



HAL
open science

Spatial coherence of monsoon onset over Western and Central Sahel (1950-2000)

Romain Marteau, Vincent Moron, Nathalie Philippon

► **To cite this version:**

Romain Marteau, Vincent Moron, Nathalie Philippon. Spatial coherence of monsoon onset over Western and Central Sahel (1950-2000). *Journal of Climate*, 2009, 22 (5), pp.1313-1324. 10.1175/2008JCLI2383.1 . hal-00321044

HAL Id: hal-00321044

<https://hal.science/hal-00321044>

Submitted on 15 Jan 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

NOTES AND CORRESPONDENCE

Spatial coherence of monsoon onset over Western and Central Sahel (1950-2000)

Romain MARTEAU ¹, Vincent MORON ^{2,3,4,5} and Nathalie PHILIPPON ¹.

¹ *UMR 5210 CNRS, Centre de Recherches en Climatologie, Université de Bourgogne, Dijon, France.*

² *UMR 6635, CEREGE, Europôle méditerranéen de l'Arbois, France.*

³ *UFR des Sciences Géographiques et de l'Aménagement, Université d'Aix-Marseille I, Aix en Provence, France.*

⁴ *International Research Institute of Climate and Society, Columbia University, New York, USA.*

⁵ *Institut Universitaire de France*

Journal of Climate, submitted.

December, 10 2007

Revised version

July, 07 2008

Second revision

22

September, 02 2008

23

24 _____

25Corresponding author address: Romain Marteau, Centre de Recherches de Climatologie, UMR 5210

26CNRS, Université de Bourgogne, Faculté des Sciences Gabriel, 6 Bd Gabriel, 21000 Dijon, France.

27E-mail: romain.marteau@u-bourgogne.fr

28**Abstract:**

29The spatial coherence of boreal monsoon onset over Western and Central Sahel (Senegal, Mali,
30Burkina-Faso) is studied through the analysis of daily rainfall data for 103 stations from 1950 to
312000. Onset date is defined using a local agronomic definition, i.e. the first wet day (> 1 mm) of
321 or 2 consecutive days receiving at least 20 mm without a 7-day dry spell receiving less than 5
33mm in the following 20 days. Changing either the length and/or the amplitude of the initial wet
34spell, or the length of the following dry spell modify the long-term mean local-scale onset date
35but has only a weak impact either on its interannual variability or its spatial coherence. Onset
36date exhibits a seasonal progression from southern Burkina-Faso (mid May) to northwestern
37Senegal and Saharian edges (early August). Interannual variability of the local-scale onset date
38does not seem to be strongly spatially coherent. The amount of common or covariant signal
39across the stations is far weaker than the inter-station noise at the interannual time scale. In
40particular, a systematic spatially-consistent, advance or delay of the onset is hardly observed
41across the whole Western and Central Sahel. In consequence, the seasonal predictability of
42local-scale onset over the Western and Central Sahel associated for example with large-scale
43sea surface temperatures, is, at best, weak.

44

45

46

47

48

49

50

51

52

531. Introduction

54The rainy season over the Sahelian belt spans only few months, mainly from July to September
55(Lamb 1978; Nicholson 1979, 1980), and is associated with the latitudinal shift of the whole
56monsoon system. Previous work has shown that the northward shift, which determines the
57large-scale onset of the rainy season across the Sudanian and Sahelian belts, usually occurs at
58the end of June, as an abrupt jump between Guinean (i.e. 5°-8°N) to Sahelian (i.e. 10°-14°N)
59latitudes (Sultan and Janicot 2000, 2003; Sultan et al. 2003; Fontaine and Louvet 2006). The
60monsoon withdrawal in late September over the Sahelian belt is much smoother (Sultan and
61Janicot 2000). "Pre-onset" scattered rains could occur over the Sahelian belt before the large-
62scale S-N jump, while most of the Sahelian seasonal rainfall are associated with westward-
63moving squall-lines (SLs) of mean horizontal extent of ~ 500 km and propagation speed of 10-

6415 m/s (i.e. Martin and Schreiner 1981; D'Amato and Lebel 1998; Laurent et al. 1998; Mathon
65et al. 2002).

66

67The timing of the start of the rainy season is crucial to decide when to plant crops (Sivakumar
681992). This is of particular importance for the Sahelian belt where economy is mostly based on
69rainfed agriculture, with weak capacity to mitigate adverse effects of interannual variability of
70rainfall (Ingram et al. 2002). In that context, any reliable prediction of the local-scale onset date
71would be of a great value to assist on time preparation of farmlands, mobilisation of seed,
72manpower and equipment, and would also reduce the risks of planting at an unfavorable time
73(Omotosho et al. 2000). Sultan et al. (2005) clearly demonstrated that the "ideal" sowing date,
74i.e. the one leading to the highest yields, is close to the large-scale onset date, defined as the
75northward jump of the Intertropical Convergence Zone (ITCZ).

76

77The definition of the onset of the rainy season over West Africa has generally followed two
78approaches: (i) a local-scale one and (ii) a large-scale one. Methods for detecting the onset of
79the rainy season at local-scale have been proposed as early as the 70's for specific Sahelian
80settings (in Niger mainly, Davey et al. 1976; Benoit 1977). Most methods rely on *in-situ* daily
81measurements of rainfall meeting subjective thresholds (Davey et al. 1976; Stern et al. 1981;
82Sivakumar 1988; Jolliffe and Sarria-Dodd 1994; Balme et al. 2005). These empirical thresholds
83are chosen according to the climatological properties of the rainy season as well as agronomic
84criteria (these points will be detailed in section 3). In this approach, the onset is primarily

85assumed as a change in the properties, frequency and/or intensity of rainfall events associated
86with the arrival of the monsoon air mass. Other parameters have also been taken into
87consideration to detect local onsets, such as evapotranspiration (Benoit 1977; Ati et al. 2002).

88

89A more recent large-scale approach is based on sub-continental indexes of observed rainfall or
90rainfall proxies such as outgoing long wave radiation (OLR) (Sultan and Janicot 2000). The
91seasonal cycles of pentad rainfall averaged over West African longitudes (e.g. 10°W-10°E)
92show an alternation of steep increases and pauses (Louvet et al. 2003) during its northward
93progression. One of these pulses appears to be associated with the abrupt northward shift of the
94ITCZ, the so-called "ITCZ jump" (Sultan and Janicot 2000). The onset is thus only defined
95from the planetary-scale northward shift of the monsoon, and a single date is given for a given
96band of longitudes.

97

98The approach of Camberlin and Diop (2003) can be viewed as an intermediate approach. In
99their study, an Empirical Orthogonal Function (EOF) analysis is applied to local-scale, daily
100rainfall anomalies in Senegal for a multi-year period. A single onset date was then computed
101for the whole country as the minimum of the cumulative sum of the leading principal
102component (PC) time series on a yearly basis. This date is representative of the local-scale onset
103dates for the stations highly correlated with the leading PC, and part of local-scale interstation
104noise is filtered out through the spatial weighting provided by the EOF.

105

106 This brief review demonstrates that at least two different strategies are used to define the onset.
107 The local-scale definition is clearly the most suitable for end-users so that they can use the
108 information as a valuable decision-making parameter. In that context, three important related
109 questions are explored in this paper:

110 1. How pertinent is the local-scale definition, proposed in previous studies for specific
111 settings across the Sahel, for a larger longitudinal belt? The previous definitions are
112 based on subjective thresholds chosen according to climatological and/or agronomic
113 features. The sensitivity of the onset date (in terms of mean and interannual variability)
114 to this parametrization has never been evaluated.

115 2. To what extent do the average and local-scale onset date match with the regional-
116 scale (i.e. as defined by Sultan and Janicot, 2000) ones? Is the abrupt jump of the ITCZ
117 noticeable across the network? These issues are related to the shape and intensity of
118 potential modes of variability of onset date. They are also intrinsically related to the
119 intensity of the spatial coherence and potential predictability of onset date.

120 3. The spatial coherence of a phenomenon is partly indicative of its potential
121 predictability: It is indeed expected that global or regional-scale sea surface
122 temperatures anomalies should induce a rather smooth, roughly spatially-uniform,
123 anomalous signal at regional-scale, at least for a flat area such as the Sahel (Moron et al.
124 2006, 2007). As forecasts of the rainy season onset is desired by user communities, an
125 estimate of its potential predictability is a first step toward this goal.

