Synoptic climatology over Senegal during the summer at two time scales

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1-Abstract. Agriculture in West Africa, critical for local populations, is extremely dependent on the summer rainy season and of its daily fluctuations. Aim of this work is to characterize the synoptic-scale meteorological events over Senegal and measure their impact on the structure and modulation of the seasonal cycle of daily rainfall over Senegal and more locally. By using mean sea level pressure and 850 hPa wind variables from NCEP/NCAR reanalyses, we have characterized the meteorological weather regimes during the summer monsoon seasons of the period 1979-2002. The Self-Organizing Maps approach of Kohonen, a clustering methodology based on non-linear artificial neural network, is combined with a Hierarchical Ascendant Classification to compute these regimes. In the first time, a family of nine weather regimes has been identified after removing the influence of seasonal and interannual time scales variability. A similar approach has also been developed by removing the influence of the mean 1979-2002 seasonal cycle and keeping interannual variability. This approach also allows using weather regimes in an operational forecasting context. We have found a strong association between these two families of weather regimes that have also themselves a strong link with daily rainfall over Senegal.

2- Methodology

We use mean sea level pressure and 850 hPa wind variables from NCEP/NCAR reanalyses to define a set of Weather Types (WT) over the 1979-2002 period during summer monsoon. The Self organizing Map, an efficient clustering methodology based on non-linear artificial neural network and Ascendant Hierarchical Classification (Figure 1), are applied to compute WTs. Two pre-processing of the data have been tested. So, two families of WTs are defined. The first family named *"pures" WTs* was obtained by removing the influence of seasonal and interannual time scales variability, in order to highlight the day-by-day variability of the atmospheric circulation. Removing only the mean seasonal cycle and then keeping the interannual variability gave the second family called *"inter-annual" WTs*. In contrary to the former approach it has the advantage to be usable in an operational context since for each day the multi-year averaged seasonal cycle can be removed.

