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GENERAL FEATURES OF THE AEROSOL OBSERVED IN THE GUINEAN SAVANNAH AT THE LEVEL OF THE ITCZ INFLUENCE OF THE DROUGHT

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Abstract—The stagnation and mixing of various air masses at the level of the ITCZ in the dry season, together with the absence of rain, favor, in the Guinean savannah, the formation of a well-aged and homogeneous aerosol made up of very active mixed nuclei. When the drought increases, the aerosol always remains an aged one, i.e. absence of particles with radius $r < 0.02\ \mu m$, no nucleation mode. However, different properties show a younger and less homogeneous aerosol, i.e. very high counts in all the categories of particles (the concentration of nuclei activated at the supersaturation $S \simeq 0.32\%$ reaches $9960\ cm^{-3}$), poor correlations between the concentrations of various groups of particles and no fog. When the fires are frequent and spread all over the savannah, a permanent addition of new particles to the local background aerosol (due to a complicated circulation) prevents the ageing of the aerosol that is observed during the usual drought with a moderate extension of bushfires.

1. INTRODUCTION

The Guinean savannah (forested savannah) in the Ivory Coast (Africa) is roughly situated between the latitudes 6° N and 8° N with the tropical rain forest to the south, and the grass-ground savannah, followed by the Sahel, to the north. It is subjected to the influence of the Saharan air masses and maritime air masses, the intersection of which is the intertropical convergence zone (ITCZ). In this article, we will consider experiments carried out in the Guinean savannah in December and January during meteorological situations characterized by the vicinity of the ITCZ throughout the dry season.

In a preceding study, we described a 24-h period during which we measured the concentrations of Aitken nuclei, cloud condensation nuclei (CCN) and large particles at each hour. We observed an aerosol of exceptional nature, particularly aged and homogeneous (Désalmand *et al.*, 1985). An attempt to describe the main nature of CCN led us to the nuclei of mixed nature with an insoluble core which might bear on its surface active sites suitable for a capillary condensation (Podzimek *et al.*, 1982; Podzimek and Désalmand, 1985).

After this measurement period selected out of 48 h (on 1 and 2 January 1982), several similar measurements (on 28 December 1982–8 January 1983) were carried out at the same station of forested savannah during a more severe drought in the next dry season. The purpose of this article is also to draw some general conclusions about the specific aerosol of the Guinean savannah at the level of the ITCZ.

2. MEASUREMENT STATION AND EQUIPMENT

2.1. *Measurement station*

The Geophysical station of Lamto is situated at about 120 km from the Atlantic Ocean in a quite unpolluted site with a very sparse population. All around the station is the forested savannah, rather dispersed with a gallery forest along the Bandama River at about 500 m from the laboratory (see Fig. 1, p. 20, Désalmand *et al.*, 1985).

2.2. *Meteorological situation*

The annual rainfall is near 1300 mm for the period 1961–1975. The ITCZ is characterized by the stagnation of the air masses and by the cyclonic whirlwinds carried towards the west by the east flow. The positions of the ITCZ are the following for the measurement periods:

1 and 2 January 1982: 150 km at the north of the ITCZ under the influence of troughs bringing the maritime air mass into the continental air mass and inversely;
28 December 1982: at the level of the station but slightly to the north;
8 January 1983: at the level of the station but slightly to the south.

The drought for the first dry season (1981–82) is 'usual' and for the second dry season (1982–83) is very intense because the ITCZ reaches the ocean several times. The vegetation particularly dries out under the influence of the Saharan air mass and bushfires are widespread over the savannah.

2.3. *Main sources of aerosols in the savannah during the dry season*

The main sources are the Saharan dust and the bushfire smoke.

(1) The Saharan dust, generally emitted in this region from the Chad and Niger basins (Dubief, 1979) was not very active during the dry season 1981–82 and much more active during the following one. It may be produced during dust outbreaks or, more frequently, as a result of sedimentation from the dust cloud at altitude through the ITCZ (weakly inclined surface) and monsoon layer. Most mineral particles are supposed to be in the size range $r \geqslant 0.1\ \mu m$.

