Prediction of seasonal water-table fluctuations in La Pampa and Buenos Aires, Argentina

Raúl Tanco · Eduardo Kruse

Abstract The fluctuation of the water table east of La Pampa province and northwest of Buenos Aires province, Argentina, influences agricultural production in the region because it is closely related to the alternation of dry and wet periods. Sea-surface temperature (SST) anomalies have been used as predictors to forecast atmospheric variables in different regions of the world. The objective of this work is to present a simple model to forecast seasonal rainfall using SST distribution in the Pacific Ocean as a predictor. Once the relationship between precipitation and water-table fluctuations was established, a methodology for the prediction of water-table fluctuations was developed. A good agreement between observed and predicted water-table fluctuations was found when estimating water-table fluctuations in the summer and autumn seasons.

Résumé Les fluctuations de la nappe à l'est de la province de La Pampa et au nord-ouest de la province de Buenos Aires (Argentine) influence la production agricole de la région parce qu'elle est étroitement liée à l'alternance de saisons sèches et humides. Les anomalies de la température de surface de l'océan (SST) ont été utilisées comme prédicteurs pour prévoir les variables atmosphériques dans différentes régions du monde. L'objectif de ce travail est de présenter un modèle simple de prévision des précipitations saisonnières en utilisant comme prédicteur la distribution des SST dans l'Océan Pacifique. Une fois que la relation entre les fluctuations des précipitations et celles de la nappe a été établie, une méthodologie de prédiction des variations de la nappe a été mise au point. Un bon accord entre les variations de la nappe observées et celles prédites a été trouvé pour les estimations des variations de nappe en été et en automne.

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R. Tanco · E. Kruse (✉)
Universidad Nacional de La Plata,
Paseo del Bosque (1900), La Plata, Argentina
e-mail: kruse@fcaglp.edu.ar
Fax: +54-221-4236591

Resumen La fluctuación del nivel freático al este de la provincia de La Pampa y al nordeste de la de Buenos Aires (Argentina) repercute en la producción agrícola de la región, ya que está íntimamente relacionada con la alternancia de períodos secos y húmedos. Se ha utilizado las anomalías de la temperatura superficial del mar (TSM) para predecir las variables atmosféricas en diferentes áreas del mundo. El objetivo de este trabajo es presentar un modelo sencillo para pronosticar la precipitación estacional por medio de la distribución de TSM en el Océano Pacífico. Una vez establecida la relación entre la precipitación y las fluctuaciones del nivel freático, se desarrolló una metodología para predecir las fluctuaciones de éste. Se obtuvo un buen ajuste entre las fluctuaciones predichas y observadas del nivel freático en las estaciones de verano y otoño.

Keywords Chacopampeana plain · forecast · sea-surface temperature · water table · groundwater-level fluctuations · agriculture

Introduction

The economic and social development east of La Pampa province and northwest of Buenos Aires province, Argentina, is influenced by the availability of water resources and its seasonal variability, which determine agricultural production. The most noticeable impacts in this region, located in the Chacopampeana Plain, are closely related to the alternation of dry and wet periods. In the hydrologic system, there is a strong relationship between atmospheric processes and the depth of the water table. Since the depth of the water-table is related to variations in precipitation, a methodology was developed to predict its pattern of fluctuation.

Short-term climatic forecasts have been of great interest for a few years (Ropelewski and Jones 1987; Lau and Shew 1988; Moura 1994). Their importance lies in the applicability of the forecasts to agriculture (i.e. crop yield), water resources (i.e. river flows), and other activities. Although many improvements have been achieved in data acquisition and model development, these must be used with care.

Rainfall forecasts have been performed using the sea-surface temperature (SST) distribution in the Pacific and

