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1 **Wet deposition fluxes of mineral dust and their relation with cold pools in the Central** 2 **Sahel**

3
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9 **Key Points:**

- 10 • More than 240 sahelian wet deposition events were classified according to the intensity of
11 the associated cold pools
- 12 • Rain events associated with cold pools contribute up to 80% of the annual wet deposition
- 13 • Washout ratios of the most convective rains under high level of dust concentrations in the
14 Sahel is around 495 [319 – 766]

16 **Abstract**

17 Based on a large number of in-situ measurements performed over a 9-years period in two Sahelian
18 stations, we investigate the drivers of the dust wet deposition in relation to the meteorological
19 situations and the PM₁₀ (Particulate Matter with diameter lower than 10 μm) surface
20 concentrations. Precipitation associated with cold pools (CP) contribute to more than 90% of the
21 precipitation amount associated with the collected wet deposition samples. The wet deposition
22 events associated with these CP control by far the wet deposition, i.e., 66% and 81%, depending
23 on the station. The dust washout ratios (WR) corresponding to the most convective events under
24 high level of dust concentrations were found to be in the range of 319–766 while WR of other kind
25 of events are depending on the dilution effect. This range of value are in the lower range of WR
26 previously estimated and used in dust modelling studies (200 – 2000).

28 **Plain Language Summary**

29 Mineral dust emitted in the atmosphere by wind erosion in arid and semi-arid areas have
30 environmental impacts on the climate, human health and on bio-geochemical cycles. The
31 atmospheric concentrations are controlled by both emission and deposition processes. In this study,
32 we focus on the study of wet deposition of mineral dust in the Sahel semi-arid region. Long-term
33 (9-years) measurements of dust concentrations, wet dust deposition and meteorological parameters
34 in two Sahelian station of the INDAAF network (International Network to study Deposition and

35 Atmospheric chemistry in Africa) are presented. Based on this dataset, we investigated the cold
36 pool meteorological situation associated to wet deposition of mineral dust.

37

38 **1 Introduction**

39 Mineral dust is emitted in the atmosphere by the wind erosion of arid and semi-arid surfaces (e.g.,
40 Bagnold, 1941; Pye, 1987). This emission only occurs when the surface wind speed exceeds the
41 wind speed threshold for wind erosion that depends mainly on soil and surface characteristics (e.g.,
42 Bagnold, 1941; Marticorena & Bergametti, 1995; Shao & Lu, 2000). Despite dust emissions are
43 pulsed and sporadic as a consequence of this threshold, global dust emissions represent more than
44 40% of the annual mass of particulate injected into the atmosphere, i.e., between 1000 and 4000
45 Mt yr⁻¹ (e.g., Boucher et al., 2013).

46

47 Wet deposition is a major removal process for atmospheric dust particles and thus a key process
48 regarding the aerosol cycle (e.g., Textor et al., 2006). The Sahel is a semi-arid region where dust
49 scavenging by rain is an important process for dust deposition. During the wet season, that extends
50 from May to October, the Sahel is under the influence of the African monsoon which flows moist
51 air from the Gulf of Guinea and controls the majority of the water fallout in the Sahelian band. At
52 that time, air mass conflicts between hot and dry Saharan flow and the moist monsoon air occur
53 on the northern part of the Inter-Tropical Front while the surface heating favors convection. This
54 leads to Mesoscale Convective Systems (MCSs) that are organized convective cells, frequently
55 followed by a stratiform region that can concern a contiguous rain area approaching up-to 100km
56 in horizontal scale in at least one direction (A.M.S, 2015; Houze, 1997). During the rainy season,
57 12% of the MCSs is responsible of 90% of the total rain amount (Lebel et al., 2003; Nicholson,
58 2013) and the most intense ones (3-4 % of the rain events) contribute up to 80% of the rainfall in
59 the Sahel (Nesbitt & Zipser, 2003; Nicholson, 2013). Cold pools (CP) are the outcome of
60 mesoscale density currents that originate from the exchange of latent heat of evaporation
61 underneath precipitating clouds into deep convective downdrafts (e.g., Harrison et al., 2021). Thus,
62 they participate in the development of new convective cells, being therefore a key mechanisms of
63 MCSs (e.g., Provod et al., 2016; Wilson and Schreiber, 1986). MCSs and the associated cold pools
64 are not only the main cause of the total rain production and its variability in the Sahel (Laurent et
65 al., 1998; Mathon et al., 2002; Vischel et al., 2019) but also a major process responsible for huge
66 dust uplift during the rainy season (Kaly et al., 2015; Marsham et al., 2008; Marticorena et al.,
67 2010; Williams et al., 2009).