(2) During fire events, various gases and particles are emitted. Some particles are about 0.1 μm in radius and are thought to be tars and others have radius around 0.02 and 0.01 μm and are thought to be ashes with mineral material (K, Na, Mg, PO_4, etc.) and carbon (Vines *et al.*, 1971). Among the most frequently occurring gases are CO_2, H_2S, SO_x, NH_3, NO_x, O_3. Therefore, bushfire smoke contains particles which have the nature and size required to be CCN; indeed, several researchers found high concentrations of CCN in bushfire smoke (Holle, 1971; Twomey, 1971).

Here, we have to mention that a harder drought (longer sojourn of the Saharan air mass) intensifies the bushfires and strengthens the production of gases, tars and ashes.

In general, the measurements were always carried out in the absence of bushfires perceptible around the station. However, the air was usually loaded with the bushfire products of the preceding days or advected from remote regions.

2.4. *Equipment*

Three types of counters were used.

A Gardner Counter allows the measurements of the concentration N_A of the Aitken nuclei activated at the supersaturation $S \simeq 180\%$, according to the manufacturer. This counter seems to undervalue the total concentration by about 30% (Podzimek *et al.*, 1982) and the minimal detectable particle size is probably around 0.005 μm.

A Thermal Gradient Diffusion Chamber (TGDC), cooled at the bottom by thermo-element electric modules and fitted with a video system. We choose three values of the difference of temperature between the two plates $\Delta T = (3°, 4°, 5°C)$. When the ambient temperature of this tropical region varies around 30°C, the corresponding supersaturations (S_{min}, S_{med}, S_{max}) are nearly: $S \simeq (0.32, 0.55, 0.84\%)$ with the corresponding concentrations (N_{min}, N_{med}, N_{max}). The concentration N_S of the nuclei activated at the supersaturation S is supposed to obey the power law adjustment of Twomey:

$$N_S = CS^k, \tag{1}$$

where C and k are appropriate constants.

Then, we distinguish the lower and higher supersaturations and find two values for the slope k of the supersaturation spectrum deduced from relation (1):

$$\begin{cases} k_1 = \log\left\{\frac{N_{med}}{N_{min}}\right\} \Big/ \log\left\{\frac{S_{med}}{S_{min}}\right\} & (2) \\ k_2 = \log\left\{\frac{N_{max}}{N_{med}}\right\} \Big/ \log\left\{\frac{S_{max}}{S_{med}}\right\}. & (3) \end{cases}$$

It requires about 5 min to complete the supersaturation spectrum.

Approximate size of CCN. According to measurements realized in other conditions, the equivalent dry radii of the particles activated at the supersaturations 0.32, 0.55, 0.84% are respectively around 0.039, 0.027, 0.020 μm. In this way, the CCN spectrum encompasses particles with equivalent dry radii between 0.02 and 0.04 μm in the Aitken size range (Fitzgerald and Hoppel, 1982).

An Optical Baush and Lomb Counter classifies large particles according to their radius $r \geqslant (0.15, 0.25, 0.50, 1.5, 2.5, 5\ \mu m)$. Let us call N_B the concentration of particles with $r \geqslant 0.15\ \mu m$.

The hourly values N_A, N_S and N_B measured during periods of 24 h are in reality the arithmetic mean of four consecutive air samplings. The daily mean is calculated with equal weight to each hourly value.

3. EXPERIMENTAL RESULTS

3.1. *Daily mean concentrations*

The observations reported in Table 1 lead to the following conclusions:

(1) The aerosol is rich in very active CCN ($\bar{N}_{0.32} \simeq 2080\ cm^{-3}$). This concentration increases with the drought (28 December with $\bar{N}_{0.32} \simeq 2980\ cm^{-3}$) and is especially high at the north of the ITCZ (8 January with $\bar{N}_{0.32} \simeq 9960\ cm^{-3}$);

(2) The same result is valid for higher supersaturations, Aitken nuclei and large particles;

(3) Taking into account the hypothesis according to which the Gardner counter underestimates the concentration N_A, we may conclude that in all the cases $\bar{N}_A \simeq \bar{N}_{0.84}$. There are no particles with equivalent dry radius $r < 0.02\ \mu m$. In general, in that season the sources of small particles are less active and the size spectrum $f(r) = -\mathrm{d}N/\mathrm{d}\log r$ is devoid of the nucleation mode.