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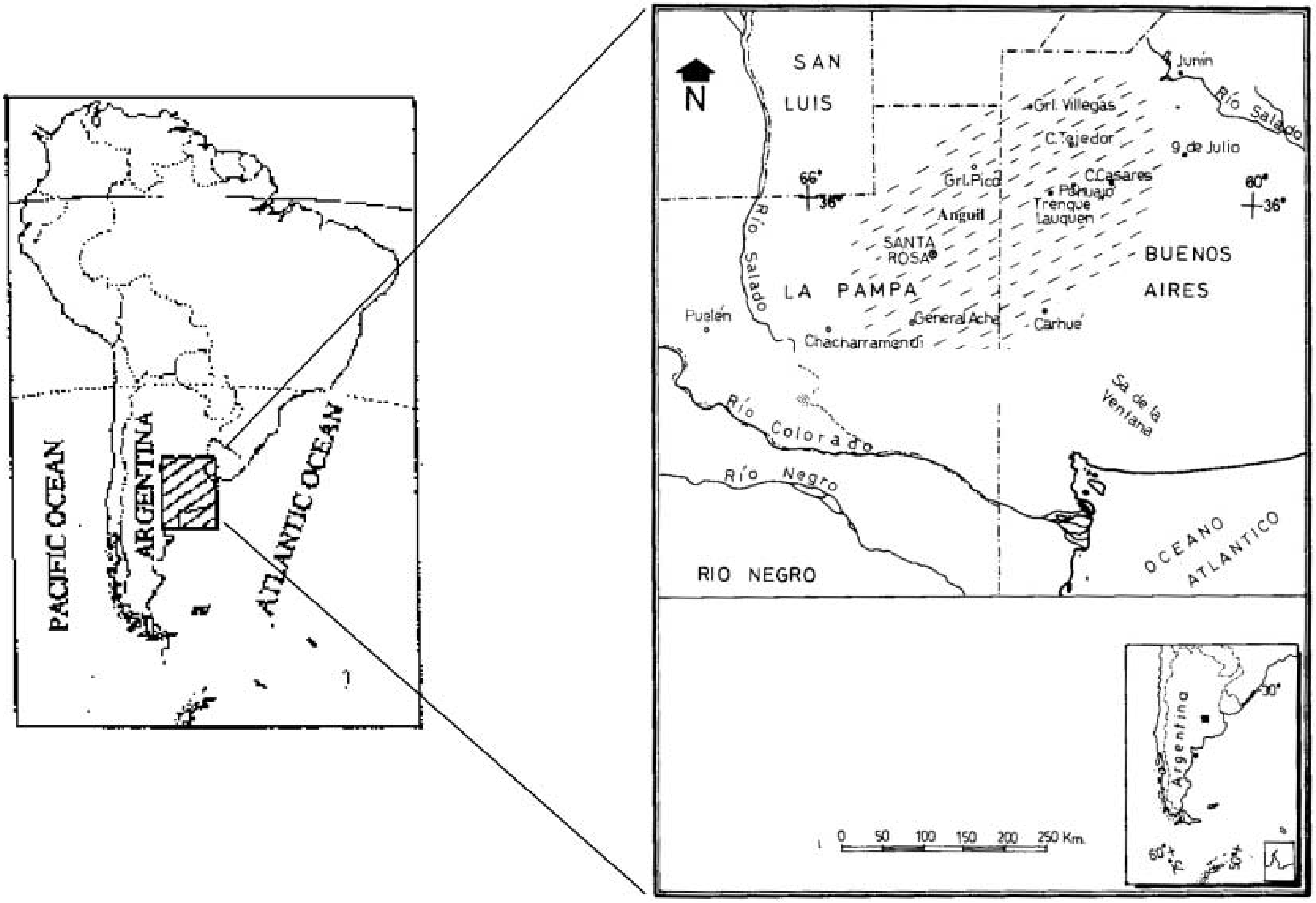

Fig. 1 Location of the study region

Atlantic Oceans as predictors. Several works have shown that a strong relationship exists between SST anomalies and patterns of rainfall and temperature in different regions around the world (Barnett 1981; Ropelewski and Halpert 1987, 1989) and that these can be applied in order to mitigate economic impacts (Cane et al. 1994; Flamenco and Berri 1996). An anomalous warming in the tropical Pacific Ocean usually produces wetter-than-normal conditions in the eastern portion of Argentina, southern Brazil, and Uruguay (Tanco and Berri 1994a).

Scope

The scope of this work is to develop a simple methodology to estimate the fluctuation of the water table in La Pampa province and in Buenos Aires province, Argentina. A forecast of seasonal rainfall is produced, using the SST anomalies in the Pacific Ocean as predictors. Then, using that forecast, and based on the relationship between rainfall and water-table level, the prediction of water-table fluctuations is generated.

A good forecast of fluctuations of the water table, generated some months in advance, could be an important tool that would help to mitigate the impact of extreme events like droughts and floods.

