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Changes in seasonal descriptors of precipitation in Burkina Faso associated with late 20th century drought and recovery in West Africa

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A B S T R A C T

Daily rainfall records of 39 stations spanning the different agro—climatic zones of Burkina Faso were analyzed to describe the evolution of five seasonal rainfall descriptors over time. The period from1941 to 2000, including the two most contrasted periods in the recent history of the Sahelian climate, i.e. the wet decades (1941–1970) and the dry decades (1971–2000), were considered. It was found that certain seasonal descriptors—namely total seasonal rainfall, number of rain-days and cessation dates of the rainy season—when aggregated into annual and national means manifested almost the same evolution pattern; while others, notably average rainfall per rain-day and onset date of the growing period, showed different patterns of evolution. It was concluded that the recent reduction in seasonal precipitation amount was related to a reduced number of rain-days in August and September, with precocious cessation of the rainy season as a consequence. However, all the seasonal descriptors showed recovery trends since the end of the 1980s, with the mean rainfall per rain-day, exhibiting the steadiest trend. But, the descriptors were more volatile during that recovery time according to the upward trends in their interannual variability. Importantly, the links between the seasonal descriptors and two sea surface

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temperature indexes were discussed in light of climate change impacts on rain-fed agriculture, the main source of food for the population of Burkina Faso. The results should be incorporated in alleviation strategies of climate change impacts in the Sahel region.

1. Introduction

In comparison with the other parts of Africa, semi-arid West Africa has witnessed the most outstanding climatic shift in the late 20th century, with a sustained 10–20% rainfall decrease and multi-year episodes of extreme drought, e.g. 1972–73 and 1982–84 (Hulme, 1992). While the decline in seasonal or annual total is well known, its intra-seasonal projection into descriptors of the "character of precipitation" (Trenberth et al., 2003) has, to date, not been documented. Consequently, we are unable to determine whether such changes, e.g. in the frequency or intensity of rainfall events, are consistent with expectations from anthropogenic climate change.

This paper aims to fill this void with the case study of Burkina Faso, where, in addition to elucidating possible mechanisms of climate change, understanding changes in the intra-seasonal precipitation patterns has practical value for farmers, the bulk of the population, depending on rain-fed agriculture. Indeed, various descriptors are used to characterize seasonal rainfall. Among them, based on the impact on crops productivity, farmers chose five in order of importance: (1) the onset date of the growing period, or rainy season, (2) the cessation date of the growing period, (3) the rainfall amount per rainy day, (4) the number of rainy days within the season, and (5) the total amount of precipitations (Ingram et al., 2002). However, the total amount of precipitations, the last descriptor, is the most studied (e.g. Camberlin and Diop, 2003; Dai et al., 2004; Diop, 1996; Giannini et al., 2003; Hulme et al., 2001; Nicholson, 2005) because of the widespread availability of monthly totals, and the ease of their processing. The others, while most important for climate change impact assessment in the agricultural domain, are less studied because the requisite daily rainfall data are rarely publicly available in sub-Saharan Africa. Under such conditions, climate change-related trends and their impacts on agriculture cannot be accurately assessed.

The goal of this study is to examine how changes in total moisture supply associated with natural variability or anthropogenic forcing may translate into intra-seasonal rainfall distribution patterns by looking at contrasted historical analogs for a tropical semi-arid region. Given the remarkable shift in total annual rainfall between the wet (1941–70) and dry (1971–2000) periods in the Sahel, this region is best placed and well indicated for such study. We analyzed changes in onset and cessation dates of the growing period, rainfall per rainy day, number of rain-days within the rainy season and seasonal rainfall in Burkina Faso (located within the Sahel region) to test whether: (i) changes in total annual rainfall translate into changes of equivalent direction and magnitude in the other rainfall descriptors and (ii) seasonal descriptors of rainfall are getting worst or better since the beginning of the drought period.

2. Data and methods

2.1. Station data selection

Long time series of daily rainfall records are scarce in Africa. A search for the largest set of locations with 60 consecutive years of daily rainfall records, i.e. two consecutive normal periods of the World Meteorology Organization (WMO), in Burkina Faso, led to the period from 1941 to 2000 for 20 stations (Table 1). This period is suitable for our purpose, as it straddles the West African 1970–1971 breakpoint between relatively wet pre-1971 (hereafter HP) and dry post-1970 (hereafter DP) conditions (Fig. 1B). However, the 20 stations do not homogeneously span the agro–climatic

Table 1
Daily rainfall time series considered at the station point scale.

