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Onset, retreat and length of the rainy season over Cameroon

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Abstract

Observed precipitation from 24 stations in Cameroon during 1962–1993 were used to study onset, retreat and length of the rainy season. Results were compared to control simulations by four IPCC 4AR AOGCMs. CSIRO-mk3.5 and MPI-echam5 AOGCMs best captured onset, retreat and duration of the rainy season. Projections for 2082–2098 under the SRES A2 emission scenario were also analysed. For that period, onset dates are expected to be later by 1 pentad or more than in the current climate and retreat by less than half a pentad in zones 1 and 2. This will lead to a slight decrease in the duration of the rainy season. The situation is reverse in zone 3, where the season will be longer. Copyright © 2012 Royal Meteorological Society

Keywords: rainfall onset; rainfall retreat; length of the rainy season; climate change; Cameroon; climate projection

1. Introduction

Rainfall onset and retreat dates are important parameters in the agricultural calendar in most tropical regions. As defined by Odekunle *et al.* (2005), the rainfall onset is the period at the beginning of the rainy season, when rainfall distribution has become adequate for crop development, while rainfall retreat refers to the period, towards the end of the rainy season, when rainfall distribution may no longer sustain crop growth. Many regions over the world are expected to suffer substantial climate modifications as a result of global warming. These changes will affect the onset and retreat of the rainy season which has become irregular over the years (Salack *et al.*, 2011), making it difficult for farmers to optimize the seed planting period and adjust to the length of the growing season (Olaniran, 1983a; Mugalavai *et al.*, 2008; Ndomba, 2010). The immediate consequences are the decrease of agricultural production and an increase risk of hunger. Therefore, the determination of the onset and retreat dates of the rainy season in various regions throughout the world have become a challenge for many researchers.

Various methods have been developed to determine onset and retreat dates of the rainy season. Odekunle(2006) classified these methods into five main categories: (1) Intertropical Discontinuity (ITD)-rainfall model (Ilesanmi, 1972a), (2) rainfall-evapotranspiration relation model (Benoit, 1977), (3) percentage cumulative mean rainfall model, based on rainfall data alone (Ilesanmi, 1972b; Adejuwon *et al.*, 1990; Adejuwon, 2006), (4) wind shear model (Omotosho, 1990a, 1990b), (5) the theta-E technique (Omotosho, 2002). Odekunle(2006) used two different methods based on rainfall data, to determine onset and retreat dates of the rainy season in Nigeria. The study established that both rainfall amount and rainy days are equally effective in the determination of the mean rainfall onset and retreat dates, but the latter method is more efficient for individual year. Omotosho(1992) proposed a simple empirical scheme for predicting onset and retreat in the West African Sahel, using upper atmosphere wind data. He considered that the poleward retreat of the subtropical jet is linked to the start of rain, whereas the destruction of the wind shear is a forerunner to the cessation of rainfall. The percentage cumulative mean rainfall is the most used method. It has the advantage of depending only on rainfall data that are readily available from direct measurements rather than other rainfall-associated factors (Odekunle *et al.*, 2005). This method was used by Olaniran(1983a) to study the onset of rains and the start of the growing season in Nigeria. The results revealed that there is no significant difference between the mean onset date obtained and the mean start of the growing season.

Most studies on rainfall onset and retreat in African countries were performed on a limited number of stations or on short time periods because of the lack of complete data series in observation. The use of satellite data or of models outputs are some palliative solutions to this issue. However, satellite data are limited to recent periods while model outputs can cover longer periods in both present and future. In view of the present global warming and its consequences on local climate variability, the use of model outputs to investigate characteristics of the rainy season (e.g. rainfall totals, rainy day frequencies, onset, retreat and length of the rainy season) is necessary in order to assess future changes and guide adaptation measures. Global and regional climate models with various

IPCC emission scenarios have been used by many authors for projecting future climate change. In the Iberian Peninsula, it was found that 5/24 IPCC GCMs (MIROC3.2-HIRES, MPI-ECHAM5, GFDL-CM2.1, BCCR-BCM2.0 and UKMO-HADGEM1) best reproduce current climate (Errasti *et al.*, 2011) and could be used for future projections. Mkankam (2000) noted that two IPCC-coupled atmosphere-ocean general circulation models (ECHAM4 and HADCM2) simulated well the present climate in Cameroon and neighbouring areas. Thus, he used their outputs to evaluate projected changes in rainfall and temperature resulting from increased concentration of greenhouse gases (GHGs) in the atmosphere for the period 2040–2070. The results revealed changes in annual rainfall within the range of present climate variability while the projected temperature increases were larger than observed variability. An evaluation of the ability of 18 GCMs to capture the West African monsoon system, found that three models (among them MPI-ECHAM5) gave reasonable simulations of the twentieth-century climate while others comprising CSIRO-Mk3.0 and MRI-CGCM2.3.2 failed to do so (Cook and Vizy, 2006). Errasti *et al.* (2011) revealed that all IPCC models do not describe the present climate with similar accuracy. Furthermore, the best models for a particular region of the earth do not always achieve the same degree of performance in other regions. Additionally, the skill of the models is different according to the meteorological variables examined.

