A contrasting seasonality of wind erosivity and wind erosion between Central and Western Sahel

C. Pierre, J.L. Rajot, I. Faye, G.S. Dorego, C. Bouet, B. Marticorena, G. Bergametti, A. Ka, B. Amar, A. Tall, et al.

A contrasting seasonality of wind erosivity and wind erosion between Central and Western Sahel

Pierre C.[1], Rajot JL.[1,2], Faye I.[3], Dorego G. S.[3], Bouet C.[1,2], Marticorena B.[4], Bergametti G.[2], Ka A.[3], Amar B.[3], Tall A.[3], Diagne N.[3], Feron A.[2]*

[1] *Institute of Ecology and Environmental Sciences (iEES-Paris), Paris, France*

[2] *Université Paris Cité and Univ Paris Est Creteil, CNRS, LISA, F-75013 Paris, France*

[3] *Centre National de la Recherche Agronomique (CNRA), Bambey, Senegal*

[4] *Univ Paris Est Creteil and Université Paris Cité, CNRS, LISA, F-94010 Créteil, France*

[*] *caroline.pierre@sorbonne-universite.fr*

4 place Jussieu, 75005 Paris, France

Abstract

Wind erosion is a major phenomenon in the Sahel, and can affect soil fertility. Studies of Sahelian aeolian erosion or erosivity are scarce and have been mainly focused on the Central Sahel. Since February 2020, the number of saltating particles and the horizontal flux of aeolian sediment were monitored in Bambey (Senegal) in combination with long-term 5-minutes wind measurements (2014-2021). These datasets enabled to assess the consistency of wind erosion and wind erosivity estimates, and thus to further analyze wind erosivity over pluriannual periods, as wind speed time-series are available over longer terms than horizontal aeolian flux. As a result, the seasonality of wind erosivity largely differs between Western and Central Sahel. In Western Sahel, wind erosivity is related to medium wind speeds during the dry season, while in Central Sahel it is mostly due to high wind speeds occurring at the monsoon onset. Additionally, horizontal flux of aeolian sediments during the dry season are of the same order in Senegal as in Western Niger, but lower than in Eastern Niger. Horizontal flux of aeolian sediments during the rainy season are lower in Senegal than in Western Niger and Eastern Niger. Altogether, annual aeolian flux thus appears significantly lower in Western than in Central Sahel, and mostly related to the dry season.

Keywords: aeolian flux, dust uplift potential, dust emissions, West Africa, dry season, rainy season

1. Introduction

Wind erosion induces the injection of massive amounts of soil particles into the atmosphere, of about 1000 to 4000 Tg per year (*Boucher et al.,* 2013). It affects the atmospheric radiative budget (e.g. *Miller et al.,* 2014), rainfall or ice nucleation (e.g. *Sassen et al.,* 2003), and soil fertility through loss and deposition of soil nutrients (*Li et al.,* 2008; *Sterk*, 2003). It has also impacts on human health (e.g. *Goudie*, 2014) and transports (*Middleton*, 2017; *Tong et al.,* 2023). These issues are of paramount importance in the Sahel, where demographic growth and climate change are large (e.g. *Dosjo and Panitz*, 2016; *Garenne*, 2016; *Monerie et al.,* 2020).

Wind erosion occurs when wind speed exceeds a threshold that depends on surface characteristics (namely, obstacles to the wind drag, like vegetation cover, and soil moisture, that increases the cohesion between soil grains). Existing studies based on ground observations show that in the Sahelian region of Mali and Niger, the seasonality of high wind speeds is related to Mesoscale Convective Systems (MCS) and to the Nocturnal Low Level Jet (NLLJ) (e.g. *Bergametti et al.,* 2017; *Marsham et al.,* 2011). MCS are convective systems typically of about 100 km large (*Houze*, 2004) occurring during the Sahelian rainy season that induce the highest annual wind speeds but over short time periods (typically less than 30 minutes before the rain starts and prevents wind erosion) (*Bergametti et al.*, 2016; 2022). NLLJ is a daily meteorological phenomenon due to air stratification during the night; in the morning, the heating of the soil surface induces thermal turbulence of air masses, and thus surface wind speeds that can exceed the threshold wind velocity (e.g. *Fiedler et al.,* 2013; *Knippertz and Todd,* 2012; *Lothon et al.* 2008). These large wind speeds are mostly westerlies during the rainy season (May to October) and easterlies during the rest of the year (*Lothon et al.* 2008; *Kaly et al.,* 2015).

Wind erosion in Central Sahel is maximum in spring (e.g. *Abdourhamane Toure et al.,* 2011). This period corresponds to the largest occurrence of high wind speeds and to the lowest vegetation coverage, that roughly coincide in these areas (*Bergametti et al.,* 2020). Yet, MCS and NLLJ relative contributions to annual wind erosivity (i.e., the potential of wind to erode) differ between Western and Eastern Niger, with a larger proportion due to the dry-season (monsoonal) wind regime in Eastern (Western) Niger, suggesting that dry-season surface wind speed could decrease from Eastern to Western Niger (*Abdourhamane Touré et al.,* 2019).

Such detailed analysis has not been performed yet for Western Sahel. However, it is necessary to characterize the seasonality of wind erosivity in this area, in order to improve the understanding of this phenomenon both at the scale of the Sahel, for its remote impacts on climate and nutrients transfer, and at the local scale, for its link to agro-pastoral practices that might mitigate it (*Pierre et al.,* 2018). Some studies suggest a distinct seasonality in this area compared to Central Sahel. For example, *Youm et al.* (2005) identified maximum wind speed in March over 1998-1999 for 5 sites located on the

Senegalese coast. Accordingly, several authors noticed wind erosion, reduced visibility or dust storms in Senegal during the dry season, mostly from January to March (*Aubert et al.,* 1947; *N'tchayi Mbourou et al.,* 1997; *Leon et al.,* 2009). Accordingly, *Marticorena et al.* (2017) reported a low contribution of wet dust deposition to total dust deposition in Senegal (Mbour) compared to Mali (Cinzana) and Niger (Banizoumbou) over 2006-2011, suggesting that dry season provides the largest contribution to total dust deposition in Western Sahel.

Further analysis is needed to specify the contribution of dry and rainy seasons to wind erosivity and wind erosion in Western Sahel on a pluriannual time-scale. We analyze long-term (2014-2021) 5-minutes wind measurements from a meteorological station of the International Network to study Deposition and Atmospheric chemistry in Africa (INDAAF) in Bambey (Senegal), and 1-year (2020) joint observations of wind speed and wind erosion flux set up from a project dedicated to wind erosion over a groundnut cropland in Sahelian Senegal (ENCAS project) located on the same site. The results are compared to similar observations from other study sites across the Sahel to highlight their respective seasonality.

2. Material and Methods

2.1. Approach

The monitoring of horizontal sediment flux with a good temporal resolution (e.g. every 1 or 2 weeks) requires frequent field work. This limitation in terms of feasibility, especially in the Sahelian area, implies that pluriannual datasets of horizontal flux of aeolian sediments are rarer than meteorological data like wind speed time-series. Therefore, this study will notably focus on the assessment of wind erosivity over pluriannual periods, following an approach now largely used in the literature (e.g. *Marsham et al.,* 2011; *Cowie et al.,* 2013, 2014, 2015; *Largeron et al.,* 2015; *Bergametti et al.,* 2017, 2022).

