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G. Bergametti, B. Marticorena, J. Rajot, G. Siour, A. Féron, et al.. The Respective Roles of Wind Speed and Green Vegetation in Controlling Sahelian Dust Emission during the Wet Season. *Geophysical Research Letters*, 2020, 47 (22), pp.e2020GL089761. 10.1029/2020GL089761 . hal-02989085

HAL Id: hal-02989085

<https://hal.science/hal-02989085>

Submitted on 9 Nov 2020

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The Respective Roles of Wind Speed and Green Vegetation in Controlling Sahelian Dust Emission during the Wet Season

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Key Points:

- Between May and September, the decrease of the high wind speeds is the main reason for the decrease of PM10 in the Central Sahel
- During the growing period (June to September), the green vegetation progressively reduces dust emission efficiency in the Sahel
- For identical wind speeds, vegetation cover characterized by NDVI higher than 0.26 reduces PM10 concentrations up to 80%

Abstract

Based on 10 years of continuous measurements of wind speed, rainfall and PM10 concentrations (i.e., concentrations of the particulate matter having a diameter lower than 10 μm) performed in two Sahelian stations, we examine how wind speed and vegetation interact during the wet season to control the dust concentration when it is due to local dust emissions. The results clearly show that the frequency of the high wind speeds is higher at the beginning of the wet season and is the main driver of the seasonal dust emission. During the second part of the wet season, the frequency of high wind speeds is much lower and, in addition, their efficiency for wind erosion and dust emission is strongly affected by the vegetation whose growth reduces progressively PM10 concentrations up to 80%.

1 Introduction

Dust emission from the Sahelian belt (and more generally from the semi-arid regions) is a complex phenomenon resulting from strong interactions between meteorological factors (such as wind speed and precipitation) and surface properties, especially the vegetation cover. Because meteorological regimes and surface properties change with time, the way by which these interactions occur varies on various time scales.

Wind speed is the real driver of wind erosion and, thus, the intensity of dust emissions is highly sensitive to any small change in wind speed: indeed, these processes are thresholded processes and depend on wind speed through power functions (e.g., Shao, 2008).

Assessing the temporal variability of wind speed is thus a key point, knowing that the characteristic time scale of variability can be less than a minute. In the Sahel, two main meteorological regimes generate wind speeds sufficient to induce wind erosion and dust emission. The Nocturnal Low-Level Jet (NLLJ) is characterized by a wind speed maximum that forms in the lower troposphere at nighttime. From sunrise to about 1200 local time, the turbulence, growing by surface heating, allows an efficient downward mixing of momentum from NLLJ to produce surface wind speeds that can be sufficiently strong to initiate dust emission. When the turbulence is the highest in the planetary boundary layer, a strong mixing reduces vertical gradients of momentum and totally dissipates the jet. This phenomenon is responsible for most of the high wind speeds occurring during morning in the Sahelian and Saharan regions (e.g., Fiedler et al., 2013; Heinold et al., 2013; Kaly et al., 2015; Knippertz, 2008; Lothon et al., 2008; Marsham et al., 2013; Parker et al., 2005). During the wet season, very high wind speeds are associated with convective cells that develop into Mesoscale Convective Systems (MCS). Such storms are predominantly nocturnal (e.g., Bouniol et al., 2012; Nesbitt & Zipser, 2003), vary in scale but most of them have sizes ranging from tens to hundreds of kilometers (e.g., Laing & Frislich, 1993; Marsham et al., 2008; Roberts & Knippertz, 2012). In areas where the soils are easily erodible, dust is lofted quasi-continuously along these fronts producing dust walls, called “haboobs,” extending over altitudes ranging from 2,000 to 5,000 m (Williams et al., 2009).

Based on 10 years of meteorological measurements at high temporal resolution in two Sahelian stations, Bergametti et al. (2017) evaluated the relative contribution to dust emission of high wind speeds linked to NLLJ and to convective events through an indicator called Dust Uplift

Potential (DUP) (Marsham et al., 2011). Their results showed that in the Central Sahel, the NLLJ controls the frequency of wind erosion events. However, the highest wind speeds occurring at that time are only slightly over the threshold wind speed (TWS) for wind erosion (i.e., the minimum wind speed allowing wind erosion to start) and thus generate probably limited dust emissions. On the opposite, their results suggested that most of the annual DUP is due to the rare but very intense high wind speed events occurring in the late afternoon and during nighttime, especially those occurring at the beginning of the rainy season. This is in agreement with the seasonal pattern of dust concentrations observed at the same stations as reported by Marticorena et al. (2010) and Kaly et al. (2015). Indeed, these authors demonstrated that very high dust concentrations (up to several mg m^{-3}) are recorded during the wet season as the consequence of intense but short events associated with the crossing of MCS. They also showed that the highest dust concentrations observed in the Sahel during the dry season are generally not locally produced but result, for a large part, from dust emitted in the Sahara desert and transported towards the Sahel in the Harmattan layer as the analyzes of the dust composition also indicates (Rajot et al., 2008).

In the Sahel, precipitation is also strongly season-dependent and closely linked to the onset and retreat of the monsoon: rain is mainly brought by MCS (e.g., Mathon et al., 2002) and occurs between May and October, the rest of the year being almost totally dry. The direct impact of precipitation on wind erosion and dust emission is to increase the soil moisture and consequently the capacity of the soil grains to be lofted. However, Bergametti et al. (2016) have shown that, in Niger, a period of less than 12 h after a rain event has finished is generally sufficient to almost fully restore the sand transport potential of a soil. This strongly suggests that the inhibition and/or reduction of dust emissions due to the increase in soil moisture following a rain event are rather limited in this region.