126

127These three issues are analyzed from a 103 rain-gauge network covering Western and Central
128Sahel (Senegal, Mali and Burkina-Faso) from 1950 to 2000. Section 2 describes the different
129daily rainfall datasets. Section 3 provides the main results in terms of (i) definition of the local-
130scale onset date, (ii) climatological mean and characteristics of the rainfall field before and after
131the onset, (iii) interannual variability and spatial coherence of onset date. Conclusions are given
132in section 4.

133

1342. Daily rainfall data

135The daily rainfall analysed in this study come from two different databases: (i) the FRIEND-
136AOC (Flow Regimes from International Experimental and Network Data - Afrique de l'Ouest et
137Centrale) group (<http://armspark.msem.univ-montp2.fr/FRIENDAOC/>), and (ii) the Senegalese
138DMN (Direction de la Météorologie Nationale) that provided us with *in situ* daily data of 103
139stations for the period 1950 to 2000 (Fig. 1).

140

141a. Rainfall data

142Data for 33 stations in Mali and 41 stations in Burkina-Faso were compiled by the FRIEND-
143AOC group from various sources (IRD – Institut de Recherche pour le Développement –,
144ASECNA – Agence pour la SECurité de la Navigation Aérienne en Afrique –, DMN –
145Direction Météorologique Nationale – and CIEH – Comité Inter-Africain d'Etudes
146Hydrauliques –).

147

148 Daily rainfall amounts recorded at 29 stations come from the Senegal DMN. Most of the
149 stations are located in the western part of the country while the eastern part is less sampled (Fig.
1501).

151

152b. *Filling the missing values*

153 Missing daily rainfall observations (less than 3%) were replaced with a local scaling (Widmann
154 et al. 2003; Ines and Hansen 2005; Schmidli et al. 2006) of daily ERA-40 rainfall. For each
155 station, the closest ERA-40 grid point is chosen, and its daily rainfall is scaled so that the
156 frequency of occurrence of wet day > 1 mm and the mean intensity of daily rainfall during wet
157 days match the long-term monthly mean of the available data. Missing entries are then replaced
158 by the calibrated ERA-40 rainfall for these particular days. Note that replacing the missing
159 entries from May to October with a simple stochastic weather generator ([Wilks 1999](#)) leads to
160 very similar results.

161

1623. **Results**

163a. *Agronomic definition of onset*

164 The local-scale agronomic definition of the onset is the most relevant to agriculture
165 management. This definition is based on local-scale daily rainfall using empirical thresholds of
166 rainfall that ensure enough soil moisture during planting and growing periods to avoid crop
167 failure (Walter 1967; Omotosho 1990 1992; Omotosho et al. 2000). Table 1 lists the different
168 thresholds used in selected previous studies dedicated to the Sahelian domain. Most of the

169studies agree on two criteria; (i) 1 or 2 consecutive days receiving at least 20-25 mm of rainfall,
170and (ii) no 7-day dry spell in the following 30 days from the onset. The threshold of 20 mm
171amount was adopted following a study by ICRISAT dedicated to millet in Niger (Davey et al.
1721976; Sivakumar 1992) and corresponds to the minimum water requirement for crop survival.
173Considering at least 2 consecutive days is a reasonable choice to take into account a rain event
174that occurs across the recording time (usually between 7 and 9 a.m local time). In fact, SLs
175develop themselves mainly in late afternoon and persist sometimes during the night (Martin and
176Schreiner 1981). The 7-day dry spell after the onset is known as the "control period" and
177prevents against "false" onsets that have disastrous consequences on germination and crop
178development (Sivakumar 1992), and require farmers to sow again while the seed's stock is
179usually small (Diop 1996). Moreover, anything less than 50 percent of the weekly crop water
180requirement (CWR) will likely lead to crop failure (i.e. Omotosho et al. 2000). The CWR
181equals at least 10 mm across the Sahel, leading to a threshold of 5 mm in 7 days to define a
182dangerous limit for crop survival after the first rains.

183

184In the current study, a wet (dry) day is defined as a day receiving more (less) than 1 mm (Diop
1851999) because (i) rainfall amounts between 0 and 1 mm are not equally reported across
186countries and stations (i.e. synoptic or not), and (ii) considering daily amounts less than 1 mm
187usually increases the interstation noise (Moron et al. 2007) when determining onset. The onset
188date (OD hereafter) is defined here as the first wet day of 1 or 2 consecutive days receiving at
189least 20 mm without any 7-day dry spell receiving less than 5 mm during the following 20 days

190counted from the onset. OD is computed from May, 1st. These criteria are obviously too
191restrictive for the driest stations and years. While less than 0.4% of station-year do not
192experience any 2-day receiving at least 20 mm during May-November season, 8.6% of onset
193are undefined when the post-onset 7-day dry spell receiving less than 5 mm in the following 20
194days is included in the definition. This percentage reaches 19% when the control period length
195is extended to 30 days from the initial wet spell. A window of 20-day is thus retained as a
196compromise between the need to consider "false" starts and a too restrictive threshold that
197excludes many stations and years. Undefined onset dates still account for 40% of years for the
19814 stations north of 15°N. In most of these cases, no rainy season is actually experienced with
199scattered rainy events spread across the season. In the following analyses (except for EOF in
200section 3d), the undefined onset dates (8.6%) are replaced by the latest available onset date
201observed across the network for the given year, weakly increasing the spatial coherence over
202the northern edge of the domain.

203

204Figure 2a displays the mean onset dates averaged over the 51 years. The mean OD exhibits a
205rather regular northward shift , mixed with a secondary northwestward one over Senegal, from
206mid May (south Burkina Faso) to early August (NW Senegal and central-northern Mali).
207Respectively, 17.9%, 31.4%, 36.1% and 12.7% of onset occur in May, June, July and August
208(Fig. 2b).

209

210*b. Mean characteristics of rainfall field before and after the onset*

211Figure 3 shows the mean characteristics of the rainfall field averaged over the 15 days before
212and 15 days after the local-scale OD. These periods are extracted for each station on a yearly
213basis, and the frequencies of occurrence of wet days receiving respectively between 1 and 20
214mm and > 20 mm are computed (Fig. 3a-d) as well as the mean length of the wet and dry spells
215(Fig. 3e-h).

216

217Before the onset, the frequency of occurrence of wet days receiving between 1 and 20 mm is far
218from zero (usually 10-20%). By contrast, the frequency of occurrence of wet days receiving >
21920 mm is very low (1-4%), but this is almost fully explained by the criteria used to define OD
220(see section 3a). The mean dry spell length is rather homogeneous, usually between 4 and 6
221days, without any clear northward increase (Fig. 3g). Similarly, the mean wet-spell length is
222rather spatially uniform, between 1 and 2 days, still without any clear northward decrease (Fig.
2233e).

224

225From the onset, the frequency of occurrence of wet day receiving between 1 and 20 mm
226increases smoothly, by a factor of 2, while the frequency of occurrence of wet day > 20 mm is
227roughly multiplied by 5. The multiplication of wet days breaks up the dry spells, that are
228consistently shorter than before the onset (less than 3 days except for several northern stations,
229Fig. 3g,h) while the mean wet spell length remains shorter than 2 days (Fig. 3i,j). In other
230terms, at local-scale, the onset is usually associated with more and wetter rainy days afterwards,
231but those wet days remain rather isolated or clustered into 2-day wet sequences. This could be

232related to the dominant influence of SLs and the usual scarcity of long-lasting wet spells at
233these latitudes.