The cumulative concentration distributions are reported in Fig. 1 where $N = N(r)$ is the concentration of particles activated at the supersaturation S which is the critical supersaturation of particles with radius $\geqslant r$. The various values of r for the different counters are given in section 2.4. Daily mean curves $N = N(r)$ reflect the data in Table 1. It is clear that the height of the curve rises with the drought and to the north of the ITCZ.

Table 1. Guinean savannah at the level of the ITCZ during the dry seasons 81–82 (first column) and 82–83 (second column): arithmetic daily mean values of Aitken nuclei concentrations N_A (cm^{-3}), CCN concentrations N_S (cm^{-3}) and large particle concentration N_B (cm^{-3}), k_1 and k_2 slopes of the supersaturation spectrum, aerosol mass concentration M (μg m^{-3})

	"Usual" drought		"Severe" drought	
LAMTO	01.01.82	02.01.82	28.12.82	08.01.83
$\bar{N}_B$ (cm^{-3})	2070	2030	4520	11,420
$\bar{N}_{0.84}$	2950	2900	4770	—
$\bar{N}_{0.55}$	2630	2570	4080	—
$\bar{N}_{0.32}$	2080	2290	2980	9960
$\bar{N}_B$	38	40	40	153
$\bar{k}_1$	0.43	0.22	0.61	—
$\bar{k}_2$	0.30	0.29	0.40	—
$\bar{M}$ (μg m^{-3})	—	—	76	354

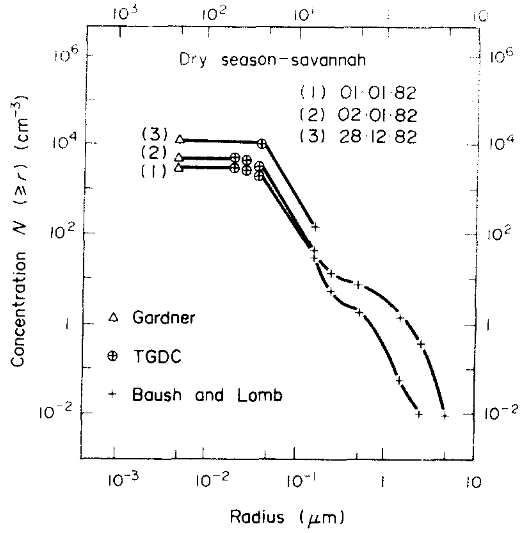

Fig. 1. Cumulative concentration distributions determined with the help of three pieces of apparatus: curve 1: at 150 km to the south of the ITCZ; curve 2: at the level of the ITCZ; curve 3: to the north of the ITCZ.

On 8 January 1983, there are no measurements with the TGDC for $\Delta T = (4°, 5°C)$ because of a failure of the thermal regulation and a breakdown of the Baush and Lomb counter happening on the same day.

3.2. *Correlations between the hourly concentrations* N_A, N_S, N_B

We tried to fit a power function to the different hourly measurements: $N_A = \alpha_1 N_S^{\beta_1}$, $N_B = \alpha_2 N_A^{\beta_2}$, $N_B = \alpha_3 N_S^{\beta_3}$ where α_i and β_i are constants. The results are reported in Table 2 with ρ being the correlation coefficient of the least square method. On 1 January 1982, the values of ρ are very high (0.7, 0.8) and reflect the feature of a very exceptional aged and homogeneous aerosol. They are much lower (0.35) on 28 December 1982, when the various categories of particles are more independent and the aerosol is younger and less homogeneous.

Figure 2 completes Table 2. It represents the hourly variations of the CCN concentrations on 1 and 2 January 1982 (in the upper part) and on 28 December 1982 (in the lower part). In the latter, very important fluctuations of N_S occur. The local circulation is very complicated indeed and the advection of CCN produced by bushfires from various remote regions may modify and hide the natural daily evolution of the 'local' CCN.