The objectives of this paper are to evaluate the performances of some IPCC-4AR model in reproducing onset, retreat and length of the rainy season in the study area, and to assess future changes under the SRES A2 GHG emission scenario. Simulations of current climate and of future perturbed climate under this emission scenario were carried out for the IPCC 4th Assessment Report (IPCC-4AR) using several GCMs. The method of the percentage cumulative mean rainfall amount was used to determine present and future climate rainfall onset and retreat dates over Cameroon. Analyses for pertubed climate were extended to the country's neighbouring areas to increase the number of model grid points used as theses areas have similar climate (Figure 1).

The work is organized as follows. In Section 2, the study area is described. In Section 3, we present data used and define the methodology. The results on stations grouping, the analysis of mean onset, retreat and length of the rainy season for both current and future climates, are in Section 4. Section 5 is devoted to concluding remarks and perspectives.

2. Study area

The study domain is located in Equatorial Central Africa between 1–13 °N and 7–18 °E. This area

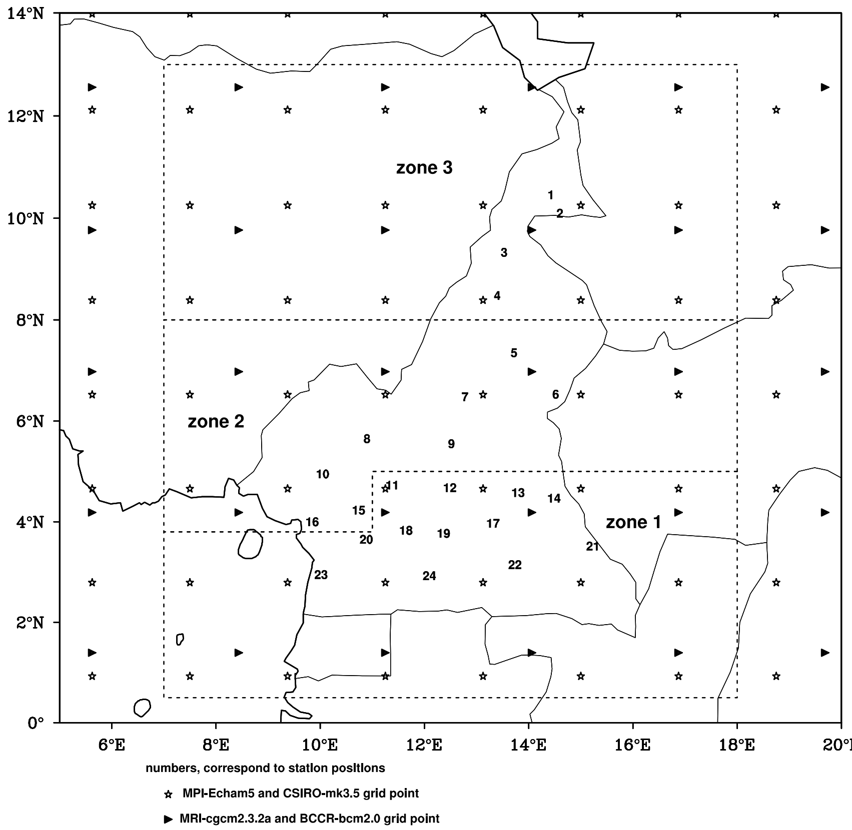

Figure 1. Study area with the geographical locations of rainfall stations (indicated by numbers) and of climate models grid points (BCCR-bcm2.0, CSIRO-mk3.5, MPI-echam5 and MRI-cgcm2.3.2a). Grid point locations for each model are indicated by a specific marker. Dashed lines show delimited zones.

encompasses the Cameroon territory. GCMs results are discussed on a wider domain including areas bordering the country (Figure 1). The climate of the area is not uniform, varying from tropical humid in the south to semi-arid and hot in the north. The southern part of the country is bordered in the west by Atlantic Ocean and is covered by dense rain forest. The northern part has a dry to arid Sahelian type climate depending on latitude. Economic activities in the area are based mostly on agriculture, generally at subsistence levels. Cacao, coffee, bananas, rubber, palm oil and cotton are the main cash crops raised by farmers. Main food crops are cassava, corn, yams, sweet potatoes and millet. Logging is another important resource in Cameroon with heavy timber exportation. More information on the country can be found in Penlap *et al*. (2004). All these activities are rainfed and almost no irrigation.