To thoroughly support this approach, we use 1-year joint measurements of three independent variables (wind speed, horizontal flux of aeolian sediments, and Saltiphone counts) to infer the wind speed threshold required to estimate wind erosivity of the longer-term wind speed time-series. A critical step to ensure the reliability of this approach will be the comparison of the so obtained wind erosivity with horizontal flux of aeolian sediments and Saltiphone counts over their common period of measurement.

In addition, to extend the analysis to the whole Sahelian area, results from Senegal will be compared to results from Niger (Banizoumbou, 13.54° N, 2.66° E) and Mali (Cinzana, 13.28°N, 5.93° W) (*Marticorena et al.,* 2010).

2.2 Site and measurements

Bambey site is located in the Groundnut Basin (14.43°N; 16.29°W), on lands of the agronomical research station (Centre National de Recherche Agronomique - CNRA) of the Senegalese Institute for Agronomic Research (Institut Sénégalais de Recherches Agronomiques - ISRA), about 60 km from the coast and 100 km east of Dakar (*Figure* 1). It is part of the Western Sahel as defined by several authors (e.g. *Lebel and Ali,* 2009; *Cowie et al.,* 2015). The current annual rainfall is approximately 500 mm. Soils are mostly sandy, with sand content of about 90% or more (e.g. *Faye et al.,* 2018).

Since 2013, a dust monitoring station from the INDAAF network has been deployed. Here, we use INDAAF 5-minute wind speed and wind direction measured at 6.0 m above ground level (agl) using a 2 dimensional (2D) sonic anemometer (WindSonic^{TM} Gill Instruments Ltd), and 5-minute rainfall measured at 1.07 m agl with an ARG100 Tipping Bucket rain gauge (Campbell® Scientific company). The accuracy of these instruments is +-2% at 12 $m.s^{-1}$, +-3°, and +-1% at 20 $mm.h^{-1}$ and their detection threshold is 0.01 $m.s^{-1}$, 1°, and 0.2 mm, respectively. Over the study period (2014-2021), INDAAF missing wind data were less than 5% in all years but 2017, which thus was discarded for the analysis.

In order to measure horizontal flux of aeolian sediment, wind erosion threshold, and aerodynamic roughness length, instruments were set up in February 2020 in the framework of the ENCAS (Erosion éolienNe en zone de Culture d'Arachide au Sahel) research project (*Figure 1*). In a groundnut field of about 100 m x 100 m (1 km from the INDAAF station), we installed a rain gauge and 5 anemometers (same as INDAAF) at 0.25m, 0.66m, 1m, 1.5m, and 1.9m agl, and a Saltiphone (*Van Pelt et al.*, 2009) at 0.08 m agl, that detects the impacts of saltating grains. These measurements were performed with 5-minute time resolution. Missing data were less than 1% over 2020 for these ENCAS dataset (wind speed and Saltiphone). Simultaneously, horizontal sediment flux was monitored using five masts of 5 sand traps each (Modified Wilson and Cooke – MWAC; *Kuntze et al.,* 1990; *Goossens et al.,* 2000) at heights of 0.05m, 0.1m, 0.2m, 0.4m, 0.8m agl, set up downwind the main wind directions of the study plot, i.e. at its southwestern corner. They were collected approximately every 2 weeks and their content was weighed with 1 mg precision. Variability of the horizontal sediment flux measured with these devices is discussed in section 2.2. The groundnut field was made bare and tilled during February 2020; wind speed (sand traps) measurements started on February 22nd (24th). Then, groundnut was cropped during the rainy season (short-cycle cultivar, sown on July 8th and 20th because of labor availability, and harvested on October 26th).

Figure 1: Up right: Location of Bambey study site in Senegal; Bottom left: drone image of the ENCAS study-site. Instruments were set-up at its southwestern corner (red star). Bottom right: Picture of the ENCAS instruments.

2.3 Horizontal flux computation

For each sampling period, the horizontal flux density q(z) (kg.m^{-2}) was obtained by dividing the mass of windblown sediments caught in MWAC samplers by their inlet area (0.50 10^{-4} m²). The horizontal flux densities were then integrated for each mast to compute the horizontal mass flux (kg.m^{-1}) between 0 and 0.8 m agl by fitting an exponential equation (least squares method) as proposed by *Fryrear and Saleh* (1993):

$$q(z) = a\, e^{(-bz)} \qquad (1)$$

were a and b are adjustment coefficients with units of kg.m^{-2} and m^{-1} respectively. The mean of horizontal flux is then computed from the 5 MWAC masts. Mean coefficient of variation among the 5 masts was low (44%), and even lower (24%) for the main erosive period.

2.4 Dust Uplift Potential

The potential erosivity of wind can be assessed by the Dust Uplift Potential (DUP), as defined by *Marsham et al*. (2011):

$$DUP(z) = u(z)^3 \left(1 + \frac{u_t(z)}{u(z)}\right)\left(1 - \frac{u_t(z)^2}{u(z)^2}\right) \quad \text{for } u>u_t, \text{ and 0 otherwise} \qquad (2)$$

where $u(z)$ is the wind speed at height z and $u_t(z)$ is the threshold wind speed for wind erosion.

The DUP provides information on the ability of wind to induce wind erosion (wind erosivity), which occurs above the threshold wind speed u_t (see **2.5**). The DUP is computed (from the 5-minute wind measurements) for the whole year with a constant threshold corresponding to a bare surface to depict the maximum potential of wind to erode.

An inhibition effect related to rainfall can be accounted for when computing the DUP, as a proxy of the soil moisture effect. Here, rainfall inhibition on DUP is estimated (in **3.1** only) by setting DUP to 0 if rain>0.4 mm in 1 hour, during the rain and 12 hours after its end, following *Bergametti et al.* (2017).

2.5 Saltiphone and wind erosion threshold

We used the methodology proposed by *Abdourhamane Toure et al.* (2011) to assess the threshold wind speed u_t required to compute the DUP. As u_t stands for a dry and bare surface (see **2.4**), we selected measurements from March 1st, 2020 to May 31st, 2020 that corresponds to a bare soil, before the onset of rainfall season and vegetation growth. Following *Abdourhamane Toure et al.* (2011), we used Saltiphone and wind measurements acquired on the ENCAS-plot and estimated u_t from the probability of saltation occurrence depending on wind speed class. Like these authors, we used wind speed classes of 0.2 m.s^{-1} (from 0 to 15 m.s^{-1}). For each wind speed class, the probability of saltation is the ratio of the number of 5-minute periods during which Saltiphone counts were recorded, divided by the total number of 5-minute periods. For each month, the wind erosion threshold is defined as the class of wind speed with the probability of saltation occurrence of 50% (*Figure 2*). We get $u_{t\ ENCAS}(1.9m)$= 4.14 m.s^{-1} (+/-0.07 m.s^{-1}) as the mean of the three monthly threshold values over this period.