3.3. *Slopes* k_1 *and* k_2 *of the supersaturation spectrum*

The daily means $\bar{k}_1$ and $\bar{k}_2$ are reported in Table 1. They are around 0.3 for 1 and 2 January 1982 and around 0.5 for 28 December 1982. These higher values show that the difference

Table 2. Guinean savannah at the level of the ITCZ during the dry season 81–82 (left part) and 82–83 (right part): the values of the coefficients α, β and the correlation factor ρ in the power relation between the hourly values of concentrations: N_A (Aitken nuclei), N_S (CCN) and N_B ($r > 0.15\ \mu m$)

Adjustment	α	β	ρ	Adjustment	α	β	ρ
$N_A = \alpha N_{1.00}^{\beta}$	1.3×10^{-3}	1.79	0.72	$N_A = \alpha N_{0.84}^{\beta}$	8.71	0.73	0.43
$N_A = \alpha N_{0.50}^{\beta}$	5.5×10^{-3}	1.64	0.74	$N_A = \alpha N_{0.55}^{\beta}$	17.50	0.66	0.36
$N_A = \alpha N_{0.25}^{\beta}$	7.4×10^{-3}	1.64	0.69	$N_A = \alpha N_{0.32}^{\beta}$	3444	0.03	0.03
$N_B = \alpha N_A^{\beta}$	4.4×10^{-3}	1.19	0.72	$N_B = \alpha N_A^{\beta}$	0.97	0.44	0.62
$N_B = \alpha N_{1.00}^{\beta}$	1.4×10^{-3}	1.28	0.86	$N_B = \alpha N_{0.84}^{\beta}$	1.25	0.41	0.34
$N_B = \alpha N_{0.50}^{\beta}$	3.8×10^{-3}	1.18	0.88	$N_B = \alpha N_{0.55}^{\beta}$	1.20	0.42	0.32
$N_B = \alpha N_{0.25}^{\beta}$	5.9×10^{-3}	1.15	0.84	$N_B = \alpha N_{0.32}^{\beta}$	4.13	0.28	0.30

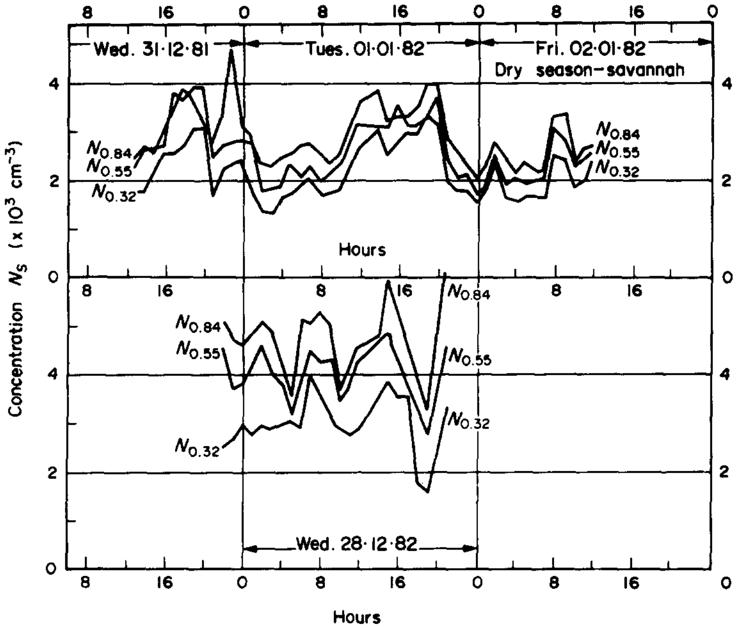

Fig. 2. Hourly variations of the CCN concentrations N_S: upper part: at 150 km to the south of the ITCZ; lower part: at the level of the ITCZ.

between the various populations of N_S is very important. Moreover, this reveals a younger aerosol with radii between 0.02 and 0.04 μm and perhaps less active (Levin *et al.*, 1966; Désalmand, 1985).

It should be noticed that $\bar{k}_1$ is significantly different from $\bar{k}_2$ for the first (0.43 and 0.30) and third day (0.61 and 0.40) and not very significant for the second (0.22 and 0.29). We deduce further that the supersaturation spectrum is convex or practically linear. In contrast, during the monsoon period in May or June, the spectrum is more concave (see Appendix) than otherwise.