Station	Data availability	Length of the data series in year
Aribinda	1954–2000	47
Banfora	1941–2000	60
Batié	1944–2000	57
Bobo-Dioulasso	1941–2000	60
Bogandé	1948–2000	53
Boromo	1941–2000	60
Dédougou	1941–2000	60
Diapaga	1941–2000	60
Diébougou	1941–2000	60
Djibo	1951–2000	50
Dori	1941–2000	60
Fada	1941–2000	60
Gaoua	1941–2000	60
Garango	1947–2000	54
Gorom-Gorom	1955–2000	46
Guilongou	1956–2000	45
Houndé	1941–2000	60
Kampti	1954–2000	47
Kantchari	1943–2000	58
Kaya	1941–2000	60
Koudougou	1941–2000	60
Koupela	1941–2000	60
Léo	1941–2000	60
Manga	1949–2000	52
Niangologo	1952–2000	49
Nouna	1941–2000	60
Orodara	1954–2000	47
Ouagadougou	1941–2000	60
Ouahigouya	1941–2000	60
Pama	1949–2008	60
Po	1942–2000	59
Sebba	1956–2000	45
Séguénéga	1956–2000	45
Sidéradougou	1955–2000	46
Tenkodogo	1941–2000	60
Tougan	1941–2000	60
Tougouri	1953–2000	48
Yako	1944–2000	57
Zabré	1954–2000	47

Bold: stations with complete records over the period 1941 to 2000.

zones in Burkina Faso (Fig. 1A). Therefore, we relaxed our requirement for completeness of record to include all stations with at least 45 consecutive years of daily rainfall records over the period 1941–2000. That raised the number of station from 20 to 39as mentioned in Fig. 1A and Table 1.

Since the results are consistent whether we use the smaller dataset of stations with complete 60-year records (results not shown herein), or the extended dataset with more complete spatial coverage, we only reported on the latter. The historical rainfall data sets were supplied by the National Meteorology Service of Burkina Faso.

2.2. Definition of the seasonal rainfall descriptors

In this study, we followed Sivakumar (1991), defining a rain-day as a day with at least 0.85 mm of rainfall (Sivakumar, 1991). The number of rainy days within the rainy season (NRD) and the seasonal precipitation amount (PA) were respectively determined by counting the number of rain-day and totalizing the daily rainfalls from May to October, corresponding to the rainy season in the Sahel