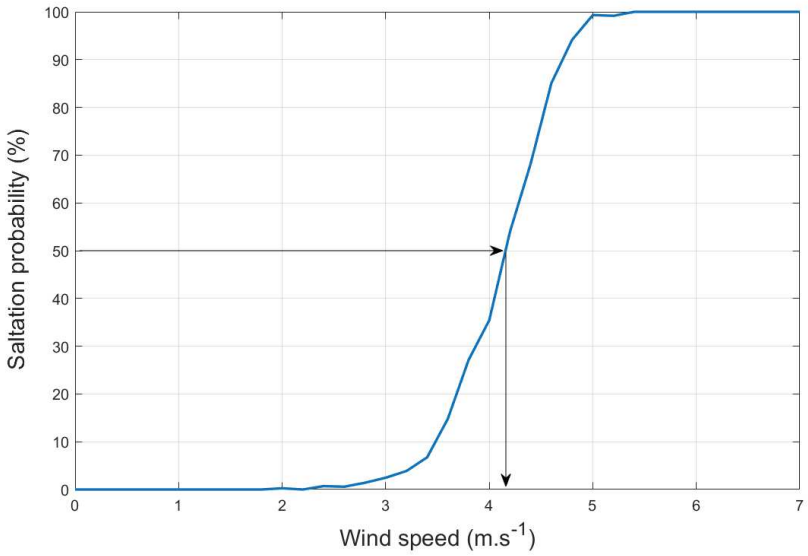

Figure 2: Wind erosion threshold $u_{t\ ENCAS}(1.9\ m)$ estimation for March 2020

Using this threshold value, DUP_{ENCAS} exhibits a remarkable agreement with both Saltiphone number of counts and horizontal flux of aeolian sediments (*Figure 3*). These three datasets being independent, this ensures the reliability of the threshold value.

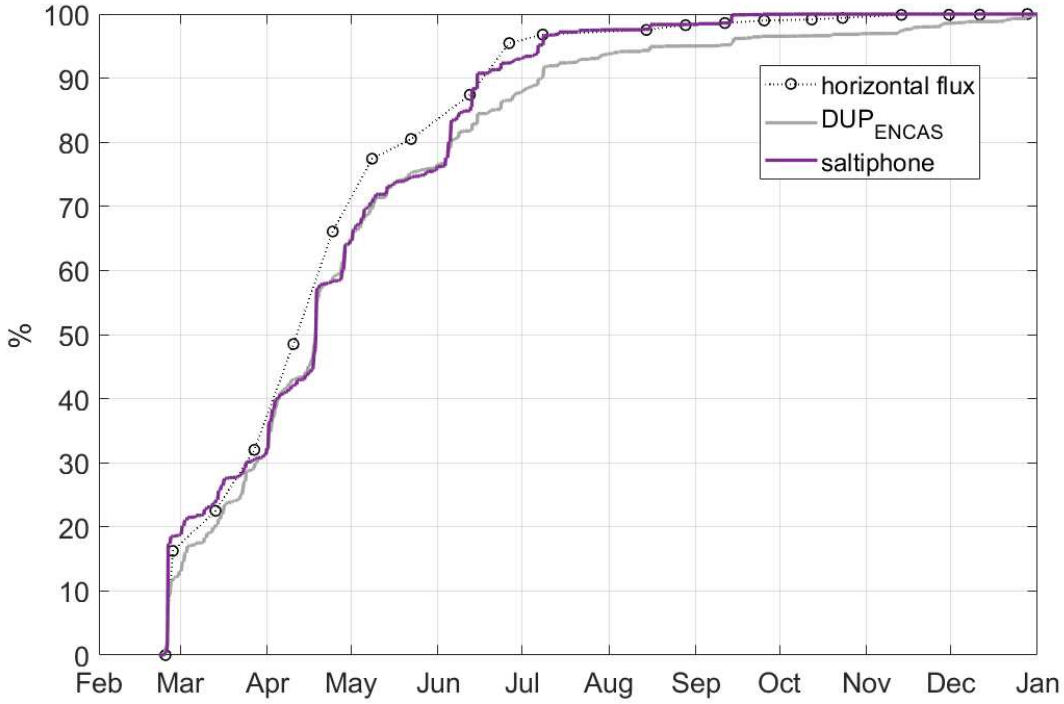

Figure 3: Normalized cumulative annual horizontal flux of aeolian sediments, DUP_{ENCAS}, and Saltiphone counts in Bambey over March-December 2020 (R=0.99 and n=21 between horizontal flux and Saltiphone counts, and between horizontal flux and DUP_{ENCAS}).

The wind erosion threshold was then applied to u_{INDAAF} to assess the DUP over the whole time-period of INDAAF measurements. The correlation coefficient between measured wind speeds $u_{INDAAF}(6\ m)$ and $u_{ENCAS}(1.9\ m)$ (the highest ENCAS anemometer) over February 22nd – December 31st, 2020 is R= 0.92 (n=89461) with a proportional coefficient of 0.85 (*Figure 4*). $u_{INDAAF}(6\ m)$ is lower than $u_{ENCAS}(1.9\ m)$ at is it located in a slight lowland and surrounded by scattered woody vegetation, but exhibits the same dynamics. The translation of u_{INDAAF} to the ENCAS-plot (to compute the DUP using the same threshold of 4.14 $m.s^{-1}$) was thus performed using this proportional coefficient of 0.85 between $u_{ENCAS}(1.9m)$ and $u_{INDAAF}(6m)$.

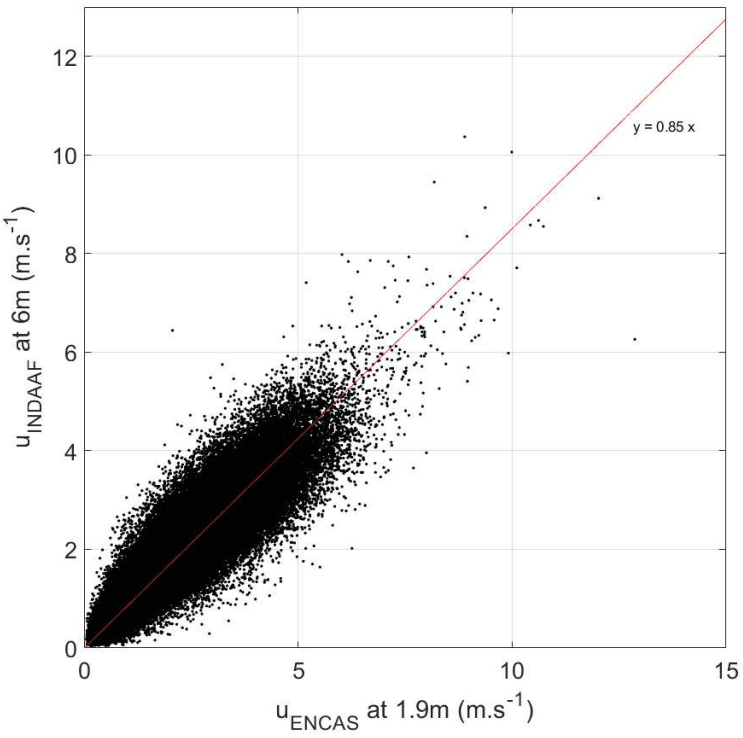

Figure 4: Scatterplot of wind speed at INDAAF station (at 6m) versus at ENCAS study site (at 1.9m) on the period February 22nd to December 31st, 2020 (R=0.92; n=89461)

3. Results and Discussion

3.1 Dust Uplift Potential

In order to further assess the reliability of the threshold wind speed applied to u_{INDAAF}, DUP_{INDAAF} was computed over 2014-2021 over March-December (to be compared to DUP_{ENCAS} over March-December 2020) and over the whole year (*Figure 5*). Normalized cumulated DUP_{ENCAS} shows a clear seasonality with about 40% of the 10-month DUP accumulated between the beginning of March and mid-April, and almost no erosive wind from mid-July to mid-December, similarly to the pluriannual mean of normalized cumulated DUP_{INDAAF}. Over the whole year, DUP_{INDAAF} reaches 20% of the annual DUP at the beginning of March, 50% around mid-April, and about 90% mid-July. In addition, DUP_{INDAAF} shows a clear climatological signal as it exhibits a very low interannual variability (minimum and maximum weekly values of the normalized cumulated DUP, reported in *Figure 5*, usually differ from the average value by about 5%, sometimes up to 10%). Thus, this 7-year mean DUP obtained for the Senegalese study site can be compared to 9-year mean DUP analyzed in previous work for two study sites in Central Sahel (*Bergametti et al.,*2017), that also show a clear climatological signal over 9-year time-series (see Fig. 5 in *Bergametti et al.,* 2017).