68

69 Several studies investigated the atmospheric load as well as the deposition in the Sahel (e.g., Drees
70 et al., 1993; Orange, 1990; Ramsperger et al., 1998; Rott, 2001). More recently, the spatial and
71 temporal variability of mineral dust deposition in the Central Sahel has been analysed by
72 Marticorena et al. (2017) using 7 years of continuous measurements. These authors have
73 documented the occurrence of deposition events as well as associated parameters such as aerosol
74 concentrations and meteorological conditions. They showed the existence of a decreasing gradient
75 of the deposition flux from east to west congruent with, but not proportional to, the PM₁₀
76 concentration gradient. The dust deposition also exhibits a strong seasonal cycle linked to the wet
77 season and wet deposition has been shown to be one of the main drivers of the variability of the
78 total dust deposition from the seasonal to inter-annual scales in the Central Sahel. Indeed, these

79 authors exhibited that the annual contribution of the wet deposition to the total deposition
80 represented on average 67 and 52% in Cinzana (Mali) and Banizoumbou (Niger), respectively.
81 The wet deposition is dominant during the wet season in this region and represent 66 to 77% of
82 total deposition from May to September in Banizoumbou and from 65 to 100% of total deposition
83 from May to October in Cinzana (Marticorena et al., 2017).
84

85 In this paper, we focus on the conditions that control the intensity of the dust wet deposition
86 occurring in the Central Sahel. Cold pools have been shown to be a frequent meteorological
87 phenomena leading to strong winds, precipitation and dust lifting in the Sahel (e.g., Knippertz et
88 al., 2009; Williams et al., 2009) and should be important regarding the wet deposition too. Long-
89 term monitoring of deposition events, aerosol and meteorological data measured conjointly in two
90 locations in the Sahelian band from 2007 to 2015 at high resolution allow to investigate how
91 different types of precipitation events affect the dust wet deposition. In addition, the contribution
92 of wet deposition events associated to cold pools to the total wet deposition in the Sahel as well as
93 the efficiency of wet deposition through washout ratios are discussed.
94

95 **2 Materials and Methods**

96 **2.1 Data acquisition**

97 The following analysis is based on the large dataset acquired in two stations of the INDAAF
98 network (International Network to study Deposition and Atmospheric chemistry in Africa). These
99 stations, located in the Central Sahel, at Banizoumbou (Niger) and Cinzana (Mali), serve as a
100 Sahelian long-term observatory to document dust concentration and deposition since their
101 installation in 2006 (Kaly et al., 2015; Marticorena et al., 2010, 2017).
102

103 Briefly, the Banizoumbou station is situated in a fallow at 2.5 km from the village of Banizoumbou
104 at 60 km east of Niamey in Niger (13.54°N, 2.66°E) while the Cinzana station is located in an
105 agronomical research station of the Institut d'Economie Rurale localized at 40 km east south-east
106 of Segou in Mali (13.28°N, 5.93°W). Between 2007-2015, precipitation in Banizoumbou is
107 ranging from 311 to 767 mm yr⁻¹ while in Cinzana, precipitation is ranging between 457 and 925
108 mm yr⁻¹. A detailed description of the sites can be found in Marticorena et al. (2010).
109

110 Rainfall was monitored using an ARG100 tipping bucket rain gauge (0.2 mm precision). In
111 parallel, other parameters characterizing the air masses at the surface have been measured such as
112 air temperature, relative humidity using 50Y, HMP50 or HMP60 Vaisala sensor and wind direction
113 and speed using a Windsonic 2-D Gill Instruments[®]. All measurements have been registered using
114 instrumentation from Campbell Scientific[®].
115

116 Dust concentrations were measured using a Tapered Element Oscillating Microbalance (TEOM
117 1400A, Thermo Scientific). The instrument is equipped with a PM₁₀ inlet, i.e., with a 50%
118 efficiency cut-off for aerodynamic diameter smaller than 10 μm. The meteorological
119 measurements and the PM₁₀ concentrations are recorded as 5-minute averages since 2006.
120