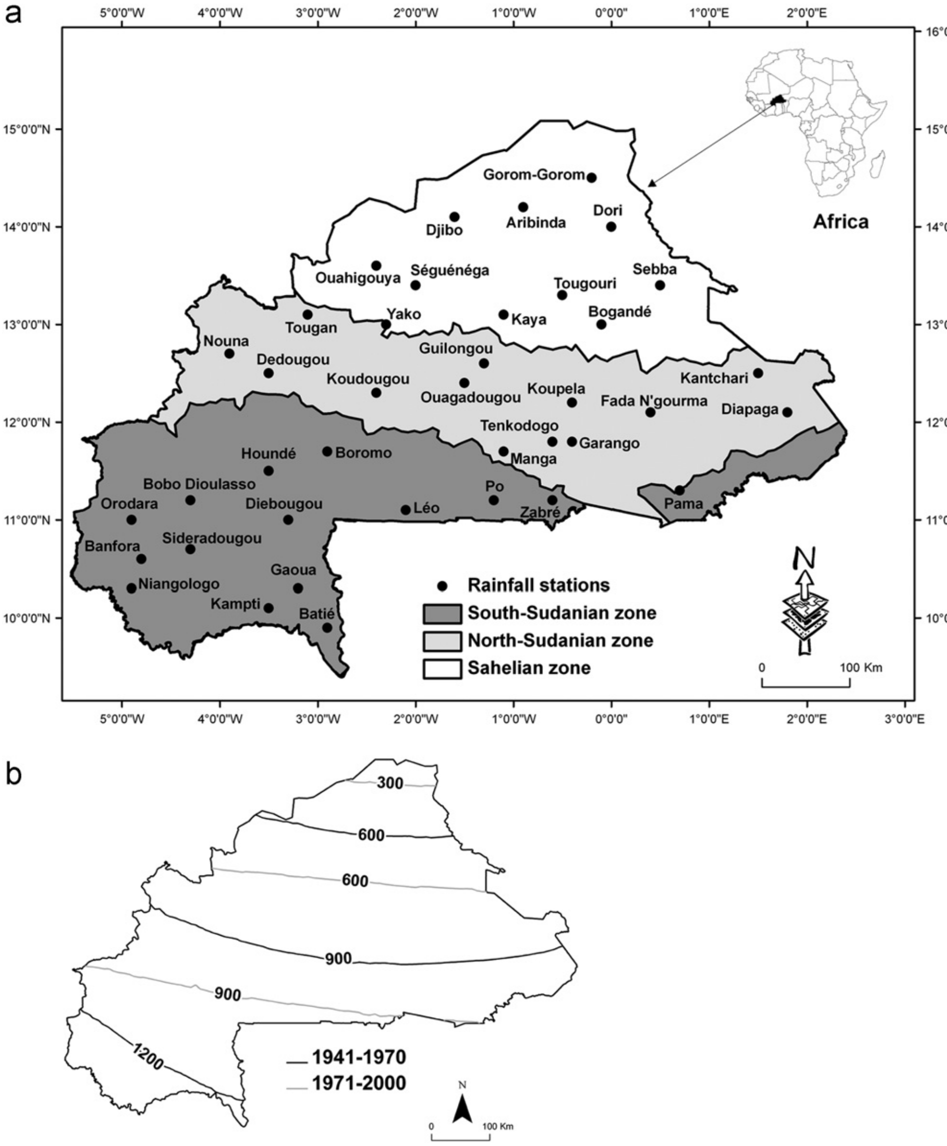

Fig. 1. (A) Agro—climatic zones in Burkina Faso (Fontes and Guinko, 1995) and rainfall stations considered and (B) annual rainfall climatology between 1941–1970 and 1971–2000.

region. Then, the average rainfall per rain-day (INT) was calculated as the ratio of PA over NRD, i.e. INT$=PA/NRD$.

The onset of the growing period (OGP) at a given location is the date after May 1st when total rainfall over three consecutive days is at least 20 mm, with no dry spell exceeding 7 days during the following 30 days (Sivakumar, 1991). The cessation date of the growing period (CGP) is the date after September 1st when the soil water content down to 60 cm depth is nil with a daily potential evapo–transpiration of 5 mm (Maikano, 2006). To consider the latter rains, useful for crops production, in the calculation of CGP, the soil water holding capacity was set to 100 mm after Traoré et al. (2000) rather than 60 mm proposed by Maikano (2006).

2.3. Methods employed to explore the evolution of seasonal descriptors

Three methods were used to explore the evolution of the seasonal descriptors in Burkina Faso between 1941 and 2000: the standardized anomalies index, the spatial methods, and the aggregation methods.

2.3.1. The standardized anomalies index

The standardized anomalies index (SAI) is applied in climatology to study the evolution of climatic variables such as rainfall, temperature,etc.Its calculation method is described by Katz and Glantz (1986).

In this study, we generated a time series of SAI for each of the seasonal descriptors (PA, NRD, INT, OGP and CGP) based on the records of the 39 stations that are considered. These series were plotted to visualize changes in each rainfall descriptor from 1941 to 2000.

2.3.2. The spatial analyses

In climatology, spatial analyses are very useful since they ease the handling of large sets of data; and they allow appreciation of a phenomenon at a broader scale.

To explore how recent reduction in seasonal rainfall has affected the other seasonal descriptors, we calculated the mean-values of each descriptor (NRD, OGP and CGP) over HP and DP respectively, at the station point scale. Afterward, a linear variogram model using the kriging module (Golden Software, 1994) was applied to interpolate these values.

At the monthly timescale, the magnitude and direction of changes from May to October, were also analyzed to determine the period of the season where the seasonal descriptors significantly changed. Therefore, a *t*-test was carried out to compare, for significance at $\alpha=0.05$, the monthly means of PA, NRD and INT of HP with that of DP. The results of the test were encoded and spatially represented.

2.3.3. The aggregation method

For a given variable, this method of analysis assigns the mean-value of different point records as a value to the space containing the points. It was successfully used for analysis of trends in OGP in the Volta basin of West Africa (Laux et al., 2008).

In this study, we applied this method to generate aggregated time series of PA, NRD, INT, OGP and CGP at the country scale. Then, these series were graphically represented to analyze the trends in the descriptors over the period from 1970 to 2000.

One of the challenges of this study was to check the evolution of the interannual variability of the seasonal descriptor. To that end, the coefficient of variation (*CV*), i.e. the ratio of the mean over the standard deviation, was calculated for each period of five consecutive years within each of the aggregated time series. These new time series were graphically represented.

3. Results

3.1. Application of the standardized index method

To make the evolution phases more visible, the graphs of the SAI time series are all smoothened through application of the method of five-year moving average. According to the results in Fig. 2, PA, NRD and CGP have almost the same evolution phases over a time since they are always superimposed. Indeed, they clearly depict the shift from the wet period to the dry period at the beginning of the 1970s. The drought is not occurred suddenly, but it is the result of a downward trend that started since 1966. From 1987 to 2000, they show an upward trend, indicating a progressive recovery from the long period of drought.