However, the seasonality of precipitation has also an indirect effect on dust emission since it controls the growth and senescence of the natural and cultivated vegetations. Large parts of Sahelian surface evolves from almost bare in May to largely covered by green herbaceous vegetation in August and September. This is particularly marked over cultivated fields where soil surface is often cleared and crop residues collected before the beginning of the rainy season, this explains why fields are much more erodible than fallow lands in the Sahel (Abdourhamane Touré et al., 2019; Biielders et al., 2002; Rajot, 2001; Sterk & Stein, 1997). Precipitation decreases from the beginning of September and stops generally in October, inducing a progressive senescence of the vegetation (Plate S1). Thus, from October to the next wet season, the remaining dry vegetation controls the percentage of cover of the surface: it continuously decreases due to agricultural practices, soil trampling, grazing and consumption by termites and gradually uncovers the surface until the start of the next wet season (e.g., Pierre et al., 2015). As a result, dry vegetation plays a major role in protecting the surface against wind erosion during the dry season and the beginning of the following wet season: Abdourhamane Touré et al. (2011) estimated that a percentage of cover of agricultural fields by vegetation residues higher than 2% could be sufficient for significantly reduce wind erosion and dust emission. On an interannual time scale, Kergoat et al. (2017), using an indicator of the dry-season nonphotosynthetic vegetation cover in the Sahel based on Moderate Resolution Imaging Spectroradiometer (MODIS), suggested that 43% of the year-to-year variance in Sahelian-mean dry-season aerosol optical depth can be explained by the change in dry vegetation cover as a consequence of differences in precipitation patterns occurring during the previous wet season. On the opposite,

the role of the green vegetation on wind erosion and dust emission in the Sahel has been less investigated despite the fact that the most intense dust emission, as mentioned before, occurs during the wet season. The measurements of PM₁₀ concentrations reported by Marticorena et al. (2010) clearly show a minimum in the core of wet season compared to the early monsoon period. In the same way, DUP is also lower in the second half of July and August indicating that a change in the intensity of the highest wind speeds significantly contributes to this decrease of dust emissions during the core of the monsoon period. However, at this period, the vegetation cover is close to its maximum and could have an additive protective effect of the surface against wind erosion. However, it is difficult to evaluate precisely how much of the changes in wind speed and vegetation cover contribute respectively to the decrease of dust concentrations along the wet Sahelian season.

In this paper, we use high temporal resolution wind speed and PM₁₀ concentration measurements over the period 2006-2015 in two Sahelian stations in combination with MODIS NDVI data to provide an assessment of the respective roles of wind and vegetation on dust emission during the wet season in the Sahel.

2 Materials and Methods

2.1 Data acquisition

The two observing stations are located close to the small villages of Cinzana (Mali, 13.28°N, 5.93°W) and Banizoumbou (Niger, 13.54°N, 2.66°E). They are about 900 km away from each other and are on the main transport route of Saharan and Sahelian dust toward the north-tropical Atlantic Ocean. The Cinzana station is embedded inside the agronomical research station of the Institut d'Economie Rurale (IER). The rainfall is about 770 mm year⁻¹, and the area of the station is protected by a vegetation cover mainly composed of shrubs and trees. In Niger, the station, installed in a more than 20 years old fallow embedded in a traditional fallows/fields area, is located at 2.5 km from the village of Banizoumbou. The rainfall is about 550 mm year⁻¹.

Meteorological measurements are performed at 6.5 m above ground level (agl) in Banizoumbou and at 2.3 m agl in Cinzana. Instrumentation has been selected based on criteria of simplicity of use and maintenance and capability to resist to severe dust and meteorological conditions. A Windsonic 2-D anemometer (Gill Instruments Ltd[®]) provides the wind speed and direction averaged over a 5 min time step. Rainfall is monitored using an ARG100 aerodynamic precipitation sensor (Campbell Scientific Instruments[®]) working according to the principle of the “tipping bucket” mechanism. It provides a contact closure at each tipping which occurs for each 0.2 mm of rainfall and the number of tips is cumulated over a 5-minute time step. Annual recovery rate during the wet season for both sites and for the period 2006–2015 were always higher than 91% for wind speed data and higher than 83% for rainfall (Table S1).

Atmospheric concentrations of Particulate Matter smaller than 10 μm (PM₁₀) are measured using a Tapered Element Oscillating Microbalance (TEOM 1400A from Thermo Scientific[®]) equipped with a standard PM₁₀ inlet (R&P[®] PM-10 operating at 16.7 LPM). More precisely, PM₁₀ means particulate matter which passes through a size selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter. At both stations, the inlet is installed at 6.5 m agl. Details on the procedure can be found in Marticorena et al. (2010) and Kaly et al. (2015).

To follow the growth and senescence of the vegetation, the normalized difference vegetation index (NDVI) is a well-adapted proxy in semiarid areas such as the Sahel (i.e., Huber and Fensholt, 2011; Tucker et al., 2005). We used NDVIs from Terra/MODIS. The vegetation indices (MOD13Q1) Version 6 data are generated every 16 days with a 250-meter (m) spatial resolution as a level 3 product (Didan, 2015). We selected the four pixels surrounding Banizoumbou and Cinzana stations and averaged the NDVI values of these four pixels in order to integrate possible local differences in vegetation cover. In fact, the standard deviations associated to this averaging were very low, most of them being lower than 1% and never exceeded 6% in Banizoumbou and 14% in Cinzana.