121 We used two criteria to define a rain event: (i) a rain event corresponds to a cumulated rainfall
122 strictly higher than 0.2 mm, i.e., the detection limit of the rain gauge; (ii) we consider that two rain

123 events are distinct from each other if the end of one event and the beginning of the following is
124 separated by at least 3 hours without rain. Based in these criteria, 520 rain events ranging from 0.4
125 to 115 mm (mean=11.8 mm, median=6.6 mm) and 363 rain events from 0.4 to 80.2 mm
126 (mean=11.4 mm, median=5.6 mm) have been collected over the period 2007-2015 in Cinzana and
127 in Banizoumbou, respectively.

128
129 Wet deposition is collected using a MTX ARS 1010 automatic deposition sampler (MTX Italia
130 SPA, Modane, Italy) installed at 5.2 m high in Banizoumbou and Cinzana. The sampler is equipped
131 with a humidity sensor that detects the beginning of each rain event and allow the collection of the
132 wet deposition only. Wet deposition was sampled continuously from 2007 to 2015. This allowed
133 to collect 288 wet deposition samples in Banizoumbou and 358 wet deposition samples in Cinzana.
134 Samples are recovered most of the time after each precipitation by the local operators or at least
135 weekly. In this latter case, a wet deposition sample can contain several wet deposition events.

136

137 2.2 Classification of rain events

138 Most of the rain events occurring in the Sahel are associated with MCSs within which the
139 convective precipitation progressively transforms into stratiform precipitation. Because we have
140 observations in a given place, the rain events we sampled do not correspond to the same stages of
141 evolution of MCS. Thus, our data set mixes both convective, stratiform and mixed rain events.
142 The different phases of MCS can be characterized at the surface by the temperature of the CP that
143 informs on the intensity of the downdrafts and thus on the convection and by other surface
144 meteorological parameters such as wind speed and direction (e.g., Flamant et al., 2009; Knippertz
145 et al., 2009).

146 Indeed, Provod et al. (2016) have described the surface properties of Sahelian CP in Niamey
147 (Niger) during the 2006 wet season showing that CP events are characterised by simultaneous
148 temperature decrease, surface pressure increases and a sudden increase in wind speed.

149 Following this work, we computed for each rain event the changes in wind speed and temperature
150 as the difference between the minimum wind speed (maximum temperature) observed during the
151 60 minutes preceding the onset of the rain and the maximum wind speed (minimum temperature)
152 observed during the 120 minutes following the onset of the rain. We also computed the maximum
153 change in wind direction occurring within 30 minutes. The method to identify CP is mainly based
154 on the study of Provod et al. (2016). Rain events are classified as CP when associated
155 simultaneously with a change in wind direction of at least 30° ($\Delta\text{Dir} \geq 30^\circ$), a decrease in
156 temperature of at least 2°C ($\Delta T \geq 2.0^\circ\text{C}$) and an increase in wind speed ($\Delta V < 0 \text{ m s}^{-1}$), the other
157 rain events being classified as NCP (Non Cold Pool). However, in addition to automated
158 processing, each event was verified individually to confirm whether it belonged to CP or NCP
159 classification. 274 and 398 rain events were associated with CP while 90 and 122 rain events
160 corresponded to NCP situations in Banizoumbou and Cinzana, respectively.

161

162 2.3 Washout ratio

163 The washout ratio, WR, is generally used to quantify the efficiency of wet deposition mechanisms
164 for a rain event (i.e., washout and rainout). WR is defined as the ratio of the concentration of a
165 species in the rain water (C_{rain}) divided to the mean surface concentration in the air (C_{air}) of the

166 rain event (e.g., Chamberlain, 1960), ρ_{air} and ρ_{rain} being respectively the density of air (here
167 expressed in $\mu\text{g m}^{-3}$) and of rain (mg L^{-1}):

$$168 \quad WR = \frac{c_{rain}}{c_{air}} \times \frac{\rho_{air}}{\rho_{rain}} \quad (1)$$

169
170 WR has been documented for different environment (e.g., Cerqueira et al., 2010; Ducret &
171 Cachier, 1992; Encinas et al., 2004; Guerzoni et al., 1995; Marticorena et al., 2017). However, its
172 application has been largely debated because of the many assumptions that are generally required
173 for its computation (e.g., Gatz, 1974; Slinn, 1974). Indeed, if WR is based on parameters that can
174 be easily measured (e.g., surface mean aerosol concentrations), the potential impact of large
175 spectras of droplet and dust is neglected and the atmospheric concentration of deposited
176 atmospheric compounds has to be assumed uniformly mixed below the cloud base.