234

235Figure 4 further illustrates the relative rainfall field near the onset date, in particular its spatial
236pattern. For each station and each year, the frequency of occurrence of daily rainfall > 1 mm for
2372 days before (Fig. 4a), and after (Fig. 4b) the local-scale onset (and their difference, Fig. 4c) is
238computed for the whole rainfall field relocated relative to the reference station (i.e. (0,0)
239location on Fig. 4). In other words, Figures 4b,c illustrate the spatial coherence of the "first
240kind", i.e. the frequency of occurrence of a wet day around a station when its onset occurs.
241Figure 4a is roughly similar to the mean climatological pattern of frequency of occurrence, i.e.
242a northward gradient, also visible in the mean onset date (Fig. 2). Considering the long-term
243mean of the frequency of occurrence of any other sample of 2 days leads roughly to the same
244pattern, except that the spatial mean varies according to the seasonal cycle of rainfall (not
245shown). The occurrence of local-scale OD slightly alters this pattern (Fig. 4b), mostly through
246an increase of the frequency of occurrence of an elongated WSW-ENE shape around the
247reference station (Fig. 4c). A small asymmetric surface of 3° - 4° ($\sim 1^{\circ}$) in longitude by 2° ($\sim 1^{\circ}$)
248in latitude around the reference station exhibits significant (at the two-sided 90% level
249according to a Student's T test) increase of the frequency of occurrence for 75% (90%) of the
250time between pre- and post-onset 2 days (Fig. 4c). Thus, figure 4 suggests that local-scale OD
251seems hardly related to coherent space-time propagating features at meso- or synoptic-scale
252and/or even the planetary-scale because neither regular northward (possibly associated with an

253 abrupt jump of the ITCZ), nor westward (possibly associated with a SL) progression appears
254 between panel (a) and (b) of Figure 4. Increasing the length of the time period averaged before
255 and after the onset to 5, 10, 20 and 30 days is associated with a wider ~ W-E belt of increased
256 frequency of occurrence of rainfall, probably in relation with the mean northward shift of the
257 overall rain belt, especially for periods lasting at least 10 days (not shown).

258

259 *c. Spatial coherence of the onset date at interannual time scale*

260 The spatial coherence of the "second kind" is the possible systematic modulation of onset dates
261 (or any other seasonal characteristic) at interannual time scale. Note that a weak spatial
262 coherence of the "first kind" (section 3b) does not necessarily forbid this effect because a large-
263 scale forcing could synchronize the onset dates in time, by systematically delaying or bringing
264 forward the onset of the rainy season at local-scale (Moron et al. 2008). The spatial coherence
265 of the OD at interannual time scale has been estimated through degrees of freedom (DOF)
266 (Moron 1994; Fraedrich et al. 1995; Bretherton et al. 1999; Moron et al. 2006) and interannual
267 variance of the standardized anomaly index (SAI) ($\text{var}[\text{SAI}]$) (Katz and Glantz 1986). The DOF
268 are computed following the equation of Fraedrich et al. (1995):

269

270
$$DOF = \frac{M^2}{\sum_{i=1}^M e_i^2}$$

271

272 where M is the number of stations and e_i , the eigenvalues of the correlation matrix. The DOF
273 varies between 1 and the rank of the correlation matrix. In the limiting case of $e_i = 1$ for all

274orders, $DOF = M$, that is, each station conveys independent information and the common
275"signal" is zero. On the other hand, if the first eigenvalue accounts for all variance of the field,
276then $DOF = 1$, that is, each station conveys the same information equal to the signal and the
277noise is zero. Note that due to finite length, the highest DOF expected for a 51×103 matrix of
278independent white noise is not 50, but rather ~ 34 . The $var[SAI]$ ranges between 0 (correlation
279of -1 between two equal-sized and perfectly out-of-phase samples), $1/M$ (~ 0.01 in our case, for
280spatially independent variations), and 1 (perfect correlation between stations) (Moron et al.
2812006, 2007).

282

283Here the DOF of the local-scale OD is high (23.7) indicating a weak spatial coherence at the
284regional scale. The $var[SAI]$ equals 0.07 and is also close to the value associated with a white
285noise time series. For comparison, the DOF and $var[SAI]$ equal 6.1 (respectively 4.8) and 0.36
286(respectively 0.41) for the May-November seasonal rainfall amounts (respectively frequency of
287occurrence of wet days > 1 mm). Therefore, according to DOF and $var[SAI]$, the agronomic
288OD is characterized by a considerable amount of inter-station noise, and in consequence, is
289assumed to be poorly predictable from large-scale predictors at the interannual time scale
290(Moron et al. 2006, 2007). To test the sensitivity of the spatial coherence to parametrization,
291 DOF and $var[SAI]$ have been computed again, by changing (i) the length of initial wet spell (L_w
292= 2 to 10 days) and (ii) the amount of rainfall received during the initial wet spell ($A_w = 1, 5,$
29310, 15, 20, 25, 30, 35 and 40 mm) while the other criterion (i.e. a 7-day dry spell receiving less
294than 5 mm in the following 20 days) is kept fixed. Note that the percentage of undefined onset

295 dates is always $< 10\%$ ~~in mean~~, except when $A_w > 25$ mm and $L_w < 4$ days (maximum of
296 undefined onset = 19.1% for $A_w = 40$ and $L_w = 2$). As before, the missing entries are replaced
297 by the latest interannual onset date, slightly increasing the spatial coherence on the northern
298 edges.

299

300 DOF and $\text{var}[\text{SAI}]$ are indeed very stable amongst the 81 different estimates; DOF varies
301 between ~ 23 and ~ 28 with 88% of values between 23 and 25 and $\text{var}[\text{SAI}]$ varies between
302 0.065 and 0.086. In other words, increasing the length and/or amplitude of the initial wet spell
303 has a very weak impact on the spatial coherence. Even the climatological long-term mean and
304 the interannual variability at local-scale are only weakly sensitive to the parametrization of A_w
305 and L_w . 52% (respectively 76%) of the local-scale mean bias between two different estimates of
306 OD are less than 5 days (respectively 10 days) in absolute value and 77% (respectively 88%) of
307 the local-scale correlations between two different estimates of OD are equal or greater than 0.7
308 (respectively 0.6). The impact of the length of the control dry spell (L_d) was also tested with A_w
309 and L_w set to 20 mm and 2 days respectively, while L_d was set equal to 5, 7, 9, 11, 13, and 15
310 days in the 20 days from the onset. Note that undefined onsets decrease almost exponentially
311 from 25% to 1% between the extreme values of L_d . DOF and $\text{var}[\text{SAI}]$ are almost stable
312 between 25 and 26 and < 0.10 respectively. In summary, the weak spatial coherence of "second
313 kind" is not related to the parametrization of the OD.

314

315

316

317*d. Interannual to interdecadal variability of the onset date*

318 To further examine the interannual variability of OD, an Empirical Orthogonal Function (EOF)
319 analysis based on its correlation matrix is computed. Note that undefined onsets are left
320 untouched here and that correlation matrix is computed only from pairs of available ODs. The
321 leading EOF mode of OD accounts for 8.7% of the total variance consistently with the weak
322 spatial coherence depicted above. By contrast, the leading EOF of the May-September seasonal
323 amount (the frequency of occurrence of wet days > 1 mm) accounts for 38.1% (respectively
324 43.4%) of the total variance. The second unrotated EOF mode of onset date explains less than
325 6.4% of total variance. The first unrotated mode (Fig. 5a) describes a relatively coherent
326 structure of OD variability mostly over Western and Central Senegal. This behaviour could be
327 at least partly related to the relatively high spatial sampling (Fig. 1), but could be also related to
328 a slightly stronger signal (Camberlin and Diop 2003). The corresponding leading EOFs of
329 seasonal amount (Fig. 5b) and frequency of occurrence of wet days > 1 mm (Fig. 5c) exhibit
330 larger scale patterns with loadings > 0.6 spread all across the domain without a clear spatial
331 gradient. The leading PC of onset date (respectively seasonal amount and frequency of
332 occurrence) (Fig. 5d) exhibits a positive (negative) and statistically significant (at one-sided
333 95% confidence level) trend, i.e. a delayed onset (decreased seasonal rainfall and frequency of
334 occurrence) from 1950-2000. The median of local-scale correlations between onset on one hand
335 and seasonal amount and frequency of occurrence on the other hand equals only -0.35.

