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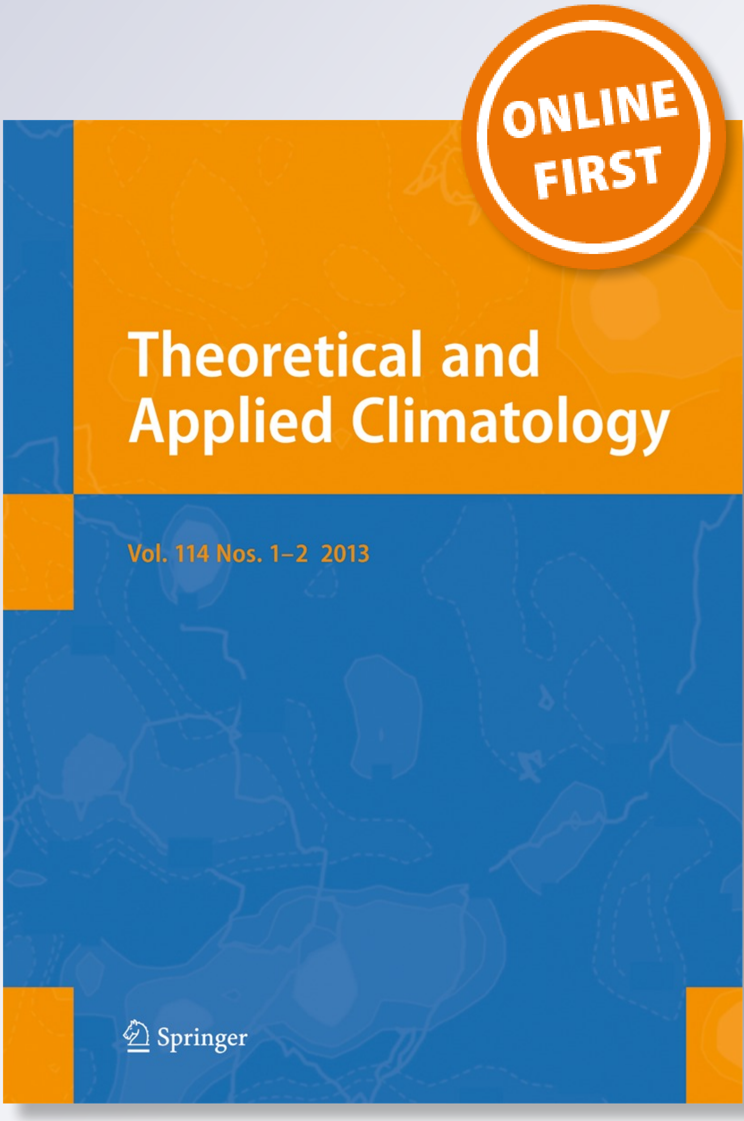
Theoretical and Applied Climatology

ISSN 0177-798X

Theor Appl Climatol
DOI 10.1007/s00704-013-1002-1



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ORIGINAL PAPER

Seasonal forecasts in the Sahel region: the use of rainfall-based predictive variables

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Received: 2 May 2013 / Accepted: 21 August 2013

Abstract In the Sahel region, seasonal predictions are crucial to alleviate the impacts of climate variability on populations' livelihoods. Agricultural planning (e.g., decisions about sowing date, fertilizer application date, and choice of crop or cultivar) is based on empirical predictive indices whose accuracy to date has not been scientifically proven. This paper attempts to statistically test whether the pattern of rainfall distribution over the May–July period contributes to predicting the real onset date and the nature (wet or dry) of the rainy season, as farmers believe. To that end, we considered historical records of daily rainfall from 51 stations spanning the period 1920–2008 and the different agro-climatic zones in Burkina Faso. We performed (1) principal component analysis to identify climatic zones, based on the patterns of intra-seasonal rainfall, (2) and linear discriminant analysis to find the best rainfall-based variables to distinguish between real and false onset dates of the rainy season, and between wet and dry seasons in each climatic zone. A total of nine climatic zones were identified in each of which, based on rainfall records from May to July, we derived linear discriminant functions to correctly predict the nature of a potential onset date of the rainy season (real or false) and that of the rainy season (dry or wet) in at least three cases out of five. These functions should contribute to alleviating the negative impacts of climate variability in the different climatic zones of Burkina Faso.

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1 Introduction

In rainfed agricultural systems—dominant in the Sahel region—timely detection of the onset date of the rainy season or growing period (OGP) is of utmost importance (Sivakumar 1988; Steward 1991; Ingram et al. 2002; Ziervogel and Calder 2003), because the OGP is significantly correlated to the length of the growing season representing one of the major factors controlling crop production in the region. Moreover, when sowing is carried out too early before the OGP, seeds and working time or labor's pay are lost because long dry spells kill the seedlings. In case of late sowing, the seedlings grow abnormally for three reasons: (1) decrease in soil temperature due to the cooling effect of the first rains, (2) reduction in soil nitrogen due to leaching and runoff, and (3) competitiveness between crops and weeds that set up after the first rains. Therefore, late sowing entails a reduction in crop production (Sarria-Dodd and Jollife 2001) that is translated into reduced food availability for both populations and livestock.

Another climatic factor that influences populations' life in the Sahel region is the seasonal rainfall amount that determines water availability for humans, animals, and plants. Le Houerou and Hoste (1977) have proven that any millimeter of rainfall contributes to produce around 1 kg/ha of consumable pasture. A poor seasonal rainfall amount causes water shortages for both animals and humans because water ponds and wells dry up earlier during the dry season (November–April). Even though the intra-seasonal rainfall distribution is the major factor that determines crop success or failure, farmers

Published online: 08 October 2013

recognize that the seasonal rainfall amount also plays a non-negligible role in crop production (Roncoli et al. 2002).