In agreement with the difference in rainfall, the vegetation is higher in Cinzana than in Banizoumbou (Figure 1) : the mean annual NDVI minimum over the considered period is 0.163 (+/- 0.008) in Cinzana while it is only 0.134 (+/- 0.006) in Banizoumbou. The mean annual NDVI maximum are 0.532 (+/-0.065) in Cinzana and 0.323 (+/-0.026) in Banizoumbou.

2.2 Data selection

To examine how wind speed and vegetation interact to control dust emission during the vegetative period in the Sahel, we selected the period ranging from 1 May to 30 September. Indeed, the period from the beginning of May to about mid-June exhibits the lowest NDVI, the vegetation having not started to grow. Moreover, at that time, the vegetative residues of the previous year being at their minimum. Thus, at that time, we can consider that the surface is almost bare or, at least, minimally protected by the vegetation. We limited the period to the end of September when the senescence becomes significant and the dry vegetation begins to control the cover of the surface. This cycle of the vegetation is illustrated by the sketch of pictures of a millet field recorded at different periods in 2007 in Banizoumbou (Plate S1).

We also selected only the periods of time for which the wind speed was greater than wind speed limits defined as 5 m s^{-1} and 4 m s^{-1} for Banizoumbou and Cinzana, respectively. These values are slightly lower than the erosion threshold wind speed (TWS) as defined by Bergametti et al. (2017) (7 and 5.5 m s^{-1} in Banizoumbou and Cinzana, respectively). Indeed, wind erosion can occur for wind speeds lower than the TWS when this latter is defined as the wind speed for which wind erosion is detected 50% of the time. The occurrence or not of wind erosion for wind speed slightly lower than this TWS is thus mainly dependent on the variance of the 5-minute average wind speed (i.e. on its probability density function). As a consequence, the PM10 concentrations corresponding to the wind speeds the closest of these thresholds can mix periods of time with local/regional wind erosion and dust and periods corresponding to “background” dust concentrations.

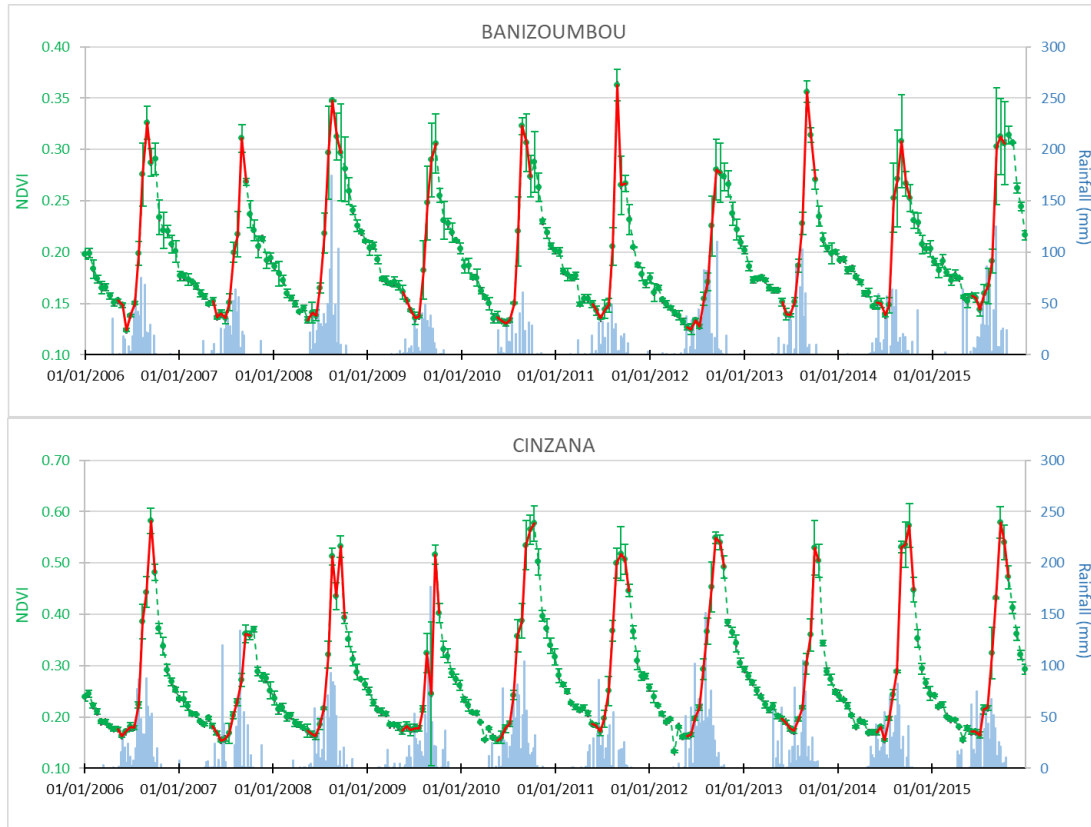


Figure 1. Weekly rainfall (in blue) and 250m MODIS NDVIs for Banizoumbou (top) and Cinzana (bottom) for the period 01/01/2006 to 31/12/2015) in green. NDVIs report here the average of the four pixels surrounding the stations, the vertical bars are the standard deviations associated to this averaging. The red line corresponds to the periods considered in this paper. For Cinzana, rainfall data are missing from 8 July 2007 to 5 August 2007.

