Characteristics of wet and dry spells in the West African monsoon system

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Abstract

Using 17 years (1998–2014) of daily TRMM 3B42 rainfall data, we provide a climatological characterization of wet and dry spells in West Africa, which should serve to assess the ability of climate model to simulate these high impact events. The study focuses on four subregions (Western and Central Sahel, Sudanian zone and Guinea Coast). Defining wet (dry) spells as sequences of consecutive days with precipitation higher (lower) than 1 mm, we describe the space-time variability of wet and dry spell occurrence. This climatology stresses the influence of the relief on the number and duration of these spells. The spatio-temporal variability of the wet and dry spells also appears to be closely related to the spatio-temporal variability of the West African monsoon. The number of wet spells of all durations and of 2–3 day dry spells have similar features with a maximum occurrence during the local rainy seasons and a spatial pattern similar to the mean annual rainfall with a north–south gradient. In contrast, dry spells lasting more than four days show some singularities such as a low occurrence over the Sahelian band or high occurrence along the Guinea Coast mainly from Ivory Coast to Benin. Moreover, the seasonal cycle of these longer dry spells presents higher occurrences at the beginning and the end of the rainy seasons.

Keywords: hydroclimatology; West Africa; wet spells; dry spells

1. Introduction

With a growing population, pressure on land and water for food production will increase in the coming decades. Moreover, according to the Food and Agriculture Organization of the United Nations (FAO, 2016), climate change will have a significant impact in sub-Saharan Africa where 90% of food production is from rain-fed agriculture which is highly dependent on the variability of the West African monsoon system. By 2080, 75 million hectares of land will no longer be suitable for rain-fed agriculture in sub-Saharan Africa (Turrall et al., 2011). Moreover, various studies suggest an evolution of rain features in West Africa over the past decades. Salack et al. (2016) showed higher occurrences of false start and early cessation of the rainy seasons, as well as more persistent dry spells compared to the 1950s–1960s while at the same time the probability of floods increased. In the Sahel, Sanogo et al. (2015) highlighted significant positive trends in the total yearly precipitation between 1980 and 2010 along with an enhancement and a prolongation of the rainy seasons. In contrast, over the Guinea Coast, no significant trend is reported even though the second rainy season tends to be more intense suggesting a later withdrawal of rains from West Africa. In this context, it is necessary to characterize observed rainfall features of the West African monsoon as a baseline for future evolution. Crop growth are especially sensitive to the wet and dry spells occurrence and duration during the rainy season (Gornall et al., 2010). Understanding the variability of wet and dry spells is therefore important to design early warning systems and hydro-agricultural infrastructures. These spells are to be associated with water balance at the land plot level to determine the occurrence of crop water stress and its timing. However, the need for information at high space-time resolution makes this approach difficult to apply to large regions. Hence, in most regional to global studies, wet and dry spells are considered to be sequences of days with rainfall over or below a given threshold. In the literature, the choice of this threshold varies from study to study. Many authors chose a 0.85 mm or a 1 mm threshold to describe wet and dry days in various parts of the world (e.g. Baron et al., 2003 and Seleshi and Camberlin, 2005 in Africa, Groisman and Knight, 2008 in the United States or Zolina et al., 2013 over Europe). This amount is a good indicator of the ending of a dry spell but is sometimes considered insufficient for crop use (Sivakumar, 1992). Facing the need to take the local climatology into account, some studies are based on a variable threshold depending on the region. For example, Ratan and Venugopal (2013) proposed a climatology of wet and dry spells in several tropical regions based on a percentage (10%) of the local climatological mean rainfall to separate between wet and dry days.

Over West Africa, very few analyses of wet and dry spell features were realized, focusing essentially on dry spells and based on local in situ observations (Sivakumar, 1992; Sanogo et al., 2015). In this paper,
we propose a characterization of the main features of wet and dry spells and their space-time variability in West Africa, using TRMM 3B42 data and a 1 mm threshold to distinguish between wet and dry days. This TRMM-derived climatology of wet and dry spells will contribute to help decision making in the agricultural sector. It should also serve to assess the ability of climate models to simulate such high impact events.