INT shows three main stages in its evolution: (1) a smooth decline between 1941 and 1965; (2) a rapid decline between 1965 and 1976 and (3) an almost steady upward trend since 1976, marking its progressive recovery from the drought.

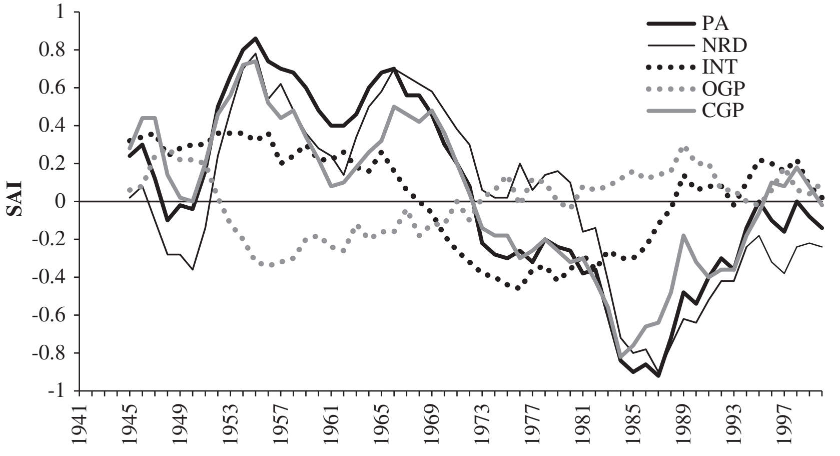

Fig. 2. Fluctuations of the rainfall descriptors in Burkina Faso between 1941 and 2000.

Table 2
Correlation matrix between the rainfall descriptors.

	PA	NRD	INT	OGP
NRD	0.874[a]			
INT	0.555[a]	0.142		
OGP	−0.392[a]	−0.434[a]	−0.024	
CGP	0.836[a]	0.740[a]	0.494[a]	−0.071

[a] The correlation is significant at $\alpha=0.01$.

OGP rapidly declines, indicating the precocious start of the rainy season, between 1947 and 1955 prior to an upward trend from 1955 to 2000.

To highlight the nature of the link existing between the five seasonal descriptors, the correlation matrix is determined. Results, reported in Table 2, show that PA is significantly correlated with the four others. But the highest correlation coefficient are recorded with NRD ($R=0.87$) and CGP ($R=0.74$). NRD is significantly correlated with OGP ($R=-0.43$) and CGP ($R=0.74$). INT is significantly correlated with CGP ($R=0.49$), while the correlation between OGP and CGP is insignificant.

3.2. *Application of the spatial methods*

The spatial analysis is applied to check the influence of a reduction in PA on OGP, CGP and NRD. Results reported in Fig. 3, exhibit a southward movement of the contour lines of OGP, CGP and NRD when we move from HP to DP. Therefore, the reduction in PA negatively influences the other descriptors and then creates tough conditions for crop production, that confirms the significant links between PA and the other seasonal descriptors in Table 2.

In rain-fed agriculture, it is crucial to know the moment of the rainy season when crops are likely to suffer from drought or flood. This information is helpful for the choice of agricultural strategies to stabilize the crops yields. The results plotted in Fig. 4 shows that stations within the same agro–climatic zone behave differently from 1 month to another and from one descriptor to another. The frequencies of stations with significant reduction in mean-values are represented in Fig. 5. It appears that most of the stations record significant reduction in NRD from June to August in the Sahelian zone and over August–September in the North and South Sudanian zones. Significant reduction in PA is mainly observed from July to September in the Sahelian zone, in August–September in the North sudanian zone and in September in the South Sudanian zone. Apart from the Sahelian zone where