177
178 WR of mineral dust have mostly been determined using concentration measurements in areas very
179 far from dust sources (e.g., Arimoto et al., 1987; Duce et al., 1991; Prospero et al., 1987) and only
180 a few studies have calculated WRs for rain events in the vicinity of emission sources. Despite its
181 limitation, WR remains used for modelling dust wet deposition in global climate models generally
182 using constant value of WR (Ginoux et al., 2001; Jung & Shao, 2006; Tegen & Fung, 1994). It
183 remains interesting to better constrain this parameter. Moreover, WR is also used to provide an
184 estimation of the wet deposition fluxes when only atmospheric particulate concentrations are
185 measured (Cheng et al., 2021; Gatz, 1974).

186
187 Dust wet deposition results both from the wash-out and of the rain-out of particles by cloud and/or
188 rain droplets.

189 Washout of aerosol particles by rain depends on the probability of collision between a raindrop
190 and a particle (Slinn, 1974). We assume in first approximation that the number of droplets is
191 proportional to the amount of measured precipitation and that the PM_{10} concentrations is a proxy
192 for the number of aerosol particles in the atmosphere. These assumptions consist of considering
193 that the size-distributions of raindrops and of aerosol particles is monomodal (or very tight) and
194 do not change over time. Since at each 5-minute time step, the dust concentration and the rainfall
195 change, we estimate the mean particulate concentrations during a rain event by weighting the PM_{10}
196 concentrations measured at a time step i by the amount of rain that fell during the same time step
197 i as follows:

$$198 \quad C_{air} = \sum_i C_{\text{PM}_{10},i} (\mu\text{g m}^{-3}) \times \frac{P_i (\text{mm})}{P_{tot} (\text{mm})} \quad (2)$$

199 $C_{\text{PM}_{10},i}$ being the PM_{10} surface concentration and P_i , the precipitation amount at the time step i ; P_{tot}
200 the precipitation amount of the rain event.

201 This allows to better represent the variation of PM_{10} concentrations regarding the rainfall time
202 steps during the event. One should keep in mind that the use of PM_{10} concentrations to represent
203 desert dust atmospheric content does not allow to account for the coarser dust that could constitute
204 a significant fraction of atmospheric concentrations and deposition. Here, PM_{10} concentration are
205 considered as a proxy of the whole dust concentration (see supplement information for further
206 details).

207
208 To compute WR, we have to assume that the dust concentrations we measured at the surface are
209 representative of the ones below the precipating cloud for CP events and that wash out is largely
210 predominant compared to rain-out. These assumptions are probably fulfilled only in the case of

211 well established convective events. During such events, atmospheric dust content is dominated by
212 local dust emission. Desboeufs et al. (2010) have shown, using a sequential rain collector, that the
213 wash-out process is by far the main contributor to the dust content of the first mm of rainfall and
214 that dust contained in these first mm are predominant in the total wet deposited mass in the Sahel.
215 Moreover, during intense convective events, the emitted dust particles are deeply mixed in the
216 atmospheric column by the intense turbulence making the hypothesis of surface dust
217 concentrations representative of the concentration in the atmospheric column reasonable.

218
219 Thus, we selected only convective precipitation (CP) events to examine the relationship between
220 PM_{10} concentrations and rainwater concentrations. Leary & Houze (1979) indicated that
221 convective rains are most of the time associated with mean rainfall rate of 10 mm h^{-1} or more. The
222 same threshold have been used by Nzeukou et al. (2004) to study convective rains in Senegal.
223 Schumacher & Houze (2006), using TRMM (Tropical Rainfall Measuring Mission Precipitation
224 Radar) observations, have found that convective rains, in west Africa, have a mean intensity of 14
225 mm h^{-1} .

226 Thus, we separate CP events depending on their mean rainfall rate (R), higher and lower than 10
227 mm h^{-1} , to compute WR. CP events with $R \geq 10 \text{ mm h}^{-1}$ being considered as the most convective
228 events.