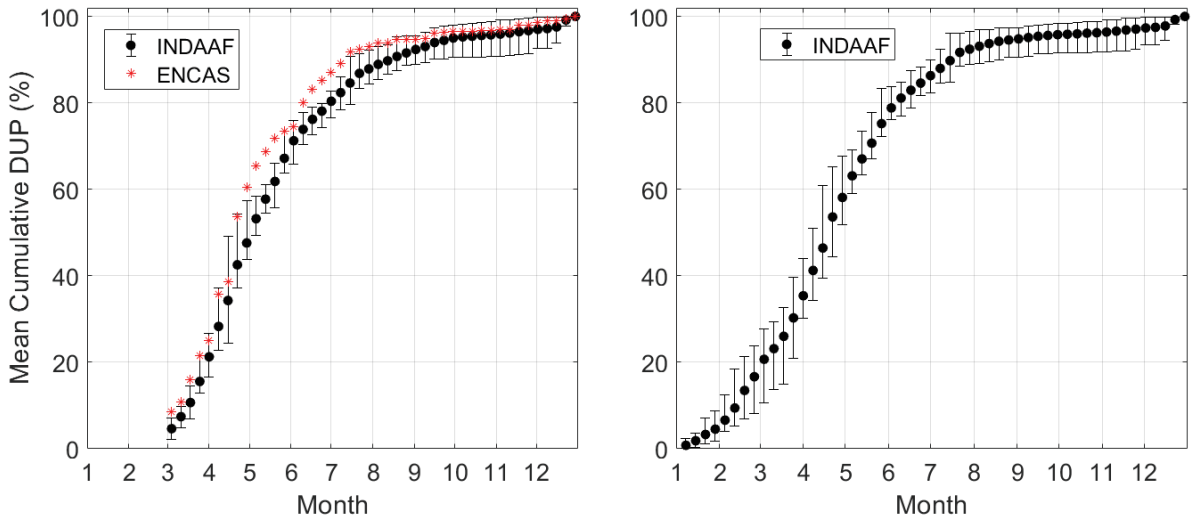

Figure 5: Annual cumulative DUP in Bambey averaged at a weekly time-step. Minimum and maximum over the period (vertical bars) are also reported for INDAAF data. Left: Cumulated and normalized over March-December 2014–2021 (but 2017) for INDAAF, 2020 for ENCAS. Right: Same as left panel but over the whole year, for INDAAF data only.

This comparison shows that the seasonality of wind erosivity in Senegal (Bambey) is different from Southwestern Niger (Banizoumbou) and Central Mali (Cinzana) over 2006-2015 (*Figure 6*), where the proportion of annual DUP sharply increases from 20% to 50% between early May and early June. *Figure 6* also shows that the 3 month-period producing the largest proportion (more than 50 %) of annual DUP in Bambey is February-March-April, whereas it is April-May-June in Banizoumbou and Cinzana (respectively about 60% and 80%). However, about 90% of the annual DUP is reached in early August for the three sites. Additionally, although there is a non-negligible range between minimum and maximum weekly values of DUP, the seasonality of wind erosivity in Bambey is clearly distinct from the ones of Cinzana and Banizoumbou.

The comparison of the seasonality of normalized cumulated DUP and normalized cumulated rainfall further shows that the first significant rains occur in Bambey by the beginning of June, reaching about 10% of the annual rainfall around mid-July. In Cinzana and Banizoumbou, they occur by the beginning of May and 10% of the annual rainfall is reached around early June, i.e. about one month earlier than in Bambey. *Kaly et al.* (2015) also observed, in Mbour (on the Senegalese coast, 80 km south of Dakar), no increase in the monthly mean wind speed during the rainy season but a maximum in February-March and a later onset of the rainy season than for Cinzana and Banizoumbou. In the following, rainy-season is thus defined as May-October in Bambey, and April-October in Banizoumbou and Cinzana (as in *Bergametti et al.,* 2017), with the dry season encompassing the rest of the year.

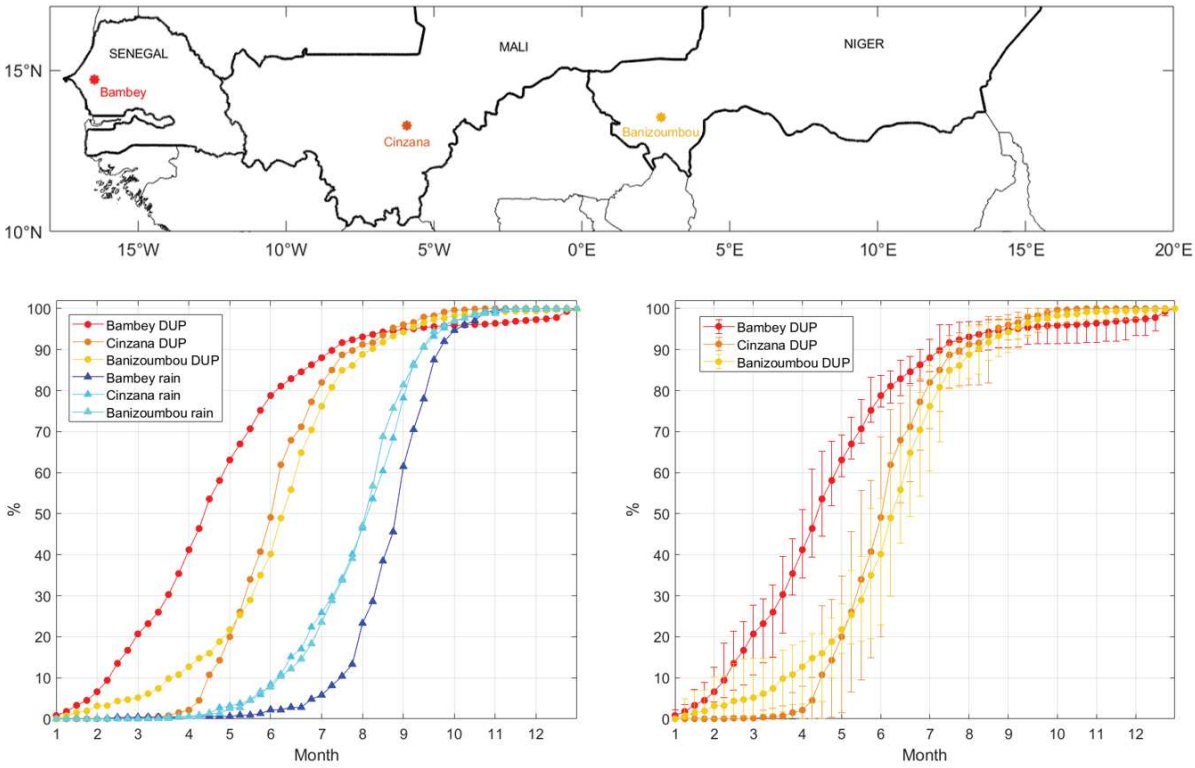

Figure 6: Top: Location of the three Sahelian sites; Bottom left: Annual cumulative DUP and rainfall averaged over 2014–2021 (but 2017) in Bambey (Senegal), 2006–2015 (but 2007) in Cinzana (Mali) and 2006-2015 (but 2014) in Banizoumbou (Niger), at a weekly time-step. Bottom right: idem for DUP only, with minimum and maximum over each weekly period (vertical bars). Figure adapted from Fig. 7 in Bergametti et al. (2017)

In Bambey, about 60% of wind erosivity is thus related to the dry season, but only 2% in Cinzana and 14% in Banizoumbou. In Bambey, the DUP shows a non-negligible contribution of December (22% of annual DUP in 2016 and 2021, and between 0 and 5% for the other years; not shown) whereas this contribution is much lower in Banizoumbou (0.6% in average) and nil in Cinzana. Altogether, DUP inhibition related to rain in Bambey is thus very low, ranging from 2% (in 2016) to 6% (in 2014) of annual DUP, whereas it is about 25% for Banizoumbou and Cinzana (*Bergametti et al.,* 2017).