336

337In order to analyse the relationships between the local-scale and the regional-scale onset date as
338defined by Sultan and Janicot (2000) through the S-N jump of the ITCZ the local-scale OD are
339extracted from 1968 (available online at <http://www.lodyc.jussieu.fr/~bslod/monsoon.htm>).
340Note that DOF of local-scale OD for the 1968-2000 period equals ~19, but this apparent higher
341spatial coherence could be an artefact of the decrease of the matrix rank from 50 to 32. The
342correlations between the large-scale and the 103 local-scale ODs are between -0.54 and 0.41,
343with only 7 values being significant at the two-sided 95% level according to a random phase
344test (Janicot et al. 1996). Moreover, the correlation between regional-scale OD as defined by
345Sultan and Janicot (2000) and a regional index (SAI) or the leading PC of onset date equals
346only 0.06 and 0.24 (both values are not significant at the two-sided 90% level). The large-scale
347onset is divided in 3 terciles of early (1969, 1982, 1985, 1973, 1978, 1994, 1996, 1999, 1993,
3481974, 1977), near-normal (1990, 1992, 1975, 1980, 1970, 1983, 1986, 1968, 1976, 1971, 1979)
349and late (1981, 1972, 2000, 1985, 1988, 1997, 1984, 1989, 1987, 1998, 1991) jumps of the
350ITCZ. The local-scale OD anomalies are then averaged for the three sets of years. There is a
351considerable amount of inter-station noise for each of the terciles and the number of stations
352where the OD anomaly is significantly different from zero (based on a one-sided t-test at the
35390% confidence level) is always less than 15% (not shown).

354

355Lastly, the teleconnections between local scale OD and four sea surface temperature (SST)
356indices, capturing ocean sectors known for exerting an influence over West African Monsoon
357were considered (i.e. Nicholson 1986; Ropelewski and Halpert 1987; Rowell et al. 1995;

358 Nicholson and Kim 1997; Janicot et al. 1996, 2001). These indices include the east equatorial
359 Pacific (NINO3.4, 170°W-120°W; 5°S-5°N), the North Tropical Atlantic (NATL: 60°W-30°W;
360 5°N-20°N), the South Tropical Atlantic (SATL: 30°W-10°E; 0°-20°S) and the Guinean Gulf
361 (GGUI: 10°W-10°E; 5°S-5°N). Figure 6 displays distribution of correlation coefficients
362 between local-scale OD and each SST indices averaged over May-July (i.e. including ~85% of
363 the local-scale onset, Fig. 1) for 1950-2000, 1950-1969 and 1970-2000. At least 50% of
364 correlation coefficients are between -0.2 and +0.2 and the significant value are usually scattered
365 in space (not shown). In summary, the teleconnections between the SST related to the ENSO
366 phenomenon, the Tropical Atlantic dipole, or Guinea Gulf and local-scale OD seem weak.

367

3684. Conclusion

369 The main goal of this paper was to analyze the spatial coherence, robustness and the interannual
370 variability of the local-scale onset date (OD) of the boreal summer monsoon over Western and
371 Central Sahel (Mali, Burkina-Faso, Senegal) from a network of 103 rain gauges (Fig. 1) with
372 almost complete records from 1950 to 2000. The local-scale OD is first defined as the first wet
373 day ≥ 1 mm of one or two consecutive day receiving at least 20 mm without any 7-day dry spell
374 receiving less than 5 mm in the following 20 days from the onset. This local-scale definition
375 follows previous studies (Stern et al. 1981; Sivakumar 1988; Omotosho 1990; Jolliffe and
376 Sarria-Dodd 1994; Omotosho et al. 2000; Dodd and Jolliffe 2001) and is best suited for end-
377 user purposes since it explicitly takes into account the rainfall demand for crop seeding and
378 survival during the first stages of growth. This analysis complements previous similar studies

379(summarized in Table 1) which typically considered a smaller subset of stations and did not
380deeply investigate the sensitivity of the mean OD and its variability related to the subjective
381parameters used in its definition such as the length and amplitude of the initial wet spell.

382

383The spatial coherence of OD is analyzed from two points of view: (i) a quasi-instantaneous
384pattern of rainfall when onset date occurs at a particular station (Fig. 4) and (ii) the
385synchronization of onset dates at interannual time scale, i.e. the possible systematic modulation
386of onset dates across the Sahelian band (Fig. 5). The spatial coherence of the "first kind"
387exhibits a small, significant increase of frequency of occurrence of rainfall relative to pre-onset
3882-day (Fig. 4c). This could be associated with a range of factors, from convective cells to meso-
389convective clusters that probably trigger the local-scale onset. The spatial coherence of the
390"second kind" is analyzed through empirical estimates of the degrees of freedom (DOF) or
391interannual variance of the Standardized Anomaly Index ($\text{var}[\text{SAI}]$). Both estimates suggest a
392weak spatial coherence, i.e. the onset date is hardly systematically synchronized at interannual
393time scales. This is also demonstrated by the weak amount of variance accounted for by the
394leading EOF (Fig. 5a). These results contrast with the seasonal amount and the frequency of
395occurrence which exhibit a large-scale pattern across the whole belt analyzed (Fig. 5b,c). The
396weak spatial coherence of the "second kind" is almost independent of the parametrizations used
397in the definition of the onset date.

398

399These suggest that large-scale potential forcing seems unable to systematically synchronize the
400occurrence of the first rains above a fixed threshold across the western and central Sahel. The
401occurrence of the local-scale onset could be hardly viewed as a systematic event across year
402and station, but merely a complex product of the multi-scale phenomena that produce rainfall
403over this area. The discrepancy between the local-scale OD defined here and the regional-scale
404onset defined by the northward jump of the monsoon is especially puzzling and needs further
405investigation. It is possible that local-scale onset as defined here could be associated either with
406a localized convective event, even before the S-N jump of the ITCZ, or with a meso-scale
407squall line. But even in this latter case, the timing of occurrence, size, location and track of the
408first squall line of the rainy season are hardly reproducible from one year to the next. In other
409words, there are too many different phenomena, or different scales of motion, that could lead to
4105-40 mm rainy event in 2-10 days at local-scale. If the northward jump of the monsoon
411enhances the probability of such events across the Sahel, the fact that ITCZ has moved to its
412northernmost seasonal location, does not necessarily induce local-scale onset everywhere at the
413same moment or even on a short time step.

414

415An important consequence is that local-scale OD appears to show little potential predictability
416based on large and regional-scale boundary conditions such as sea surface temperatures and/or
417soil moisture (Folland et al. 1986; Philippon and Fontaine 2002; Douville et al. 2007). This is
418because the regional-scale seasonal potential predictability implies that the variable of interest
419shares a variable, but significant, amount of common or covariant information at this scale, at

420least for a flat area as Sahel. The fact that seasonal rainfall amount and frequency of occurrence
421are far more spatially-coherent than the onset date (i.e. DOF equals respectively 6.1, 4.8, and
42223-28) suggests that most of the seasonal predictability of rainfall over the Sahelian belt is
423actually not associated with a systematic delay or advance of the local-scale onset as defined
424here, but stands out for example as a seasonally-varying or constant systematic modulation of
425the frequency of occurrence of rainfall across the season (Moron et al. 2007). This is not a
426trivial result, because local-scale onset sometimes conveys a spatially-consistent signal and
427potential predictability, as in Indonesia (Moron et al. 2008). This analysis emphasizes also the
428need to carefully examine the context of any local-scale analysis of the onset, because the weak
429spatial coherence implies a potential large uncertainty due to random sampling. More work is
430also needed to look at other definitions of the onset, for example integrating the daily rainfall in
431time and/or in space. The spatial noise is not necessarily evenly distributed across the scales and
432it would be interesting to look at intermediate scales between the local-scale and large-scale
433onsets. In particular, any definition that filters out some of the local-scale noise as the
434cumulative daily rainfall anomalies (Camberlin and Diop 2003; Liebmann et al. 2007) is
435especially appealing in this context. The apparent spatial increase of the signal over Western
436and Central Senegal (Fig. 5a) warrants also further studies.

437

438**Acknowledgements:** We acknowledge the FRIEND-AOC group and Senegal DNM for
439providing us the rainfall data. R. Marteau is partly supported by the AMMA program. Based on
440a French initiative, AMMA was built by an international scientific group and is currently

441funded by a large number of agencies, especially from France, UK, US and Africa. It has been
442the beneficiary of a large financial contribution from the European Community's sixth
443Framework Research Program. Detailed information on scientific coordination and funding is
444available on the AMMA International web site: <http://www.amma-international.org>. ECMWF
445ERA-40 data used in this study have been freely obtained from the ECMWF Data Server
446(<http://www.ecmwf.int>). We thank Gil Mahé and Benjamin Sultan for fruitful discussions.
447Lastly, we thank two anonymous reviewers and the editor of this paper (D. Straus) for their
448constructive comments which help us on clarifying the goals and results of our paper, and lastly
449Bradfield Lyon (IRI, Columbia University) for his careful reading of the revised version of this
450paper

451

452References

453Ati, O.F., Stigter, C.J., and Oladipo, E.O., 2002: A comparison of methods to determine the
454 onset of the growing season in Northern Nigeria. *Int. J. Climatol.*, **22**, 731-742.