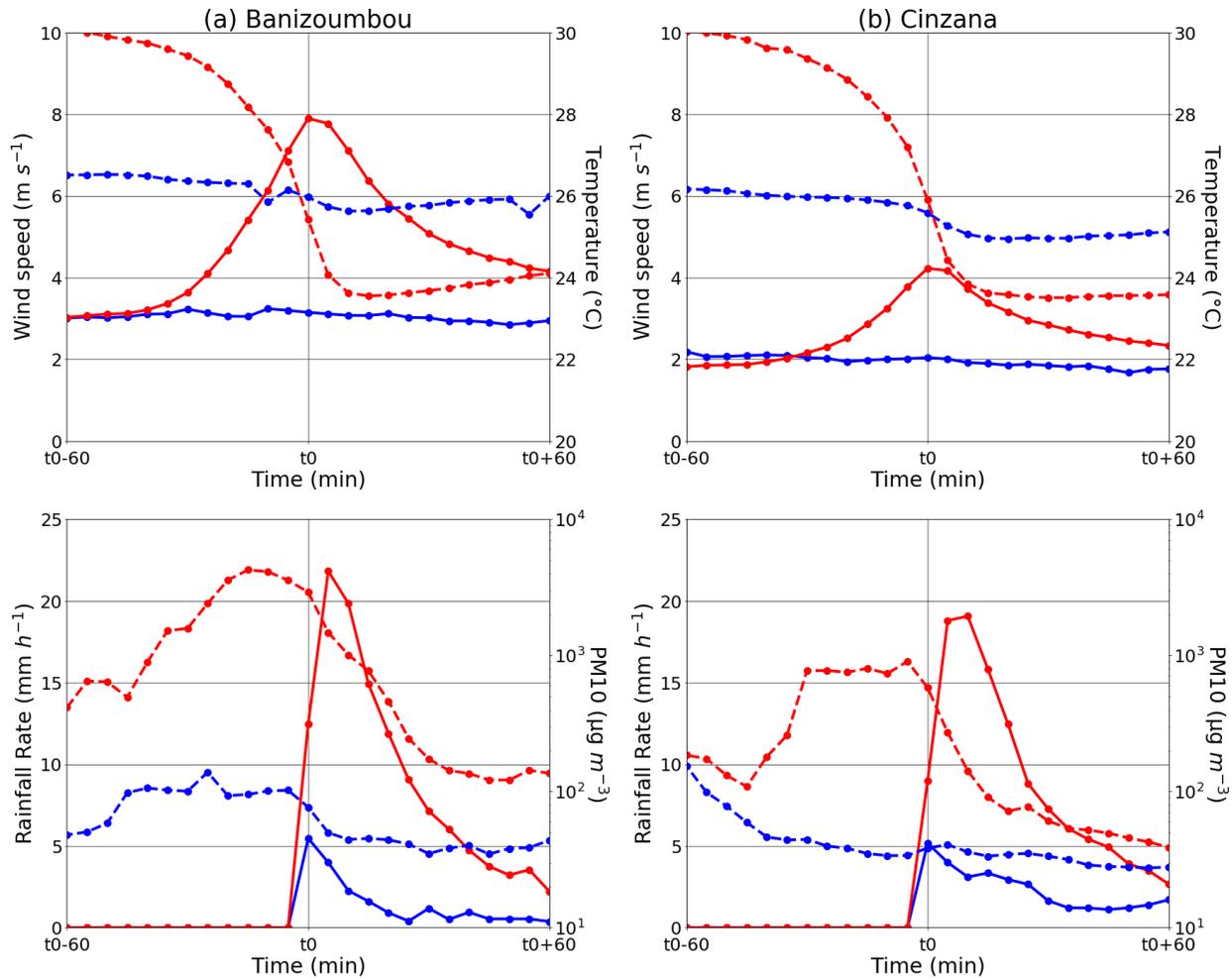
229

230 **3 Results**

231 3.1 General characteristics of the rain events

232 Figure 1 reports the temporal evolution of the mean of the surface meteorological parameters and
233 PM_{10} for CP and NCP events, centered around the beginning of the rain events. In Banizoumbou,
234 CP events are characterized by simultaneous temperature decrease ($7.7 \pm 3.5^\circ\text{C}$) and increase in
235 wind speed ($7.3 \pm 3.6 \text{ m s}^{-1}$) while NCP events are followed by a lower temperature decrease
236 ($2.1 \pm 4.0^\circ\text{C}$) and a lower increase in wind speed ($2.3 \pm 1.8 \text{ m s}^{-1}$). A similar behaviour is observed
237 in Cinzana, where CP events exhibited simultaneous temperature decrease of $7.9 \pm 3.6^\circ\text{C}$ and wind
238 speed increase of $4.3 \pm 2.0 \text{ m s}^{-1}$ and of $2.2 \pm 1.8^\circ\text{C}$ and $1.6 \pm 1.2 \text{ m s}^{-1}$ for NCP events. With regard
239 to the rainfall rate, CP events are characterized by a mean (median) rainfall rate of 11.4 (9.2) mm
240 h^{-1} in Banizoumbou and 11.1 (8.7) mm h^{-1} in Cinzana while NCP events have an average rain
241 intensity of 6.8 (4.0) and 5.4 (3.7) mm h^{-1} , respectively. Rainfall structures of CP and NCP have
242 similar pattern with higher mean rainfall rates computed over 5 min (up to 20 mm h^{-1} for CP and
243 5 mm h^{-1} for NCP events) at the beginning of the rain events that decreases after 5 to 15 minutes.

244



245
 246 **Figure 1.** Mean surface temperature, wind speed, rainfall rate and PM₁₀ concentration of the
 247 identified meteorological situations in two sites, on the left Banizoumbou (216 CP and 60 NCP)
 248 and on the right Cinzana (377 CP and 110 NCP). CP and NCP events are represented in red and
 249 blue, respectively. Solid lines correspond to left-hand axis and dashed lines correspond to right-
 250 hand axes. t₀ corresponds to the start of the rain.

251