In the Sahel region, smallholder farmers perpetually face two fundamental questions: (1) when is the right period for sowing, and (2) what will be the nature (wet or dry) of the ongoing rainy season. These people have developed a range of empirical predictive indexes (Roncoli et al. 2002) to take advantage of the ongoing rainy season. Some of these indexes, regularly used, are the rainfall records (e.g., rainfall amount or number of rainy days over a given period, date, or amount of the first big shower of the season…) over the first months of the rainy season. But the accuracy of these empirical predictive methods remains unclear because few studies have so far explored this issue.

This study aims to assess the accuracy of using rainfall-based variables over May–July period to predict (1) the nature (real or false) of a potential onset date of the rainy season, and (2) the nature (wet or dry) of the ongoing season in Burkina Faso. We aim to clearly show whether the use of empirical seasonal predictions contributes to reducing the negative effects of climate variability on rural populations' livelihood.

2 Methodological approach

2.1 Dataset

In the Sahel region, long and complete daily rainfall records are rare, and when they exist, they are not publicly available. In the database of the national meteorological service of Burkina Faso, we found 51 stations with long (30 consecutive years or more) and complete daily records (Table 1). We considered these stations because they provide appropriate spatial coverage of the different agro-climatic zones in Burkina Faso as depicted in Fig. 1.

2.2 Climatic zones in Burkina Faso

We grouped the stations into different climatic zones (CLZ) based on the pattern of intra-seasonal distribution of precipitation. To that end, we followed the approach of Laux et al. (2008) that consists of relating each station to a principal component (computed on the records of the 51 stations from 1971 to 2000) according to the rule of the highest correlation coefficient value. For this analysis, the period 1971–2000 was considered because complete data are available at all the considered stations over this period. Finally, we applied a Kriging Method (Golden software 1994) to map the limits of each CLZ.

Assembling the stations into climatic zones is of utmost importance in this study since it downplays the likely biases in climate datasets at the station point scale, making statistical results more reliable and robust because of large size samples and facilitating the presentation of results. Furthermore, it takes into account the rainfall spatial variability that characterizes the climate in the Sahel region (Graef and Haigis 2001).

2.3 Definitions

2.3.1 The onset date of the rainy season

We defined OGP following the hybrid method of Ati et al. (2002) that combines different definitions in Table 2 because it yielded reasonable OGP for every year at all the stations considered in this study; it guarantees seeds germination and the survival of seedlings after sowing. According to that definition, the OGP is the date—from May first onward—at which 25 mm of rainfall is accumulated over a 10-day period and no dry spell of seven or more days occurs within the following 30 days. Therefore, the potential OGP is the date—from May first onwards—at which 25 mm of rainfall is recorded over a 10-day period. If a dry spell of 7 days or more is recorded within the following 30 days, the potential OGP is false, otherwise it is real. The frequencies of the real OGP, in the CLZs, were plotted to evaluate the chance of getting real OGP in case of a potential OGP.

The definition of the OGP has been a major concern for agro-climatologists, as demonstrated by the numerous attempts described in Table 2. Authors have tried to improve or complete previous definitions to better fit the reality on the ground. For instance, Ati et al. (2002) demonstrated that Sivakumar's (1988) method leads to late OGP in northern Nigeria, while Kowal and Kassam (1978) and Benoit (1977) do not take into account the effects of long dry spells representing a real threat for seedlings. The methods proposed by Jollife and Sarria-Dodd (1994) and Sarria-Dodd and Jollife (2001) considered the effects of dry spells, but the real OGPs were too late compared to the observed ones on the ground (Ati et al. 2002). To determine OGP in the Volta basin region, Laux et al. (2008) applied a fuzzy logic approach based on the definition of Stern et al. (1981) that does not yield an onset date for every year, due to the inflexibility of its constraints which have to be fulfilled simultaneously.

2.3.2 Wet and dry rainy seasons

According to Serra (1960), when a long time series of seasonal rainfall is ranked from the lowest to the highest value, dry, normal, and humid seasons, respectively, represent 35, 30, and 35 % of the total number of the seasons in the series. But in Burkina Faso, farmers distinguish two types of rainy season: (1) wet seasons that correspond to humid or normal seasons, and (2) dry seasons. Because we want to test the perception of these populations, the notions of wet and dry season were considered in this paper. Thus at each station, after ranking the

Table 1 Data availability at the considered stations

Station	Time series	Number of years	Station	Time series	Number of years
Aribinda	1954–2000	47	Koupela	1923–2000	78
Banfora	1922–2008	87	Kourouma	1960–2007	48
Barsalgo	1960–2000	41	Léo	1920–2008	89
Batié	1944–2000	57	Mahadaga	1962–2000	39
Bobo-Dioulasso	1920–2008	89	Manga	1949–2000	52
Bogandé	1948–2008	61	Mangodara	1961–2008	47
Boromo	1922–2008	87	Niangologo	1952–2008	57
Bourzanga	1963–2000	38	Nouna	1940–2000	61
Boulsa	1958–2000	43	Orodara	1954–2008	55
Dédougou	1922–2008	87	Ouagadougou	1920–2008	89
Diapaga	1930–2008	79	Ouahigouya	1923–2006	84
Diébougou	1923–2008	86	Ouargaye	1958–2008	51
Djibo	1951–2000	50	Pama	1949–2008	60
Dori	1923–2000	78	Po	1942–2008	67
Fada	1920–2008	89	Sapouy	1959–2000	42
Gaoua	1921–2008	88	Sebba	1956–2000	45
Garango	1947–2008	62	Séguénéga	1956–2006	51
Gayéri	1971–2008	38	Sidéradougou	1955–2008	53
Gorom–Gorom	1955–2000	46	Tansila	1963–2008	46
Guilongou	1956–2000	45	Tenkodogo	1926–2007	82
Houndé	1922–2008	87	Thiou	1965–2000	36
Kampti	1954–2000	47	Tougan	1933–2000	68
Kantchari	1943–2000	58	Tougouri	1953–2008	56
Kaya	1920–2000	81	Yako	1944–2006	63
Koudougou	1920–2000	81	Zabré	1954–2000	47
Kouka	1971–2000	30			