455Balme, M., Galle, S. and Lebel, T., 2005: Démarrage de la saison des pluies au Sahel :
456 variabilité aux échelles hydrologique et agronomique, analysée à partir des données
457 EPSAT-Niger. *Sécheresse*, **16**, 15-22.

458Benoit, P., 1977: The start of the growing season in Northern Nigeria. *Agric. For. Meteorol.*,
459 **18**, 91-99.

460Bretherton, C.S., Widmann, M., Dymnikov, V.P., Wallace, J.M., and Bladé, I., 1999: The
461 effective number of degrees of freedom of a time varying field. *J. Clim.*, **12**, 1990-2009.

462Camberlin, P. and Diop, M., 2003: Application of daily rainfall principal component analysis
463 to the assessment of rainy season characteristics in Senegal. *Clim. Res.*, **23**, 159-169.

464D'Amato, N. and Lebel, T., 1998: on the characteristics of the rainfall events in the Sahel with
465 a view to the analysis of climatic variability. *Int. J. Climatol.*, **18**, 955-974.

466Davey, E.G., Mattei, F., and Solomon, S.I., 1976: An evaluation of climate and water
467 resources for the development of agriculture in the Soudano-Saelian zone of West
468 Africa. *WMO Special Environment Report No. 9*.

469Diop, M., 1996: A propos de la durée de la saison des pluies au Sénégal. *Sécheresse*, **7**, 7-15.

470Diop, M., 1999: Caractérisation du facteur hydrique en agriculture pluviale au Sénégal: le cas
471 de l'arachide et du mil. *Thèse de doctorat*, Université de Bourgogne, Dijon, 185 p.

472Dodd, D.O.S. and Jolliffe, I.T., 2001: Early detection of the start of the wet season in semiarid
473 tropical climates of western Africa. *Int. J. Climatol.*, **21**, 1251-1262.

474Douville, H., Conil, S., Tyteca, A., and Voldoire, A., 2007: Soil moisture memory and West
475 African monsoon predictability: artefact or reality? *Clim. Dyn.*, DOI 10.1007/s00382-
476 006-0207-8.

477Folland, C.K., Palmer, T.N., and Parker, D.E., 1986: Sahel rainfall and worldwide sea
478 temperatures. *Nature*, **320**, 602-607.

479Fontaine, B. and Louvet, S., 2006: Sudan-Sahel rainfall onset : definition of an objective
480 index, types of years, and experimental hindcast. *J. Geophys. Res.*, **111**,
481 doi:10.1029/2005JD007019.

482Fraedrich, K., Ziehmann, C., and Sielmann, F., 1995: Estimates of spatial degrees of freedom.

483 *J. Clim.*, **8**, 361-369.

484Ines, A.V.M. and Hansen, J.W., 2005: Bias correction of daily GCM outputs for crop
485 simulation studies. *Agric. For. Meteorol.*, **138**, 44-53.

486Ingram, K.T., Roncoli, M.C., and Kirshen, P.H., 2002: Opportunities and constraints for
487 farmers of west Africa to use seasonal precipitation forecasts with Burkina-Faso as a
488 case study. *Agric. Syst.*, **74**, 331-349.

489Janicot, S., Moron, V., and Fontaine, B., 1996: Sahel drought and ENSO dynamics. *Geophys.*
490 *Res. Lett.*, **23**, 515-518.

491Janicot, S., Trzaska, S., and Pocard, I., 2001: Summer Sahel-ENSO teleconnection and
492 decadal time scale SST variations. *Clim. Dyn.*, **18**, 303-320.

493Jolliffe, I.T. and Sarria-Dodd, D.E., 1994: Early detection of the start of the wet season in
494 tropical climates. *Int. J. Climatol.*, **14**, 71-76.

495Katz, R.W. and Glantz, M.H., 1986: Anatomy of a rainfall index. *Mon. Wea. Rev.*, **114**,
496 764-771.

497Lamb, J.P., 1978: Case studies of tropical Atlantic surface circulation patterns associated
498 with subsaharan weather anomalies: 1967 and 1968. *Mon. Wea. Rev.*, **106**, 1052-1055.

499Laurent, H., D'Amato, N., and Lebel, T., 1998: How important is the contribution of the
500 Mesoscale Convective Complexes to the Sahelian rainfall? *Phys. Chem. Earth*, **23**, 629-
501 633.

502Liebman, B., Camargo, S., Seth, A., Marengo, J.A., Carvalho, L.M.V., Allured, D., Fu, R.,

503 and Vera, C.S., 2007: Onset and end of the rainy season in South America in
504 observations and the ECHAM 4.5 Atmospheric General Circulation Model. *J. Clim.*, **20**,
505 2037-2050.

506 Louvet, S., Fontaine, B., and Roucou, P., 2003: Active phases and pauses during the
507 installation of the West African monsoon through 5-day CMAP rainfall data (1979-
508 2001). *Geophys. Res. Lett.*, **30**, doi:10.1029/2003GL018058.

509 Martin, D.W., and Schreiner, A.J., 1981: Characteristics of West African and east Atlantic
510 cloud clusters: a survey from GATE. *Mon. Wea. Rev.*, **109**, 1671-1688.

511 Mathon, V., Laurent, H., and Lebel, T., 2002: Mesoscale convective system rainfall in the
512 Sahel. *J. Appl. Meteo.*, **41**, 1081-1092.

513 Moron, V., 1994: Guinean and Sahelian rainfall anomaly indices at annual and monthly scales
514 (1933-1990). *Int. J. Climatol.*, **14**, 325-341.

515 Moron, V., Robertson, A.W., and Ward, M.N., 2006: Seasonal predictability and spatial
516 coherence of rainfall characteristics in the tropical setting of Senegal. *Mon. Wea. Rev.*,
517 **134**, 3248-3262.

518 Moron, V., Robertson, A.W., Ward, M.N., and Camberlin, P., 2007: Spatial coherence of
519 tropical rainfall at the regional scale. *J. Clim.*, **20**, 5244-5263.

520 Moron, V., Robertson, A.W., and Boer, R., 2008: Spatial coherence and seasonal
521 predictability of monsoon onset over Indonesia. *J. Clim.*, in press.

522 Nicholson, S., 1979: Revised rainfall series for the West-African subtropics. *Mon. Wea.*

- 523 *Rev.*, **107**, 620-623.
- 524 Nicholson, S., 1980: The nature of rainfall fluctuations in sub-tropical Africa. *Mon. Wea.*
- 525 *Rev.*, **108**, 473-484.
- 526 Nicholson, S., 1986: The quasi-periodic behavior of rainfall variability in Africa and its
- 527 relationship to the Southern Oscillation. *Arch. Meteo. Geophys. Bio.*,
- 528 **A 34**, 311-348.
- 529 Nicholson, S. and Kim, J., 1997: The relationship of the El Niño-Southern Oscillation to
- 530 African rainfall. *Int. J. Climatol.*, **17**, 177-135.
- 531 Omotosho, J.B., 1990: Onset of thunderstorms and precipitation over northern Nigeria. *Int. J.*
- 532 *Climatol.*, **10**, 849-860.
- 533 Omotosho, J.B., 1992: Long-range prediction of the onset and end of the rainy season in the
- 534 West African Sahel. *Int. J. Climatol.*, **12**, 369-382.
- 535 Omotosho, J.B., Balogun, A.A., and Ogunjobi, K., 2000: Predicting monthly and seasonal
- 536 rainfall, onset and cessation of the rainy season in West Africa using only surface data.
- 537 *Int. J. Climatol.*, **20**, 865-880.
- 538 Philippon, N., and Fontaine, B., 2002: The relationship between the Sahelian and previous 2nd
- 539 Guinean rainy seasons: a monsoon regulation by soil wetness ? *Ann. Geophysicae*, **20**, 575-582.
- 540 Ropelewski, C.F. and Halpert, M.S., 1987: Global and regional scale precipitations associated
- 541 with El Niño/Southern Oscillation. *Mon. Wea. Rev.*, **115**, 985-996.