General Features

The Chacopampeana Plain is very extensive, covering an area of approximately 1 million km^2. It contains subregions with different hydrological features, among which are the eastern part of La Pampa province and the northwestern part of Buenos Aires province (80,000 km^2). The location of the study region is shown in Fig. 1. The mean annual rainfall is about 750 mm and the mean temperature is 16 °C. The rainfall pattern in the region consists of alternating dry and humid periods, with the first half of the century being drier than the second.

The main physical features of the plain are its low topographic slope, about 0.1 m/km, the lack of a drainage network, and the presence of permeable sediments at the surface. The landscape can be differentiated into minor topographic forms that are important hydrologically. They include slightly noticeable elevations alternating with depressions that are in the form of soft, somewhat aligned crinkles and represent typical paleodune environments.

From a hydrogeological view point, the region is covered by recent, permeable, fine sands and silts forming the dunes in which several successive eolic cycles have

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been recognized. In the low, interdune areas, finer sediment with lower relative permeability has been found. On the surface of the dunes are sandy sediments that lie over silt containing varying proportions of sand and clay, and usually calcareous materials known as "sedimentos pampeanos" (Kruse et al. 1993).

Data

Monthly rainfall data from Anguil station (Fig. 1) were used. The data were provided by INTA (Instituto Nacional de Tecnología Agropecuaria), covering a period from 1950–1997. From the monthly values, four time series were generated. Each time series contains the total rainfall for a different season: summer (December, January, and February); autumn (March, April, and May); winter (June, July, and August); and spring (September, October, and November).

For example, the first time series consists of total rainfall for the summer season from 1950–1997. Before the analysis, all the rainfall data were converted to anomalies, which was done by subtracting the corresponding historical mean-seasonal rainfall from each value in the series. Monthly values of SST were obtained from NOAA (US National Oceanic and Atmospheric Administration) (Reynolds 1988; Reynolds and Marcise 1993), covering the period 1950–1997, and the data were distributed in a regular grid with a spatial resolution of $2\times2°$.

Water-table data were provided by INTA, covering the period from 1973–1996. For this study, one representative observation point (well), located in Anguil, was chosen. Seasonal values for water-table change were calculated as follows: each value was calculated as the difference in the water table between the beginning and the end of that season. For example, the winter water table was calculated as the level of the water table in August minus the level in June.

Methodology

The methodology used in this work is very simple, as a first step in the evolution of more complicated models which could be developed in the future. Several computational experiments were carried out in order to determine the possibility of predicting seasonal rainfall in the eastern part of La Pampa province and in the western part of Buenos Aires province using SST as a predictor.

To define the strength of the relationship, the correlation coefficient between the SST time series at each grid point in the ocean and the rainfall time series was computed. This coefficient measures the linear-relationship strength between variables. A value close to one means that the variables are strongly correlated, so if the value of one of the variables is known, the value of the other variable could be predicted. A value close to zero means that the variables are not linearly related. Although this method is very simple, it provides an initial estimate of the predictability of seasonal rainfall and seasonal water-table change.

The analysis was carried out using software called CLIMLAB (Tanco and Berri 1994b). In each experiment, the correlation coefficient between the seasonal rainfall time series and the SST time series for each grid point in the ocean was calculated.

The results are shown as correlation maps, where regions in the ocean with the highest correlation coefficient with the rainfall time series can be identified. This methodology was repeated using different rainfall seasons and different SST periods as predictors. Once the regions in the ocean with the highest correlation coefficients were identified, a spatial average for that region was calculated for each year. Thus, two time series were obtained, with Vp being the total rainfall at Anguil station for a given season and Vt being the spatial average of SST for a given period. The regression parameters were computed for the equation $Vp=a\times Vt+b$, where a and b are the slope and the intercept of the linear model, respectively. Using these parameters, a time series of estimated rainfall was calculated and compared with the observed rainfall data.

To measure the relationship between estimated and observed rainfall, a contingency table with three categories (terciles) was used. The categories were calculated, ordering each time series in ascending order and dividing them in three parts of equal length. All the data in the first third correspond to the below-normal rainfall category. The data in the second third correspond to the near-normal rainfall category, and the last third correspond to the above-normal rainfall category.

When both values, estimated and observed, fall in the same category for a given year, the forecast is said to be correct. This is done for all the years in the period analyzed, and then the percentage of correct forecasts was calculated. The best season to forecast rainfall is identified as that with the highest percentage of correct forecasts. Once the best season to forecast rainfall was found, the same procedure was applied to predict seasonal water-table change based on predicted seasonal rainfall.