3. Data and methodology

3.1. Data used

Five data sets were used in the study: daily rainfall data from 24 measuring stations in Cameroon and simulated daily rainfall from MPI-echam5, MRI-cgcm2.3.2a, BCCR-bcm2.0 and CSIRO-mk3.5. Station rainfall data provided by the Cameroon Meteorological Services are the same successfully used by Penlap *et al*. (2004). The geographical positions of the stations are shown in Figure 1. Table I indicates their names, locations and altitudes. Some stations have missing values, representing at most less than 4% of total data. Simulated rainfall were obtained from the World Climate Research Program's (WCRP's) Coupled Model Inter-comparison Project phase 3 (CMIP3) multi-model dataset at the Lawrence Livermore National Laboratory, USA. They were produced for IPCC 4th Assessment Report (4AR) (Meehl *et al*., 2007). Echam5 is a model of the Max Planck Institute (MPI-echam5) for Meteorology in Germany (Roeckner *et al*., 1996) while cgcm2.3.2a and mk3.5 are respectively from the Meteorological Research Institute (MRI-cgcm2.3.2a) in Japan (Yukimoto *et al*., 2006) and the Australian Commonwealth Science and Industrial Research Organization (CSIRO-mk3.5) (Gordon *et al*., 2002). Model bcm2.0 is from the Bjerknes Centre for Climate Research (BCCR-bcm2.0), University of Bergen, Norway (Furevik *et al*., 2003). A 32-year data for the current climate (1962–1993) and a 19-year (2082–2098) of the future climate under the SRES A2 emission scenario were analysed. Grid points for each of the four IPCC 4AR models are shown in Figure 1. Echam5 and Mk3.5 have the same grid spacing (208 km) while Cgcm2.3.2a and Bcm2.0 have spacings of 310 km.

3.2. Methodological approach

The method adopted in this study for the determination of onset and retreat dates was the cumulative percentage mean rainfall amount (Ilesanmi, 1972a). Daily rainfall data for each year were grouped into 5-day means (pentads). This grouping was performed on non-overlapping 5-day means starting at pentad 1 (1 to 5 January) and ending at pentad 73 (27 to 31 December). In the first step of the method, the percentage of mean annual rainfall was determined at 5-day intervals. Next, cumulative percentages were calculated for the full year. Finally, the timings of the accumulation of 7–8% and of 90% of the annual rainfall were taken as onset and retreat of rains respectively. The length of the rainy season was defined simply as the period between onset and retreat dates. According to the method adopted here, the monsoon rainy season, between onset and retreat accounts for 83.5% of annual rainfall.

In the first part of the analysis, the temporal mean onset and retreat dates of the rainy season were first calculated for each station of the domain. Second, the following criteria were used to divide the study domain into sub-domains or zones: stations where both onset and retreat dates are different by 4 pentads at most were assigned to a common climatic zone. The 4-pentad interval appeared to be the one giving reasonable separate zones (stations spatially grouped) as compared to interval of 1, 2 or 3 pentads (Figures not shown). For model outputs, zone definitions were extended to neighbouring areas of Cameroon in order to increase the number of grid points used. Some studies on domains comprising our study area (Olaniran,

Table I. Geographical positions and altitudes of the 24 rainfall stations used. Stations are grouped per defined climatic zones. They are also assigned numbers used to represent them in Figure 1.

Region	N°	Station name	Lon (°E)	Lat (°N)	Alt (m)
Zone 1	11	Bafia	11.25	4.73	500
	12	Nanga-éboko	12.37	4.68	623
	13	Bertoua	13.68	4.58	668
	14	Batouri	14.37	4.47	650
	17	Abong-mban	13.20	3.97	693
	18	Yaoundé	11.53	3.83	753
	19	Akonolinga	12.25	3.77	671
	20	Eséka	10.77	3.65	228
	21	Yokadouma	15.10	3.52	534
	22	Lomié	13.62	3.15	624
	23	Kribi	09.99	2.95	10
	24	Sangmélima	11.98	2.93	712
Zone 2	5	Ngaoundéré	13.57	7.35	1104
	6	Meiganga	14.0	7.20	1027
	7	Tibati	12.63	6.48	873
	8	Koundja	10.75	5.65	1210
	9	Yoko	12.37	5.55	1027
	10	Nkongsamba	09.93	4.95	816
	15	Ngambé	10.62	4.23	610
	16	Douala	09.73	04.00	5
Zone 3	1	Maroua	14.26	10.46	423
	2	Kaélé	14.45	10.10	386
	3	Garoua	13.38	9.33	241
	4	Poli	13.25	8.48	436

1989, 1983b) can justify this extension. Next, observed and simulated data were analysed in every zone by calculating for each year and at each station (grid point) onset and retreat dates and length of the rainy season. Annual results were averaged for stations (grid points) within each zone giving a 32-year time series per zone for both observations and model outputs. Finally, means, standard deviations and interannual variability were analysed and compared. Statistics on how each model reproduces the observed parameters (onset and retreat dates and duration of the rainy season) were estimated as the ratio of the observed number of parameters simulated correctly to the total number of cases.

Climate change evaluations were based on comparisons between current climate and future SRES A2 scenario perturbed climate. The A2 scenario recognized as the most severe (Cook and Vizy, 2006) assumes strong CO2, CH4 and SO2 increases throughout the twenty-first century (except for SO2, which declines after 2030) (IPCC, 2001). Knowledge about how models respond to these changes are useful for predictions of economic impacts.

