwest and positive in the centre. During the 1970s higher percentage of long sequences is presented in almost all the region but soil water storage responds to precipitation anomalies. Percentage of AD is higher in the southwest and lower in the northeast.

During winter (Figure 7(c)), positive anomalies of OM are found in 1990s while negative anomalies of OM are found in 2000s, both related to lower and higher occurrence of long sequences, respectively. Anomalies in OM are opposite in sign to anomalies in CD and AD.

Anomalies of the percentage of soil water storage under the different categories are not relevant during spring (Figure 7(d)). However, the few cases with higher anomalies respond to one variable or the other depending on which of them is stronger. Decadal analysis showed that both amount and frequency of precipitation are relevant for soil water storage.

4. Conclusions

Long dry sequences were characterized complementary with the amount of precipitation and potential evapotranspiration in the east-northeast of Argentina. Since rain-fed agricultural production is one of the most important economic activities in the study region, this analysis was focused on the impact of the precipitation distribution on soil water storage.

One aspect to study the precipitation frequency is through the analysis of dry spells. Taking into account the crop requirements and water losses in soil, a threshold of 5 mm was used for the accumulated precipitation of two consecutive days, below which a rainy day was considered as part of the dry spell. Besides, dry spells longer than 15 days were analysed because of the relevance of the impact over soil water storage.

The region of study is characterized by northeast-southwest gradient in accumulated precipitation and east–west gradient in winter long sequences. Seasonal analysis of probability and severity of long sequences and return period of 15 days threshold implied higher and more frequent precipitations in summer whereas the opposite was found in winter. In addition, western stations presented the highest probability of long dry sequences and severity and lower accumulated precipitation of the region of study, representing a source of vulnerability for the agriculture activity.

Under agricultural production processes, multiple variables act in continuous interaction, spatially and temporally. In soil-atmosphere system each property is not an isolated event, but is a function of some of its components interacting together with others. In this sense, soil water storage not only responds to precipitation distribution but also to evapotranspiration. Therefore, soil water storage presented wetter conditions during winter because evapotranspiration is lower than precipitation while higher values of precipitation are below evapotranspiration during summer generating drier conditions in soil. It was pointed on the relevance of water recharge during autumn which is possible in the study region because of high values of precipitation whereas evapotranspiration is lower, comparing to summer time.

Several studies showed progressive increase in precipitation throughout the lasts decades in the region of study, displacing the agriculture border westward. This change was accompanied by an improvement in technology and adaptation strategies. However, decadal variability may represent another source of vulnerability for the western stations, where changes in land use where recently applied.

In the decadal analysis, specific seasons and stations in particular decades were identified where soil water storage was influenced by the amount or frequency of precipitation. For example, in the southwest of the region, between 10 and 25% more (less) cases under OM occurred during winter in the decade 1990 (2000), related to the lower (higher) occurrence of long sequences. In general, the decade of 1970s showed homogeneous spatial behaviour whereas higher spatial variability characterized the other decades.

This study showed a concordance between the amount and frequency of precipitation. The decadal analysis suggested that soil water storage responds to one variable or the other depending on the magnitude of the anomalies. Additionally, the impact of dry spells depends on the crop and the time of the year, being flowering-fructification the more sensible period for the crops to the scarce of water. Long dry sequences during flowering-fructification stages severely influence the yield of summer crops which are also limited by high values of evapotranspiration exceeding precipitation. During autumn, the harvest of summer crops is carried out. Hydric requirements for winter crops are satisfied by water storage produced during autumn and winter precipitation, when sowing and vegetative growing occurs. When precipitation exceeds evapotranspiration in February, it contributes to water recharge. Thus, the scarce of precipitation during these seasons can limit growing stages of winter crops. Finally, flowering-fructification of winter crops takes place during spring, constituting critical months regarding available water in soil. These results constitutes a starting point for the analysis of the changes on precipitation distribution and how they impact soil water storage which contributes to the design of strategies of adaptation to eventually attenuate the vulnerability of the agriculture production.