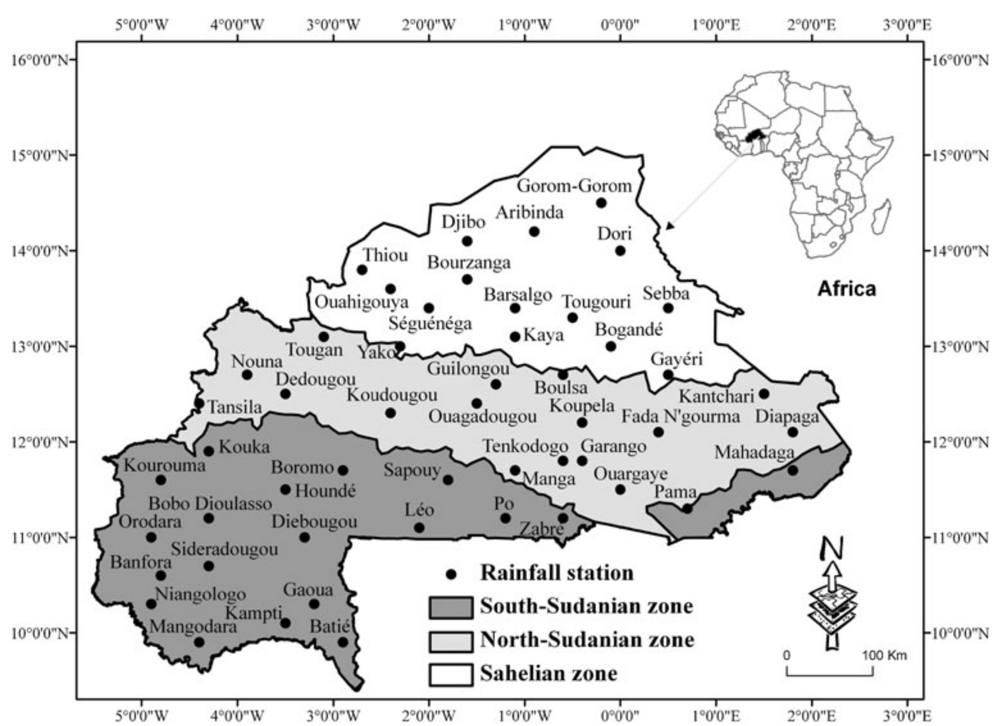

Fig. 1 Agro-climatic zones in Burkina Faso (after Fontes and Guinko 1995) and localization of the considered rainfall stations

Table 2 Different definitions of the onset date of the growing period in the Sahel region

Author	Criteria for onset	Criteria for false start
Kowal and Knabe (1972)	At least 25 mm of rainfall in 10-day period	Rainfall less than 0.5 PET in the next 10 days
Benoit (1977)	Rainfall at least equal to 0.5 PET over any period	A 5-dry-day period immediately following
Kowal and Kassam (1978)	At least 25 mm of rainfall in 10 days	Rainfall less than 0.5PET in the next 10 days
Stern et al. (1981)	At least 25 mm of rainfall within a 5-day period; the starting day and at least two over days in this 5-day period are wet	A 10-dry-day period in the following 30-day period
Sivakumar (1988)	At least 20 mm of rainfall within a 3-day period	A 7-dry-day period in the next 30 days.
Samba (1998)	At least 10 mm of water in the top 15 cm of the soil	Crops' water requirement less than 50 % in the 20 following days
Jollife and Sarria-Dodd (1994)	At least 25 mm of rainfall recorded on at least three rainy days over a 5-day period	A 7-dry-day period during the next 30 days
Omotosho et al. (2000)	At least 20 mm of rainfall on at least two rainy days in a 7-day period.	Soil water content less than 50 % of local crops water requirement in the following 3 weeks
Traoré et al. (2000)	At least 30 mm of water in the top layers of the soil	Soil water content below 15 mm in the next 20 days
Sarria-Dodd and Jollife (2001)	At least 25 mm of rainfall on at least three rainy days within a 6-day period	A 10-dry-day period in the following 40 days
Ati et al. (2002)	At least 25 mm within a 10-day period	A 7-dry-day period in the next 30 days

PET potential evapotranspiration

seasonal rainfall amounts from the lowest to the highest, the top 35 % of the series represents the dry seasons and the remainder (65 %) the wet seasons.

2.4 Discriminant analysis

The objective of this analysis is to derive, from rainfall-based predictors, very simple functions to discriminate between real and false OGP, and between wet and dry rainy season in each CLZ. In this case, the linear discriminant analysis is the best indicated statistical test since it provides simpler and accurate discriminant functions (Krzanowski 1988). We performed this analysis, in each CLZ, to identify (1) among 15 rainfall-based variables (Table 3) the best to discriminate between real and false OGP, and (2) among 21 other rainfall-based variables (Table 4) the best to discriminate between wet and dry rainy seasons. These variables were considered because they characterize the pattern of the rainfall distribution over the May–July period.