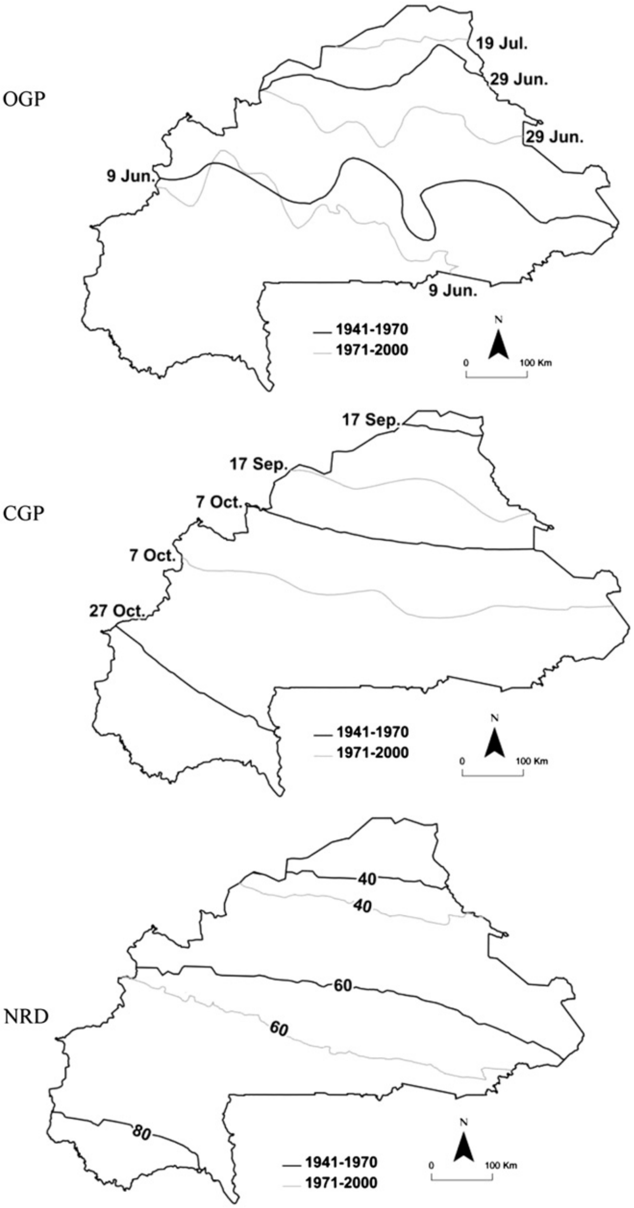

Fig. 3. Changes in the mean-values of the seasonal descriptors in Burkina Faso.

50% and 30% of the stations show a significant decrease in INT over July and September respectively, significant reduction in INT is rare in the other climatic zones.

3.3. Application of the aggregation methods

The records of the descriptors at the station point scale are aggregated to form a new time series, from 1970 to 2000, at the country scale. Then, after plotting the times series, the linear regression

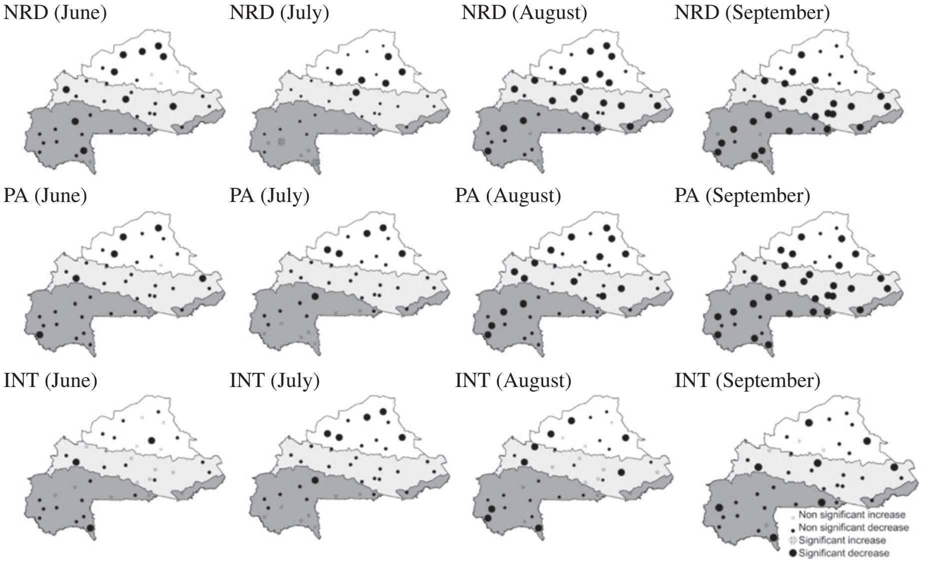

Fig. 4. Changes in monthly means of the seasonal descriptors from HP to DP. PA (month)=monthly precipitation amount; NRD (month)=Monthly number of rainy days; INT (Month) =Monthly rainfall mean intensity.