4. Results and discussion

4.1. Grouping based on onset and retreat dates of the rainy season

A total of three zones were defined in the study domain (Figure 1) using the criteria presented in the methodology section. These zones are similar to those defined using other criteria (Olaniran, 1989, 1983b). Thus we can consider:

(1) The equatorial forest zone (zone 1) mostly covered by dense forests and having two rainy seasons;
(2) The Midland zone (zone 2) which predominantly covers highlands where topography effectively extends the length of the humid period, due to localized convection and orographic effects (Olaniran, 1983b);
(3) The Sahelian zone (zone 3), where the tropical continental air mass predominates, except during the Monsoon season when the tropical maritime air mass covers the area for 3 to 5 months at most (Olaniran, 1983b).

Table II shows the range of onset and retreat dates for each zone.

4.2. Comparative study of mean onset and retreat dates and lengths of the rainy season under the current climate (1962–1993)

Mean onset and retreat dates and lengths of the rainy season as well as associated standard deviations for each zone are shown in Table III for observed and simulated data. As expected, rainfall onset and retreat follow the northward move of the ITD during the months of March to August and its southward retreat between September and October, respectively. Similar spatial migrations of onset and retreat dates were observed in many African countries, for example in Nigeria, Senegal and western Kenya (Odekunle, 2004; Mugalavai *et al*., 2008; Salack *et al*., 2011). Retreat is more abrupt as it takes only 8 pentads compared to 12 for onset. This rapid retreat was also observed in neighbouring Nigeria (Ayoade, 1974; Odekunle, 2006). Earliest onset is in zone 1, south of the study domain, on the 16th pentad of the year (17th–21st March), followed by zone 2 four pentads (20 days) later, and latest onset, close to 2 months (11 pentads) after zone 1, is in the northernmost stations (Table III(a)). Retreat starts in the North and moves South (Table III(b)) and time lags between zones are less than for onset dates. Uncertainties are higher (higher standard deviations) on onset than on retreat dates. The length of the rainy season (Table III(c)) decreases from South to North: 25 consecutive pentads (4 months) in zone 3, 37 (6 months) in zone 2 and 45 (7.5 months) in zone 1. This is in agreement with annual rainfall amounts observed in theses areas. The spatial variation in duration affects the choice of crop types and farming techniques, depending on zones in order to avoid losses due to insufficient number of rainy days. That is why in Kenya where the maximum length of the growing season is about 4 months, irrigation is recommended during the short rainy season as a way of supplementing the limited rainfall (Mugalavai *et al*., 2008)). The increase in the length of the rainy season from zone 3 to zone 1 may be explained by the annual migration of the ITD, which controls the Monsoon influx of humid maritime air into the continent. This favourable rainfall-producing factor has the least residence period over zone 3.

The value of standard deviation of a time series can be used to elucidate temporal variability (Syed *et al*., 2010). For onset date, observed standard deviations of 2 pentads in zone 1 and 3 pentads in zones 2 and 3 indicate that interannual variability of this parameter is lower in the Equatorial forest zone. Retreat dates

Table II. Range of mean onset and retreat dates of the rainy season for each zone. Results are given in pentad number and the corresponding calendar dates are in parentheses. The first pentad is the period from January 1 to January 5.

Sub-domain	Onset date range	Retreat date range
Zone 1	15th–17th pentad (12 March–26 March)	60th–62th pentad (23 October–6 November)
Zone 2	19th–21st pentad (1 April–15 April)	55th–59th pentad (22 September–22 October)
Zone 3	25th–29th pentad (1 May–25 May)	52nd–54th pentad (13 September–27 September)

Table III. Mean onset and retreat dates and lengths of the rainy season for the period 1962–1993 in the three zones. Onset and retreat dates are in pentads number ± standard deviation. The corresponding calendar ranges dates are between brackets without the standard deviations. Lengths of the rainy season are in pentads and the equivalent number of days are indicated in parentheses.

Data	(a) Onset date			(b) Retreat date			(c) Length (*retreat–onset*)		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Observation	16th pentad ± 2 (17–21 March)	20th pentad ± 2 (6–10 April)	28th pentad ± 3 (16–20 May)	61st pentad ± 1 (22 October–1 November)	57th pentad ± 1 (8–12 October)	53rd pentad ± 2 (18–22 September)	45 pentads ± 2 (225 days)	37 pentads ± 3 (185 days)	25 pentads ± 3 (125 days)
BCCR-bcm2.0	12th pentad ± 2 (25 February–1 March)	22nd pentad ± 2 (16–20 April)	29th pentad ± 3 (21–25 May)	64th pentad ± 1 (12–16 November)	59th pentad ± 1 (18–22 October)	54th pentad ± 2 (23–27 September)	52 pentads ± 2 (260 days)	36 pentads ± 2 (180 days)	25 pentads ± 4 (125 days)
CSIRO-mk3.5	14th pentad ± 2 (7–11 March)	20th pentad ± 2 (6–10 April)	24th pentad ± 2 (26–30 April)	63rd pentad ± 1 (7–11 November)	57th pentad ± 1 (8–12 October)	52th pentad ± 1 (13–17 September)	49 pentads ± 2 (245 days)	37 pentads ± 2 (185 days)	28 pentads ± 2 (140 days)
MPI-echam5	14th pentad ± 2 (7–11 March)	19th pentad ± 2 (1–5 April)	26th pentad ± 2 (6–10 May)	63th pentad ± 1 (7–11 November)	60th pentad ± 1 (23–27 October)	56th pentad ± 1 (3–7 October)	49 pentads ± 2 (245 days)	40 pentads ± 2 (200 days)	30 pentads ± 2 (150 days)
MRI-cgcm2.3.2a	6th pentad ± 2 (26–30 January)	16th pentad ± 2 (17–21 March)	29th pentad ± 2 (21–25 May)	66th pentad ± 1 (22–26 November)	58th pentad ± 1 (13–17 October)	49th pentad ± 1 (29 August–2 September)	60 pentads ± 2 (300 days)	42 pentads ± 2 (210 days)	20 pentads ± 2 (100 days)