3.4. *Size spectrum* f(r) = −dN/dlog r

In the CCN size range, we dispose of two methods to calculate $f(r)$. The first one is the definition $f(r) = -\mathrm{d}N/\mathrm{d}\log r$ and the second consists of using the approximative relations presented in another article (Désalmand, 1985)

$$f_2 \simeq \frac{3}{2} k_2 N_2 \quad \text{for} \quad 0.020 \leqslant r \leqslant 0.027\,\mu\text{m} \tag{4}$$

$$f_1 \simeq \frac{3}{2} k_1 N_1 \quad \text{for} \quad 0.027 \leqslant r \leqslant 0.039\,\mu\text{m}, \tag{5}$$

with $N_2 = (N_{max}\,N_{med})^{1/2}$ and $N_1 = (N_{med}\,N_{min})^{1/2}$.

The slope s of the size spectrum in a log–log diagram is given by

$$s \simeq 3\frac{\log\,(k_2 N_{max}{}^{1/2}/k_1 N_{min}{}^{1/2})}{\log\,(S_{min}/S_{max})}. \tag{6}$$

Both methods give for $f(r)$ the same values (deviation 10%), probably because of the same numerical values of r taken out from the article by Fitzgerald and Hoppel (1982).

The daily mean values $\bar{f}_2, \bar{f}_1$ are reported in Table 3. They increase with the drought. The slope $\bar{s}$ has a tendency to be positive; the interest of this remark is that during the monsoon period this slope, $\bar{s}$, is clearly negative (see Appendix).

Table 3. Guinean savannah at the level of the ITCZ during the dry season 81–82 (first column) and 82–83 (second column): calculated daily mean of size spectrum $f(r)$ and slope of the distribution curve

LAMTO	"Usual" drought 01.01.82	02.01.82	"Severe" drought 28.12.82	08.01.83
$\bar{f}_2$ (cm^{-3})	1130	1150	2450	—
$\bar{f}_1$ (cm^{-3})	1510	760	3030	·
$\bar{s}$	+0.90	−1.26	+0.67	—

The whole spectra are represented in Fig. 3. In the range of large particles ($r \geq 0.1$ μm), the Junge law is not valid because one can observe a stationary section near $r = 0.5$ μm. For $r \geq 1$ μm, the slopes are around −4 as for the Junge law.

3.5. *Aerosol mass concentration*

A filter exposed on 28 December 1982 by the staff of the Geophysical station at Lamto indicated a daily mean mass concentration of 76 μg m^{-3}. This poor content in large particles was confirmed by the daily mean concentration $\bar{N}_B \simeq 40$ cm^{-3} and was due to the absence of Saharan dust outbreak carried by the north-east winds.

In contrast, the aerosol mass concentration was $\bar{M} \simeq 354$ μg m^{-3} on 8 January 1983 and the corresponding concentration of large particles was $\bar{N}_B \simeq 153$ cm^{-3}. For this period, the Saharan dust was more abundant whereas more numerous fires produced larger quantities of particles (tars, ashes). These high counts also revealed a younger aerosol.

3.6. *Occurrence of a fog*

A wet fog occurred on 1 January 1982 at 5:00 a.m., when the relative humidity reached the value $H \simeq 99\%$ (visibility < 100 m) and disappeared when $H \simeq 98\%$ without hysteresis. This shows a very homogeneous population of mixed nuclei in the concerned size range.

On the contrary, no fog appeared on 28 December 1982, when the maximal humidity reached the same value $H \simeq 99\%$. One can deduce that the mixed nuclei did not carry enough