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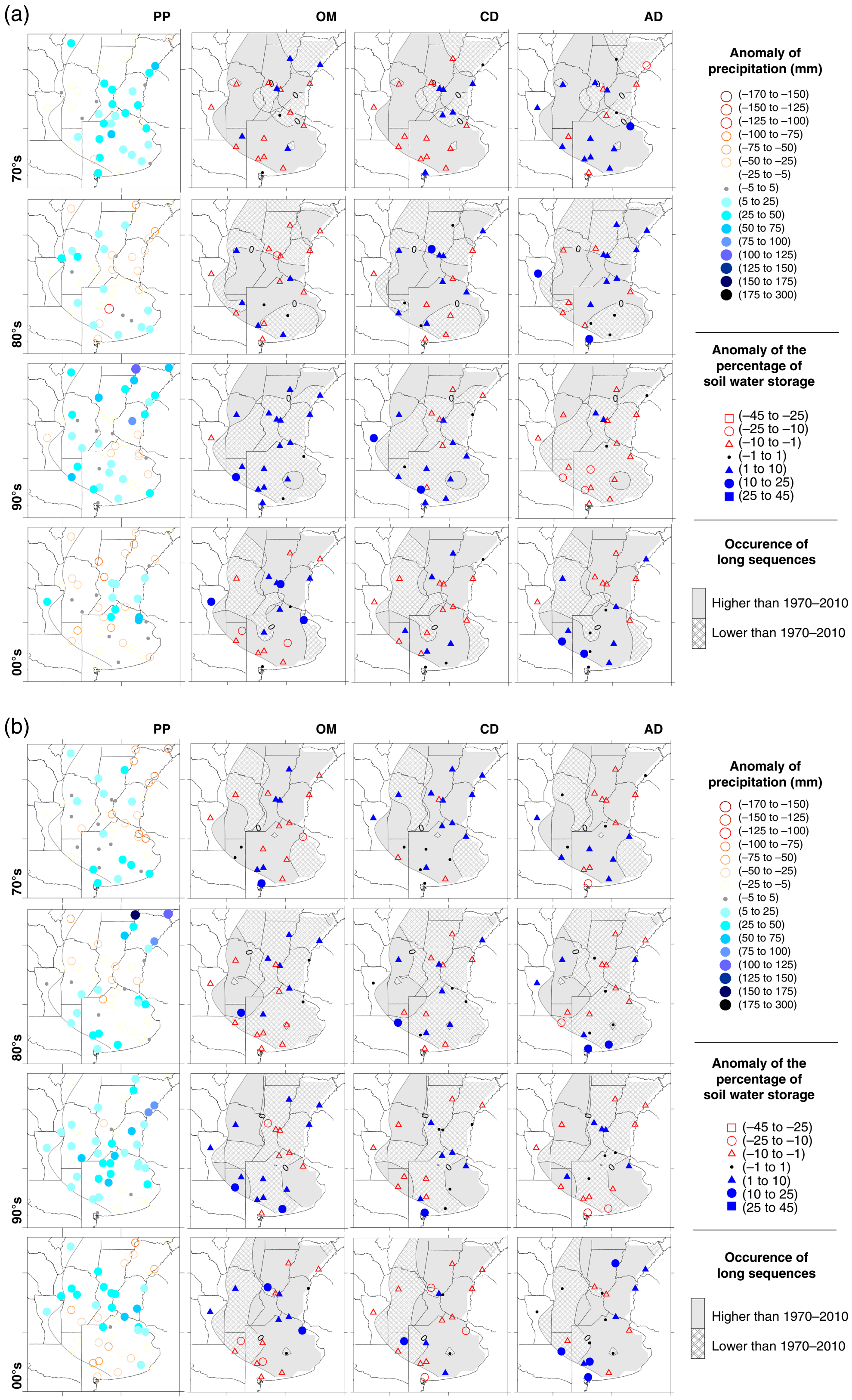

Figure 7. (a) In each station: anomaly of seasonal accumulated precipitation (PP, left panel) and anomaly of the percentage of cases under each water storage category, per decade, for summer. In shading, if the occurrence of long sequence of the decade is higher or lower than the occurrence in the whole period. (b) Same as (a), for autumn. (c) Same (a), for winter. (d) Same as (a), for spring. [Colour figure can be viewed at wileyonlinelibrary.com].