Our observations are in agreement with the characteristics of MCS observed in the Sahelian area. These MCS usually form in Eastern and Central Sahel and propagate westward (*Houze*, 2004; *Futyan and Del Genio*, 2007), reaching their maximum intensity before weakening when approaching Western Sahel (*Roca et al.,* 2005; *DeLonge et al.,* 2010), with typical trajectory from genesis to lysis of about 1000 km and a typical lifetime of about 1 day (*Vizy and Cook,* 2018). Wind erosivity in western Sahel is thus mostly due to the winds occurring during the dry season.

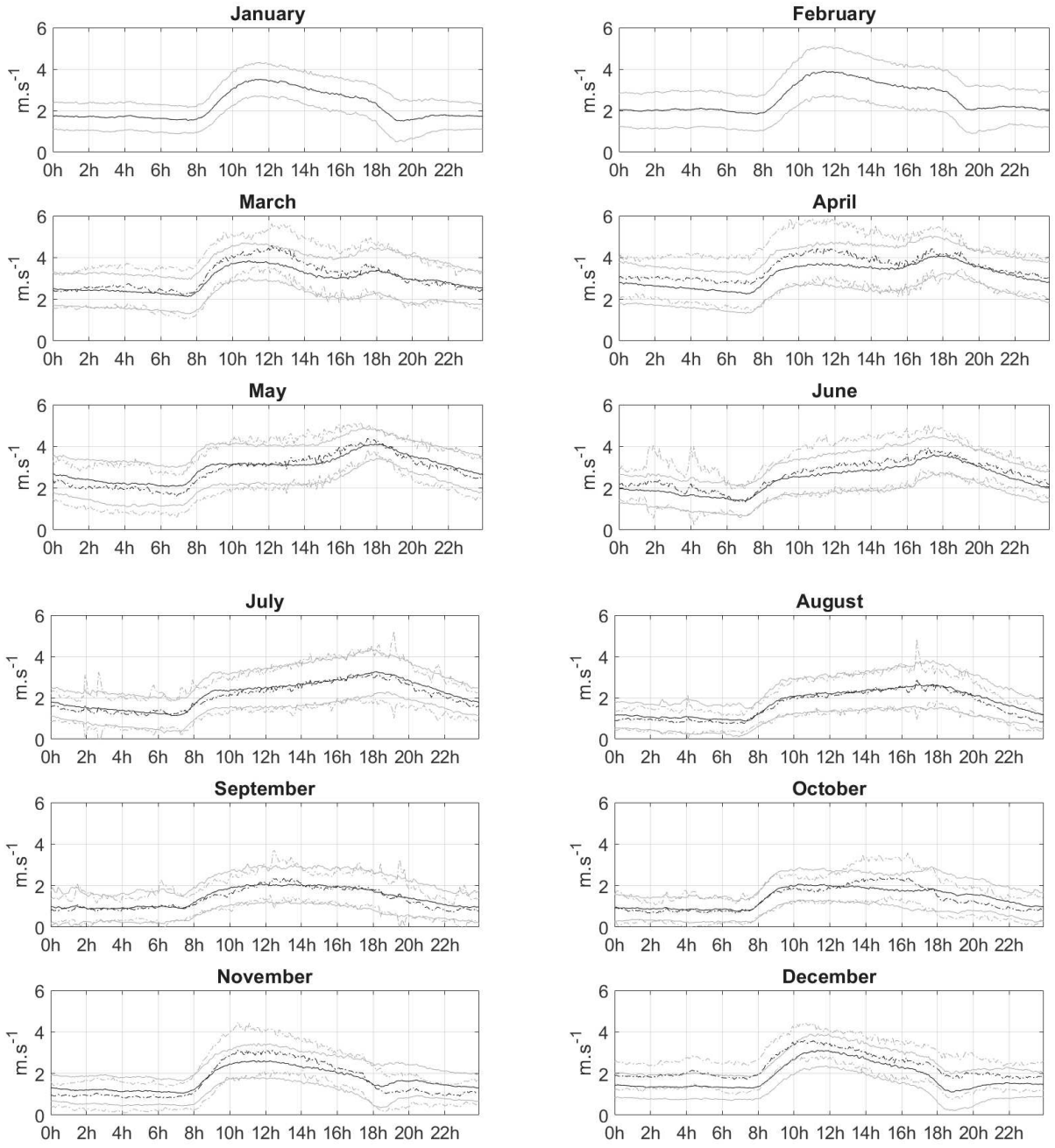

Figure 7: Diurnal cycle of wind speed: 2014-2021 pluriannual mean of the 5-minutes INDAAF values averaged over each month and their standard deviation (continuous lines); idem for ENCAS wind speed but on the period March 1st to December 31st, 2020 (dotted lines)

In order to check if high wind speeds in Bambey were related to NLLJ, we analyzed the diurnal cycle of wind speed (*Figure 7*): it exhibits a slight increase in the morning during the dry season, likely related to the NLLJ, yet in a lesser extent than for the other Sahelian sites (see Fig. 1 in *Bergametti et al.,* 2022). It

234 also exhibits a daily maximum in the late afternoon during the end of the dry season and the rainy
235 season, which differs from other Sahelian study sites.
236