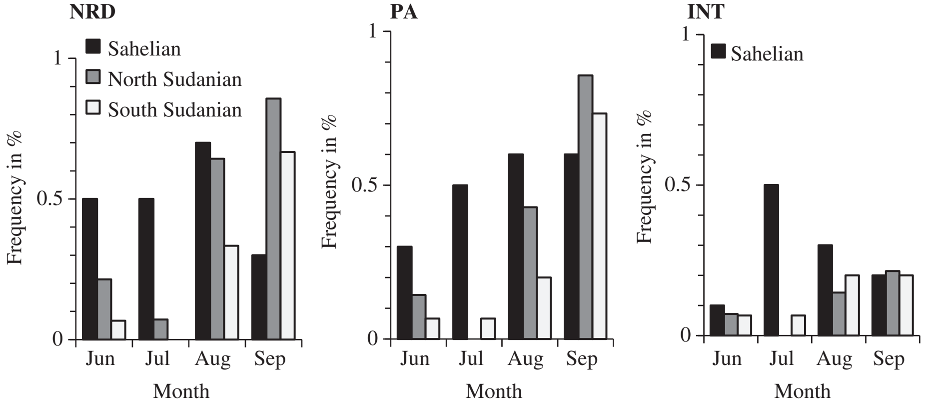

Fig. 5. Frequencies of stations with significant decrease in mean-values of the seasonal descriptors.

line and the 5 years moving average are superimposed on the plots in Fig. 6. It appears that INT is the unique descriptor with a significant upward trend. The curves of the 5 year moving averages indicate that PA, NRD and CGP decline up to a period comprised between 1985 and 1990. From this period up to 2000, these descriptors are smoothly recovering from the drought. OGP is the only descriptor that shows an unclear trend in its evolution.

The year-to-year variability of the seasonal descriptors represents an obstacle that considerably reduces the impacts of crop production strategies in the Sahel region. Results, reported in Fig. 7, depict an upward trend in all the descriptors. PA is the descriptor that exhibits the steadiest trend.

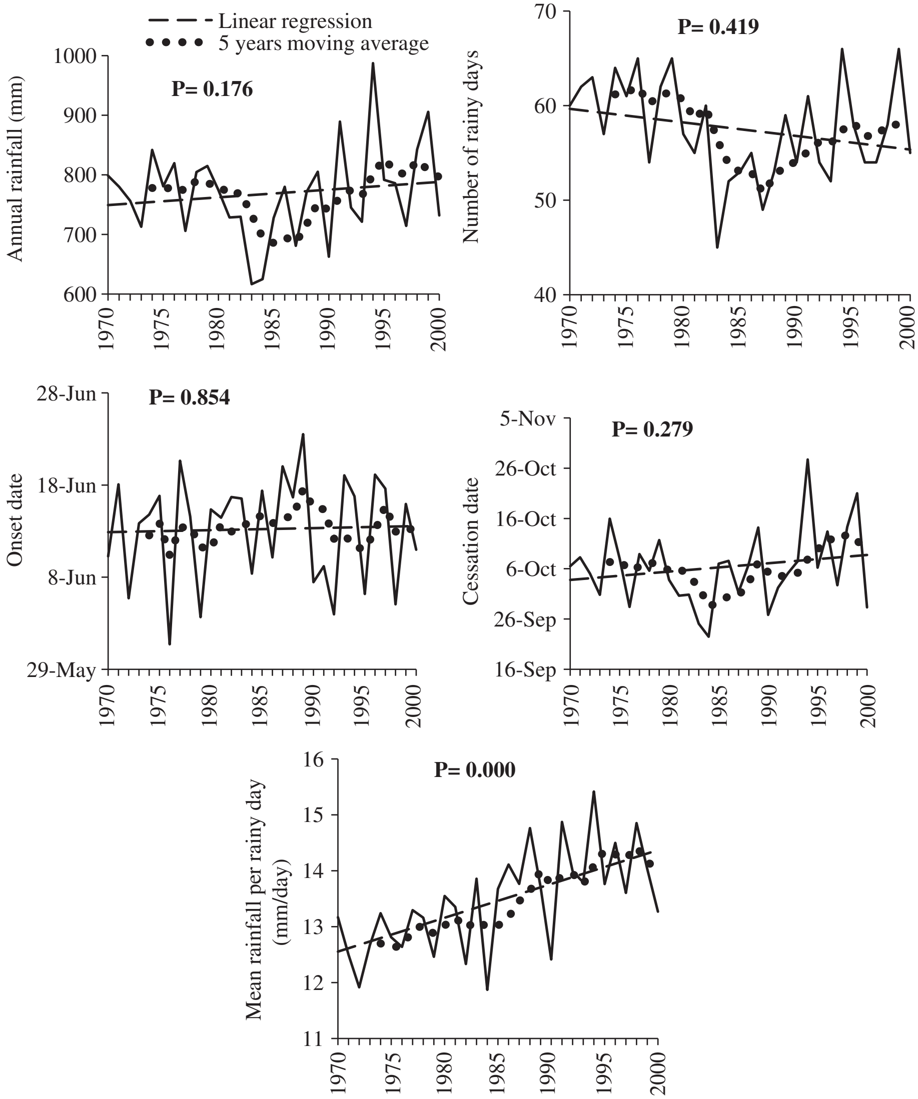

Fig. 6. Analysis of trends in the seasonal descriptors in Burkina Faso. *P* is the *t*-test probability value for the significance of the linear regression.