The accuracy of the functions (derived from the linear discriminant analysis) was assessed in light of their classification statistics. Indeed, when a linear discriminant analysis is performed, statistics are simultaneously generated to indicate the rate of the correctly classified individuals of the different

Table 3 Predictive variables to distinguish between real and false onset dates of the growing period

Variable	Description
DATE	Date of the potential onset of the rainy season (1=1 January, 366=31 December)
W_5	Number of wet days in the 5-day period preceding the potential onset
R_5	Amount of rainfall in the 5-day period preceding the potential onset
W_{10}	As W_5 but referring to 10 days
R_{10}	As R_5 but referring to 10 days
W_{15}	As W_5 but referring to 15 days
R_{15}	As R_5 but referring to 15 days
W_{20}	As W_5 but referring to 20 days
R_{20}	As R_5 but referring to 20 days
W_{25}	As W_5 but referring to 25 days
R_{25}	As R_5 but referring to 25 days
W_{30}	As W_5 but referring to 30 days
R_{30}	As R_5 but referring to 30 days
PW_5	Number of wet days in the 5-day period following the potential onset
PR_5	Amount of rainfall in the 5-day period following the potential onset

Table 4 Predictive variables to discriminate between the wet and dry rainy seasons

Variable	Description
$Date_5$	First day of the year with 5 mm of rainfall (1=1 January, and 366=31 December)
$Date_{10}$	As $Date_5$ but referring to 10 mm
$Date_{15}$	As $Date_5$ but referring to 15 mm
$Date_{20}$	As $Date_5$ but referring to 20 mm
$Date_{25}$	As $Date_5$ but referring to 25 mm
DW_{13}	Number of wet days in the 13th dekad of the year
DR_{13}	Rainfall amount in the 13th dekad of the year
DW_{14}	As DW_{13} but referring to the 14th dekad of the year
DR_{14}	As DR_{13} but referring to the 14th dekad of the year
DW_{15}	As DW_{13} but referring to the 15th dekad of the year
DR_{15}	As DR_{13} but referring to the 15th dekad of the year
DW_{16}	As DW_{13} but referring to the 16th dekad of the year
DR_{16}	As DR_{13} but referring to the 16th dekad of the year
DW_{17}	As DW_{13} but referring to the 17th dekad of the year
DR_{17}	As DR_{13} but referring to the 17th dekad of the year
DW_{18}	As DW_{13} but referring to the 18th dekad of the year
DR_{18}	As DR_{13} but referring to the 18th dekad of the year
DW_{19}	As DW_{13} but referring to the 19th dekad of the year
DR_{19}	As DR_{13} but referring to the 19th dekad of the year
DW_{20}	As DW_{13} but referring to the 20th dekad of the year
DR_{20}	As DR_{13} but referring to the 20th dekad of the year

Dekad: 10-day period, 13th decade: first dekad of May, 20th dekad: second dekad of July

groups. A higher rate (≥50 %) of well-classified individuals indicates an accurate linear discriminant function.

When a linear discriminant function is derived from a dataset, another independent dataset is required to validate its discriminatory power (Krzanowski 1988). For that reason, in each CLZ, the records of a randomly chosen station were withdrawn from the analysis to be used to validate the linear discriminant function that was derived from the records of the other stations.

3 Results

3.1 Climatic regions in Burkina Faso

This part of the study aims to divide Burkina Faso into different zones based on the pattern of intra-seasonal distribution of precipitation events. Thus, considering the daily rainfall data records of 51 stations over the period 1971–2000, principal component analysis using the variance–covariance matrix option led to nine principal components with eigenvalues greater than 1. The ensemble of these principal components explains 57 % of the daily precipitation variance in Burkina Faso.

After relating each station to the corresponding principal component according to the highest correlation coefficient rule, nine CLZs are identified in Fig. 2. Afterward, we perform a second principal component analysis, this time on each CLZ separately. The percentage of daily rainfall variance that is explained by the first principal component in each CLZ is reported in Table 5. These percentages vary between 47 and 58 %.

Following Camberlin and Diop (2003) and Laux et al. (2008), we assumed that the first principal components are representative of the seasonal characteristics in the CLZs. Thus, the graphs of 10-day moving averages of the values of the first principal components (Fig. 3) characterize the mean patterns of the intra-seasonal rainfall distribution that is marked by sudden and frequent downward trends.

3.2 Frequency of the real OGP

In Burkina Faso, the chance of the first potential OGP to be real is between 28 and 43 %. In other words, the first potential OGP is more likely to be false (Fig. 4).

3.3 Discriminant analysis

Based on the 15 discriminatory variables described in Tables 3, nine discriminant linear functions, to distinguish between the real and false OGP in the nine CLZs, are derived and reported in Table 6. The potential OGP (Date) is the discriminatory variable that is selected in all the CLZs to explain false or real OGPs, and its coefficients in the functions are positive while the last terms of the functions are negative.

The functions to discriminate between wet and dry seasons are reported in Table 7. The date of the first important shower (≥15 or ≥25 mm depending on the zones) is chosen as one of the best predictive variables in all the CLZs, and its coefficients in the functions are negative, while those of the other variables are positive. In addition, rainfall amounts per dekad are recurrently chosen as better discriminatory variables than variables representing the number of rainy day per dekad.

