REPLY to "The Sahelian drought may have ended during the 1990s"

The 1990s rainfall in the Sahel: the third driest decade since the beginning of the century

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INTRODUCTION

In the discussed paper (L'Hôte *et al.*, 2002) the authors deal with the annual rainfall amounts over the last century and conclude that the drought that affects the Sahel since about 1970 was still going on during the 1990s. So, in this response, the answers to the two main questions in the discussion by Ozer *et al.* (2003) are addressed, which are about (a) the representativeness of the index used in the original study, and (b) the continuation or the end of the drought during the 1990s. Moreover, the authors recall and show that the recent floods in the Sahelian urban areas can be related to hydrological factors other than increases in the rainfall amounts.

SAHELIAN OR WEST AFRICAN RAINFALL?

The name Sahel has frequently been given to regions more southerly than the strictly-speaking Sahelian region, by similarity to the climatic impacts on the environment. For example, in Nicholson (1998), the Sahel region stretches southwards to 10°N, and is divided into three separate areas (northern, central and southern), in which average rainfall fluctuation time series are very similar to one another, and similar to the series of the Soudano-Guinean zone (more to the south). The area used by L'Hôte *et al.* (2002) is roughly identical to that used by Lamb (1985), which he called "Sub-Saharan area". Except for Sarh, the 21 stations are far north of 10°N, which is a commonly used limit between Sahelo-Sudanian areas and more humid southern regions of West Africa (Janicot, 1992). Moreover, the rainfall reduction since 30 years now puts some of the formerly more humid stations into Sub-Sahelian climate conditions (Tambacounda, Ouagadougou, and to a lesser extent Sarh and Bamako). Finally, in the

present discussion about the Sahelian drought, Ozer *et al.* (2003) also refer to the station of Kolda in Senegal with about 1050 mm annual rainfall.

Nevertheless, the authors agree that the adjective Sahelian could be changed to "Sub-Saharan" or "Sahelo-Sudanian".

CAN RECENT FLOODS IN SAHEL URBAN AREAS BE RELATED TO THE END OF THE DROUGHT?

Several authors have shown significant recent changes in the hydrology of the Sahelian rural and urban areas, yet these changes are not necessarily related to the rainfall amounts. For example, in a recent paper, Mahé *et al.* (2002) show that the runoff coefficient of a Sahelian river in Burkina Faso has increased by 108% between 1972 and 1996, despite the reduction of rainfall. This is due to changes in surface conditions, because of the increase in population and related agricultural activities, having a heavy impact on vegetation and groundwater. In another paper, Mahé *et al.* (2003) show that all the Sahelian rivers are affected by this phenomenon in both Burkina Faso and Niger.

With reference to the recent flood in Niamey, the reader is referred to the results of Le Barbé & Lebel (1997), showing that the lasting drought which has affected Niger for more than 20 years is associated with a decrease in the number of rainy events, rather than with a reduction in the mean event rainfall, and that this decrease is more pronounced for the core of the rainy season. Furthermore, in Niamey, as in most of the African towns, the population growth has been very high in the last 30 years, and people have settled in areas that are liable to flooding. So, the increase in floods in the towns seems related to demographic and anthropogenic factors rather than to an increase in rainfall, as shown for instance for other regions (Neppel *et al.*, submitted). Under these conditions, a relationship between the recent floods in the Sahelian towns and the annual rainfall amounts is without doubt inadequate.

DOES THE DROUGHT REALLY CONTINUE UNTIL 2000?

According to several authors (Lubès-Niel *et al.*, 1998; Paturel *et al.*, 1998), the non-parametric Pettitt (1979) statistical test allows one to detect only one change point in a series. Therefore, in order to obtain an additional date of jump which is not the main one near 1970 corresponding to the great drought, it seems necessary to cut the 1921–2000 series. By cutting the 1921–2000 series after the negative jumps, as it is understood Ozer *et al.* did for five stations in Senegal and Niger, the Pettitt test shows that the rainfall average is higher during the 1990s, mainly because of two isolated wet years 1994 and 1999. But these calculations do not show that there are significant signs of a new period as wet as before the drought, because this wet period is not taken into consideration in the series. Applying the Pettitt test to each of the 21 stations of the index in the 1921–2000 period, the authors found the following distribution, which was not exhibited in the paper under discussion: (a) 18 stations with negative jumps between 1963 and 1971 (last years before drought), mode in 1969 for five stations, (b) one station without jump (Nguigmi), and (c) two stations with other dates of negative jumps: 1976 at Ouagadougou and 1961 at N'djamena. Using the Bayesian

estimation of Lee & Heghinian (1977), which also shows only one jump, roughly the same results were obtained.