2. Data and method

The study is done using TRMM 3B42 v7 rainfall product for a 17-year period from 1998 to 2014. These data are derived from a combination of calibrated microwave and infrared precipitation estimates (Kummerow et al., 1998; Huffman et al., 2007). The TRMM 3B42 rainfall product is available at temporal and spatial resolutions of 3 h and 0.25° × 0.25°. Several validation studies of the TRMM 3B42 rainfall data have been done over West Africa with ground-based observations and the rainfall product is generally considered reliable, especially at larger space and time scales (Nicholson et al., 2003; Pierre et al., 2011). Besides, Amekudzi et al. (2016) showed that TRMM is suitable for agricultural and other hydro-climatic impact studies over the region given its ability to capture the dry spells as well as the onset, peak and cessation of the rainy season. We consider a domain covering West Africa as presented in Figure 1 (20°W–20°E and 0–20°N). In this region, the annual precipitation follows mainly a latitudinal gradient with less than 400 mm per year in the Northern Sahel and more than 1500 mm per year along the coast of the Gulf of Guinea. The rainiest regions (more than 2000 mm yearly) are located over the ocean at the south-west of the Gulf of Guinea and off the western Atlantic coast. Over the continent, the highest annual rain accumulation are measured over mountain ridges with elevation higher than 1000 m: the Fouta Djalon and Guinean Backbone mountains (spanning Guinea, Sierra Leone and Liberia) and the Adamawa plateau at the frontier between Nigeria and Cameroun. Other singularities compared with the latitudinal gradient can be noted. They are usually related to the topography, such as the Jos plateau (1280 m above sea level on average) in central Nigeria where annual rain accumulation reaches 1400 mm while it is below 1000 mm in this latitude band.

For the present analysis, the 3-hourly rainfall data from TRMM 3B42 have been aggregated at a daily time step. Then, we define each day as wet or dry using a threshold of 1 mm/day. Wet (respectively dry) spells are sequences of consecutive wet (dry) days, preceded and followed by dry (wet) days. Besides, a wet (dry) day that is surrounded by two dry (wet) days is defined as an isolated wet (dry) day. We analyze the spatial and temporal variability of these wet and dry events using the four subregions represented in Figure 1: Western Sahel (18°–10°W and 12.5°–17.5°N), Central Sahel (10°W–10°E and 12.5°–17.5°N), Sudanian region (8°W–10°E and 9°–12.5°N) and the Guinea Coast (8°W–4°E and 5°–9°N). The mean annual precipitation in these subregions is respectively 575, 430, 1047 and 1247 mm. Besides, these subregions differ in their seasonal cycle due to the meridional migration of the Intertropical Convergence Zone (ITCZ). Thus, the Guinea Coast displays two rainy seasons from April to July and in September–October while only one
rainy season is observed from June to September to the north.
Moreover, wet and dry spells are assessed for various duration categories. Dry spells have been analyzed for durations of 2–3, 4–6, 7–15 and 16–21 days similarly to what was done by previous authors (e.g. Sivakumar, 1992). The duration categories of wet spells are chosen to correspond to the different synoptic systems causing rain in West Africa. The wet spells lasting 2–3 and 4–5 days are associated with the so-called ‘3–5 days’ African Easterly Waves (AEWs) and the 6–9 days wet spells are chosen with reference to the ‘6–9 days’ African Easterly Waves (Diedhiou et al. 1998, Wu et al., 2013). These AEWs are both synoptic disturbances known to influence mesoscale convective systems over West Africa. The 10–20 days is another variability mode of the African monsoon rainfall that may result from regional coupled land-atmosphere interactions (e.g. Grodsky and Carton, 2001; Mounier and Janicot, 2004).