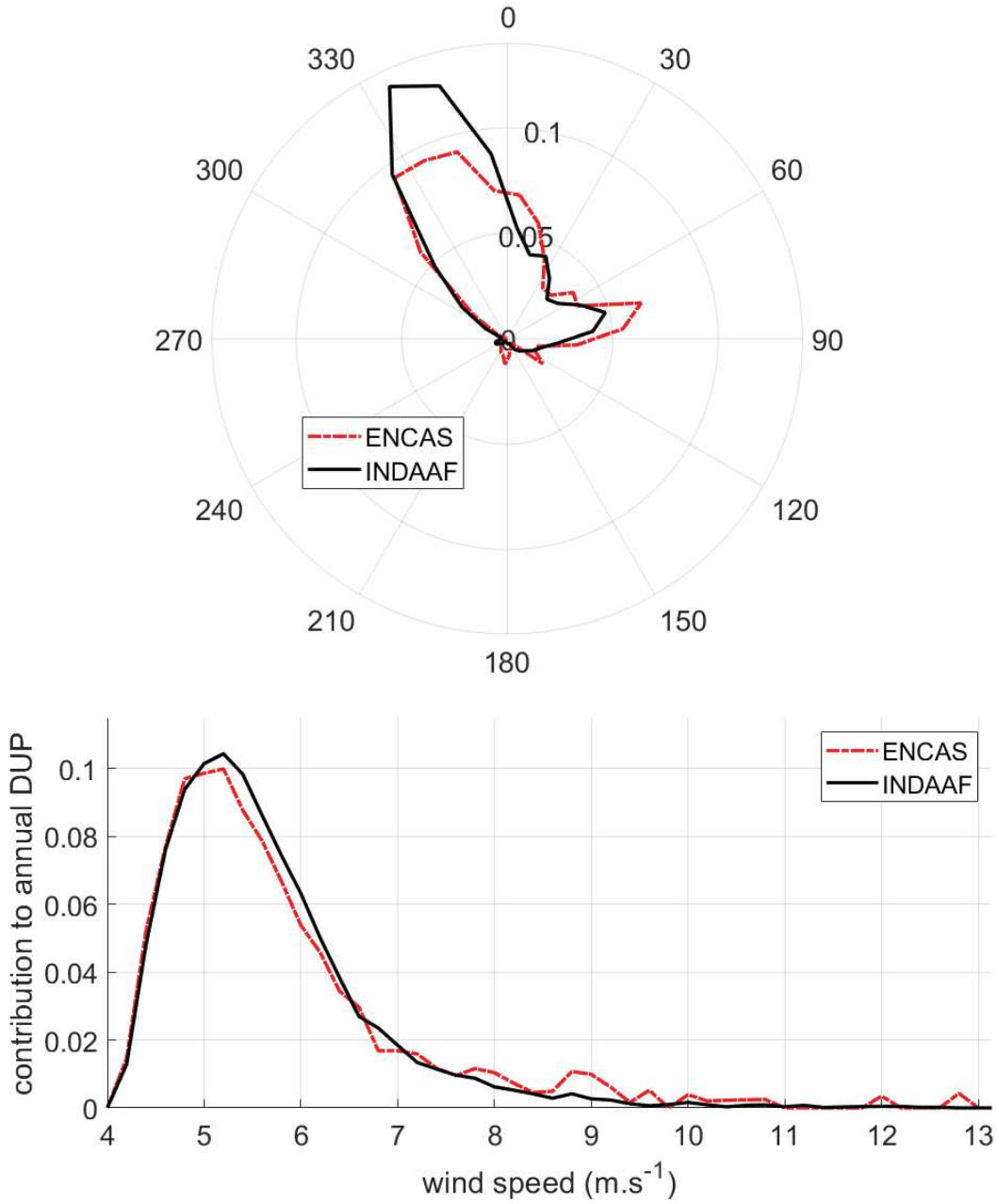

Figure 8a: Contribution to annual DUP by wind direction in Bambey: INDAAF 2014-2021 pluriannual mean (black); ENCAS March 1st to December 31st, 2020 (red).

8b: Contribution to annual DUP by wind speed over 2014–2021 (but 2017) in Bambey: INDAAF 2014-2021 pluriannual mean (black); ENCAS March 1st to December 31st, 2020 (red)

237

238 A large proportion of annual DUP in Bambey is provided by north-northwestern winds, as illustrated for
239 both ENCAS and INDAAF wind measurements in *Figure 8a.* In terms of pluriannual mean (INDAAF

240 measurements), 35% of annual DUP is provided by directions 320°- 350° (potentially related to the sea
241 breeze), thus as much as the proportion of DUP (35%) provided by northern to eastern winds (0°-90°,
242 i.e. Harmattan wind regime). The contribution of winds blowing from other directions (90°-320°) is low
243 (21%); more specifically, contribution of winds from 150°-300° is about 5% of the annual DUP.
244 Accordingly, *Kaly et al.* (2015) observed in Mbour almost no southwestern winds.
245 Furthermore, a large part of annual DUP in Bambey is due to wind speeds ranging between 4.14 and 6
246 $m.s^{-1}$, for both ENCAS and INDAAF measurements (*Figure 8b*). In terms of pluriannual mean (INDAAF
247 measurements), 76% of annual DUP is provided by these wind speed classes, and 16% by wind speeds
248 ranging between 6 and 7 $m.s^{-1}$. Only 3% of the annual DUP is related to wind speeds larger than 8 $m.s^{-1}$,
249 and 1% to wind speed larger than 10 $m.s^{-1}$. This is in agreement with results by *Cowie et al* (2015) who
250 observed a narrow shape of wind speeds contribution to DUP just above the threshold for western
251 Sahel.

252

253 *3.2 Aeolian flux*

254 The analysis of the seasonality of wind erosivity across the Sahel can be further substantiated by
255 scrutinizing the few recent measurements of local wind erosion in this area. The horizontal flux of
256 aeolian sediments (G) in Bambey (2020) exhibits a marked seasonality (*Figure 3*), with about 70% of the
257 annual flux accumulating from late February (start of measurements) to the end of April. This seasonality
258 is in agreement with that observed by *Niang* (2019) in northern Senegal. G measured in Bambey
259 amounted 564 $kg.m^{-1}$ from February 24th to December 31st, 2020.
260 As the ENCAS-plot was made bare at the beginning of ENCAS monitoring, and as wind erosivity for this
261 study site is very low during the rainy season (i.e. when vegetation starts growing), the most relevant
262 comparison to existing measurements in the Sahel is with other bare surfaces (*Table 1*). Over the dry
263 season only, G in Bambey (Senegal) reaches comparable amounts as for a bare surface in Banizoumbou
264 (Western Niger) over 2006-2008. As the rainy-season contribution to annual G is very low in Bambey
265 compared to Banizoumbou, annual G is also much lower. Dry-season and rainy-season G in Bambey are
266 both much lower than observations for a bare dune in Kilakina (southeastern Niger, 13.72°N, 10.75°E)
267 over 2012-2016. Annual flux is thus much larger in Kilakina than in Bambey.
268

	Bambey 2020	Banizoumbou (2006-2008)	Kilakina (2012-2016)
G dry season (kg.m^{-1})	**405**	*388 +/- 96*	*2047 +/- 1207*
G rainy season (kg.m^{-1})	**159**	*828 +/- 490*	*2180 +/- 1014*
G total (kg.m^{-1})	**564**	*1461 +/- 446*	*4228 +/- 1669*
Prop dry season (%)	**72**	*27 +/- 1*	*44 +/- 23*

Prop rainy season (%)	28	*73 +/- 1*	*56 +/- 23*

Table 1: Horizontal flux amounts (kg.m^{-1}) and proportion for the rainy season and dry-season in Bambey (Senegal; this study), Banizoumbou (western Niger; Abdourhamane Toure et al., 2011), and Kilakina (eastern Niger; Abdourhamane Touré et al., 2019), for a bare surface.

Altogether, this suggests that: (i) wind erosivity during the dry-season would be of similar amplitude in Senegal and Western Niger, but larger in Eastern Niger, and that (ii) the rainy-season wind erosivity is much lower in Western Sahel than in Central Sahel. However, interannual variability of these observed horizontal fluxes is relatively large and these results thus need to be further substantiated by long-term measurements.

4. Conclusion

The combination of datasets from long-term wind measurements (INDAAF) and 10-month wind and wind erosion measurements (ENCAS) provides a deep insight into the seasonal characteristics of wind erosion and wind erosivity in Senegal. The analysis of both datasets demonstrated that the largest proportion of annual wind erosivity in Western Sahel occurs from February to April – thus during the dry-season - and is related to wind speed just above the erosion threshold likely related to a Low Level Jet. This observation clearly differs from what have been observed in Central Sahel, where most wind erosivity is due to high winds from convective systems at the onset of the rainy season (around June). However, amounts of horizontal flux of aeolian sediments during the dry season are of the same order in Senegal and in western Niger, but lower than in eastern Niger. As the rainy season only induces a very low horizontal flux in Senegal, its annual aeolian flux (in mass) is thus sensibly lower than for study sites in Central Sahel.