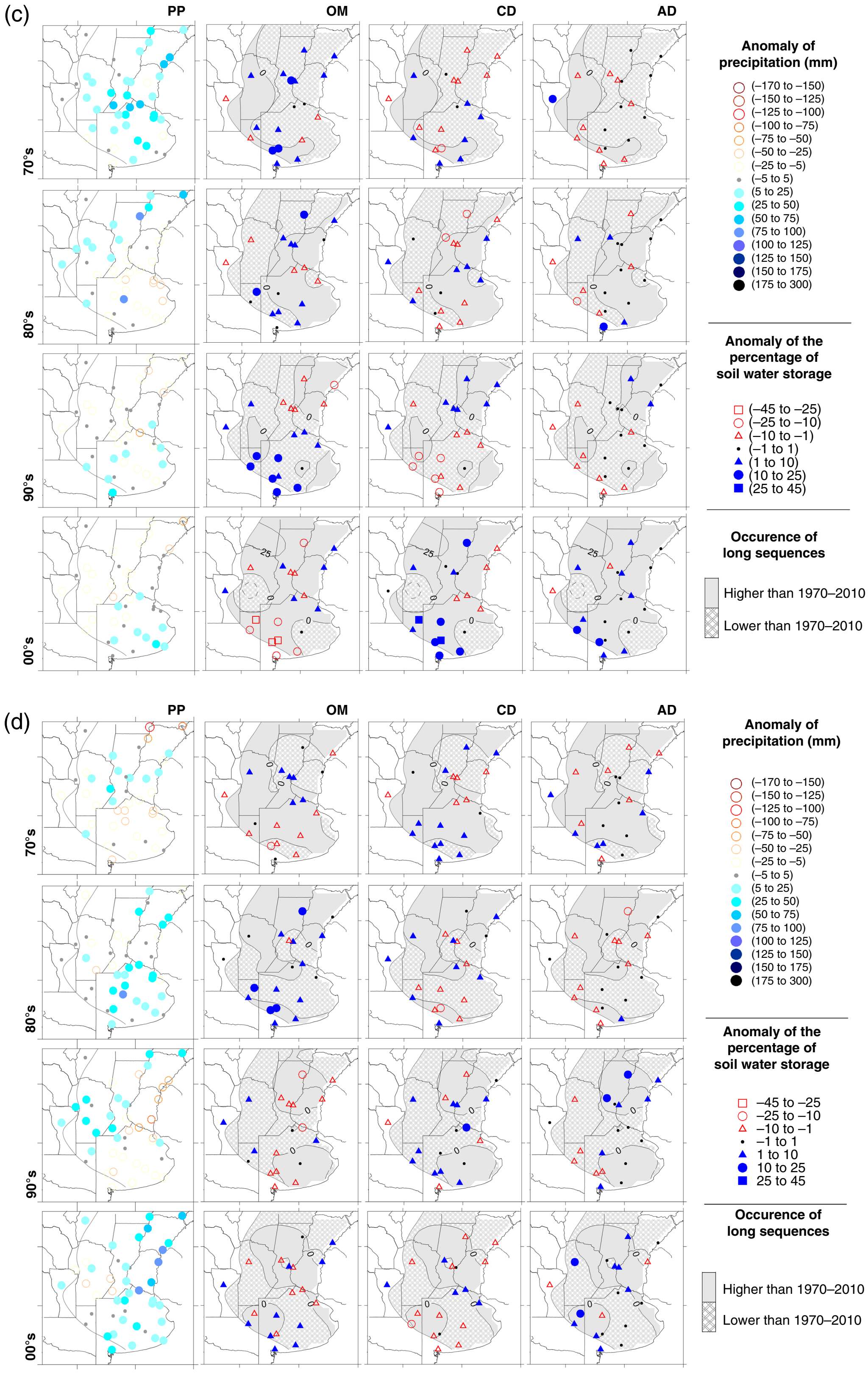

Figure 7. continued

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