and lengths of the rainy season in all the three zones show lower amplitudes of fluctuations than onset dates (Figures not shown). Extreme values (minima and maxima) observed in the interannual variability of onset dates are much farther from their means, compared to retreat and duration of the rainy season. In general, models outputs poorly reproduce these interannual variations (correlation coefficient $|r| < 0.5$). However MPI-echam5 in most cases do the best job.

Of the four general circulation models, only MPI-echam5 has an onset date within one standard deviation of observations in all the three zones. A similar analysis shows that CSIRO-mk3.5 gives good onset in zones 1 and 2, while BCCR-bcm2.0 and MRI-cgcm2.3.2a succeed in only one zone. Based on this criterion, three models have the right simulation in zone 3 and two in the other zones. Because there is less dispersion on retreat dates (standard deviation of 1), no model is on target in zone 1, one is in zone 2 and two are in zone 3. For both onset and retreat, boxplot diagrams (Figure 2(a) and (b)) indicate that dispersion between models is low, the models tending to agree more among them than with observations. Their poor performance on retreat dates translates into poor results for the length of the season (Figure 2(c)) which are mostly off target in zone 1 but slightly better in zones 2 and 3. It is also to be noted that MRI-cgcm2.3.2a is often even out of the range of extreme observations.

A quantitative verification of the model simulations are needed in order to objectively analyse and compare their performances. In Figure 2, numbers expressed in percentages and represented below each model box-plots are statistical probabilities for models to capture the observed parameters (onset and retreat dates and length of the rainy season). In zone 1, CSIRO-mk3.5 and MPI-echam5 show better results than the other two models. While their statistical probabilities for predicting onset date are greater than 50% (61% for CSIRO-mk3.5 and 58% for MPI-echam5), they give poor results for retreat date and duration (less than 10%). In zone 2, CSIRO-mk3.5 shows best results and also has the greatest statistical probability (100% for both onset date and duration, 81% for retreat date). The second best performance is by MPI-echam5 for onset (94% of statistical probability for prediction) and by BCCR-bcm2.0 for duration (85%). Other models show poorer results (less than 50%). In zone 3, the best statistical probability for prediction is by MPI-echam5 for onset date (74%), CSIRO-mk3.5 for retreat date (75%) and BCCR-bcm2.0 for duration of the rainy season (78%). For onset and retreat dates, the second best is BCCR-bcm2.0. Overall, CSIRO-mk3.5 shows highest combined statistical probability for prediction of onset and retreat dates and duration of the rainy season, followed by MPI-echam5. MRI-cgcm2.3.2a shows lowest statistical probability.