4. Discussion

When aggregated over all 39 stations in Burkina Faso and all months between May and October, number of rainy days (NRD) and date of cessation of the growing period (CGP) are the quantities most immediately and directly related to total precipitation amount (PA), as shown in Fig. 2. They follow the regional evolution from anomalously wet conditions in the 1950s to a decline in the 1970s and partial recovery since the end-1980s. This observation is in concordance with previous findings: the decrease in precipitation amount between HP and DP is linked to decrease in number of rainy days (Hess et al., 1995; Le Barbé and Lebel, 1997; Le Barbé et al., 2002). In addition, the highest records of stations with significant reductions in number of rainy days over DP in August and especially in September, i.e. the end of the rainy season in the Sahel region, is consistent with our

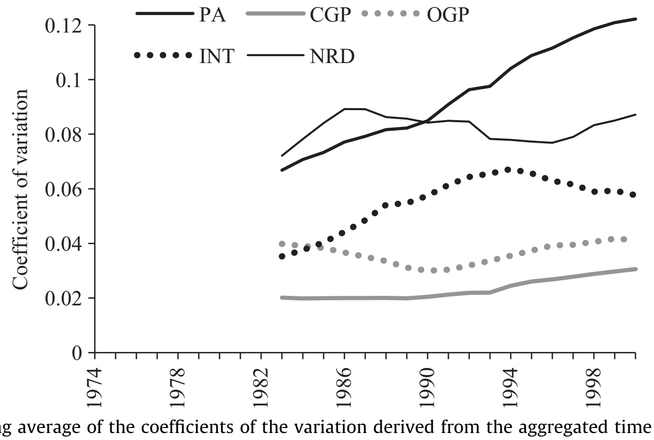

Fig. 7. Ten year moving average of the coefficients of the variation derived from the aggregated time series of the seasonal descriptors.

findings that CGP is closely related to PA. Thus the recent decline in PA entailed precocious demise of CGP over DP as observed by Sivakumar (1992) in Niger. Furthermore, the southward movement of the contour lines during DP showed that the onset date of the rainy season (OGP) has also changed towards tardy occurrence.

The tardy occurrence of OGP coupled with the early demise of CGP caused an important shortening of the rainy season with consequences in agriculture. However this is in partial contrast with some investigations (Kouressi et al., 2008; Le Barbé and Lebel, 1997; Traoré et al., 2000) that finds insignificant changes in the duration of the rainy season in the Sahel region between the wet and dry periods. Le Barbe and Lebel (1997) made use of a large number of stations, but they considered hydrologic definition of OGP and CGP that speaks to the implication of using hydrologic versus agro–climatic definitions of OGP and CGP. The others (Kouressi et al., 2008, Traoré et al., 2000) used agro–climatic definitions, as used here, but fewer stations that raised the issue of the requisite number of rain gauges for accurate capture of the evolution of seasonal descriptors at the local and the regional scales. Because of the important spatial variability in Sahel rainfall (Graef and Haigis, 2001) the higher the number of rain gauges, the better the results expected. That is why this study used a large number of rainfall stations. One other reason that could justify other studies' observation of non-significant change in length of the rainy season is the close relationship between the length of the rainy season and OGP (Diop, 1996; Sivakumar, 1988; Traoré et al., 2000) that definitely contributed to downplay the reduction extent in length of the rainy season since changes in OGP were less important than those in CGP over DP.