We eliminate the samples collected during rain events higher than 0.2mm and we also discarded all the 24-hour periods following the end of a rain event to eliminate the effect of the soil moisture on wind erosion. We also eliminate the obvious cases of advection of dust (i.e., high dust concentrations during several hours without continuous high wind speeds). Finally, 33861 and 17263 couples of 5-minute data (synchronous wind speed and PM10 concentrations) were retained for Banizoumbou and Cinzana, respectively. This represents between 5 and 10% of the number of couples of data acquired during the wet seasons 2006-2015.

Thus, we assume that the selected PM10 concentrations are representative either of a background level (for the lower wind speeds) or of local dust emissions. This assumption is supported by the power-3 dependence of the average PM10 concentrations with wind speed for the selected data set (Figure S1).

3 Results

3.1 The role of wind speed

Figure 2 reports the monthly distributions of wind speeds for different wind speed limits for the period 1 May to 30 September and for the years 2006-2015. The frequency of wind speeds higher than $\geq 5 \text{ m s}^{-1}$ and 4 m s^{-1} in Banizoumbou and Cinzana, respectively represents the frequency of potential dust emission while the distribution of the high wind speeds (HWS) ($\geq 8 \text{ m s}^{-1}$ in Cinzana and $\geq 9 \text{ m s}^{-1}$ in Banizoumbou) can be seen as a proxy of the most intense dust emission. It should be noted that HWS represent only a small part of the wind speeds greater than 5 m s^{-1} (about 3% in Banizoumbou) and 4 m s^{-1} (0.5% in Cinzana).

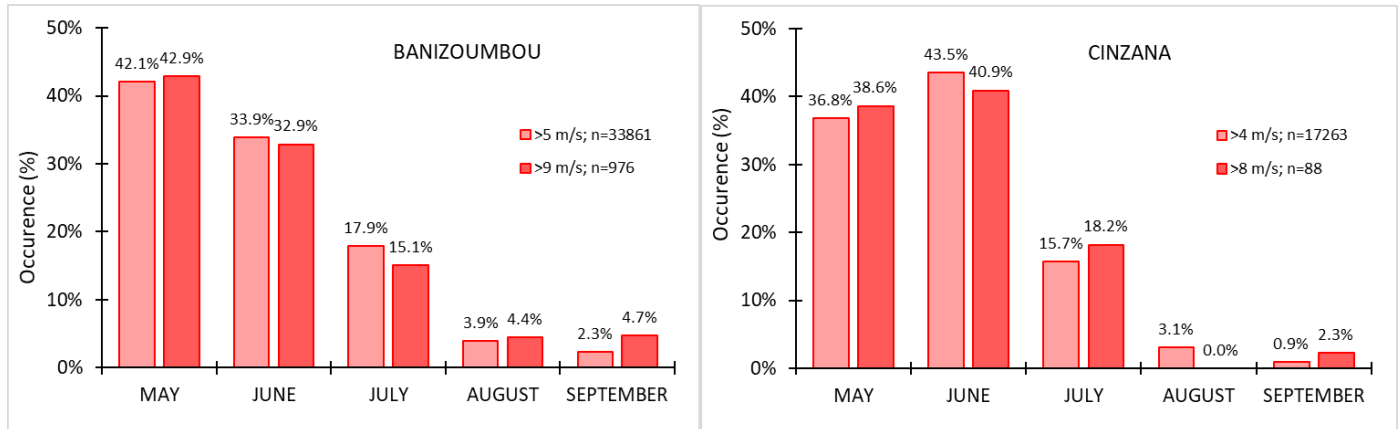


Figure 2. Distribution of the occurrence (%) over the rainy season (May to September) of wind speeds higher than 5 m s^{-1} (light red) and 9 m s^{-1} (dark red) in Banizoumbou and higher than 4 m s^{-1} (light red) and 8 m s^{-1} (dark red) in Cinzana. Wind speed are measured from 2006 to 2015.

Most of the wind speeds that are susceptible to generate dust emission occur in May and June with 80.3% in Cinzana and 76% in Banizoumbou. 94% and 82% of wind speeds in Cinzana and Banizoumbou, respectively are only of one or two meters above the TWS. Most of them ($>62\%$ in Cinzana, 54% in Banizoumbou) occur in the morning between 0600 and 1400 UTC and are directly linked to the breakdown of the NLLJ. The strong decrease in the occurrence of these wind speeds from May-June to August-September is in agreement with the observations performed by Lothon et al., (2008) in Niamey (Niger) or with those reported by Sterk (2003). They indicate that the percentage of occurrence of the NLLJ decreases continuously during the wet season, i.e., from 85% in April to 52% in October.

A decreasing trend in the occurrence of the HWS when progressing in the season is also observed. However, their diurnal patterns differ significantly from those of the wind speeds $\geq 4 \text{ m s}^{-1}$ and 5 m s^{-1} since 81% and 62% of the HWS in Cinzana and Banizoumbou, respectively, occurs between 1700 and 0500 UTC. These strong winds are, for most of them, produced at the leading edge of the cold-pool outflow generated by evaporating precipitation from convective systems (e.g., Knippertz and Todd, 2012). This decrease in the occurrence of HWS is progressive and leads to the fact that the contribution of August and September to the HWS occurrences over the wet season is very low.

These observations confirm that the occurrence of both the most frequent and the most intense high wind speeds decreases drastically when moving from the first stage of the wet season to the

core of the monsoon period suggesting that this decrease of the occurrence of the highest wind speed is the major phenomenon explaining the strong decrease of dust concentrations during the second part of the wet season (e.g., Marticorena et al., 2010).