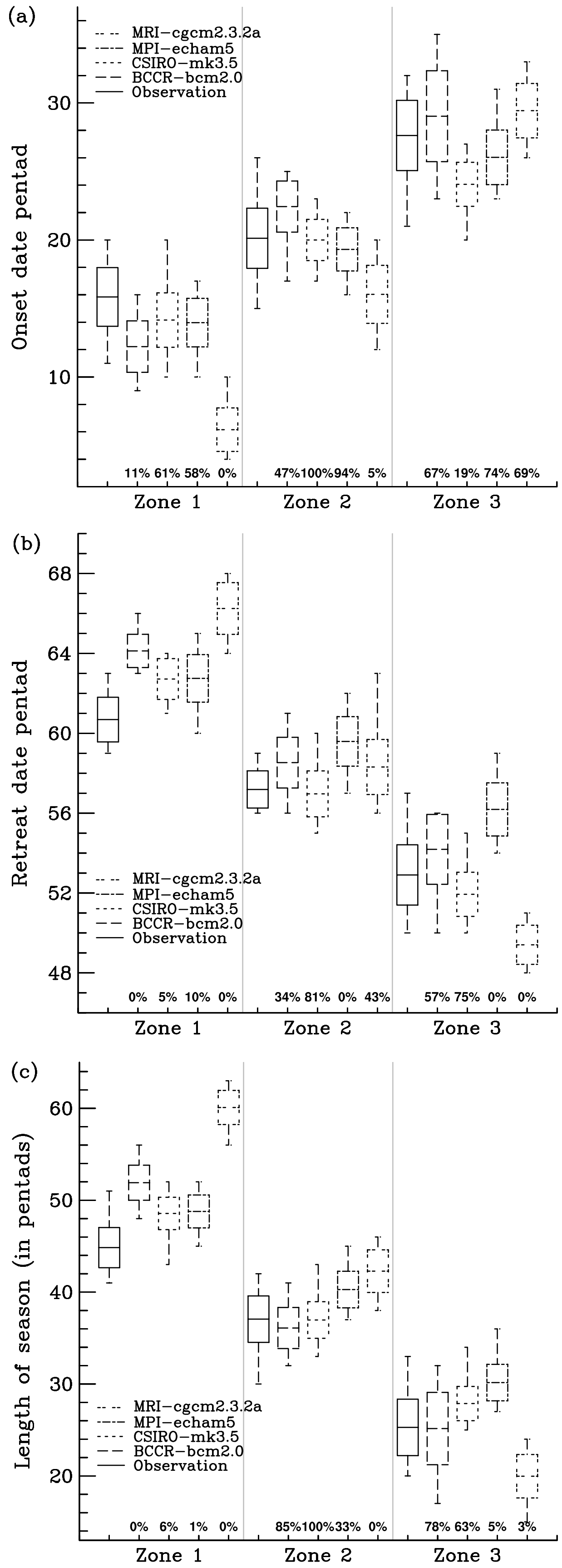

Figure 2. Onset date, retreat date and duration of the rainy season for observation and models simulations. Numbers expressed in percentage and presented below each model boxplot represent the statistical probability for each model to forecast the observed onset date (a), retreat date (b) and duration of the rainy season (c).

4.3. Onset and retreat dates and length of the rainy season under a perturbed climate

To assess the effect of increased GHG concentration in the atmosphere on onset and retreat dates and length of the rainy season, projected dates for the period 2082–2098 were analysed. These were determined from the outputs of GCM simulations using the same methodology presented earlier.

Results under the perturbed climate of a given GCM were compared to its own simulation of current climate. Differences in onset and retreat dates of the rainy season and in duration between future and present climates are shown in Figure 3(a), (b) and (c), respectively. Surprisingly there are no great changes

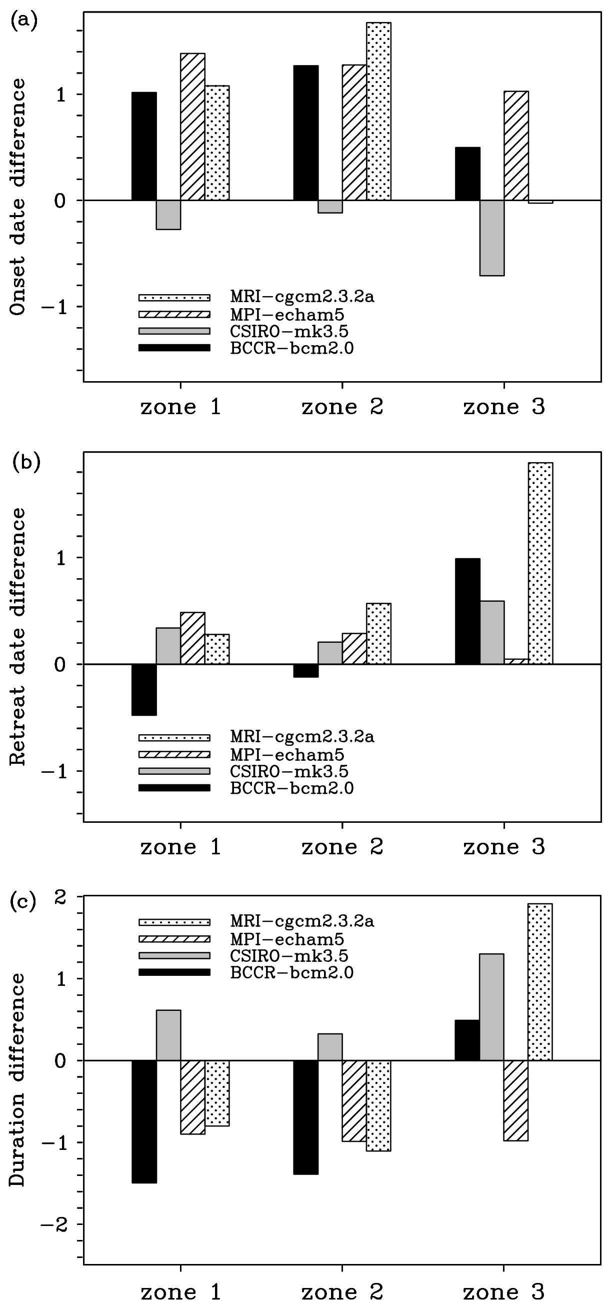

Figure 3. Gap between mean future and mean current climate dates for onset (a), retreat (b) and differences in the duration (c) of the rainy season. Vertical axis are graduated in pentads.