Results

The rainfall season with the highest probability of being predicted is DJF (December, January, and February), using as predictor the mean SST value in the region called Niño3 in the Pacific Ocean (90–150°W; 5°S–5°N). The best correlation was found using the average August–September SST to predict total rainfall in the period DJF. The correlation coefficients computed are statistically highly significant, as shown in Fig. 2.

Table 1 shows the relationship between observed and predicted total rainfall using three categories: below normal (B), near normal (N), and above normal (A). The table is statistically significant at a 96% confidence level. When observed rainfall falls in the B category, in 62.5%

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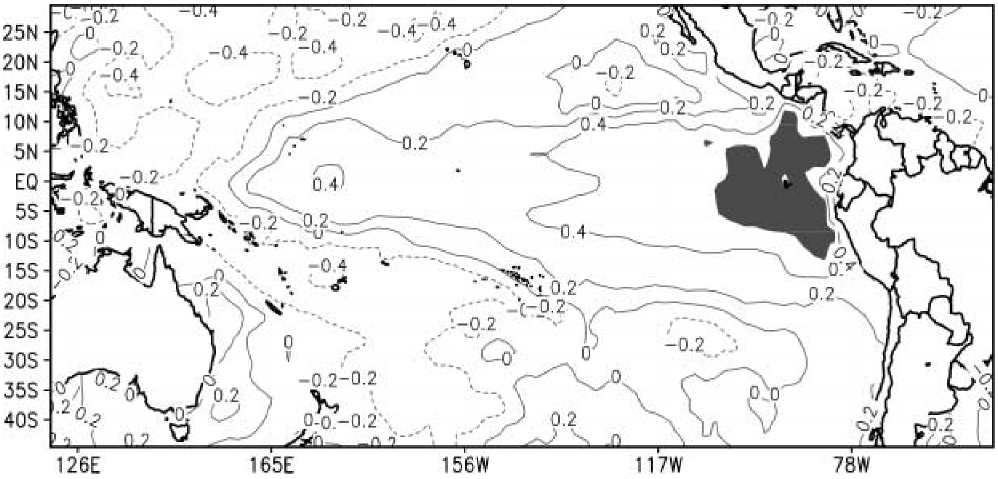

Fig. 2 Correlation coefficients between the SST average for August–September (*n*th year) and total seasonal rainfall in La Pampa for the period December–January–February [(*n*+1)th year]. *Shaded region* has values above 0.6

Table 1 Relationship between observed and predicted total rainfall for the period DJF, using three categories: below normal (<195 mm), normal, and above normal (>280 mm)

Predicted	Observed		
	Below	Normal	Above
Below	10	2	2
Normal	5	9	3
Above	1	5	11

Table 2 Contingency table for observed and predicted variation of the water table for the period DJF. Percentage of correct forecasts is 58%

Predicted	Observed		
	Below (<–0.2 m)	Normal	Above (>0.3 m)
Below	4	3	1
Normal	3	4	1
Above	1	1	6

Table 3 Contingency table for observed and predicted variation of the water table for the period MAM. Percentage of correct forecasts is 62.5%

Predicted	Observed		
	Below (<–0.3 m)	Normal	Above (>0.3 m)
Below	5	1	2
Normal	2	5	1
Above	1	2	5

Table 4 Contingency table for observed and predicted variation of the water table for the period JJA. Percentage of correct forecasts is 37.5%

Predicted	Observed		
	Below (<–0.3 m)	Normal	Above (>0.3 m)
Below	2	2	4
Normal	3	4	1
Above	3	2	3

of the cases the predicted value falls in the same category, and in 6.2% of the cases it falls in the A category, giving an erroneous forecast.

When observed rainfall falls in the A category, in 68.7% of the cases the predicted value falls in the same category, and in 12.5% of the cases it falls in the B category. The percentage of correct forecasts is 62.5% (30 of 48). Figure 3 shows the percentage of correct forecasts considering, for each rainfall season, different two-month periods in the predictor side (SST). As mentioned above, DJF is the season with best predictability performance, while the remaining seasons show low predictability.

Using predicted summer rainfall (DJF), the fluctuations of the water table were estimated for the same season. Figure 4 shows the time series of the predicted and observed water-table fluctuations for the period DJF. The correlation coefficient between the time series is 0.8, which is statistically highly significant. Using predicted summer rainfall (DJF), the water-table fluctuations for the period MAM were also estimated. The correlation coefficient between the observed and predicted time series is 0.65, which is also statistically significant at a 95% confidence level, as shown in Fig. 5.