3. Results

3.1. Wet spells
Figure 2 shows the average number of wet spells lasting 2–3, 4–5, 6–9 and 10–20 days. The shortest wet spells are the most frequent in the study region. Moreover, for all the studied durations, the spatial pattern of the number of wet spells is similar to that of the annual total precipitation (Figure 1). The number of wet spells displays a latitudinal gradient and is maximum in the same areas as those with high annual precipitation such as the Guinean backbone, the Adamawa Plateau or the Jos Plateau indicating the influence of both the relief and the latitudinal migration of the ITCZ. The yearly average of the number of the 2–3 day spells ranges from less than 10 events in the Sahel to more than 30 in the Gulf of Guinea and off the western coast of Guinea and Sierra Leone. Around 15 annual wet spells of 2–3 days are noted over the Adamawa Plateau. This small amount in comparison with the annual rainfall may be caused by the blocking role of the topography resulting in longer wet spells in this area. On average, the 4–5 day wet spells occur less than twice a year north of 12.5°N (in the Sahel) and about 7 to 10 times in the areas with high annual rain accumulation (over Guinea Coast and in mountainous areas). Concerning longer wet spells (6–9 and 10–20 days), less than 1 or 2 events occur each year over almost all the domain, except in the Fouta Djalon-Guinean backbone and the Adamawa regions where more than six (respectively three) wet spells of 6–9 days (respectively 10–20 days) occur.

For a more precise analysis of the number of wet spells and their seasonal variability, we present in Figure 3 different features of the wet spells number in the four selected subregions (see Figure 1). Figure 3(a) shows the 17-year (1998–2014) climatology of the annual number of wet spells of different durations per gridbox (0.25° × 0.25°) for each of the four subregions. It is important to notice that isolated wet days are more frequent in the four subregions than wet spells of all durations and are twice as many in the Guinean or Sudanian area as in the Sahel. Moreover, the ratio of the number of isolated wet days to 2-day wet spells is higher in the driest regions. It is close to 4 in the two Sahelian regions while it is around 2.4 in the Sudanian and Guinean areas. The actual number of rainy days contributed by wet spells of different durations is another interesting quantity, which is plotted in Figure 3(b). More precisely, if there are \( N_d \) wet spells lasting \( d \) days in a season, these wet spells contribute \( d \times N_d \) days to the total number of rainy days. It shows that the major contribution to all the rainy days is from the isolated wet days. Moreover, almost no wet spell longer than 10 days are observed in the selected subregions, as previously noted in Figure 2. These results are consistent with those described in Ratan and Venugopal (2013) for
their ‘arid regions’ (category corresponding to the studied subregions).

The seasonal variability of the number of wet spells of different durations in each of the four subregions is presented in Figure 3(c). The 10–20 day wet spells are not shown because there are too few events. For a relevant comparison with the seasonal cycle of rainfall associated with the evolution of the West African Monsoon, the monthly mean of daily rainfall is also indicated. It appears that the number of wet spells displays the same seasonal cycle as daily rainfall, in all of the four subregions and for the different duration categories studied (2–3, 4–5 and 6–9 days). Therefore, for all the durations and in the four regions, the number of wet spells is maximum during the rainy season: between June and September in the two Sahelian regions and between April and October in the Sudanian area. Over Guinea Coast, two peaks of similar magnitude are observed corresponding to the long and short rains from April to July and from September to November, with a lower number of wet spells in August during the little dry season.

3.2. Dry spells

The characterization of the space-time variability of wet spells is repeated for dry spells. Figure 4 shows the average number of dry spells lasting 2–3, 4–6, 7–15 and 16–21 days. As expected, the longer the considered duration, the fewer the dry spells. Overall, the large-scale spatial pattern and order of magnitude of the number of the 2–3 day dry spells is similar to the number of 2–3 day wet spells, with a latitudinal gradient and maximum occurrence off Guinea and in the Gulf of Guinea with up to 30 events each year. For longer dry spell duration, the latitudinal gradient is less pronounced and the maximum of the number of dry spells moves to the coast of Ghana and Ivory Coast with values of about 15 dry spells of 4–6 days, 10 dry spells lasting 7–15 days and more than 2 dry spells of 16–21 days on average each year. The spatial pattern of these longer dry spells differs from that of long wet spells with regions such as the Sahel or the coasts from Benin to Ivory Coast displaying large numbers of dry spells and low numbers of wet spells. Another noteworthy feature is the presence in the Sudanian band of a minimum in the number of dry spells lasting more than a week, with less than four dry spells of 7–15 days and less than one dry spell of 16–21 days on average each year. Moreover, for all durations, the mountainous areas (Fouta Djalon, Adamawa and Jos Plateaus) vary from their neighboring regions displaying fewer dry spell events. This result highlights the role of the topography in the triggering of precipitation in West Africa.