Altogether, our results show that the seasonality of wind erosivity is not homogeneous over the Sahel. MCS are likely to provide less high wind speeds in Senegal than in Central Sahel. Dry-season wind erosivity in Western Sahel is similar to that in Western Niger, which is lower than in Eastern Niger. Rainy-season wind erosivity decreases from Western Niger to Senegal, but with approximately similar amplitude between Eastern and Western Niger. Thus, in order to prevent wind erosion and soil nutrients depletion (e.g. through land use practices), attention should be paid to the location in the Sahel and the associated seasonality of erosive winds. Further investigations are needed to interpret this contrasted seasonality in relation with climate mechanisms in the Sahel.

Acknowledgements

The French National Observatory Service INDAAF is supported by the INSU/CNRS, the IRD (Institut de Recherche pour le Développement), and the Observatoire des Sciences de l'Univers EFLUVE and Observatoire Midi-Pyrénées. This work was supported by the ENCAS (Erosion éolieNne d'une surface Cultivée en Arachide au Sahel) research program funded by LEFE-EC2CO fund call of the French National Institute of Sciences of the Universe (INSU). The authors would like to thank the French and African PIs and operators for maintaining the INDAAF and ENCAS stations and for the ENCAS monitoring.

Data Availability Statement

The INDAAF data are distributed through the INDAAF website (https://indaaf.obs-mip.fr/catalogue). The ENCAS data used in this manuscript are available for download for research and educational purposes in DataSuds (https://doi.org/10.23708/LNZLZF).

Références

Abdourhamane Touré, A., Rajot, J. L., Garba, Z., Marticorena, B., Petit, C., & Sebag, D. (2011). Impact of very low crop residues cover on wind erosion in the Sahel. *Catena*, 85(3), 205–214. https://doi.org/10.1016/j.catena.2011.01.002

Abdourhamane Touré, A. A., Tidjani, A. D., Rajot, J. L., Marticorena, B., Bergametti, G., Bouet, C., ... & Garba, Z. (2019). Dynamics of wind erosion and impact of vegetation cover and land use in the Sahel: A case study on sandy dunes in southeastern Niger. *Catena*, *177*, 272-285.

Aubert, G., Dubois J., Maignien R. (1947). L'érosion éolienne dans le Nord-Ouest du Sénégal : observations effectuées lors de l'exécution d'une mission d'étude des sols à arachide, organisée par l'Office de la Recherche Scientifique Coloniale, et le Service de l'Agriculture de l'Afrique Occidentale Française. In : *Congrès de pédologie méditerranéenne.* sl : AFES, p. 443-450. Conférence de Pédologie Méditerranéenne, Montpellier; Alger (FR; DZ), 1947/05/09-20)

Bergametti, G., Rajot, J. L., Pierre, C., Bouet, C., & Marticorena, B. (2016). How long does precipitation inhibit wind erosion in the Sahel? *Geophysical Research Letters*, 43, 6643–6649. https://doi.org/10.1002/2016GL069324

Bergametti, G., Marticorena, B., Rajot, J. L., Chatenet, B., Féron, A., Gaimoz, C., ... & Zakou, A. (2017). Dust uplift potential in the Central Sahel: an analysis based on 10 years of meteorological measurements at high temporal resolution. *Journal of Geophysical Research: Atmospheres*, *122*(22), 12-433.

Bergametti, G., Marticorena, B., Rajot, J. L., Siour, G., Féron, A., Gaimoz, C., ... & Zakou, A. (2020). The respective roles of wind speed and green vegetation in controlling Sahelian dust emission during the wet season. *Geophysical Research Letters*, *47*(22), e2020GL089761.

Bergametti, G., Rajot, J. L., Marticorena, B., Féron, A., Gaimoz, C., Chatenet, B., ... & Zakou, A. (2022). Rain, wind, and dust connections in the Sahel. *Journal of Geophysical Research: Atmospheres*, *127*(3), e2021JD035802.

Boucher, O., Randall, D., Artaxo, P., Bretherton, C., Feingold, G., Forster, P., et al. (Eds.), (2013). *Climate change 2013: The physical basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change* (pp. 571–657). Cambridge, UK: Cambridge University Press. https://doi.org/10.107/CBO9781107415324.016

Bouniol, D., Couvreux, F., Kamsu-Tamo, P. H., Leplay, M., Guichard, F., Favot, F., & O'Connor, E. J. (2012). Diurnal and seasonal cycles of cloud occurrences, types, and radiative impact over West Africa. *Journal of Applied Meteorology and Climatology*, 51(3), 534–553. https://doi.org/10.1175/JAMC-D-11-051.1

Cowie, S. M., Knippertz, P., & Marsham, J. H. (2013). Are vegetation-related roughness changes the cause of the recent decrease in dust emission from the Sahel?. *Geophysical Research Letters*, *40*(9), 1868-1872.

Cowie, S. M., Knippertz, P., & Marsham, J. H. (2014). A climatology of dust emission events from northern Africa using long-term surface observations. *Atmospheric Chemistry and Physics*, *14*(16), 8579-8597.

Cowie, S. M., Marsham, J. H., & Knippertz, P. (2015). The importance of rare, high-wind events for dust uplift in northern Africa. *Geophysical Research Letters*, *42*(19), 8208-8215.

DeLonge, M. S., Fuentes, J. D., Chan, S., Kucera, P. A., Joseph, E., Gaye, A. T., & Daouda, B. (2010). Attributes of mesoscale convective systems at the land-ocean transition in Senegal during NASA African Monsoon Multidisciplinary Analyses 2006. *Journal of Geophysical Research: Atmospheres*, *115*(D10).

Dosio, A., & Panitz, H. J. (2016). Climate change projections for CORDEX-Africa with COSMO-CLM regional climate model and differences with the driving global climate models. *Climate Dynamics*, 46, 1599–1625. https://doi.org/10.1007/s00382-015-2664-4

Faye, B., Webber, H., Diop, M., Mbaye, M. L., Owusu-Sekyere, J. D., Naab, J. B., & Gaiser, T. (2018). Potential impact of climate change on peanut yield in Senegal, West Africa. *Field Crops Research*, *219*, 148-159.

Fiedler, S., Schepanski, K., Heinold, B., Knippertz, P., & Tegen, I. (2013). Climatology of nocturnal low-level jets over North Africa and implications for modeling mineral dust emission. *Journal of Geophysical Research: Atmospheres*, *118*(12), 6100-6121.

Fryrear, D. W., & Saleh, A. (1993). Field wind erosion: vertical distribution. *Soil Science*, *155*(4), 294-300.

Futyan, J. M., & Del Genio, A. D. (2007). Deep convective system evolution over Africa and the tropical Atlantic. *Journal of Climate*, *20*(20), 5041-5060.

Garenne, M. (2016). La pression de la population dans les pays sahéliens francophones: Analyse des estimations et projections de population 1950–2100 (Ferdi Working Pap. 168, p. 26).

Goossens, D., Offer, Z., & London, G. (2000). Wind tunnel and field calibration of five aeolian sand traps. *Geomorphology*, *35*(3-4), 233-252. https://doi.org/10.1016/S0169-555X(00)00041-6

Goudie, A. S. (2014). Desert dust and human health disorders. *Environment international*, *63*, 101-113.

Houze Jr, R. A. (2004). Mesoscale convective systems. *Reviews of Geophysics*, *42*(4).