A low correlation coefficient was found when estimating water-table fluctuations in JJA from the DJF rainfall forecast. Results are summarized in Tables 2, 3, and 4 using contingency tables. The limits for the categories are negative when the water table deepens and positive if it becomes shallower. The correlation coefficient for the predicted and observed time series is much lower than in the previous cases, 0.2, as shown in Fig. 6.

Discussion

A characteristic of the flatland east of the La Pampa province and northwest of the Buenos Aires province is

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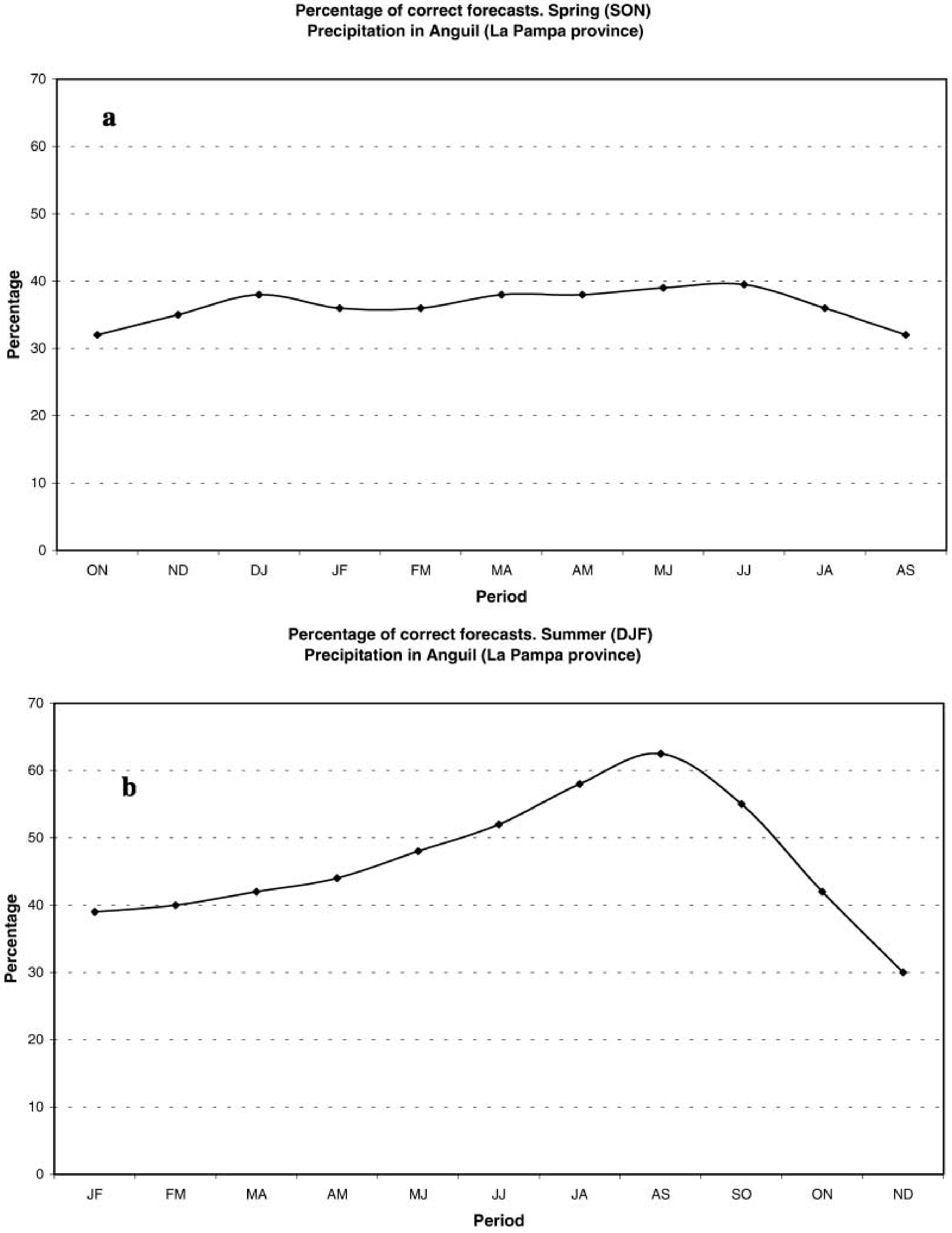

Fig. 3a–d Percentage of correct seasonal rainfall forecasts, considering different periods for the SST as the predictor