3.2 The role of vegetation

Although the frequency of high wind speeds and their intensity decreases when progressing in the wet season, a non-negligible fraction of wind speeds able to generate dust emissions is recorded in July, August and September. At that time the vegetation has begun to grow addressing the question of its role in limiting wind erosion and dust emission. Thus we compared the dust concentrations resulting from the data selection described in 2.2 for different NDVI and wind speed classes, starting in May (from an almost bare soil) to finish in September (with a well-developed vegetation).

Because of the difference in the vegetation cover between Banizoumbou and Cinzana, we used slightly different NDVI classes for each site. The limits of these NDVI classes were defined based on the PM10 mean values computed, for a given wind speed class, for each NDVI value. Consecutive NDVI values for which the mean PM10 concentrations were the most similar were then included in the same NDVI class (Figure 3). The limits of the lowest NDVI class for Banizoumbou (0.15) and Cinzana (0.20) are close to the NDVI threshold value of 0.15 chosen by Kim et al. (2013; 2017) to separate the bare desert surfaces from the vegetated area in the Sahelian transition zone.

Both in Banizoumbou and Cinzana, the PM10 concentrations decrease progressively for a same wind class when the NDVIs increase (Figure 4). This strongly suggests that when the vegetation grows, its protective effect against wind erosion and dust emission increases. This effect is especially well-marked for the highest NDVI class ($NDVIs > 0.26$) and for the wind speed classes higher than 8 and 6 $m\ s^{-1}$ in Banizoumbou and Cinzana, respectively (i.e. those for which wind speed is always over the threshold for wind erosion). Note that in Cinzana almost no wind speed higher than 10 $m\ s^{-1}$ are recorded when the NDVIs are higher than 0.2.

Table 1 reports, in a more quantitative way, the percentage of decrease of the PM10 concentrations for the different NDVI and wind speed classes when normalized to the lowest NDVI class (i.e., an almost bare soil corresponding to $NDVIs < 0.15$ in Banizoumbou and $NDVIs < 0.20$ in Cinzana). The decrease in PM10 concentrations due to the vegetation cover is significant : from almost bare surfaces to the intermediate NDVI classes, PM10 concentrations are reduced by about 30% and the reduction can exceed 80% for the highest NDVI classes. These results, when integrated over the whole wet season, suggest that vegetation could reduce dust emission by 15% and 3% in Banizoumbou and Cinzana, respectively (see Text S2 for the detail of the computation)

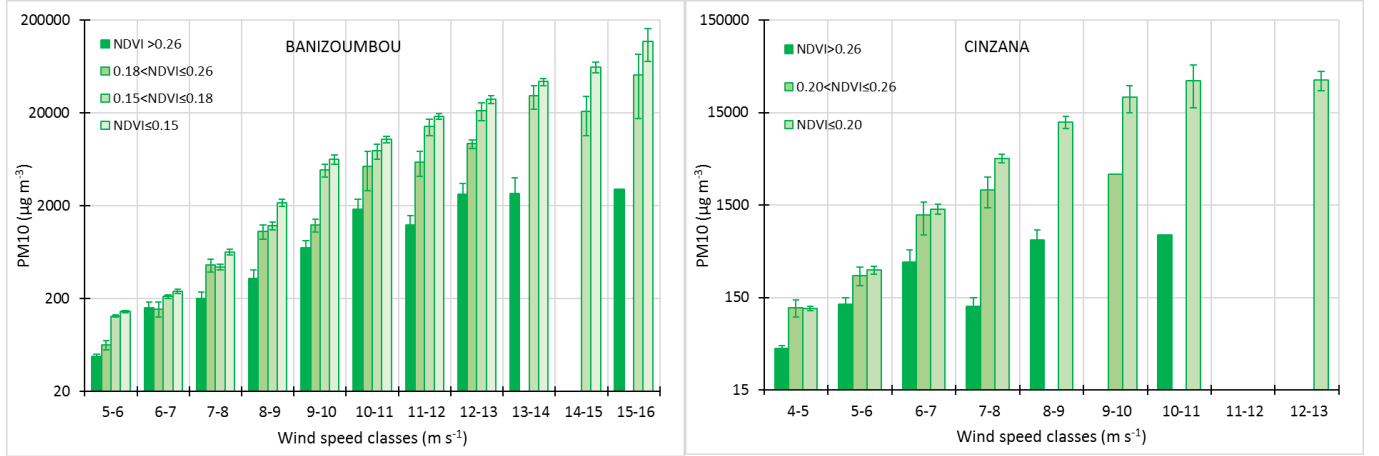


Figure 3. Mean PM10 concentrations ($\mu\text{g m}^{-3}$ in logarithmic scale) for different wind speed and NDVI classes in Banizoumbou (left panel) and Cinzana (right panel). The bars correspond to \pm one error-type (σ/\sqrt{n}).