542Rowell, D.P., Folland, C.K., Maskell, K., and Ward, M.N., 1995: Variability of summer
543 rainfall over tropical North Africa (1906-1992): Observations and modelling. *Quart. J.*
544 *Meteo. Soc.*, **113**, 669-674.

545Schmidli, J., Frei, C., and Vidale, P.L., 2006: Downscaling from GCM precipitation : a
546 benchmark for dynamical and statistical downscaling methods. *Int. J. Climatol.*, **26**,
547 679-689.

548Sivakumar, M.V.K., 1988: Predicting rainy season potential from the onset of rains in
549 southern sahelian and sudanian climatic zones of West Africa. *Agric. For. Meteo.*, **42**,
550 295-305.

551Sivakumar, M.V.K., 1992: Empirical analysis of dry spells for agricultural applications in
552 West Africa. *J. Clim.*, **5**, 532-539.

553Stern, R.D., Dennett, M.D., and Garbutt, D.J., 1981: The start of the rains in West Africa. *Int.*
554 *J. Climatol.*, **1**, 59-68.

555Sultan, B., and Janicot, S., 2000: Abrupt shift of the ITCZ over West Africa and intra-seasonal
556variability. *Geophys. Res. Lett.*, **27**, 3353-3356.

557Sultan, B., Janicot, S., and Diedhiou, A., 2003: The West African monsoon dynamics. Part I :
558 Documentation of intraseasonal variability. *J. Clim.*, **16**, 3389-3406.

559Sultan, B., and Janicot, S., 2003: The West African monsoon dynamics. Part II : The "pre-
560 onset" and the "onset" of the summer monsoon. *J. Clim.*, **16**, 3407-3427.

561Sultan, B., Baron, C., Dingkuhn, M., Sarr, B., and Janicot, S., 2005: Agricultural impacts of

562 the large-scale variability of the West African monsoon. *Agric. For. Meteo.*, **128**, 93-
563 110.

564Walter, M.W., 1967: Length of rainy season in Nigeria. *Niger. Geogr. J.*, **10**, 123-128.

565Widmann, M., Bretherton, C.S., and Salaté, P., 2003: Statistical precipitation downscaling
566 over the Northwestern United States using numerically simulated precipitation as a
567 predictor. *J. Clim.*, **16**, 799-816.

568Wilks, D.S., 1999: Interannual variability and extreme-value characteristics of several
569 stochastic daily precipitation models. *Agric. For. Meteorol.*, **93**, 153-169.

570

571 **Figures captions**

572 **Figure 1:** Location of the 103 Sahelian rain-gauge used in this study.

573 **Figure 2:** (a) Climatological (1950-2000) local-scale onset date (b) distribution of cumulative
574 frequency of the local onset date (25, 50 and 75 percentiles are indicated by vertical dashed
575 line)

576 **Figure 3:** Rainfall field statistics averaged over the 15 days before (left column) and from
577 (right column) the local-scale onset date. Mean frequency of occurrence ($\times 100$) of wet days
578 receiving between 1 and 20 mm (a, c) and more than 20 mm (b, d). Mean wet spell length (e, f)
579 and dry spell length (g, h) in tenth of day.

580 **Figure 4:** Mean frequency of occurrence of daily rainfall > 1 mm for 2-day before (a) and from
581 (b) the local-scale onset, and the "(b) minus (a)" difference (c). All fields are relocated
582 relatively to the reference station (coordinates = 0,0). In the latter panel, the simple (double)
583 circles indicate a relative location where 75% (90%) of the differences (b)-(a) are significant at
584 the two-sided 90% level according to a Student's T test.

585 **Figure 5:** (a) Leading unrotated empirical orthogonal function (EOF) modes of the local-scale
586 onset date, expressed as loadings, i.e. correlation between the corresponding Principal
587 Component (PC) and the raw data. (b) Leading unrotated EOF of seasonal (MJJAS) amount of
588 rainfall. (c) Leading unrotated EOF of seasonal (MJJAS) frequency of occurrence of rainfall $>$
589 1 mm. Bold squares displaying correlations statistically significant at the two-sided 95%
590 confidence level according to a Bravais-Pearson test. (d) leading principal component

591 timeseries of onset date (bars), seasonal amount (circle) and frequency of occurrence of rainfall
592 (upper triangle).

593 **Figure 6:** Boxplot of correlation coefficients between local-scale onset date and NINO3.4,
594 Tropical Atlantic dipole and Guinea gulf SST index for periods 1950-2000, 1950-1969 and
595 1970-2000. Boxes are bounded by the first quartile, and third quartile of the distribution and the
596 internal horizontal line is the median. Whiskers extend from the box out to the most extreme
597 data value within 1.5 by the interquartile range. The boxes have lines at the lower quartile,
598 median, and upper quartile values. The whiskers are lines extending from each end of the boxes
599 to show the extent of the range of the data within 1.5 by the interquartile range from the upper
600 and lower quartiles. The outliers are displayed by a cross. Outliers, displayed by a cross, are
601 data with values beyond the ends of the whiskers. Italic values indicate the number of local-
602 scale correlations significant at two-sided 95% confidence level according to a random phase
603 test (Janicot et al. 1996).

604

605**Tables captions**

606**Table 1.** Criteria of the agronomic definitions of the local-scale onset date of the rainy season
607used in selected previous studies. All of these definitions start from daily rainfall observed at
608rain-gauge stations.

609

610

611

612

613

614

615

616

617

618

619

620

621

622

623

624

625

626

627

628

629

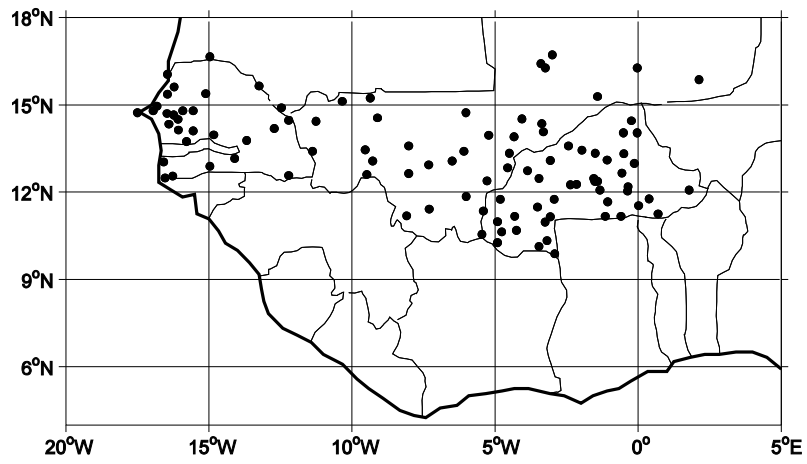
Authors	Data	Details of definitions	Study area	Number of stations	Study period
Stern et al. (1981)	Daily rainfall	- 2 successive days - receiving at least 20 mm	Transect S/N Benin, Nigeria, Niger, Mali	11 stations	1934-1965
Sivakumar (1988)	Daily rainfall	- 3 consecutive days - accumulating at least 20 mm - no dry period of 7 or more consecutive days in the following 30 days	Niger Burkina-Faso	58 stations	25 Years (not specified)
Omosho (1990, 1992)	Daily rainfall	- first 4 falls receiving at least 10 mm - no dry spell of 7-day between any 2 such rains	Northern Nigeria & West Africa	3 stations	1973-1988
Dodd and Jolliffe (1994)	Daily rainfall	- 5 consecutive days (with at least two other wet days in the period) - accumulating at least 25 mm - no dry period of 7 or more consecutive days in the following 30 days	Burkina-Faso	22 stations	1902-1989

630**Table 1.** Criteria of the agronomic definitions of the local-scale onset date of the rainy season
631used in selected previous studies. All of these definitions start from daily rainfall observed at
632rain-gauge stations.