Kaly, F., Marticorena, B., Chatenet, B., Rajot, J. L., Janicot, S., Niang, A., Yahi, H., Thiria, S., Maman, A., Zakou, A., Coulibaly, M., Koné, I., Traoré, S., Diallo, A., & Ndiaye, T. (2015). Variability of mineral dust concentrations over West Africa monitored by the Sahelian Dust Transect. *Atmospheric Research*, *164*, 226-241.

Knippertz, P., & Todd, M. C. (2012). Mineral dust aerosols over the Sahara: Meteorological controls on emission and transport and implications for modeling. *Reviews of Geophysics*, 50, RG1007. https://doi.org/10.1029/2011RG000362

Kuntze, H., Beinhauer, R., Tetzlaff, G. (1990). Quantification of Soil Erosion by Wind: I. Final Report of the BMFT project. Project No. 0339058 A, B, C. Institute of Meteorology and Climatology, University of Hannover.

Largeron, Y., Guichard, F., Bouniol, D., Couvreux, F., Kergoat, L., & Marticorena, B. (2015). Can we use surface wind fields from meteorological reanalyses for Sahelian dust emission simulations?. *Geophysical Research Letters*, *42*(7), 2490-2499.

Lebel, T., & Ali, A. (2009). Recent trends in the Central and Western Sahel rainfall regime (1990–2007). *Journal of Hydrology*, *375*(1-2), 52-64.

406 Léon, J. F., Derimian, Y., Chiapello, I., Tanré, D., Podvin, T., Chatenet, B., ... & Deroo, C. (2009). Aerosol vertical
407 distribution and optical properties over M'Bour (16.96° W; 14.39° N), Senegal from 2006 to 2008. *Atmospheric*
408 *Chemistry and Physics*, *9*(23), 9249-9261.
409
410 Li, J., Okin, G. S., Alvarez, L., & Epstein, H. (2008). Effects of wind erosion on the spatial heterogeneity of soil
411 nutrients in two desert grassland communities. *Biogeochemistry*, *88*, 73–88. https://doi.org/10.1007/s10533-008-
412 9195-6
413
414 Lothon, M., Said, F., Lohou, F., & Campistron, B. (2008). Observation of the diurnal cycle in the low troposphere of
415 West Africa. *Monthly Weather Review*, 136(9), 3477–3500. https://doi.org/10.1175/2008MWR2427.1
416
417 Marsham, J. H., Knippertz, P., Dixon, N. S., Parker, D. J., & Lister, G. M. S. (2011). The importance of the
418 representation of deep convection for modeled dust-generating winds over West Africa during summer.
419 *Geophysical Research Letters*, 38, L16803. https://doi.org/10.1029/2011GL048368
420
421 Marticorena, B., Chatenet, B., Rajot, J. L., Bergametti, G., Deroubaix, A., Vincent, J., … Zakou, A. (2017). Mineral
422 dust over West and Central Sahel: Seasonal patterns of dry and wet deposition fluxes from a pluriannual sampling
423 (2006-2012). *Journal of Geophysical Research: Atmospheres*, 122, 1338–1364.
424 https://doi.org/10.1002/2016JD025995
425
426 Marticorena, B., Chatenet, B., Rajot, J. L., Traoré, S., Coulibaly, M., Diallo, A., … Zakou, A. (2010). Temporal
427 variability of mineral dust concentrations over West Africa: Analyses of a pluriannual monitoring from the AMMA
428 Sahelian Dust Transect. *Atmospheric Chemistry and Physics*, 10(18), 8899–8915. https://doi.org/10.5194/acp-10-
429 8899-2010
430
431 Middleton, N. J. (2017). Desert dust hazards: A global review. *Aeolian research*, *24*, 53-63.
432
433 Miller, R. L., Knippertz, P., Perez Garcia-Pando, C., Perlwitz, J. P., & Tegen, I. (2014). Impact of dust radiative forcing
434 upon climate. In P. Knippertz, & J. B. Stuut (Eds.), *Mineral dust: A key player in the Earth system* (Chapter 11, pp.
435 327–357). Dordrecht, The Netherlands: Springer. https://doi.org/10.1007/978-94-017-8978-3_13
436
437 Monerie, P. A., Wainwright, C. M., Sidibe, M., & Akinsanola, A. A. (2020). Model uncertainties in climate change
438 impacts on Sahel precipitation in ensembles of CMIP5 and CMIP6 simulations. *Climate Dynamics*, 55, 1385–1401.
439 https://doi.org/10.1007/s00382-020-05332-0
440 Niang, S. (2019). Sécheresse climatique et dynamique éolienne sur la côte nord du Sénégal : sensibilité dunaire et
441 estimation des débits massiques dans le Gandiolais. NAAJ. *Revue africaine sur les changements climatiques et les*
442 *énergies renouvelables*, 1(1), 111-135. DOI : 10.46711/naaj.2019.1.1.6
443

N'Tchayi, G. M., Bertrand, J., & Nicholson, S. E. (1997). The diurnal and seasonal cycles of wind-borne dust over Africa north of the equator. *Journal of Applied Meteorology*, 36, 868–882.

Pierre, C., Kergoat, L., Hiernaux, P., Baron, C., Bergametti, G., Rajot, J. L., ... & Marticorena, B. (2018). Impact of agropastoral management on wind erosion in Sahelian croplands. *Land Degradation & Development*, *29*(3), 800-811.

Priestley, C.H.B., 1959. Turbulent Transfer in the Lower Atmosphere. *Univ. Chicago Press*, Chicago, 130 p..

Roca, R., Lafore, J. P., Piriou, C., & Redelsperger, J. L. (2005). Extratropical dry-air intrusions into the West African monsoon midtroposphere: An important factor for the convective activity over the Sahel. *Journal of the Atmospheric Sciences*, *62*(2), 390-407.

Sassen, K., DeMott, P. J., Prospero, J. M., & Poellot, M. R. (2003). Saharan dust storms and indirect aerosol effects on clouds: CRYSTAL-FACE results. *Geophysical Research Letters*, *30*(12), 1633. https://doi.org/10.1029/2003GL017371

Sterk, G. (2003). Causes, consequences and control of wind erosion in Sahelian Africa: A review. *Land Degradation & Development*, *14*(1),98–108. https://doi.org/10.1002/ldr.526

Tidjani, A.D., Bielders, C.L., Ambouta, K.J.-M., 2009. Dynamique saisonnière des paramètres déterminant l'érosion éolienne sur les pâturages dunaires du Niger oriental. *Geo-Eco-Trop*. 33, 39–56.

Tong, D. Q., Gill, T. E., Sprigg, W. A., Van Pelt, R. S., Baklanov, A. A., Barker, B. M., ... & Vimic, A. V. (2021). Health and safety effects of airborne soil dust in the Americas and beyond. *Reviews of Geophysics*, e2021RG000763.

Van Pelt, R. S., Peters, P., & Visser, S. (2009). Laboratory wind tunnel testing of three commonly used saltation impact sensors. *Aeolian Research*, *1*(1-2), 55-62.

Vizy, E. K., & Cook, K. H. (2017). Mesoscale convective systems and nocturnal rainfall over the west African Sahel: Role of the inter-tropical front. *Climate Dynamics*. https://doi.org/10.1007/s00382-017-3628-7

Youm, I., Sarr, J., Sall, M., Ndiaye, A., & Kane, M. M. (2005). Analysis of wind data and wind energy potential along the northern coast of Senegal. *Revue des Energies Renouvelables*, *8*(2), 95-108.