in either onset or retreat dates. Three of the models (MPI-echam5, BCCR-bcm2.0 and MRI-cgcm2.3.2a) show late onset of 1 pentad in all zones, while CSIRO-mk3.5 has approximately normal start in zones 1 and 2 and early start of about 1 pentad in zone 3. Retreat occurs mostly earlier, but by less than 1 pentad, except for MRI-cgcm2.3.2a in zone 3 where it is almost 2 pentads earlier. Rainy seasons are shorter by approximately 1 pentad in zones 1 and 2 and longer in zone 3 by up to 2 pentads. These changes are all within the range of variability of current climate simulated by each model and could not be considered significant. This result corroborates that of Mkankam (2000) given the strong relationship between onset and rainfall attributes (Stewart, 1991; Ati *et al*., 2002). The shortening of the rainy season is one of the most feared result of anthropogenic climate change. But projections under the SRES A2 scenario by the four models used here indicate that to the end of the twenty-first century, no major perturbations of the seasons are expected, and it will be possible to continue growing the same crops as at present time in Cameroon.

5. Concluding remarks and perspectives

Daily precipitations for 24 meteorological stations in Cameroon were used to define climatic zones in the domain 1–13 °N and 7–18 °E located in Equatorial Central Africa. Zones were defined, each of them characterized by stations with close onset and retreat dates of the rainy season. Next, onset and retreat dates and lengths of the rainy season for the current climate (1962–1993) calculated from both observations and four IPCC 4AR AOGCMs (BCCR-bcm2.0, CSIRO-mk3.5, MPI-echam5 and MRI-cgcm2.3.2a) outputs were studied and compared for each zone. Projections of impact of climate change on onset and retreat dates and length of the rainy season were assessed with these same models under the SRES A2 GHG emission scenario over the period 2082–2098.

In general, the rainy season begins earliest and ends latest south of the domain while earliest retreat dates are seen north of the domain. Thus, the length of the rainy season increases southwards. Amplitudes of fluctuations are stronger for onset date than for retreat. Model results for current climate are close to observations when they were considered with the corresponding standard deviations. CSIRO-mk3.5 and MPI-echam5 perhaps because of their higher spatial resolution, show the best performances and are then more appropriate than the two other models for determining onset, retreat and length of the rainy season over Cameroon and neighbouring areas. The low spatial resolution of BCCR-bcm2.0 and MRI-cgcm2.3.2a may have contributed to their poor results in most cases. For future climate (2082–2098) and according to three of the four models results, onset and retreat dates are expected in most cases to be later by about 1 pentad (5 days) than in the present climate. The CSIRO-mk3.5 and BCCR-bcm2.0 models are not part of the consensus for onset and retreat dates respectively. As for the duration of the rainy season, an increase of approximately 1 pentad (5 days) is expected in zone 3 and a decrease of the same range elsewhere. MPI-echam5 in zone 3 and CSIRO-mk3.5 in zones 1 and 2 however disagree.

The results of this study reveal that high spatial resolutions seem to positively impact simulations of general circulation models. This point to the need in future investigations to assess the performances of regional climate model. Being able to predict onset and retreat dates within days would be of more benefit to local farmers. Also recasting results in terms of probabilities is necessary to evaluate risks of false starts of rain which are problematic for sowing season (Hess *et al*., 1995).

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References

Adejuwon JO. 2006. Variability and the severity of the little dry season in Southwestern Nigeria. *Journal of Climate* **19**: 483–493.

Adejuwon JO, Balogun EE, Adejuwon SA. 1990. On the annual and seasonal patterns of rainfall fluctuations in Sub-Saharan West-Africa. *International Journal of Climatology* **10**: 839–848.

Ati OF, Stigter CJ, Oladipo EO. 2002. A comparison of methods to determine the onset of the growing season in Northern Nigeria. *International Journal of Climatology* **22**: 731–742.

Ayoade JO. 1974. A statistical analysis of rainfall over Nigeria. *Journal of Tropical Geography* **39**: 11–23.

Benoit P. 1977. The start of the growing season in Northern Nigeria. *Agricultural Meteorology* **18**: 91–99.

Cook K, Vizy E. 2006. Coupled model simulations of the West African monsoon system: twentieth- and twenty-first-century simulations. *Journal of Climate* **19**: 3681–3703.

Errasti I, Ezcurra A, Sáenz J, Ibarra-Berastegi G. 2011. Validation of IPCC AR4 models over the Iberian Peninsula. *Theoretical and Applied Climatology* **103**: 61–79.

Furevik T, Bentsen M, Drange H, Kvamsto N, Sorteberg A. 2003. Description and evaluation of the Bergen climate model: ARPEGE coupled with MICOM. *Climate Dynamics* **21**: 27–51.

Gordon HB, Rotstayn LD, McGregor JL, Dix MR, Kowalczyk EA, O'Farrell SP, Waterman LJ, Hirst AC, Wilson SG, Collier MA, Watterson IG, Elliott TI. 2002. *The CSIRO Mk3 Climate System Model [Electronic publication]*. CSIRO Atmospheric Research: Aspendale (CSIRO Atmospheric Research technical paper; no. 60), 130 pp.