It is interesting to mention a few unpublished results of the original study using the procedure of segmentation of Hubert *et al.* (1989), which allows one to detect several jumps in a series. The procudure was applied at a 1% significance level of the Scheffe test on each of the 21 stations over the 1921–2000 period. Three years were found to have positive jumps after 1990: 1993 at Nema, Mauritania, 1995 at Sarh, Chad, and 1998 at Tombouctou, Mali. In L'Hôte *et al.* (2002), these results were omitted because only one, at Sarh, is significant, with regard to the need for at least five years after the jump. In fact, Nema cannot be retained either because (a) there is no jump detected with other methods (Pettitt and Lee & Heghinian tests), and (b) with Hubert's procedure the series shows a lot of additional jumps which are very different from those at the other stations: 1949(+), 1958(–) and 1982(–), where (+) represents a positive jump and (–) a negative one.

In a recent paper, Ardoin *et al.* (2003) used Hubert's segmentation procedure on 54 West African rainfall stations over the 1975–1998 period and found only two stations with real positive jumps occurring in 1987: Thyou in Burkina Faso, with about 550 mm annual rainfall, and Kita in Mali (1000 mm). Using the permutation approach on 37 rainfall stations of the Senegal, Gambia and Upper Niger watersheds over the same period, 1975–1998, resulted in finding only four stations with significant statistical changes between the 1980s and the 1990s series. Hence, the conclusion that the drought was still going on during the 1990s.

CONCLUSION

The observations show that two humid years occurred during the 1990s (against one during the 1970s and none during the 1980s), so that the 1990s precipitation average is higher than during the 1980s and roughly equal to the 1970s. Nevertheless, only few statistical results, often calculated upon dry periods, by Ozer *et al.* (2003) and by Ardoin *et al.* (2003), suggest positive jumps for a few stations during the 1990s. By using Hubert's segmentation procedure on the 80-year period (1921–2000), only one station out of 21 shows a significantly positive jump during the 1990s (but no jump is detected with the Pettitt test).

So, there are not yet significant statistical signs to say that a new positive jump towards wetter conditions, as before 1970, has occurred, or was occurring during the 1990s. The drought was still going on during the 1990s. To know, from a statistical point of view, whether the great drought may be ending, it will be necessary to update the calculations with the forthcoming years on long periods including at least two decades before the year 1970.

However, it would be a great hope if the few signs of a reduction in the drought intensity over the Sahelo-Sudanian areas during the 1990s augur the advent of a new humid period.

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DISCUSSION of "Analysis of a Sahelian annual rainfall index from 1896 to 2000; the drought continues" *

The Sahelian drought may have ended during the 1990s

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Abstract The severe drought that affects the Sahel since the late 1960s has been very closely studied and monitored during the last three decades. Recently, after several wet years, it was questioned from a statistical point of view whether the drought was over. The conclusions of a recent study were that the rainfall deficit was not over at the end of 2000 and that the drought continues. The analysis of the change points in the station rainfall time series suggests differentiating these findings. There is now growing evidence that there is a potential shift towards a more humid state. However, the present analysis shows that the assumption that a significant increase in rainfall may have occurred around the early 1990s could only be verified at the customary confidence level in about 10 years from now.

Key words Sahel; rainfall; Pettitt test; discontinuity

La sécheresse sahélienne pourrait s'être terminée durant les années 1990

Résumé La sécheresse qui touche la région sahélienne depuis la fin des années soixante a été extrêmement bien étudiée et suivie au cours des trois dernières décennies. Récemment, à la suite de quelques années fortement pluvieuses, certaines recherches ont été menées pour tenter de voir si cette sécheresse était statistiquement terminée. Les conclusions d'une récente étude montrent que ce déficit pluviométrique n'est pas terminé en fin 2000 et que la sécheresse continue. Sur la base de l'analyse de la première rupture pluviométrique, nous pensons qu'il est nécessaire de nuancer ces propos. Plusieurs signes suggèrent qu'une tendance vers une période plus humide pourrait s'être amorcée aux alentours des années 1990. Cependant, la continuité de la période de sécheresse ou l'identification d'une rupture pluviométrique vers des conditions plus humides ne pourra se vérifier statistiquement que dans une dizaine d'années.

Mots clefs Sahel; précipitations; test de Pettitt; rupture de tendance

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INTRODUCTION

Since the late 1980s, the Sahel of West Africa has recorded some years with rainfall amounts well above the 1961–1990 average (Nicholson *et al.*, 1996, 2000) that may announce the end of the severe period of aridity that started by the end of the 1960s. Together with this rainfall increase in some recent years, floods have been reported in some urban areas of the Sahel. To give a few examples, Niamey was devastated by torrential rains in 1998 (Ozer, 2000) and Dakar, Saint Louis and Kaolack in Senegal were flooded in 1999 and again in 2000 (Sene & Ozer, 2002). Some analysts consider these floods as a new phenomenon related to wetter conditions recently prevailing in the Sahel. In this context, the paper by L'Hôte *et al.* (2002) provides an interesting update of the rainfall trend in West Africa spanning the end of the 19th century and the full 20th century. However, the choice of the stations used for the study of the Sahelian rainfall evolution and the power of the statistical tests in individualizing abrupt changes over short time periods may be questioned.

SAHELIAN OR WEST AFRICAN RAINFALL?