Regarding the dataset used to derive the functions, 51–76 % of the real OGP and 66–78 % of the false OGP are correctly classified in Table 8, while 60–74 % of the wet seasons and 64–78 % of the dry seasons are well predicted in Table 9. The total number of correctly classified events is 62–75 % and 64–75 %, respectively, in Tables 8 and 9. Almost the same discriminatory power of the functions is observed through the validation statistics in the tables. According to the values within the P column in the tables, the χ^2 test, performed to know whether it is worth using the derived functions, is significant at α=0.001. An example of the discriminatory power of the derived functions, at the station point

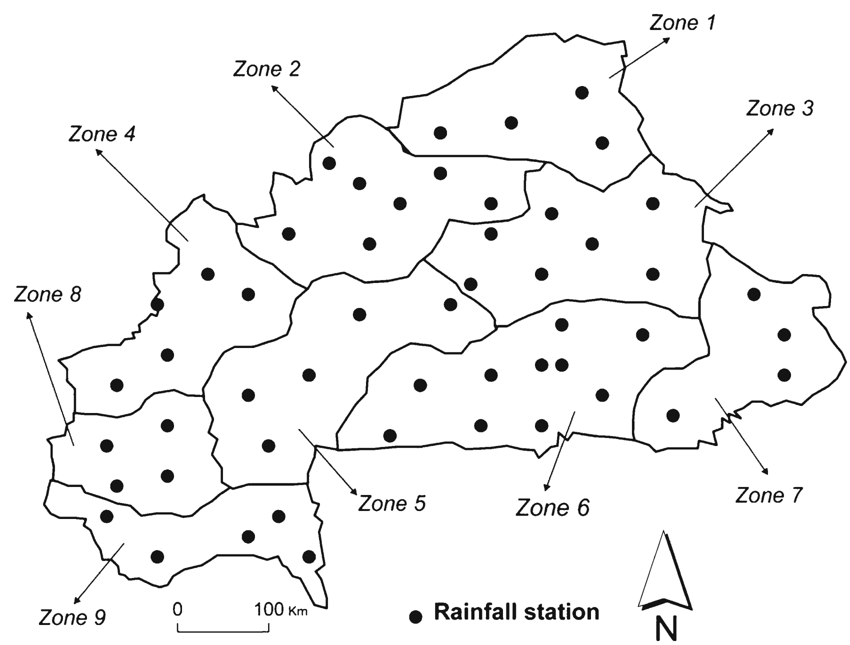

Fig. 2 Climatic zones in Burkina Faso based on the pattern of the intra-seasonal precipitation

scale, is shown in Fig. 5 where the well (empty circle) and the badly (black circle) classified individuals of each groups (false or real OGP) are represented. It appears that the well-classified events remain dominant at the station point scale.

4 Discussion

Based on the pattern of intra-seasonal distribution of precipitations, Burkina Faso can be divided into nine CLZs. According to the number (51) of stations considered, these results are more refined than those of Laux et al. (2008) who identified two CLZs in Burkina Faso using a total of 12 stations. According to Camberlin and Diop (2003) and Laux et al. (2008), the first principal component derived from the station records within a CLZ is representative of the mean pattern of rainfall distribution over time. This interpretation is confirmed in this study through the pretty high rate (47–58 %) of the daily rainfall variance that is explained by the first principal components in Table 5. The values in this table also indicate the level of spatial coherence between stations in the same CLZ since they represent the chance of getting a rainfall event extending over an entire climatic zone. Thus, following the hierarchical spatial scales of tropical weather phenomena proposed by Houze and Cheng (1977), in CLZs 3 and 9, where the first principal component explained less than 50 % of the daily rainfall variability, most of the rainfall events are associated with small scale individual convective cells (i.e., cumulus scale). In the other CLZs, rainfall events are mainly associated with mesoscale convective complexes and cloud clusters that yield rains more extended in space and lengthier in time (Cheng et al. 1996; Rickenbach and Rutledge 1998). Therefore, the spatial variability of the features of the rainy season (OGP, end and length of the rainy season) could be higher in zones 3 and 9 comparatively with the others. The causes of these differences between the CLZs are not well established, but they might be linked to differences in land cover, as echoed by Xue and Shukla (2003).

Table 5 Proportion of daily rainfall variance explained by the first principal component

Zone	Explained variance (%)
1	54
2	52
3	49
4	55
5	58
6	51
7	54
8	56
9	47

The positive coefficient of "Date" in the discriminant functions and the negative values of the last term of the functions indicate that an early potential OGP is likely to be false, while a late one is likely to be real because a positive record of the functions indicates a higher chance of a potential OGP to be real, and a negative record indicates the opposite. The frequency of the real OGP (Fig. 4) and the recurrence of long dry spells, marked by sudden downward trend of the intra-seasonal rainfall (Fig. 3), show that the real OGP is most of the time preceded by false OGPs in all the CLZs. Therefore, at the beginning of the rainy season, it is risky to sow after important rainfall events without taking into account any clue to forecast the climatic