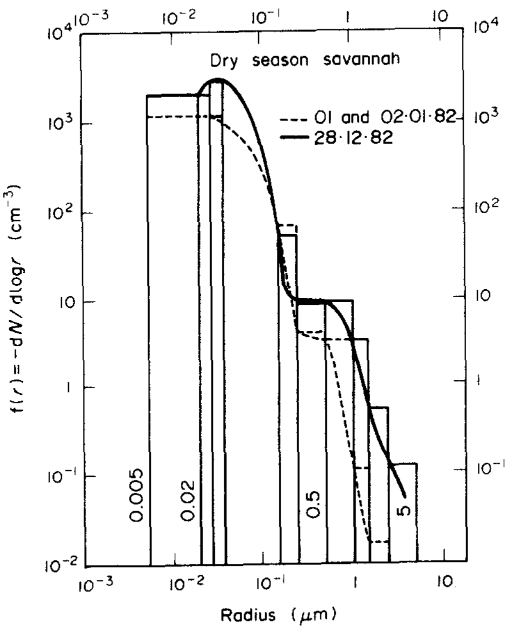

Fig. 3. Size distributions $f(r) = -\mathrm{d}N/\mathrm{d}\log r$ determined with the help of three pieces of apparatus: dotted line: at 150 km to the south of the ITCZ; full line: at the level of the ITCZ.

soluble material and that the mixing of aerosols or adsorption of gases was insufficient. This observation once more shows a younger aerosol in this size range.

On 8 January 1983, no fog formed because of the low relative humidity ($H \simeq 58\,\%$). The Saharan air masses were slightly moistened by contact with the savannah but not sufficiently to activate mixed nuclei.

The above-mentioned facts enable a hypothesis on the possible nature of nuclei to be established: the particulates are probably mixed nuclei. Most of them are composed of an insoluble core of clay from Saharan dust or tar from bushfire smoke on which are deposited soluble material (Na, Mg, . . . from ashes or SO_3, . . . from gases) produced by bushfires. This hypothesis takes into account the two main sources of aerosols in the Guinean savannah during the dry season.

4. GENERAL CONCLUSION

Several 24 h measurements were performed in the Guinean savannah at the level of the ITCZ in the long dry season. The results of a first study are confirmed and the influence of the drought is put in evidence.

In all the cases, we have to consider the aerosol as an aged one for the following reasons: there are no particles with radii $r < 0.02\,\mu m$ and $\overline{N}_A \simeq \overline{N}_{0.84}$. As we always took measurements one day at least after the local fires, we may assume that the major source of small particles in the Guinean savannah is the bushfire and that nuclei are predominantly constituted of tars (insoluble material) or ashes (partly soluble material) on which soluble gases may be adsorbed. Saharan clay may also play a part in the formation of mixed nuclei.

The slopes of the supersaturation spectrum are rather small (0.61 is the maximal daily mean value). In conformity with the hypothesis expressed elsewhere, this aged aerosol presents a convex or linear CCN spectrum. This spectrum is associated to a calculated size spectrum increasing or stationary with increasing radius in the size range (0.02–0.04 μm).

Furthermore, this new study shows the influence of the drought. During a severe drought, we observe the following properties. The concentrations in all the particle sizes increase, particularly in the north of the ITCZ (which may appear as a zone of accumulation). The increase of the concentrations is the evident consequence of more numerous bushfires. From different points of view, the aerosol is younger and less homogeneous (higher values of slopes k, lower correlations between the various concentrations, no fog and higher concentrations of very large or small particles). This also can be considered as a consequence of more frequent and extended bushfires. The local aerosol is constantly renewed by the addition of new particles or gases which may be locally formed or advected from remote regions by the rather complicated atmospheric circulation. The time duration is, however, not sufficient for an effective ageing of the prevailing aerosol which, due to that, remains less homogeneous and active than during a usual drought with less numerous and less extended fires.

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APPENDIX

Supersaturation spectrum for four days of the rainy season in the Guinean savannah: 29 May 1981 (1st column); 30 May 1981 (2nd column); 14 June 1981 (3rd column); and 15 June 1981 (4th column)

$\bar{N}_{0.84}$	1130	810	1320	1070
$\bar{N}_{0.55}$	880	680	1090	900
$\bar{N}_{0.32}$	680	580	960	800
$\bar{k}_1$	0.50	0.29	0.24	0.23
$\bar{k}_2$	0.57	0.50	0.48	0.55
$\bar{J}_2$	850	560	860	810
$\bar{J}_1$	580	270	370	290
$\bar{s}$	−1.43	−1.60	−2.58	−2.39

For these four 24 h periods of the rainy season, the daily mean CCN spectrum is concave and the size spectrum curve slope decreases with increasing r.