 252 CP events are characterised by an increase of PM₁₀ concentrations as a consequence of the increase
 253 of wind speed. Indeed, wind speed and PM₁₀ concentrations increase and reach a maximum during
 254 the 30 minutes preceding the onset of the rain but for a short duration, with an average of 10 to 15
 255 minutes. When the rain starts, PM₁₀ concentrations decrease until they reach values that are
 256 generally lower than those recorded before the rain event starts. Even if the general pattern is
 257 similar on both sites, it can be noted that wind speed and PM₁₀ concentrations are significantly
 258 higher in Banizoumbou than in Cinzana.

259
 260 Regarding NCP events, not any significant increase in PM₁₀ concentrations before the beginning
 261 of the rain nor any variation during the rain event is observed, the wind speed never exceeding the
 262 minimum threshold wind speed for erosion (of the order of 7.0 and 5.5 m s⁻¹ for Banizoumbou and
 263 Cinzana, respectively; Abdourhamane Toure et al., 2011; Bergametti et al., 2017).

264

265 **Table 1.** Contribution (%) by types of rain event to the rainfall and annual wet deposition fluxes.
 266 * Years with missing meteorological data in Banizoumbou. Average values in the text do not
 267 take into account these years for their computation.

	2007	2008*	2009*	2010	2011	2012	2013	2014*	2015
Banizoumbou	Wet deposition fluxes								
CP	61,7%	88,1%	93,4%	45,5%	77,5%	71,6%	66,0%	76,6%	72,9%
NCP	1,4%	0,0%	1,4%	0,0%	0,4%	2,5%	0,7%	16,2%	2,4%
NA	36,9%	11,9%	5,2%	54,5%	22,1%	25,9%	33,2%	7,2%	24,7%
	Rainfall								
CP	96,4%	98,6%	97,8%	91,1%	97,5%	85,9%	94,0%	95,1%	94,0%
NCP	3,6%	1,4%	2,2%	8,9%	2,5%	14,1%	6,0%	4,9%	6,0%
Cinzana	Wet deposition fluxes								
CP	95,5%	88,2%	83,4%	86,1%	88,5%	85,6%	47,8%	74,5%	78,4%
NCP	4,3%	3,7%	11,0%	4,6%	3,4%	2,1%	14,7%	17,4%	4,7%
NA	0,2%	8,1%	5,6%	9,2%	8,1%	12,3%	37,6%	8,1%	16,8%
	Rainfall								
CP	91,4%	93,5%	76,9%	92,3%	86,9%	95,0%	93,2%	92,4%	95,5%
NCP	8,6%	6,5%	23,1%	7,7%	13,1%	5,0%	6,8%	7,6%	4,5%