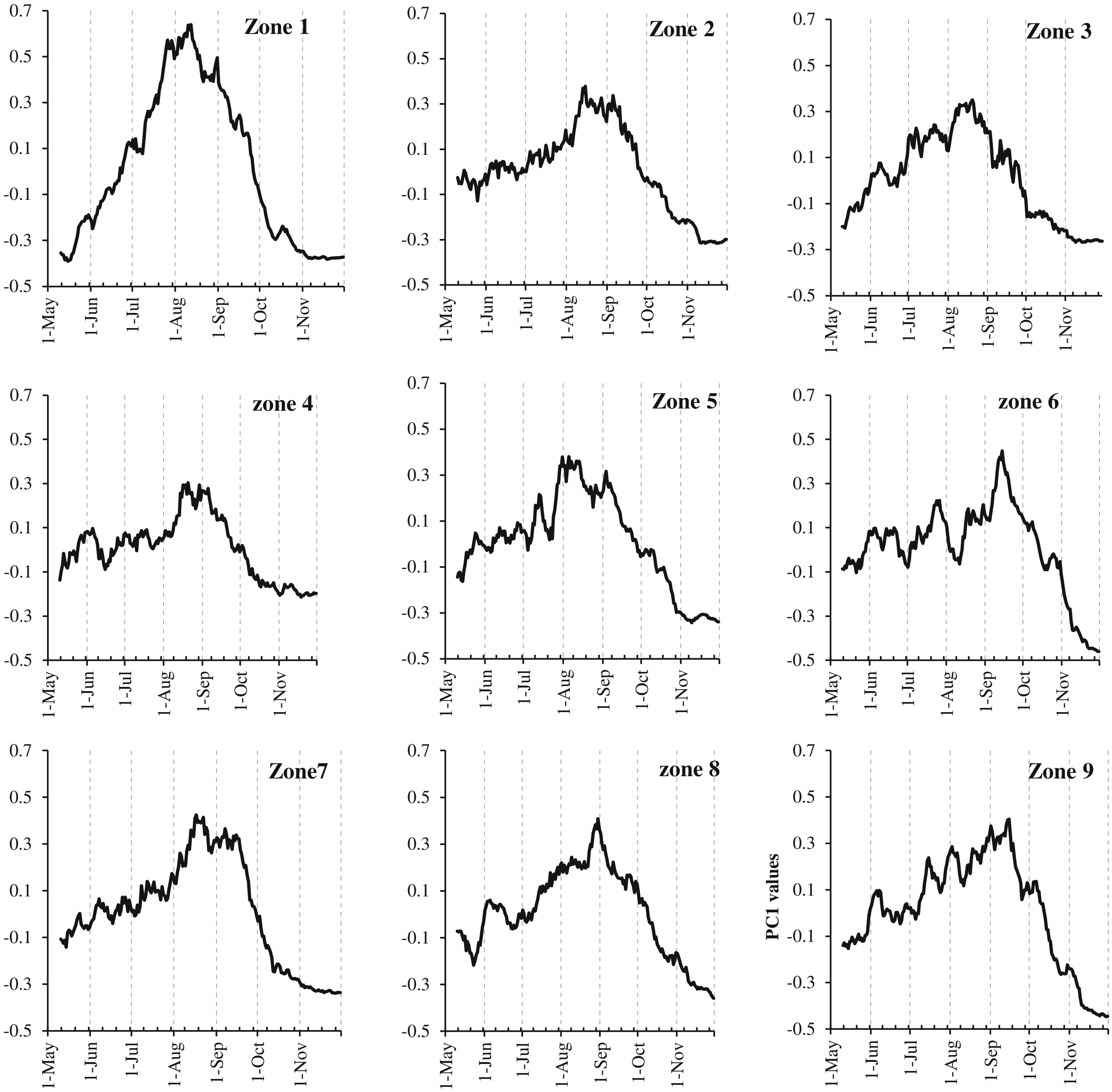

Fig. 3 Mean patterns of the intra-seasonal rainfall distribution in Burkina Faso, 1971–2000 PC1: the first principal component

events during the following days. This is in disagreement with Sarria-Dodd and Jollife (2001) who found that the first potential OGP is more likely to be real in the Sahel region. The difference is due to the inflexible criterion of "at least three rainy days"—considered by these authors in the definition of the OGP—that delays OGP comparatively with the date considered as OGP on the ground (Ati et al. 2002).

The derived functions to discriminate between the real and false OGPs are better than guessing according to the result of the χ^2 test (Table 8). Therefore, based on the date of the potential OGP (Date) and the rainfall records over the 30-day period prior and the 5-day period after the potential OGP, it is possible to distinguish between the false and real OGPs in at least three cases out of five (Table 8). Such findings are also echoed by Sarria-Dodd and Jollife (2001) at the station point scale in Burkina Faso and Mali. Moreover, Laux et al. (2008) find that the number of rainy days within the 5-day period after the potential OGP and the rainfall amount within the 25-day period prior to the potential OGP are the most interesting predictive variables to discriminate between the false and real OGPs in the zones identified within the Volta basin encompassing Burkina Faso and Ghana. Consequently, based

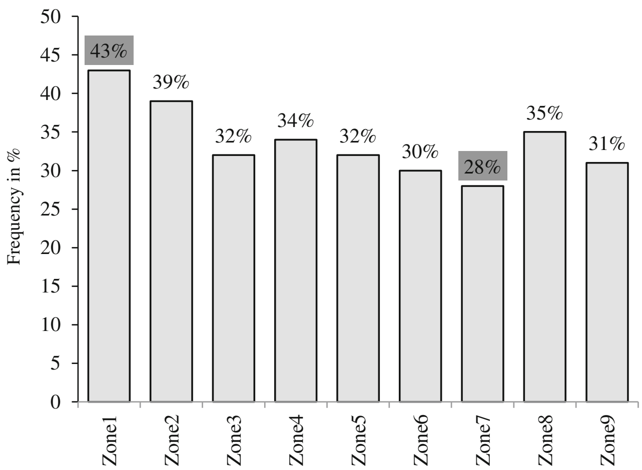

Fig. 4 Frequency of the real onset date of the rainy season in the climatic zones of Burkina Faso

on rainfall record over the May–July period, the real OGP can be predicted with some accuracy in the Sahel region. This is of great importance in agriculture since the loss of seeds, the waste of labor, and the late sowings can be considerably reduced. The assurance of getting successful sowings can prompt farmers to shift to improved seeds and early sowing, decisions which are critical to improve and stabilize crop production in rainfed agricultural system. Finally, the use of the functions to detect the real OGP could help alleviate climate change impacts since Laux et al. (2010) have proven that crop yields are likely to increase under climate change if sowing dates are appropriate.