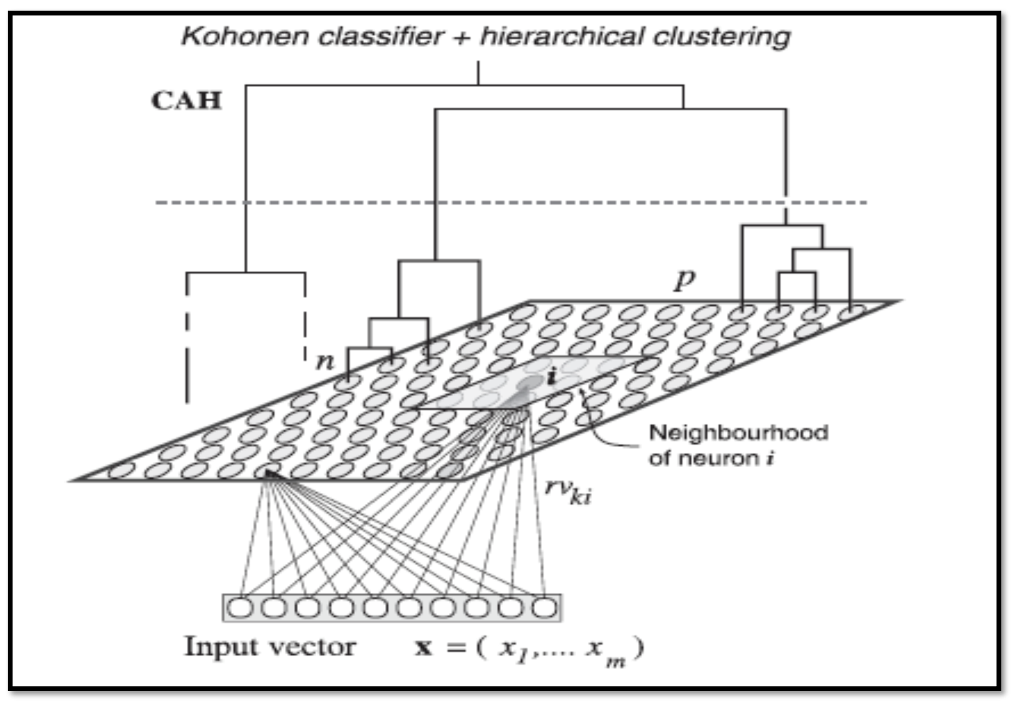


Figure 1. Self organizing map + Ascendant hierarchical classification

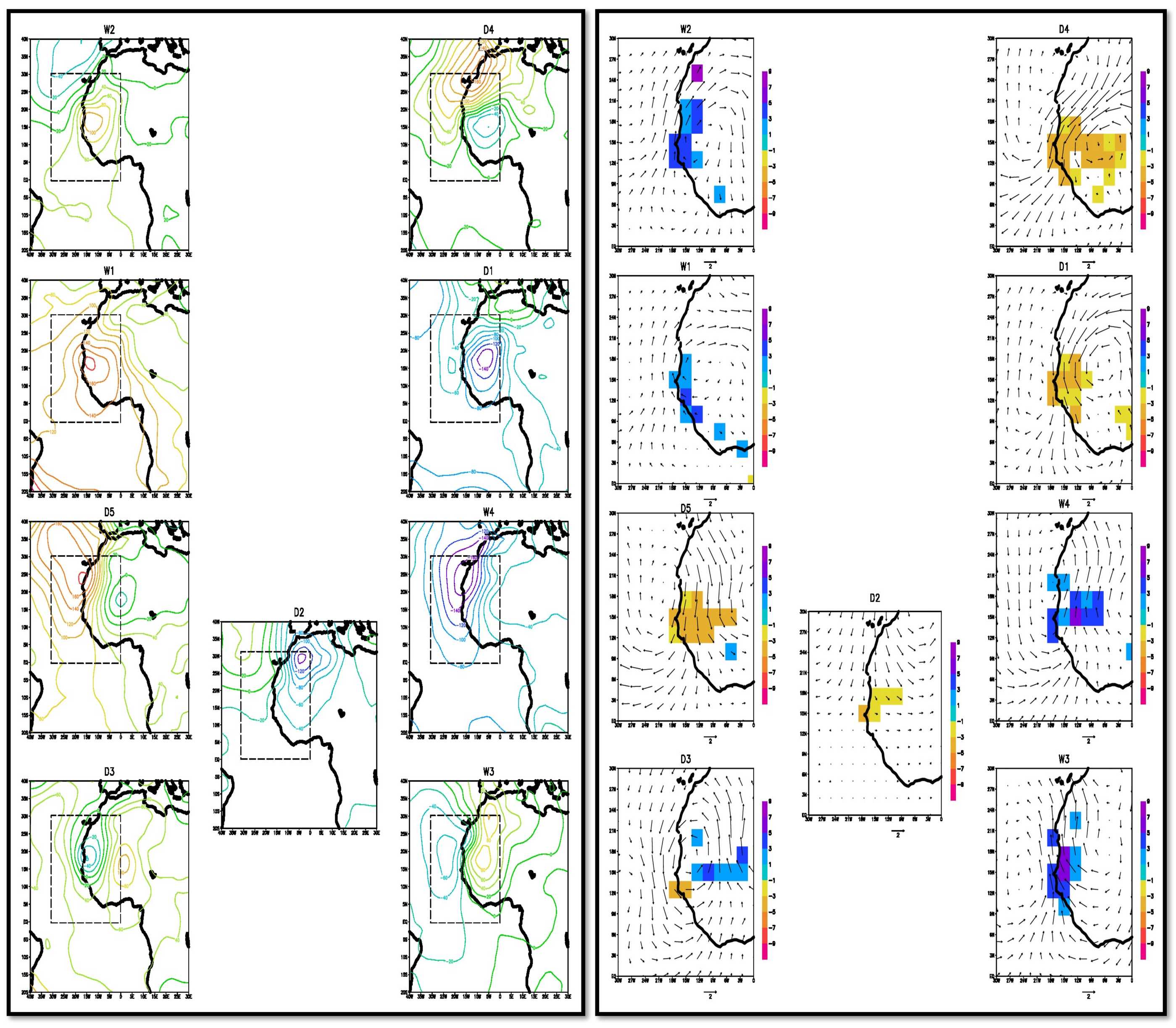


***Figure 2. (Left)** The 9 weather regimes "pures" represented by their mean sea level atmospheric pressure anomaly field at t=0 (unit Pa). The box represents the area considered in the clustering scheme. **(Right)** The 9 weather regimes "pures" represented by 925 hPa mean wind anomaly fields (vectors) and the rainfall test values (shaded) at t=0. Only significant wind vectors are displayed. (rule : significant positive anomalies: test value > 2; significant negative anomalies: test value < -2; no significance : -2 < test < 2;).*

Tableau 1. Relative frequency of Cx synoptic weather regimes occurrences (lines) for each "pure" synoptic weather regimes as defined in Part I (columns). Each value represents the number of Cx occurrences for each "pure" regime multiplied by 105 and divided by the total number of Cx occurrences and by the total number of the "pure" weather regime occurrences. Values higher than 50 are bold.