268 Over the 2007 – 2015 period, the annual number of CP events ranges from 24 to 36 (mean=30) in
 269 Banizoumbou and from 31 to 56 (mean=44) in Cinzana. The CP events in the Sahel represent 78%
 270 of the rain events measured in Banizoumbou and in Cinzana. Despite the annual variability, the
 271 contribution of CPs and NCPs events to rainfall is roughly similar from one year to the next : CP
 272 events contribute for 93±4% in Banizoumbou and for 91±6% in Cinzana (Table 1).
 273

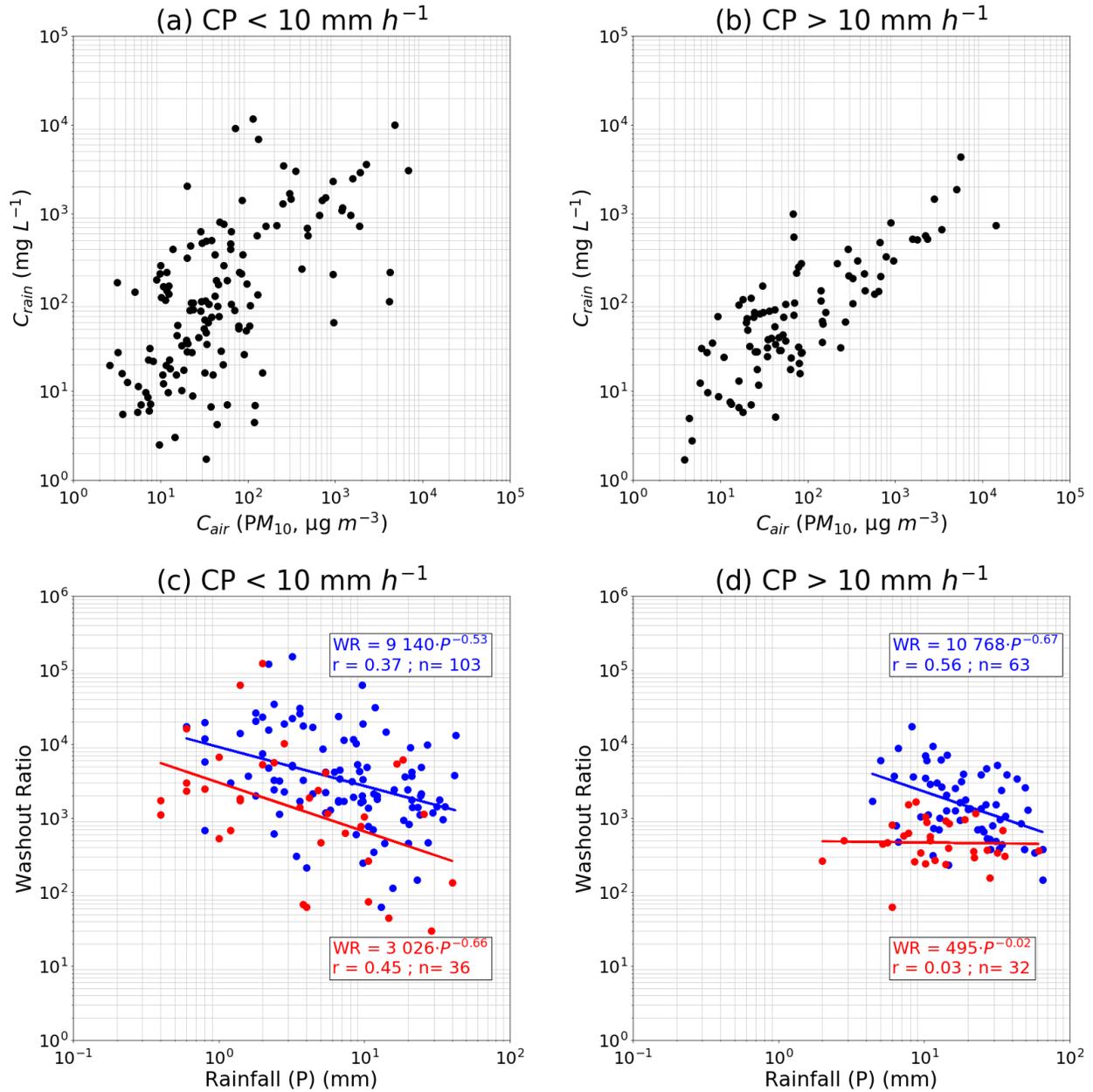
274
 275 Between 2007 and 2015, the wet deposition fluxes range from 38.0 to 117.6 g m⁻² yr⁻¹ and from
 276 43.2 to 116.2 g m⁻² yr⁻¹ in Banizoumbou and Cinzana, respectively, i.e., exhibiting an interannual
 277 variability of a factor of three at both sites. The wet deposition contributes for 50±12% and 71±20%
 278 of the total deposition in Banizoumbou and Cinzana, respectively.
 279