BANIZOUMBOU															
Wind speed class (m s^{-1})	NDVI≤0.15			0.15<NDVI≤0.18				0.18<NDVI≤0.26				NDVI >0.26			
	C ($\mu\text{g m}^{-3}$)	σ	n	C ($\mu\text{g m}^{-3}$)	σ	n	Decrease (%)	C ($\mu\text{g m}^{-3}$)	σ	n	Decrease (%)	C ($\mu\text{g m}^{-3}$)	σ	n	Decrease (%)
5-6	144	549	12803	129	249	4010	-10.4	63	272	1603	-56.3	47	100	983	-67.3
6-7	239	1025	6172	209	424	1654	-12.4	154	631	540	-35.5	158	382	250	-33.8
7-8	634	2017	2576	439	828	700	-30.7	460	1012	200	-27.5	199	352	106	-68.7
8-9	2156	5930	925	1218	1706	225	-43.5	1048	1688	87	-51.4	326	579	51	-84.9
9-10	6334	13512	327	4852	6490	72	-23.4	1231	1484	56	-80.6	702	857	35	-88.9
10-11	10387	10851	158	7786	8266	32	-25.0	5334	10222	18	-48.6	1821	2385	20	-82.5
11-12	18284	12429	90	14246	11271	16	-22.1	5898	4730	7	-67.7	1231	965	8	-93.3
12-13	27844	19675	51	21117	14971	10	-24.2	9278	1429	2	-66.7	2648	2028	6	-90.5
13-14	43479	19560	26	30795	19524	5	-29.2			0		2690	2287	3	-93.8
14-15	61911	26986	11	20771	16177	3	-66.5			0				0	
15-16	117335	151371	11	51446	48275	2	-56.2			0		2997	-	1	-97.4
>16	284974	353340	3	74742	27923	3	-73.8			0				0	
Mean							-34.8				-54.3				-80.1
Standard Deviation							20.7				17.5				19.2

CINZANA													
Wind speed class (m s^{-1})	NDVI≤0.20			0.20<NDVI≤0.26				NDVI >0.26					
	C ($\mu\text{g m}^{-3}$)	σ	n	C ($\mu\text{g m}^{-3}$)	σ	n	Decrease (%)	C ($\mu\text{g m}^{-3}$)	σ	n	Decrease (%)		
5-6	114	533	10596	116	885	1364	1.8	42	98	929	-63.2		
6-7	296	1458	2979	259	905	232	-12.5	126	298	173	-57.4		
7-8	1356	4329	648	1164	3030	44	-14.2	361	790	38	-73.4		
8-9	4783	6539	154	2196	2363	9	-54.1	121	80	9	-97.5		
9-10	11900	13208	54			0		626	245	2	-94.7		
10-11	22061	33632	22	3211	-	1	-85.4			0			
11-12	32932	39074	6			0		706	-	1	-97.9		
12-13			0			0				0			
13-14	33703	11167	2			0				0			
Mean							-32.9				-80.7		
Standard Deviation							36.0				18.3		

Table 1. Percentages of the PM10 decrease for different NDVI classes and for different wind speed classes. The percentage of decrease is computed using the mean PM10 concentrations for NDVI <0.15 (for Banizoumbou) and <0.20 (for Cinzana) as the reference for each wind speed class. In green are reported the means for which the difference is statistically significant when we compared to the corresponding wind class for the NDVI class <0.15 in Banizoumbou and <0.20 in Cinzana (in blue). In brown, the means for which the number of data is too low to apply statistical tests (see Text S1).

4 Conclusion

Results show that the highest wind speeds, both in frequency and in intensity, occur at the early stage of the monsoon period (May-June) and are responsible for most of the high dust concentrations recorded during the Sahelian wet season. At that time, the new vegetation is not developed and does not play any role in controlling dust emission. During the second part of the wet season (August-September), the intensity and the frequency of wind speeds higher than the erosion threshold decrease. However, the remaining cases of dust emission are strongly affected by the presence of the vegetation since the PM10 concentrations are reduced (up to 80%) compared to the May-June PM10 concentrations measured for similar wind speeds.

The growth of the vegetation changes the proportion of bare soil during the wet season and absorbs a fraction of the wind energy, decreasing the shear stress acting on the surface and thus leading to an apparent increase of the TWS. These two effects certainly take part in the observed decrease in PM10 concentrations when NDVI increases but in different proportions depending on the land use. In the Sahel, when the natural vegetation grows, there are parts of the surface that remain bare, leading to patches (e.g., Hiernaux et al., 2009), without significant change of the TWS. At the beginning of the rainy season, the growth of the herbaceous vegetation decreases the percentage of bare surfaces in fallow and rangeland (Pierre et al., 2014). In the cultivated field most of the surfaces remains bare due to the repeated weeding all along the first part of the rainy season maintaining the surface highly erodible (e.g., Klaij & Hoogmoed, 1996). Then, after the first phenological stage of vegetation, when the millet begin to grow it tends to increase the TWS despite the vegetation cover remain low (Abdourhamane Touré et al., 2011). This suggests that the impact of growing vegetation on dust emission could vary in time and space in the Sahel according to land uses. We suspect that the progressive diminution of the fraction of bare soil should be the dominant factor at the beginning of the wet season and that the change in TWS could be more and more efficient when the vegetation, especially in the cultivated fields, tends to reach its maximum.