	D5	D4	D3	D2	D1	W1	W2	W3	W4
C1	47	**70**	8	**70**	**88**	0	6	1	16
C2	**118**	**91**	19	19	14	**67**	35	4	1
C3	8	13	28	40	44	15	41	49	43
C4	4	**102**	18	46	**114**	2	13	10	12
C5	**55**	24	14	**61**	9	36	**58**	36	1
C6	29	12	**59**	5	3	**110**	**64**	**52**	7
C7	2	4	14	40	**81**	0	5	12	**108**
C8	8	9	**121**	32	0	24	36	36	42
C9	0	0	11	23	8	5	36	**104**	**73**

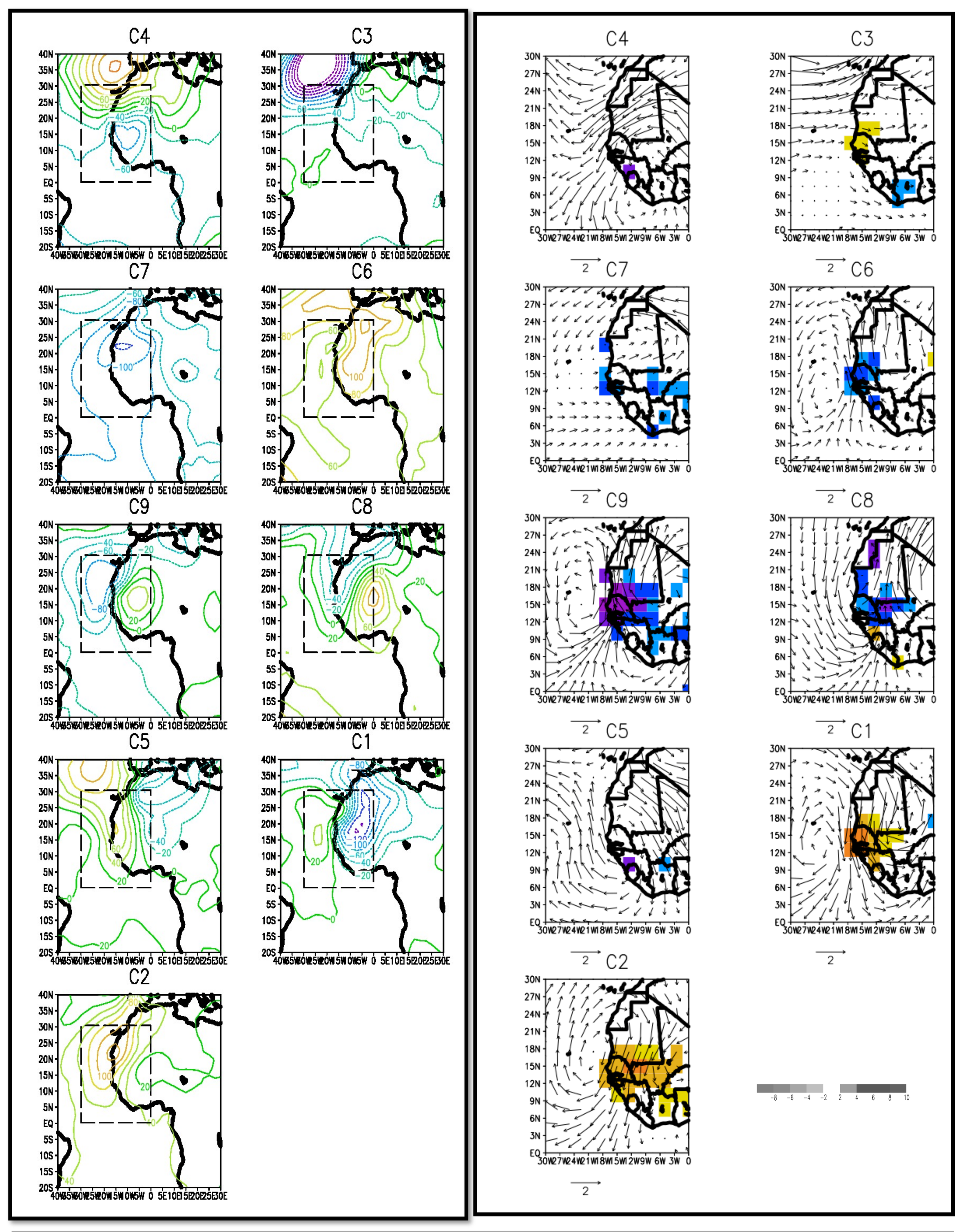
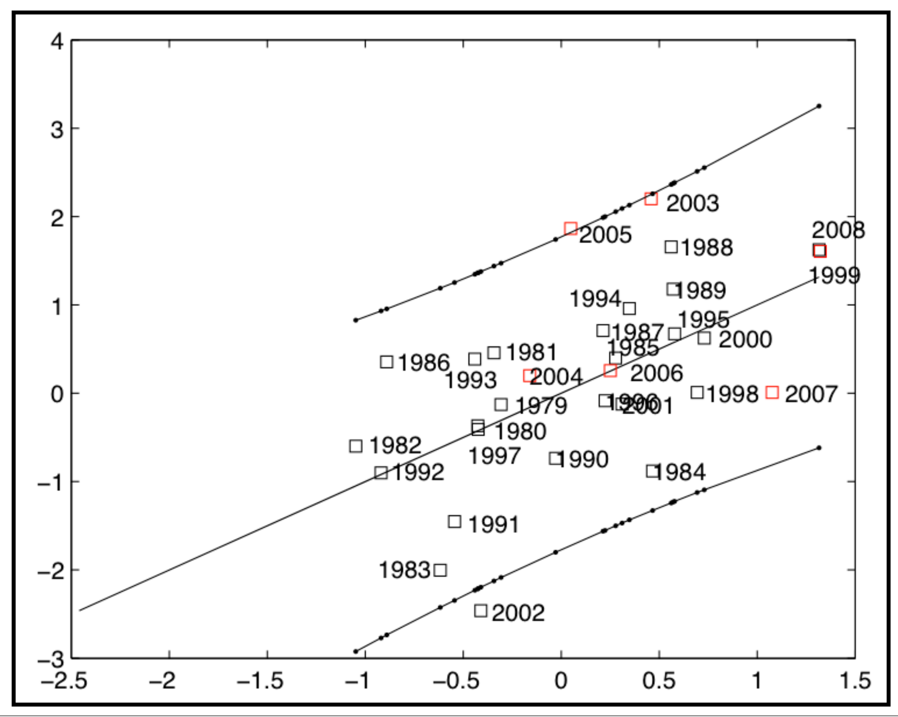