As is commonly accepted, the West African Sahel is the semiarid belt separating arid-like conditions in the north and the dry sub-humid conditions southwards. As specified by L'Hôte *et al.* (2002), the Sahel is roughly defined by yearly rainfall depths ranging from 300 to 700 mm. However, from the 21 stations chosen by L'Hôte *et al.* (2002) to calculate their Sahelian annual rainfall index, only eight are located within the Sahel (refer to Table 1 in L'Hôte *et al.*, 2002). Seven of the stations used are in arid-like conditions and the six remaining are located in the Sudanese climatic zone, with extremes in average yearly rainfall over the 1921–2000 period ranging from 145 mm (Agadez, Niger) to 1105 mm (Bobo Dioulasso, Burkina Faso). Moreover, Nguigmi, Niger, one of these non-Sahelian stations selected, does not exhibit any abrupt change over the 1921–2000 period and therefore does not reflect the trend of the Sahelian rainfall.

The selection of stations outside the 300–700 mm yearly rainfall belt may impact on the results of the statistical tests that are made on the calculated annual rainfall index, because rainfall behaviour is different according to its climatic location. In addition, it has been shown that the "great drought" of the late 1960s did not occur at the same time in West Africa (Gautier *et al.*, 1998; Paturel *et al.*, 1998; Tarhule & Woo, 1998); it was first identified in the northwestern part in 1968 and later in the southeastern area in 1974 (Morel, 1995, 1998). Therefore, the Sahelian annual rainfall index produced by L'Hôte *et al.* (2002) should rather be seen as a West African annual rainfall index.

DOES THE DROUGHT REALLY CONTINUE UNTIL 2000?

Recently, Sene & Ozer (2002) applied the non-parametric Pettitt (1979) statistical test on a yearly rainfall index for Senegal calculated from 10 stations for the 1921–2000 reference period. No abrupt change towards more humid conditions was detected after the beginning of the drought in 1969. However, by analysing each station alone, they

found that the drought had ended in Kolda, where a significant abrupt change was detected in 1992. In addition, in two other locations, results suggested that continuous dry conditions may have ended between the mid-1980s and the early 1990s as a break of low significance (associated probability between 5 and 20%, see Paturel *et al.*, 1998) was observed.

Were these results obtained just by mere coincidence, or do they reflect the beginning of a wetter period? To answer this question, one has to investigate the start of the dry period initiated in the late 1960s. To do so, only the records of the eight stations situated in the Sahelian belt used by L'Hôte *et al.* (2002) are analysed since 1921 using the Pettitt change point test. The results are reported in Table 1. It appears that, on average, the negative break point occurred in 1968, but that the jump is only significant since 1980. In other words, it took 12 years to identify the discontinuity in the Sahelian yearly rainfall. Although the detection of the change point was relatively fast (less than 10 years) in some stations, it took more than 15 years to identify it in other locations (Niamey, Tahoua and N'Djamena). In other words, using the Pettitt (1979) statistical test, the beginning of the great drought in the late 1960s, which seems now evident to the scientific community, would not have been that obvious if applied in the mid to late 1970s, a period during which the Sahel was dramatically suffering from that widespread extreme rainfall deficit (Dai *et al.*, 1998; Nicholson, 1998).

Table 1 Beginning year of the drought, year at which the Pettitt change point test applied to the annual rainfall series (1921–...) yielded a significant result (associated probability below 5%, see Paturel *et al.*, 1998), and time lag in years between the beginning of the drought and its statistical identification.

Station	Negative break	Significant since	Years needed
Saint Louis	1970	1978	8
Dakar	1968	1977	9
Mopti	1972	1984	12
Kayes	1967	1980	13
Niamey	1970	1985	15
Zinder	1965	1972	7
Tahoua	1969	1986	17
N'Djamena	1962	1981	19
Average	**1968**	**1980**	**12**

The recent years (since the jump until 2001) were analysed in more detail for the five stations located in Senegal and Niger. It appears that for three of them, Saint Louis, Niamey and Tahoua, a break of low significance has occurred in 1993, 1989 and 1989 respectively. These jumps are identified since 2001 in Saint Louis and since 1999 in the two stations of Niger. Do these trends maybe announce the end of the great drought? It is too early to know for sure and only rainfall records of the next decade will provide an answer.

In addition, an even longer period of data may be needed to identify any discontinuity towards more humid conditions in the Sahelian belt when compared to the analysis of the jump in 1968. Indeed, the drought of the early 1970s and 1980s was widespread and persistent all over the study area (Nicholson, 1985, 1993; Ozer, 1995), while recent wet years were isolated and often limited to few sectors (Nicholson *et al.*, 2000).

CONCLUSIONS

Rainfall records from Sahelian stations only have to be taken into account to analyse the semiarid belt where fragile rainfed agriculture is practised. The analysis of historical rainfall shows that statistical tests respond with a relatively long time lag to strong variations. Although this discussion has shown station-wise evidence that the Sahelian drought may have ended in the 1990s, the statistical analysis suggests that scientists should wait some further 10 years before inferring any conclusion with the customary level of confidence about the continuation or ending of the present drought.

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