Acknowledgments

Measurements in Banizoumbou and Cinzana are performed in the framework of the French National Observatory Services INDAAF that is supported since 2010 by the Observatoire des Sciences de l'Univers EFLUVE, the INSU/CNRS and the IRD. The treatment of the data was performed in the framework of the research programs CAVIARS supported by the French National Agency for Research (ANR-12-SENV-0007-01) and DustClim supported by the European Commission under the ERA4CS action – Joint Call on Researching and Advancing Climate Services Development, Grant Agreement no. 690462 – ERA4CS – H2020-SC5-2014-2015/H2020-SC5-2015-one-stage. The authors would like to thank the Institut d'Economie Rurale (IER) in Mali for hosting one of our stations and in particular Dr. Zoumana Kouyaté, Delegate of the Station de Recherche Agronomique de Cinzana (Mali) for the help in logistics and local management. This work has also strongly benefited from the administrative support of the representations of IRD in Niger and Mali, thanks to all of them. The MODIS MOD13Q1 products were retrieved from the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (<https://lpdaac.usgs.gov/products/mod13q1v006>). The wind speed and PM10 data are distributed at an hourly time resolution through the INDAAF website: <https://indaaf.obs-mip.fr/>. The data used in this manuscript are available for download for research and educational purposes at the following web link <http://www.lisa.u-pec.fr/fr/donnees> maintained by

Laboratoire Interuniversitaire des Systèmes Atmosphériques. We also thank the two anonymous reviewers for their helpful comments.

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Supporting Information

Text S1: Statistical Treatment

The *t*-test for independent samples was used to determine if the PM₁₀ mean concentration for a given wind speed class of the lowest NDVI class is significantly different from the PM₁₀ mean concentration for the same wind speed class but for another NDVI class. We used *t*-test only when the number of observations was greater or equal to 30 for each wind speed class. We used two non-parametric tests (Wilcoxon-Mann-Whitney test and Kolmogorov-Smirnov test) when the number of observations for a wind speed class was between 6 and 29. We did not perform statistical test when the number of observations was lower than 6 for one of the wind speed classes. We classically fixed significance level as $\alpha=0.05$. The computations were made using XLSTAT®.

Text S2: Computation of the respective role of wind speed and vegetation in controlling dust emission

A rough computation was performed in order to estimate the respective role of wind speed and vegetation in controlling dust emission. By assuming that the PM₁₀ concentrations for the lowest NDVI class and for a given wind speed class correspond to the PM₁₀ concentration level expected for this wind speed class before the vegetation begins to grow, one can roughly estimate the overall theoretical effect of the vegetation growth during the rainy season on the total "emitted" concentrations. For this, we first calculate the total concentration measured over the rainy season (= number of wind occurrences multiplied by the average PM₁₀ concentration of each wind class of each NDVI class). We then calculated the theoretical concentration that would have been produced if there was no vegetation (= number of wind occurrences multiplied by the average PM₁₀ concentration of each wind speed class of the lowest NDVI class). The difference between these two computations provides a rough estimate of the effect of vegetation during the whole rainy season. It is estimated to 15% for Banizoumbou and to 3% for Cinzana.