The date of the first important shower of the season is a good discriminatory variable to predict the nature of the rainy season in all the CLZs (Table 7). Its negative coefficient in the functions indicates that when this event occurs early, the rainy season is likely to be wet, and when it happens late, the season is likely to be dry. That is because positive records of the functions indicate higher chance of getting a wet season, while negative ones herald dry season. But the better predictions are made when the date of the first important rain is combined with the rainfall amount of some dekads over the May–July period (Tables 7 and 9). Thus, based on the date of the first important shower of the season and the pattern of rainfall distribution over the May–July period, the nature of the ongoing season can be well predicted in at least three cases out of five (Table 9). Such predictions are of great importance in the Sahel region since they could prevent herders from losing their animals because of unexpected drought, leading to precocious detection of zones at risk of food insecurity and prompt implementation of appropriate mechanisms to assist vulnerable populations. That is because crop production, in some extent, depends on the nature of the rainy season, the seasonal rainfall being significantly correlated with both the number of rainy days and the end date of the growing period (Lodoun et al. 2013).

The functions to discriminate between the false and real OGPs and between the humid and dry seasons are powerful

Table 6 Linear functions to discriminate between the real and false onset dates of the rainy season in the climatic zones of Burkina Faso

Zone	Discriminant function
1	$0.033\text{Date}-0.079\text{R}_{10}+0.087\text{R}_{20}-6.064$
2	$0.033\text{Date}+0.069\text{R}_{10}+0.032\text{PR}_{5}-5.824$
3	$0.040\text{Date}+0.032\text{R}_{10}+0.439\text{PW}_{5}-6.528$
4	$0.039\text{Date}+0.192\ \text{W}_{30}-5.707$
5	$0.028\text{Date}+0.299\ \text{W}_{10}+0.030\text{PR}_{5}-4.390$
6	$0.044\text{Date}+0.029\text{PR}_{5}-5.714$
7	$0.042\text{Date}+0.030\text{PR}_{5}-5.642$
8	$0.055\text{Date}+0.044\ \text{W}_{30}+0.018\text{PR}_{5}-6.564$
9	$0.053\text{Date}+0.027\text{PR}_{5}-6.115$

Table 7 Linear functions to discriminate between the wet and dry seasons in the climatic zones of Burkina Faso

Zone	Discriminant function
1	$0.020\text{Date}_{20}+0.035\text{DR}_{14}+0.243\text{DW}_{17}+0.452\text{DW}_{18}+0.020\text{DR}_{20}+0.772$
2	$0.011\text{Date}_{25}+0.020\text{DR}_{14}+0.020\text{DR}_{17}+0.029\text{DR}_{19}-0.214$
3	$0.022\text{Date}_{25}+0.253\text{DW}_{14}+0.221\text{DW}_{15}+0.018\text{DR}_{16}+0.014\text{DR}_{17}+0.012\text{DR}_{18}+0.015\text{DR}_{19}+0.700$
4	$0.015\text{Date}_{25}+0.020\text{DR}_{14}+0.021\text{DR}_{17}+0.019\text{DR}_{19}+0.010\text{DR}_{20}-0.693$
5	$0.013\text{Date}_{25}+0.010\text{DR}_{14}+0.012\text{DR}_{15}+0.013\text{DR}_{17}+0.016\text{DR}_{19}+0.013\text{DR}_{20}-1.250$
6	$0.009\text{Date}_{25}+0.0125\text{DR}_{13}+0.012\text{DR}_{14}+0.011\text{DR}_{16}+0.013\text{DR}_{17}+0.014\text{DR}_{18}+0.016\text{DR}_{19}+0.018\text{DR}_{20}-2.631$
7	$0.028\text{Date}_{15}+0.015\text{DR}_{19}+0.024\text{DR}_{20}+1.546$
8	$0.026\text{Date}_{15}+0.017\text{DR}_{17}+0.014\text{DR}_{18}+0.016\text{DR}_{19}+0.012\text{DR}_{20}-0.204$
9	$0.049\text{Date}_{15}+0.018\text{DR}_{15}+0.016\text{DR}_{19}+0.010\text{DR}_{20}+2.894$

Table 8 Discriminatory power of the functions to predict the real and false onset dates of the growing season

Zone	Classification statistics				Validation statistics		
	P	Real OGP	False OGP	Total	Real OGP	False OGP	Total
1	0.000	76 %	67 %	70 %	70 %	65 %	66 %
2	0.000	66 %	75 %	72 %	54 %	67 %	64 %
3	0.000	75 %	66 %	68 %	68 %	74 %	72 %
4	0.000	66 %	72 %	70 %	83 %	58 %	66 %
5	0.000	64 %	72 %	70 %	78 %	67 %	70 %
6	0.000	66 %	75 %	72 %	88 %	59 %	66 %
7	0.000	68 %	78 %	75 %	65 %	74 %	72 %
8	0.000	51 %	70 %	65 %	74 %	56 %	62 %
9	0.000	54 %	66 %	62 %	52 %	79 %	72 %

Table 9 Discriminatory power of the functions to predict the wet and dry seasons

Zone	Classification statistics				Validation statistics		
	P	Wet season	Dry season	Total	Wet season	Dry season	Total
1	0.000	72 %	78 %	74 %	63 %	81 %	70 %
2	0.000	62 %	69 %	65 %	73 %	59 %	68 %
3	0.000	72 %	64 %	69 %	60 %	79 %	66 %
4	0.000	73 %	78 %	74 %	62 %	63 %	62 %
5	0.000	70 %	69 %	70 %	53 %	84 %	64 %
6	0.000	74 %	77 %	75 %	55 %	69 %	60 %
7	0.000	66 %	66 %	66 %	82 %	62 %	75 %
8	0.000	60 %	70 %	64 %	51 %	79 %	61 %
9	0.000	65 %	68 %	66 %	76 %	60 %	70 %

tools to reduce the negative impacts of climate variability in Burkina Faso, because (1) due to the simplicity of these functions people with low literacy level are able to use them, and (2) the discriminatory variables (daily rainfall records) are publicly available in rural areas. The determination of the requisite rainfall records merely requires a rain gauge that is so far the most commonly used meteorological equipment in the Sahel region, particularly in Burkina Faso, where most of the localities are endowed with at least one rain gauge. This is quite different from forecasting methods in use in the region that require climatic data such as upper-level wind speed (Omotosho 1990, 1992, 2008) or equivalent potential temperature of surface synoptic data (Omotosho et al. 2000) or sea surface temperatures, all of which are not publicly available.