633
634
635
636
637
638
639
640
641
642
643
644
645
646
647

648 **FIGURES:**

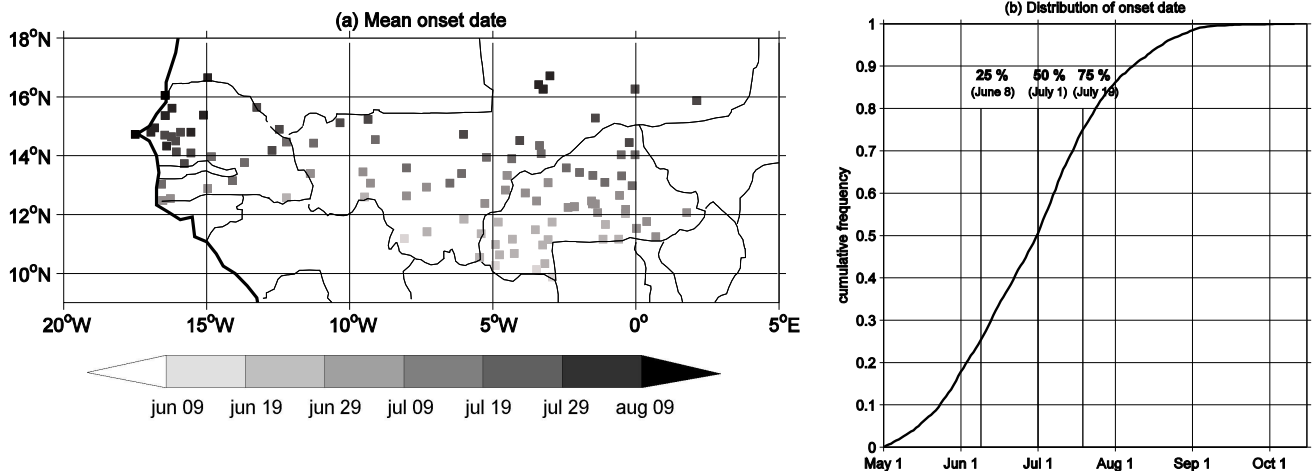
649



650

651 **Figure 1.** Location of the 103 Sahelian rain-gauge stations used in this study.

652

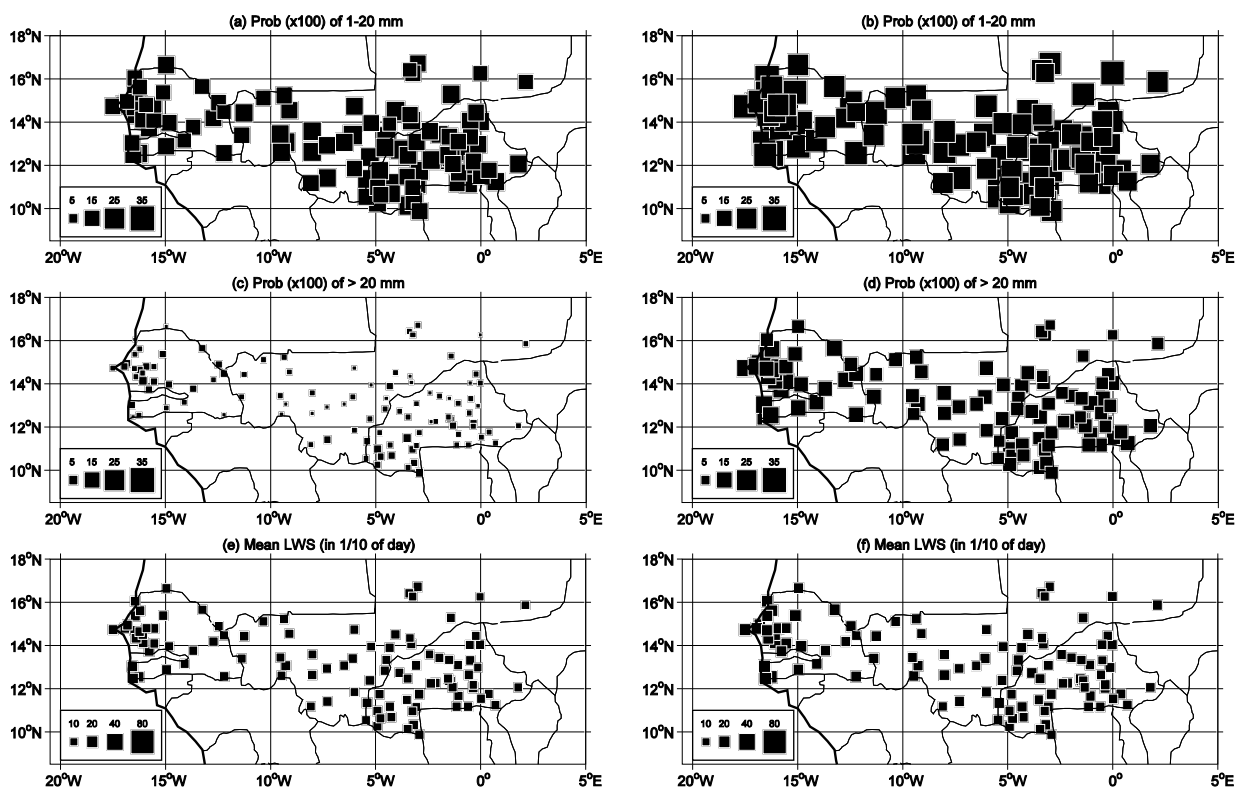


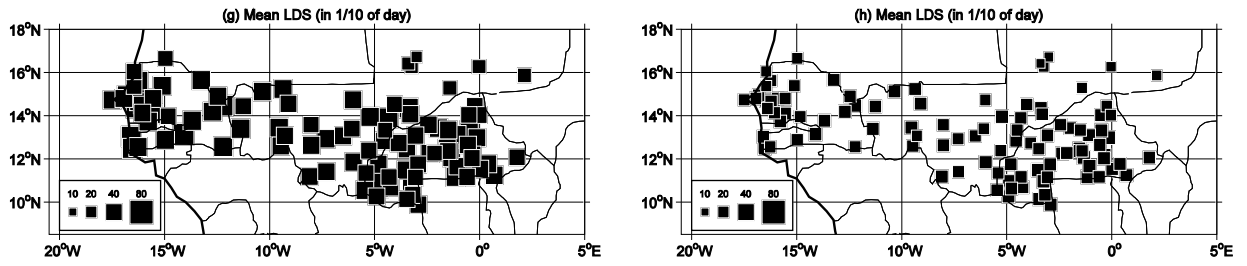
653

654 **Figure 2 :** (a) Climatological (1950-2000) local-scale onset date (b) distribution of cumulative
 655 frequency of the local onset date (25, 50 and 75 percentiles are indicated by vertical dashed
 656 line).

657

658





659

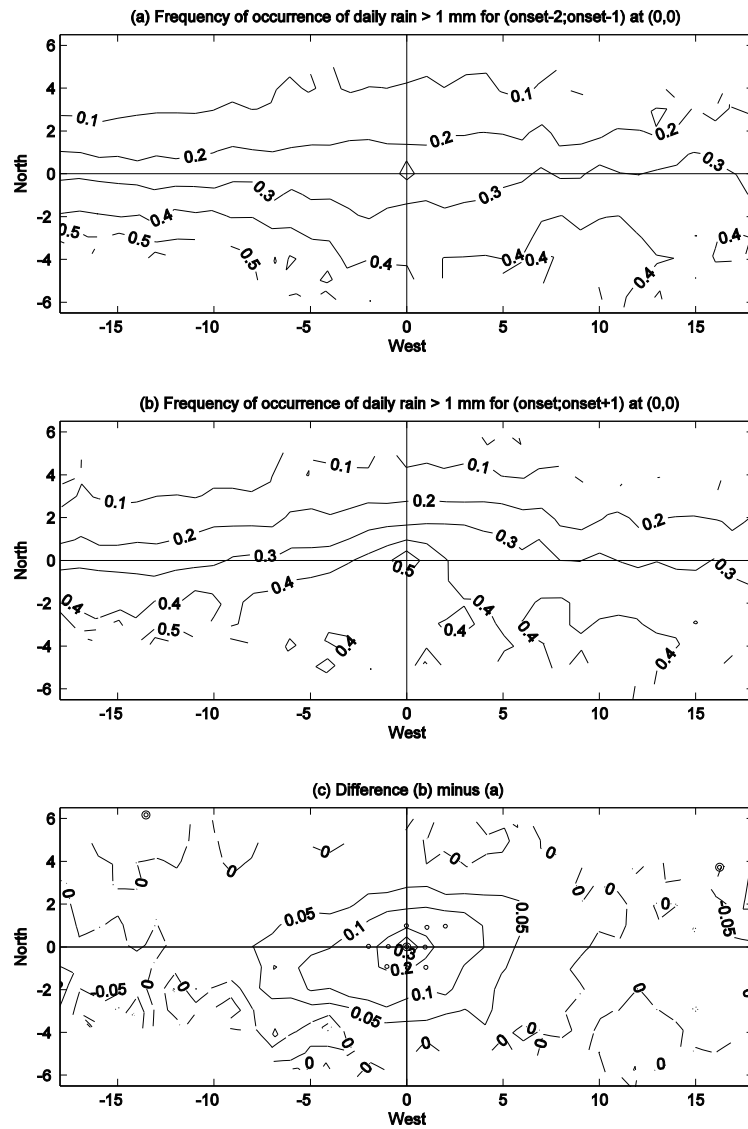
660**Figure 3.** Rainfall field statistics averaged over the 15 days before (left column) and from (right
 661column) the local-scale onset date. Mean frequency of occurrence ($\times 100$) of wet days receiving
 662between 1 and 20 mm (a, c) and > 20 mm (b, d). Mean wet spell length (e, f) and dry spell
 663length (g, h) in tenth of day.