***Figure 3. (left)** The 9 weather regimes "inter-annual" represented by their mean sea level atmospheric pressure anomaly field at t=0 (unit Pa). The box represents the area considered in the clustering scheme. **(Right)** The 9 weather regimes "inter-annual" represented by 925 hPa mean wind anomaly fields (vectors) and the rainfall test values (shaded) at t=0. Only significant wind vectors are displayed. (rule : significant positive anomalies: test value > 2; significant negative anomalies: test value < -2; no significance : -2 < test < 2).*



P = - 0.057 *t1 - 0.14 *t2 + 0.05*t3 + 0.11*t4 - 0.09*t5 - 0.15*t6 + 0.14*t7+ 0.02*t8 + 0.12*t9

t_x the test-value for the weather regime "inter-annual " Cx

***Figure 4.** Diagram of observed/computed standardized rainfall anomalies (mm day-1) from 1979 to 2008 with WTs "interannual". The regression equation is computed using the years 1979 to 1999 and it is applied on 2000-2008 as test years (red square). The upper and lower boundaries represent the estimate interval at a 95% significance level.*

Figure 1 : We first applied an unsupervised classification using a neural network based model, the SOM (Self Organizing Map, Kohonen, 1984) similar to that done by Niang et al (2003). The aim was to summarize the information contained in the Learning Set by producing a small number of reference vectors (***rvs***) that are statistically representative of it. The large number of subsets provided by the SOM map allowed us to take into account the complexity of the dataset but may have prevented us from synthesizing some geophysical information embedded in the Learning Set, such as spatial or temporal specificities. To counteract this difficulty, we decided to aggregate this large number of subsets into a smaller number of types based on the similarities of the subsets using a hierarchical ascendant classification (HAC; Jain and Dubes, 1988) using the Ward distance for the intra-classes similarity.