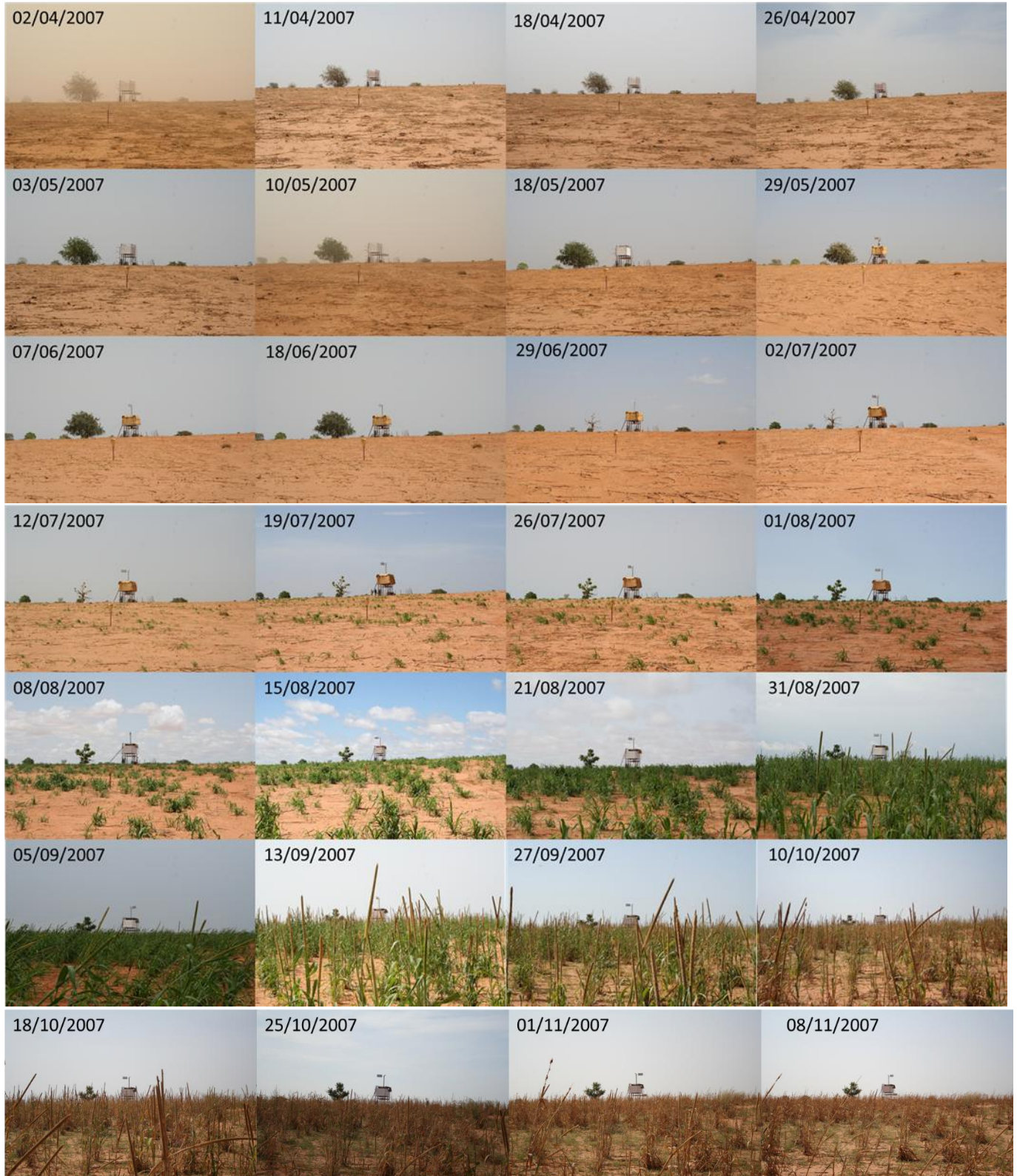


Plate S1. Time sketch of a millet field in Banizoumbou from 2/04/2007 to 8/11/2007 (Photos: J.L. Rajot).

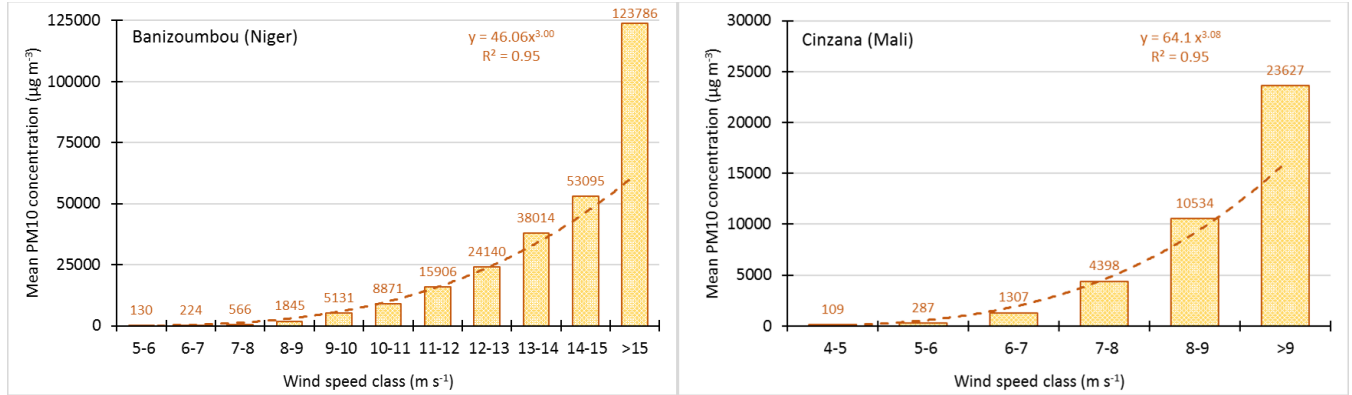


Figure S1. Mean PM₁₀ concentrations ($\mu\text{g m}^{-3}$) for different wind speed classes in Banizoumbou (left panel) and Cinzana (right panel) for the period May 1 to September 30 and for years 2006-2015.

Banizoumbou (Niger)											
	Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Wind speed	<i>number of data</i>	44036	44035	44059	42789	44039	44040	43936	44064	40126	44009
	<i>number of missing data</i>	28	29	5	1275	25	24	128	0	3938	55
	<i>% of missing data</i>	0.06%	0.07%	0.01%	2.89%	0.06%	0.05%	0.29%	0.00%	8.94%	0.12%
Rainfall	<i>number of data</i>	44040	44035	36903	42789	44039	44040	43936	44048	40123	43996
	<i>number of missing data</i>	24	29	7161	1275	25	24	128	16	3941	68
	<i>% of missing data</i>	0.05%	0.07%	16.25%	2.89%	0.06%	0.05%	0.29%	0.04%	8.94%	0.15%
PM10	<i>number of data</i>	37199	40383	41738	33284	41803	40832	40244	2073	33649	34464
	<i>number of missing data</i>	6865	3681	2326	10780	2261	3232	3820	41991	10415	9600
	<i>% of missing data</i>	15.58%	8.35%	5.28%	24.46%	5.13%	7.33%	8.67%	95.30%	23.64%	21.79%

Cinzana (Mali)											
	Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Wind speed	<i>number of data</i>	43937	36808	43944	44010	43855	43913	44063	42109	44063	44060
	<i>number of missing data</i>	127	7256	120	54	209	151	1	1955	1	4
	<i>% of missing data</i>	0.29%	16.47%	0.27%	0.12%	0.47%	0.34%	0.00%	4.44%	0.00%	0.01%
Rainfall	<i>number of data</i>	43937	36810	43945	44010	43858	37643	44064	42109	44063	44060
	<i>number of missing data</i>	127	7254	119	54	206	6421	0	1955	1	4
	<i>% of missing data</i>	0.29%	16.46%	0.27%	0.12%	0.47%	14.57%	0.00%	4.44%	0.00%	0.01%
PM10	<i>number of data</i>	39292	34932	42833	29841	43000	43606	42102	38805	40895	41703
	<i>number of missing data</i>	4772	9132	1231	14223	1064	458	1962	5259	3169	2361
	<i>% of missing data</i>	10.83%	20.72%	2.79%	32.28%	2.41%	1.04%	4.45%	11.93%	7.19%	5.36%

Table S1. Recovery rates of the wind speed, rainfall and PM₁₀ data in Banizoumbou (Niger) and Cinzana (Mali) for the period May 1 to September 30 and for years 2006-2015.