664

665

666

667



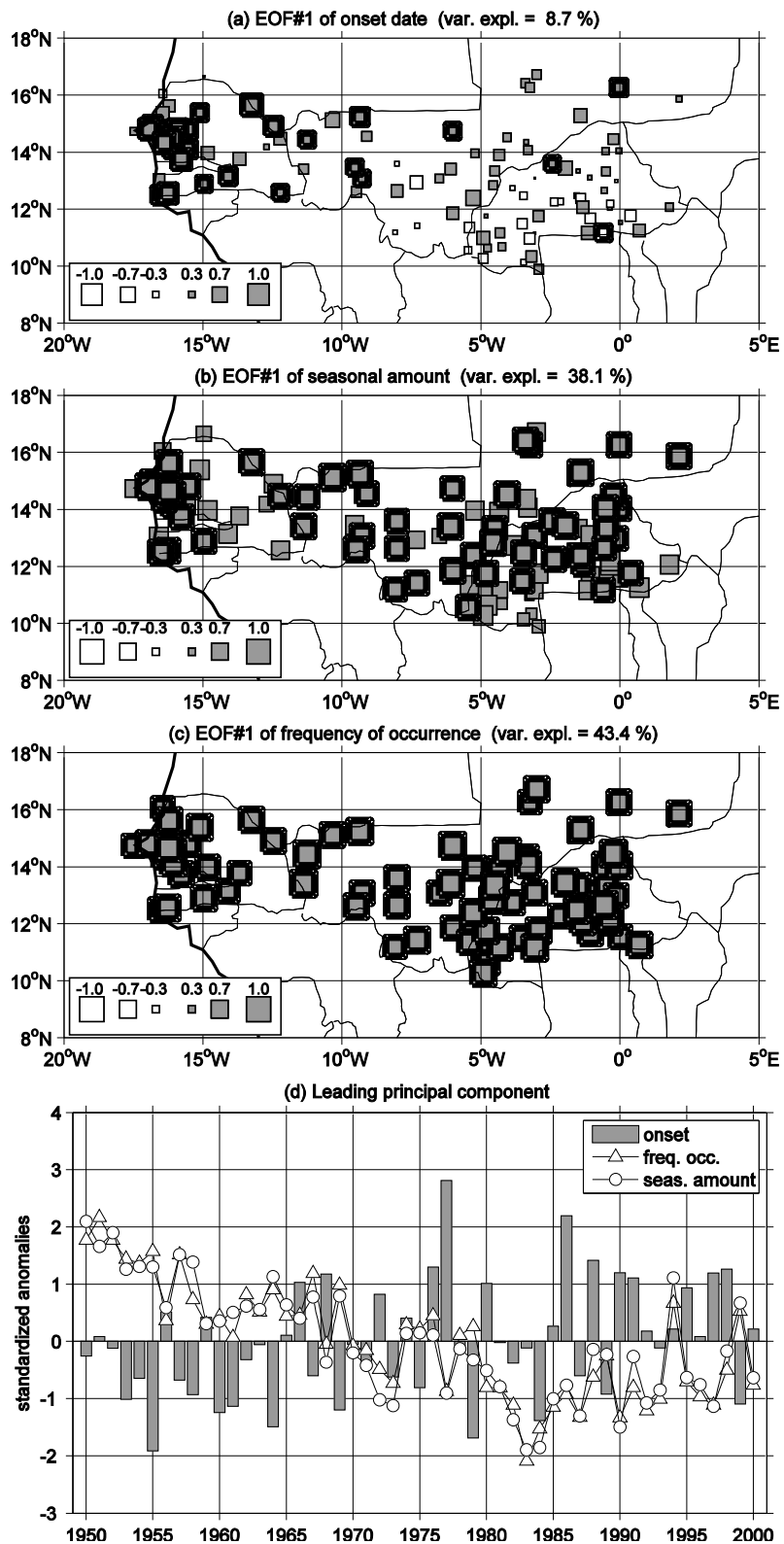
668

669**Figure 4.** Mean frequency of occurrence of daily rainfall > 1 mm for 2-day before (a) and from
 670(b) the local-scale onset, and the "(b) minus (a)" difference (c). All fields are relocated
 671relatively to the base station (coordinates = 0,0). In the latter panel, the simple (double) circles
 672indicate a relative location where 75% (90%) of the difference (b)-(a) are significant at the two-
 673sided 90% level according to a Student's T test.

674

675

676



677

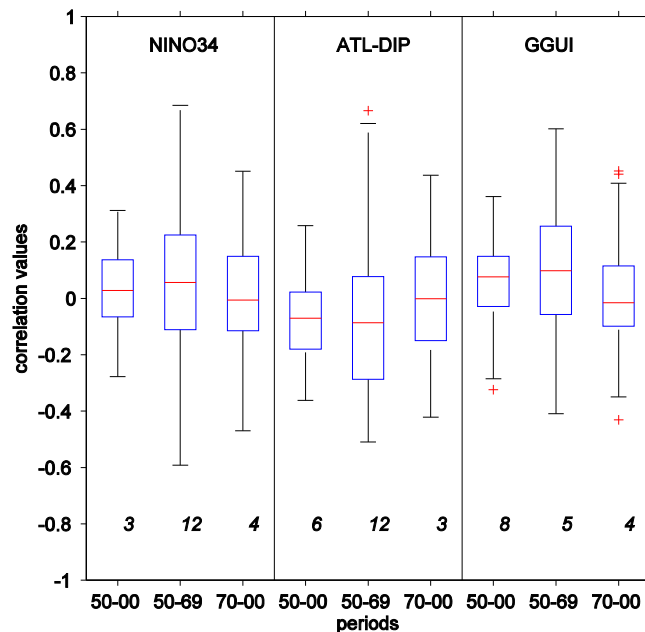
678**Figure 5.** (a) Leading unrotated empirical orthogonal function (EOF) modes of the local-scale
 679onset date, expressed as loadings, i.e. Pearson correlation between the corresponding Principal
 680Component (PC) and the raw data. (b) Leading unrotated EOF of seasonal amount of rainfall.
 681(c) Leading unrotated EOF of frequency of occurrence of rainfall > 1 mm. (d) Leading principal
 682component timeseries of onset date (bars), seasonal amount (circle) and frequency of

683 occurrence of rainfall (upper triangle). Bold squares displaying correlations statistically
 684 significant at the two-sided 95% confidence level according to Bravais-Pearson test.

685

686

687



688

689 **Figure 6** : Boxplot of correlation coefficients between local-scale onset date and NINO3.4,
 690 Tropical Atlantic dipole and Guinea gulf SST index for periods 1950-2000, 1950-1969 and
 691 1970-2000. Boxes are bounded by the first quartile, and third quartile of the distribution and the
 692 internal horizontal line is the median. Whiskers extend from the box out to the most extreme
 693 data value within 1.5 by the interquartile range. The boxes have lines at the lower quartile,
 694 median, and upper quartile values. The whiskers are lines extending from each end of the boxes
 695 to show the extent of the range of the data. The outliers are displayed by a cross. Outliers,
 696 displayed by a cross, are data with values beyond the ends of the whiskers. Italic values indicate
 697 the number of local-scale correlations significant at two-sided 95% confidence level according
 698 to a random phase test (Janicot et al., 1996).

699

700