Because of the high spatial variability of rainfall in the Sahel region (Sicot 1991; Graef and Haigis 2001), small scale seasonal predictions are useful to complete the regional or subregional seasonal predictions proposed by the African Centre of Meteorology Application for Development (ACMAD) and national meteorological services to assist end-users in better planning their activities since 1998. Therefore, the discriminant functions proposed in this paper are not intended to replace existing ones in the Sahel region but to help farmers make decision at the farm scale. Since each prediction method has its strength and weakness, and since the Sahel climate is very difficult to predict because of its great variability, a prediction based on several predictive methods might be better than the one based on one method.

The findings in this paper confirm that in the Sahel region, the rainfall distribution pattern at the beginning of the rainy season conveys indices that help forecast the real OGP and the nature of the rainy season. But according to the accuracy of the derived discriminant functions, the use of these functions cannot 100 % prevent farmers from suffering adverse effects of drought, particularly the effects of recurrent long dry spells within the rainy season, as shown in Fig. 3. That is why in addition to these predictions, complementary agricultural techniques aiming to alleviate the impacts of drought in rural areas (e.g., soil and water conservation methods and crop varieties tolerant to drought) remain very important and must be encouraged.

Under forthcoming climate change, the derived functions could still help farmers alleviate the negative impacts of climate variability on their livelihoods because of two reasons: (1) the type of datasets (the mixture of long records from several stations) used in the linear discriminant analysis, making the derived functions robust since these datasets are likely to encompass almost all the possible patterns of intra-annual rainfall, and (2) any change in rainfall patterns will be mainly translated into a change in the rainfall amount or in the number of rainfall day that represents the discriminatory variables in the functions. But if the climate change leads to a total change in the pattern of the intra-seasonal rainfall, then the derived functions will no longer be useful. That is why, in the future, it will be necessary to regularly check the accuracy of these functions over time.

5 Conclusion

In this paper, we investigated whether in Burkina Faso features of the ongoing rainy season can be predicted from the

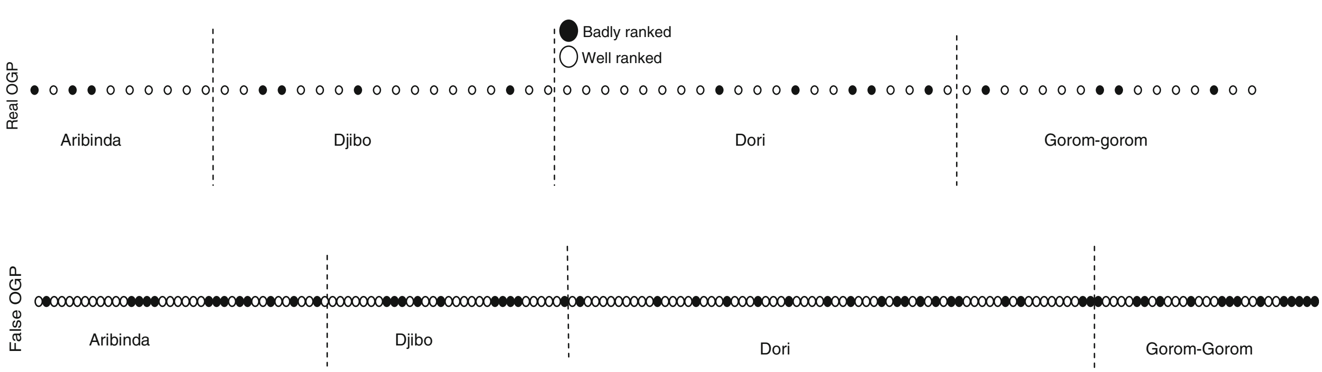

Fig. 5 Discrimination between real and false onset dates of the rainy season in the climatic zone 1

pattern of intra-seasonal rainfall over the May–July period. We found that the patterns of intra-seasonal rainfall at the beginning of the rainy season is a clue to accurately predict the onset date of the growing period (OGP) and the nature (wet or dry) of the rainy season. These forecasts might contribute to improving populations' life because their simplicity allows them to be broadly used to prevent waste of seeds and labor caused by recurrent false onset dates of the rainy season, and they can prompt farmers to adopt efficient agricultural practices such as improved seeds. In addition, they can enable herders to avoid losing their livestock due to unexpected droughts and assist policymakers and stakeholders in precocious identification of zones at risk of food insecurity for a timely relief. Consequently, the extension of these analyses to the other countries in the Sahel region is to be considered in the plans aiming to alleviate the negative impacts of climate variability on populations' livelihoods.

Acknowledgments This study was supported by: (1) African Climate Change Fellowship Program (ACCFP) managed by the global change System for Analysis, Research and Training (START) and (2) the "Community management of crop diversity to enhance resilience, yield stability and income generation in changing West Africa climates" (CODEWA) project managed by the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) under GTZ project number 07.7860.5-001.00. We are also thankful to the national meteorological service of Burkina Faso for the datasets.

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