Figure 2 : Nine weather regimes have been highlighted using the mean sea level pressure and 850 hPa wind field as variables. These regimes have been labeled according the rainfall probability distribution in the Ziguinchor area. W (respectively D) designating the weather regimes with positive (negative) rainfall anomalies relative to the mean, D5….D1 being dry (ranked from the driest one D5 to the less dry one D1) while W1…W4 being wet (ranked from the less wet one W1 to the wettest one W4). They have been associated together into three classes from meteorological considerations. Two of these regimes (D3 and W3) represent the classical 3-5-day African easterly waves with a mean wavelength of about 3000 kilometers. Three other regimes (D5, D2, W4) are characterized by a modulation of the semi-permanent trough located along the western coast of West Africa and may be interpreted in terms of the 6-9-day easterly waves, located more to the north than the 3-5-day easterly waves. The last four weather regimes (D1, D4, W1, W2) are characterized by a more or less strong north-south dipole of circulation which was not particularly highlighted in the literature up to now. They can be interpreted as a northward/southward displacement of the Saharan depression for two of them, and a filling/deepening of this depression for the other two. The circulation patterns of all these nine weather regimes are very consistent with the associated anomaly patterns of 925 hPa mean wind anomaly fields and rainfall over the Senegal.

Figure 3 : Nine weather regimes "inter-annual" are defined. These regimes have been labeled according to the rainfall probability distribution over Senegal from C1 (the driest one) to C9 (the wettest one). The circulation patterns of all these nine weather regimes are very consistent with the associated anomaly patterns of with rainfall. These regimes have been then gathered into different groups depending mainly on their main transition circuit. The first group of C9, C5, C1 and C8 is included in a closed circuit. These regimes are characterized by a modulation of the semi-permanent trough located along the western coast of West Africa and an opposite modulation on the east. A short derivation of this circuit is provided by the connection C5-C2-C1. C2 is quite similar to C5 except that pressure anomalies located east of the African coast are weak. C2 is the most persistent regime and it induces high negative rainfall anomalies over Senegal. So the connection C2-C1, where C1 is the driest and the most persistent regime over Senegal, can provide important dry sequences. Another derivation is the connection C8-C6-C2-C1. C6 corresponds to a westward displacement of the C8 pattern but with a weaker structure. It provides moderate positive rainfall anomalies. The entry into the circuit C9-C5-C1-C8 is provided by the connection C4-C7-C9. C4 represents a southward location of the SHL, already identified in "pure" synoptic regimes classification. It is followed by a deepening of the SHL in C7 and by a westward displacement of this pressure anomaly field leading to the C9 pattern. No significant transition provides an entry into C4 meaning that the transitions towards this regime are made by chance. The last weather regime is C3 whose high negative pressure anomalies are mainly located outside of the classification domain.

Figure 4 : It indicates that there is some dependence between the summer rainfall anomalies of the weather regimes occurrences. Moreover most of the signs of the regression coefficients are consistent with the regimes property: the driest regimes C1 and C2 contribute negatively to the summer rainfall while the wettest ones C7, C8 and C9 contribute positively. The test applied on the year 2000 to estimate the rainfall forecast on an independent year shows a good result. So we can conclude that in their ensemble the weather regimes can explain significantly summer rainfall interannual variability over Senegal.

Table 1 : We have found a relatively good correspondence between "pure" and "interannual" Cx synoptic weather regimes giving dry or wet occurrences over Senegal. This has enabled to interpret most of the time the Cx patterns in terms of "pure" synoptic regimes. However the respective patterns can be somewhat different especially in amplitude as the initial filtering procedures are different.

Next Step:

- ❖ Evaluate the skill of the numerical weather forecasts in terms of weather pattern occurrences
- ❖ To generalize this approach at other areas (as Sahel and Guinean Coast) and other seasons (spring and fall)

Gueye et al, 2010: Weather regimes over Senegal during the summer monsoon season using Self Organizing Maps and Hierarchical Ascendant Classification. Part 1: Synoptic time scale. Climate Dynamics doi: 10.1007/s00382-010-0782-6.

Gueye et al, 2012: Weather regimes over Senegal during the summer monsoon season using Self Organizing Maps and Hierarchical Ascendant Classification. Part 2: Interannual variability. Climate Dynamics doi: 10.1007/s00382-012-1346-8.