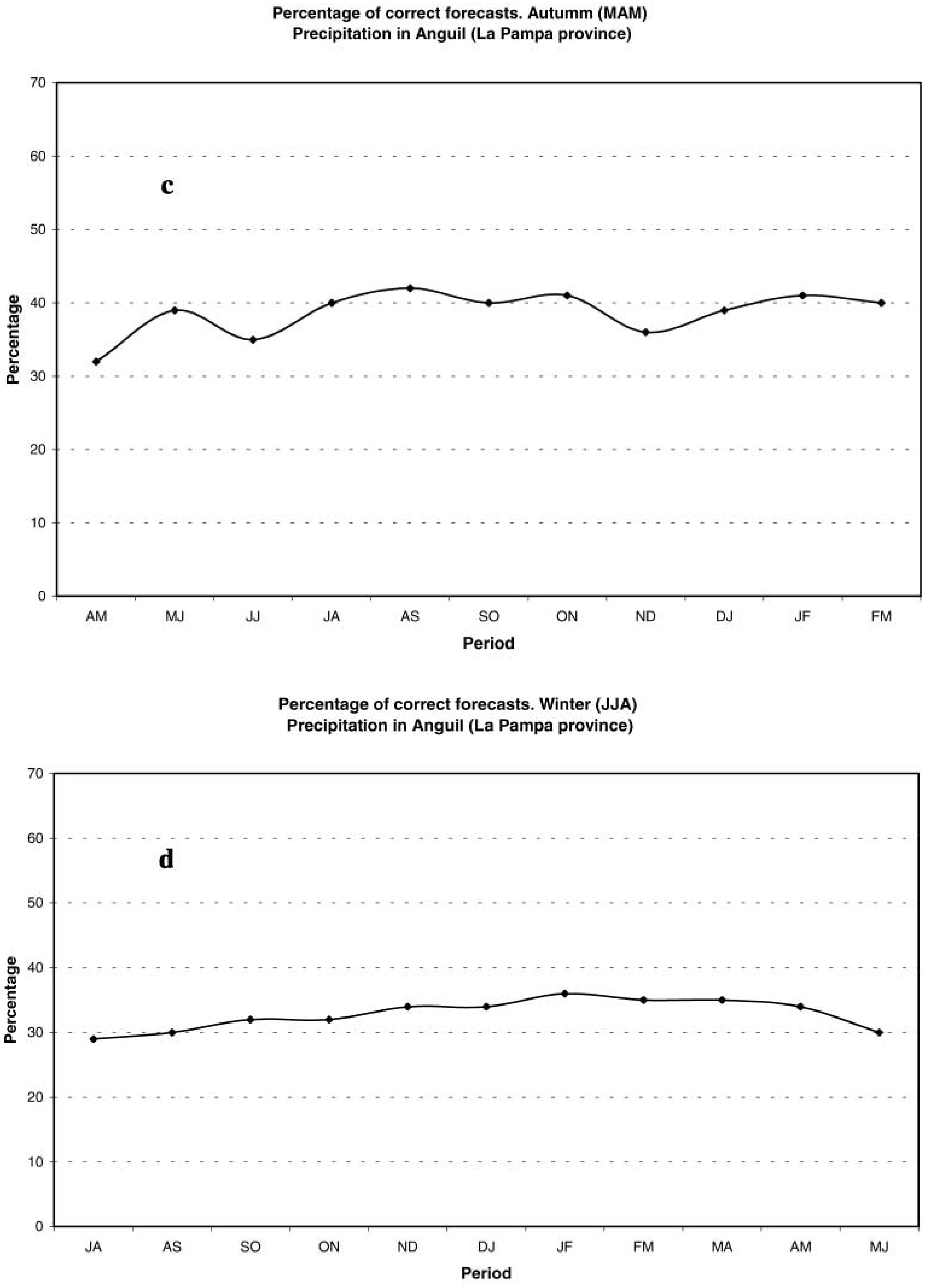

Fig. 3c–d Legend see page S. 343

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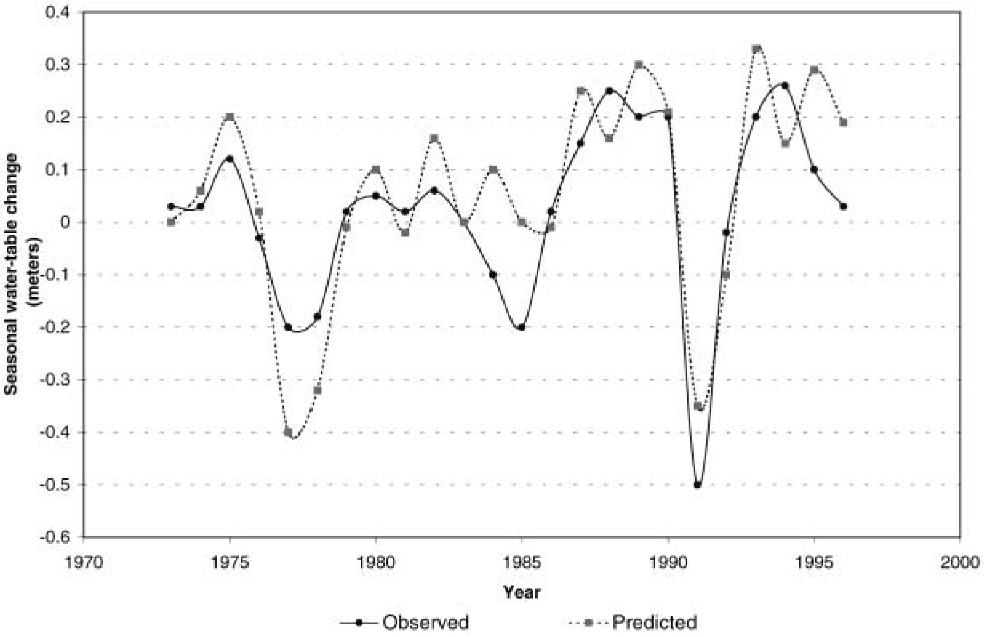

Fig. 4 Observed and predicted seasonal water-table change for DJF, using rainfall forecast for the period DJF as the predictor

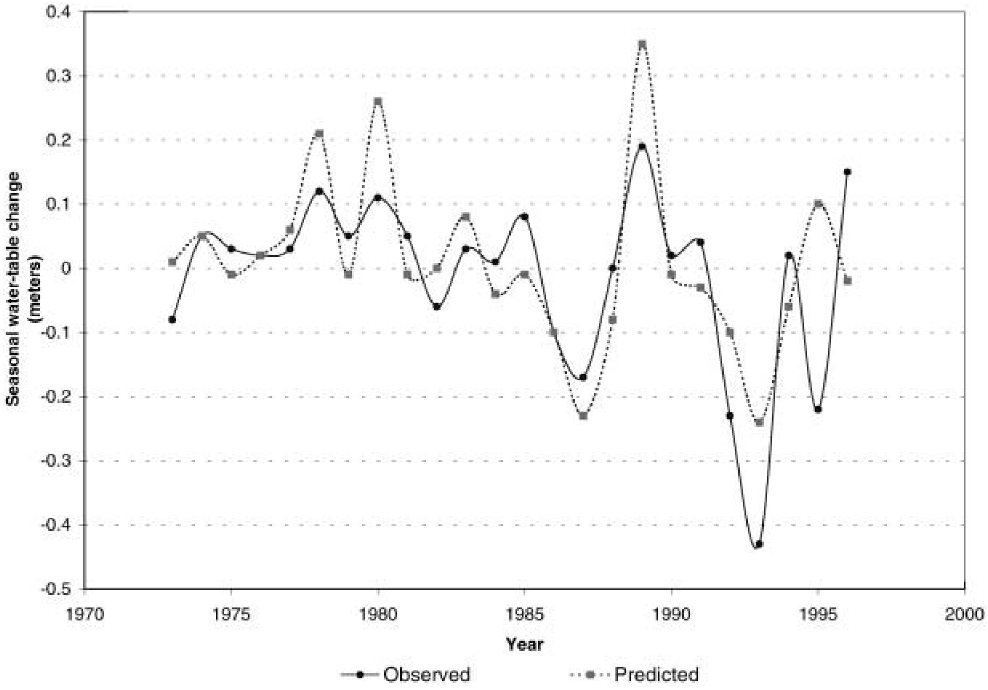

Fig. 5 Observed and predicted seasonal water-table change for MAM, using rainfall forecast for the period DJF as the predictor

its low morphological energy. As a consequence, the features that provide natural water storage (surface depressions and groundwater storage) and for the vertical movement of water (evapotranspiration and infiltration) dominate over those involved in the horizontal movement of water (surface and subsurface runoff). The fact that the water table is often very close to the surface indicates that surface waters and groundwater are strongly related, so that they should be treated as a hydrological unit. Therefore, the water-table fluctuations are important factors for the analysis and prediction of the behavior of the hydrological processes.