Similarly to what was shown for wet spells, Figures 5(a) and (b) present the 17-year climatology of the annual number of dry spells of different durations and the actual number of dry days contributed by these dry spells for each of the four selected subregions. In the four subregions, the isolated dry days are the more numerous than dry spells of all duration and the number of dry spells decreases with their duration. This decrease is more pronounced in the wettest regions (Sudanian zone and Guinea Coast). The
main contribution to the dry days comes from dry spells lasting 2 days in the four selected subregions, which is consistent with the conclusion presented, by Ratan and Venugopal (2013) in other parts of the world. The contribution of short dry spells (less than 7 days) is more important in the Sudanian zone and Guinea Coast than in the Sahel. However, the contribution of dry spells lasting more than 10 days is more important in the Western and Central Sahel than in the Sudanian band. The Guinea Coast has a little more long dry spells than the other subregions which is rather counter-intuitive and may be due to a longer rainy season leading to more possibilities to have a dry spell between two rainy days. It is noteworthy that short (1 or 2 days) wet events occur more frequently than short dry events while long (over 3 days) wet spells are fewer than long dry spells.

The seasonal variability of the number of dry spells is displayed in Figure 5(c). Unlike for wet spells, the seasonal cycle of the number of dry spells differs depending on the considered duration of the dry spell. In the four subregions, dry spells lasting 2–3 days mostly occur during the rainy seasons with maximum occurrence in August in the two Sahelian and the Sudanian regions and in May–June and September over Guinea Coast with weaker occurrence during the little dry season in August. In the Sudanian zone and Guinea Coast, an important number of such dry spells is also noticed just before the rainy season in April and May. For longer dry spells, the seasonal cycle is less in phase with that of daily rainfall. In particular, the number of dry spells decreases in the middle of the rainy season, in August in the Central and Western Sahel and from June to September in the Sudanian region. In the Guinea Coast area, the 4–6 day dry spells are the most frequent at the beginning of the first rainy season in April and at the end of the second one in October. Regarding the 7–15 day dry spells, their occurrence is maximum at the very beginning of the first rainy season in March, during the little dry season in August and at the very end of the second rainy season in November.

4. Conclusion

This paper describes the spatial and temporal variability of wet and dry spells in West Africa based on TRMM 3B42 data, from 1998 to 2014. Thanks to its spatial resolution, this climatology of wet and dry spells should serve to assess the ability of climate models to simulate such events. It appears that the number of wet and dry spells decreases with their duration. Moreover, isolated wet days contribute the most to the total number of rainy days, while the major contribution to the dry days is from 2-day dry spells. These results confirm those of Ratan and Venugopal (2013) in other tropical regions. Despite these common specificities, the number of wet and dry spells varies spatially. The number of 2–3 day wet and dry spells show similar large-scale pattern and seasonal cycle while for events lasting more than 4 days, the main features are different whether one consider wet or dry spells. In some regions such as the south of Guinea Coast, few long wet spells are observed while long dry spells are more numerous than in the rest of the domain. Concerning the longest dry spells considered in this study (16–21 days), they occur on average once a year in the Sahel band but also over most of the Guinean region and up to twice a year along the coasts of Ivory Coast and Ghana. The relief has a particular influence leading to shorter dry spells and longer wet spells over the mountainous regions than in their neighboring area. The spatio-temporal variability of the number of wet and dry spells also appears to be linked to the spatio-temporal migration of the ITCZ. The wet spells of all duration and the short dry spells display a large-scale spatial pattern and a diurnal cycle similar to those of the mean rainfall indicating the variability associated with the West African monsoon. These wet and dry events are more frequent in the Guinea Coast than in the Sudanian zone or Sahel and

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they occur mainly during the local rainy seasons. They seem to occur mainly near the core of the ITCZ, both spatially and temporally. In contrast, longer dry spells appear to be more frequent on the sides of this rainfall core: just north or south of it and at the beginning and at the end of the local rainy seasons. Therefore, wet and dry spells occurrence have a major influence on the duration of the rainy season, in particular through ‘false onset’ or early or late cessation of the season. Improving short-term forecasting and decadal trends of the wet and dry spells and their variability is thus a major issue for the agricultural sector in West Africa. To that purpose, further studies are needed to understand the large-scale atmospheric and surface drivers leading to these events.