Mean rainfall per rain-days (INT) displays the most interesting, and to date unexplained, behavior. INT began its decline in the early 1960s, preceding the declines in PA and NRD. It started its recovery in the early 1980s, again preceding the recoveries of PA and NRD (Fig. 2). It displays the clearest, most significant upward trend since 1970s (Fig. 6) when NRD were decreasing. That is why rains are more volatile, and risk of floods higher during DP (West et al., 2008). Is this trend a signature of anthropogenic climate change—the expectation that with atmospheric warming, an increase in specific humidity would drive events of increased intensity? We put forth an interpretation that calls for such attribution indirectly, through the influence of the oceans on the climate of semi-arid West Africa. Given the well known relationship between changes in the oceans around Africa and the late 20th century evolution of rainfall in the Sahel (Giannini et al., 2003; Bader and Latif, 2003; Lu and Delworth, 2005; Hagos and Cook, 2008), we posit that (i) as the tropical oceans, including the Indian Ocean, began to show a consistent warming trend in $\sim$1970, they raised the threshold for deep convection, reducing the number of rainy days, but also raising the potential for an increase in intensity (Chiang and Sobel, 2002; Neelin et al., 2003), and (ii) such potential became realizable at the end of 1970s, as the subtropical North Atlantic began to warm, bringing about increased moisture inflow with the monsoon. To quantitatively explore these relationships,

Table 3
Correlation between sea surface temperature indexes and seasonal descriptors.

	glotrosst	Not-glotrosst
PA	−0.317[b]	0.375[b]
NRD	−0.360[b]	0.244[a]
INT	0.009	0.339[b]

glotrosst = global tropical oceans index; nat-glotrosst = difference index between the subtropical north atlantic and the global tropical oceans.
[a] Significant correlation at $\alpha = 0.05$
[b] Significant correlation at $\alpha = 0.05$.

the correlation coefficient between two indices of global sea surface temperature (SST) and PA, NRD and INT were calculated. The two indices are: a global tropical oceans index (glotrosst), i.e. SST averaged between 20 °S and 20 °N, and a difference index between the subtropical North Atlantic, between 10° and 40 °N; 75 and 15 °W, and the global tropics (Not-glotrsst). Results reported in Table 3 show that the first index is indeed best correlated with NRD, the second with INT and PA. Therefore, changes in rainfall over the Sahel region can be partly attributed to changes in SST. More importantly these relationships clearly indicate the likely changes that are going to happen in Sahel rainfall according to the direction and magnitude of future changes in SST. Thus the ongoing global warming is likely to cause reduction in NRD and an increase in PA and INT. Consequently the Sahel region will undergo longer dry spells within the agricultural season and recurrent floods leading to more food insecurity because of food crops failure. That idea is also backed by New et al. (2006) who notice statistically significant trends in daily rainfall intensity and dry spell duration in the West African region.

As shown in Fig. 2 all the seasonal descriptors are recovering since the end of the 1980. That is in concordance with Alexander et al. (2006) and Dai et al. (2004) that conclude that all the precipitation indices show a tendency toward wetter conditions throughout the 20th century. However, during this recovery period, the interannual variability of the descriptors is increasing over time (Fig. 7). An increase in year-to-year variation of seasonal descriptors is also noticed in Niger by Sivakumar (1992) during the dry decades. Furthermore, it is not so far proven that this recovery entails better repartition of rainfall within the season. For that reason cropping in the Sahel region is still risky despite the recovery of rainfall descriptors.

However, farmers can take advantage of the recovery of the seasonal descriptors if they accept to shift for efficient water harvesting technologies. Indeed, it is shown that a supplemental irrigation coupled with a use of fertilizer can significantly contribute to the improvement and stabilization of crop yields in the Sahel region (Rockström et al., 2002).

5. Conclusion

This study sought to document the evolution of five seasonal descriptors in Burkina Faso from 1941 to 2000 based on daily rainfall records of 36 stations spanning the agro–climatic zones.

The annual precipitation (PA), the number of rain-days (NRD) and the cessations dates of the growing season (CGP) showed the same patterns of evolution due to the tight links existing between them. Consequently, the recent decline in PA was essentially translated into a significant decrease in NRD and a precocious occurrence of CGP that resulted in worse conditions for food crop production.

The difference in the behavior of the average rainfall per rain-day (INT) compared to that of the other descriptors could be explained by changes in the sea surface temperatures (SST) and be seen as a signal of the anthropogenic climate forcing during these last decades. If nothing is done to reverse its rapid upward tendency, the Sahel region could face recurrent floods that will jeopardize food production.

The study clearly showed that all the seasonal descriptors are in a recovery phase since end-1980s. But that does not necessarily mean the end of the dry period since despite this recovery the descriptors' values remain far removed from what they were during the wet decades (1941–1970). Furthermore, the relationship between the seasonal descriptor and SSTs indicate that ongoing global warming could result in increased INT and PA, and a decreased NRD. That will trigger recurrent crop failure due to longer dry spells and floods. For that reason, strategies aiming to improve and stabilize food crop production such as water harvesting technologies should be encouraged and even improved for more efficiency.

Acknowledgments

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