During a dry period, the water table deepens and the existing surface depressions are dry. Conversely, during a wet period, the water table reaches the surface in low areas. In this case the input of water to the hydrological system exceeds the output, resulting in an increase in the overflow from the system.

This region represents a productive agricultural system. Significant crops include wheat, corn, sunflower, and soybean. For agriculture there are two factors to consider regarding the influence of water-table fluctuations. One is linked to the operational problems and the other is related to the water requirements of the crops. In

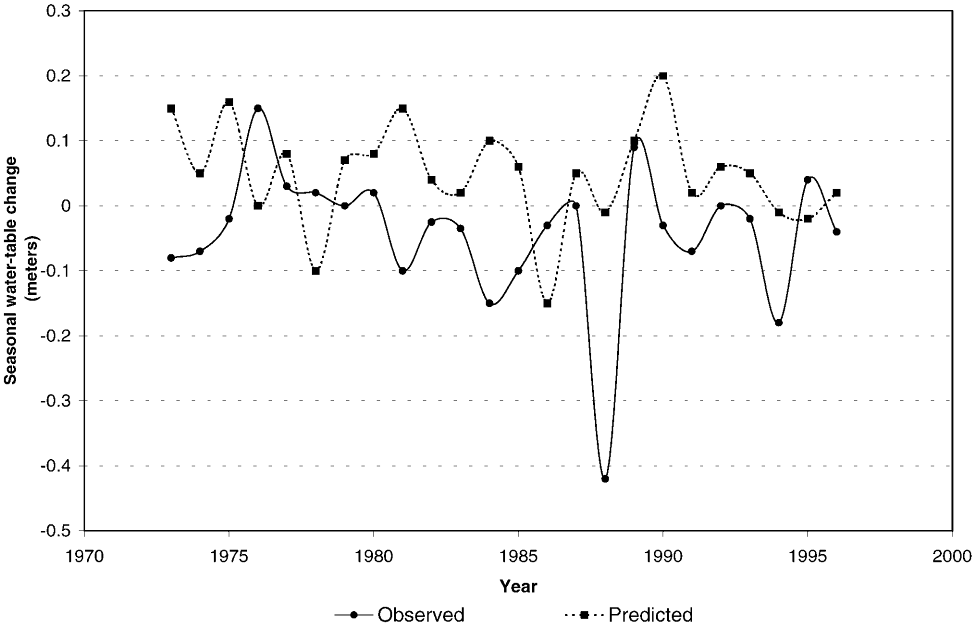

Fig. 6 Observed and predicted seasonal water-table change for JJA, using rainfall forecast for the period DJF as the predictor

humid periods the magnitude of the waterlogged areas associated with the shallow depth of the water-table directly affects sowing and harvesting operations. It determines the area available for cultivation. In a dry period the depressions are empty as the water table increases its depth. Under these conditions the soil-water content is low and may reach drought levels.

Analysis of the sowing and harvesting times in relation to water demand results in the establishment of critical seasons when the water-table fluctuations become significant for agricultural activities. The summer (DJF) is a critical season because wheat harvesting, sunflower and soybean sowing, and the higher demand for water by corn and soybeans occur then.

Although the methodology used in this study, linear regression, is very simple, it could give an approximation of the predictability of seasonal rainfall based on SST data. The forecast of the water-table fluctuations, generated in October, using August and September SST to predict the rainfall in December, January and February, would help to define a type of "hydrologic-alert service" for farmers and thus implement a means of diminishing possible damages derived from the floods or droughts.

Conclusions

A simple model was developed to predict seasonal fluctuations of the water table. First, the relationship between SST in the Pacific Ocean and seasonal rainfall in Anguil was established. The highest correlation coefficients were found to be between SST in August–September (average) and summer rainfall (December, January, and February) of the following year. Overall, the percentage of correct forecasts was 62.5%.

The rainfall forecast was then used to estimate seasonal fluctuations of the water table for three seasons. Good results were achieved when estimating the summer and autumn water-table fluctuations, but in the case of winter, estimates of water-table variations results were not good.

In order to improve the ability of the model to forecast water-table fluctuations, some other variables will have to be taken into account, such as evapotranspiration, air temperature, land use, antecedent moisture content, etc.

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