Hess TM, Stephens W, Maryah UM. 1995. Rainfall trends in the north east arid zone of Nigeria 1961–1990. *Agricultural and Forest Meteorology* **74**: 87–97.

Ilesanmi OO. 1972a. An ampirical formulation of the onset, advance and retreat of rainfall in Nigeria. *Journal of Tropical Geography* **34**: 17–24.

Ilesanmi OO. 1972b. Aspect of the precipitation climatology of the July–August rainfall minimum of southern Nigeria. *Journal of Tropical Geography* **35**: 51–59.

IPCC. 2001. *The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, In Houghton JT, Ding Y, Griggs DJ, Noguer M, VanderLinden PJ, Dai X, Maskell K, Jhonson CA (eds). Cambridge University Press: Cambridge, UK; p. 881.

Meehl GA, Covey C, Delworth T, Latif M, McAvaney B, Mitchell JFB, Stouffer RJ, Taylor KE. 2007. The WCRP CMIP3 multi-model dataset: a new era in climate change research. *Bulletin of the American Meteorological Society* **88**: 1383–1394.

Mkankam KF. 2000. Validation of general circulation climate models and projections of temperature and rainfall changes in Cameroon and some of its neighboring areas. *Theoretical and Applied Climatology* **67**: 97–107.

Mugalavai EM, Kipkorir EC, Raes D, Rao MS. 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. *Agricultural and Forest Meteorology* **148**: 1123–1135.

Ndomba PM. 2010. Development of rainfall curves for crops planting dates: a case study of Pangani River Basin in Tanzania. *Nile Basin Water Science and Engineering Journal* **3**: 13–27.

Odekunle TO. 2004. Rainfall and the length of the growing season in Nigeria. *International Journal of Climatology* **24**: 467–479.

Odekunle TO. 2006. Determining rainy season onset and retreat over Nigeria from precipitation amount and number of rainy days. *Theoretical and Applied Climatology* **83**: 193–201.

Odekunle TO, Balogun EE, Ogunkoya OO. 2005. On the prediction of rainfall onset and retreat dates in Nigeria. *Theoretical and Applied Climatology* **81**: 101–112.

Olaniran OJ. 1983a. The onset of the rains and the start of the growing season in Nigeria. *Nigerian Geographical Journal* **26**(1 and 2): 81–88.

Olaniran OJ. 1983b. The monsoon factor and the seasonality of rainfall distribution in Nigeria. *Malaysian Journal of Tropical Geography* **7**: 38–45.

Olaniran OJ. 1989. A study of climatic variability in Nigeria based on the onset, retreat, and length of the rainy season. *International Journal of Climatology* **9**: 253–269.

Omotosho JB. 1990a. Onset of thunderstorms and precipitation over Northern Nigeria. *International Journal of Climatology* **10**: 849–860.

Omotosho JB. 1990b. Synoptic meteorology: pathway to seasonal rainfall prediction for sustainable agriculture and effective water resource management in West Africa but Nigeria in particular. *Journal of the Nigerian Meteorological Society (NMS)* **3**(2): 81–86.

Omotosho JB. 1992. Long-range prediction of the onset and end of the rainy season in the West African Sahel. *International Journal of Climatology* **12**: 369–382.

Omotosho JB. 2002. Synoptic meteorology: pathway to seasonal rainfall prediction for sustainable agriculture and effective water resources management in West Africa but Nigeria in particular. *Journal of the Nigerian Meteorological Society* **3**: 81–89.

Penlap KE, Matulla C, Storch HV, Mkankam Nkamga F. 2004. Downscaling of GCM scenarios to assess precipitation changes in the little rainy season (March–June) in Cameroon. *Climate Research* **26**: 85–96.

Roeckner E, Arpe K, Bengtsson L, Christoph M, Claussen M, Dumenil L, Esch M, Giorgetta M, Schlese U, Schulzweida U. 1996. The atmospheric general circulation model ECHAM4: model description and simulation of present day climate. Max Planck Institute for Meteorology, Report No.218, Hamburg, Germany, 90 pp.

Salack S, Muller B, Gaye AT. 2011. Rain-based factors of high agricultural impacts over Senegal. Part I. Integration of local to subregional trends. *Theoretical and Applied Climatology* **106**: 1–22, DOI: 10.1007/s00704-011-0414-z.

Stewart JL. 1991. Principle and performance of response farming. In *Climatic Risk in Crop Production. Models and Management for the Semi-Arid Tropics and Sub-Tropics*, Ford W, Muchow RC, Bellamy ZA (eds). CAB International: Wallingford.

Syed FS, Yoo JH, Körnich H, Kucharski F. 2010. Are intraseasonal summer rainfall events micro monsoon onsets over the western edge of the South-Asian monsoon? *Atmospheric Research* **88**: 341–346.

Yukimoto S, Noda A, Kitoh A, Hosaka M, Yoshimura H, Uchiyama T, Shibata K, Arakawa O, Kusunoki S. 2006. Present-day climate and climate sensitivity in the Meteorological Research Institute Coupled GCM Version 2.3 (MRI-CGCM2.3). *Journal of the Meteorological Society of Japan* **84**: 333–363.