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References

Amekudzi LK, Osei MA, Atiah WA, Aryee JNA, Ahiatuku MA, Quansah E, Preko K, Danuor SK, Fink AH. 2016. Validation of TRMM and FEWS Satellite Rainfall Estimates with Rain Gauge Measurement over Ashanti Region, Ghana. *Atmospheric and Climate Science* 6: 500–518.

Barron J, Rockström J, Gichuki F, Hatibu N. 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology* 117: 23–37.

Diedhiou A, Janicot S, Viltard A, de Felice P. 1998. Evidence of two regimes of easterly waves over West Africa and the tropical Atlantic. *Geophysical Research Letters* 25: 2805–2808.

FAO. 2016. Food and agriculture - key to achieving the 2030 agenda for sustainable development. *Food and Agriculture Organization of the United States* 15499: 32.

Gornall J, Betts R, Burke E, Clark R, Camp J, Willet K, Wiltshire A. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 365: 2973–2989.

Grosky SA, Carton JA. 2001. Coupled land/ atmosphere interactions in the West African Monsoon. *Geophysical Research Letters* 28: 1503–1506.

Groisman PY, Knight RW. 2008. Prolonged dry episodes over the conterminous United States: new tendencies emerging during the last 40 years. *Journal of Climate* 21: 1850–1862.

Huffman GJ, Adler RF, Bolvin DT, Gu G, Nelkin EJ, Bowman KP, Hong Y, Stocker EF, Wolff DB. 2007. The TRMM multisatellite precipitation analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. *Journal of Hydrometeorology* 8: 38–55.

Kummerow C, Barnes W, Kozu T, Shiue J, Simpson J. 1998. The tropical rainfall measuring mission (TRMM) sensor package. *Journal of Atmospheric and Ocean Technology* 15: 809–817.

Mounier F, Janicot S. 2004. Evidence of two independent modes of convection at intraseasonal timescale in the West African summer monsoon. *Geophysical Research Letters* 31: L16116.

Nicholson SE, Some B, McCollum J, Nelkin E, Klotter D, Berte Y, Djallo BM, Gaye I, Kpabeba G, Ndiaye O, Noupouzoukou, Tanu MM, Thiam A, Toure AA, Traore AK. 2003. Validation of TRMM and other rainfall estimates with a high-density gauge dataset for West Africa. Part II: Validation of TRMM Rainfall Products. *Journal of Applied Meteorology and Climatology* 42: 1355–1368.

Pierre C, Bergametti G, Maticorena B, Mougin E, Lebel T, Ali A. 2011. Pluriannual comparisons of satellite-based rainfall products over the Sahelian belt for seasonal vegetation modeling. *Journal of Geophysical Research: Atmospheres* 116: D18201.

Ratan R, Venugopal V. 2013. Wet and dry spell characteristics of global tropical rainfall. *Water Resources Research* 49: 3830–3841.

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Salack S, Klein C, Giannini A, Sarr B, Worou ON, Belko N, Bliefernicht J, Kunstman H. 2016. Global warming induced hybrid rainy seasons in the Sahel. *Environmental Research Letters: ERL. 11: 104008.

Sanogo S, Fink AH, Omotosho JA, Ba A, Redl R, Ermert V. 2015. Spatio-temporal characteristics of the recent rainfall recovery in West Africa. *International Journal of Climatology: A Journal of the Royal Meteorological Society. 35: 4589–4605.

Seleshi Y, Camberlin P. 2005. Recent changes in dry spell and extreme rainfall events in Ethiopia. *Theoretical and Applied Climatology 83: 181–191.

Sivakumar MVK. 1992. Empirical analysis of dry spells for agricultural applications in West Africa. *Journal of Climate 5: 532–539.

Turral H, Burke J, Faures J-M. 2011. Climate Change, water and food security. *FAO Water Reports 36, Food and Agriculture Organization of the United Nations, p. 15.

Wu M-LC, Reale O, Schubert SD. 2013. A characterization of African easterly waves on 2.5–6-day and 6–9-day time scales. *Journal of Climate 26: 6750–6774.

Zolina O, Simmer C, Belyaev K, Gulev SK, Koltermann P. 2013. Changes in the duration of European wet and dry spells during the last 60 years. *Journal of Climate 26: 2022–2047.