280 In this paper, we focus on rainy events for which concomitant information on the meteorological
 281 parameters, wet deposition fluxes and PM₁₀ concentrations measurements is available. Among
 282 these, we considered only those corresponding to a single rain event or due to a single rain type
 283 (i.e., CP or NCP). These events contribute for 55±15% of the annual wet deposition fluxes in
 284 Banizoumbou and 77±12% in Cinzana, respectively. The contribution of CPs and NCPs events is
 285 roughly the same each year (Table 1). CP events contribute to 66±11% of the annual wet deposition
 286 fluxes in Banizoumbou and to 81±14% in Cinzana while NCP events contribute to 1±1% and
 287 7±6% of the annual wet deposition fluxes in Banizoumbou and Cinzana, respectively. The
 288 remaining part, corresponding to samples composed of different rain types, are not attributable to
 289 a specific type of rain events and are classified as NA (Table 1). It must be noted that the biggest
 290 wet deposition sample contribute in average to 30±10% of the annual wet deposition fluxes in
 291 Banizoumbou and to 26±13% in Cinzana.
 292

293 3.2 Washout Ratios

294 Figures 2 (a-b) show that there is a significant relationship between C_{rain} (C_{rain} = F_w^{event} / P) and
 295 C_{air} for CP events regardless of their rainfall rate, F_w^{event} being the wet deposition flux of the rain

296 event. However, values are less scattered for CP events with $R > 10 \text{ mm h}^{-1}$, thus the relationship
 297 between the two variables is stronger ($C_{\text{rain}} = 0.17 C_{\text{air}} + 125 \mid r = 0.56$) than for CP events with R
 298 $< 10 \text{ mm h}^{-1}$ ($C_{\text{rain}} = 0.66 C_{\text{air}} + 448 \mid r = 0.36$).
 299 This allows us to calculate WR for each event using equation (1), and to document the dependency
 300 of the WR with the precipitation amount.
 301



302
 303 **Figure 2.** (a-b) Concentration of particles in rain (C_{rain} , mg L^{-1}) as a function of surface PM_{10}
 304 concentration (C_{air} , $\mu\text{g m}^{-3}$) for CP events in both sites for, (a) CP with $R < 10 \text{ mm h}^{-1}$ ($n = 139$)
 305 and (b) CP with $R \geq 10 \text{ mm h}^{-1}$ ($n = 95$). (c-d) Washout ratios as a function of rainfall (P , mm) in
 306 both sites for, (c) CP with $R < 10 \text{ mm h}^{-1}$ and (d) CP with $R \geq 10 \text{ mm h}^{-1}$ and regarding two
 307 concentrations regimes : in blue, $C_{\text{air}} < 100 \mu\text{g m}^{-3}$ and in red, $C_{\text{air}} \geq 100 \mu\text{g m}^{-3}$.
 308

309 Figures 2 (c-d) illustrate the variation of the WR as a function of the rainfall. The results are
310 presented for two dust concentration regimes higher and lower than $100 \mu\text{g m}^{-3}$. One can observe
311 a decreasing trend of the WR with the rainfall amount for CP events associated to $R < 10 \text{ mm h}^{-1}$
312 for both concentrations regimes (figure 2-c). This is due to the so-called dilution effect (Desboeufs
313 et al., 2010; Jaffrezo et al., 1990; Marticorena et al., 2017): the first drops have a higher washout
314 efficiency due to the fact that PM_{10} concentration is higher at the beginning of the rain. The longer
315 it rains, the fewer dust particles are left in the atmosphere for being scavenged; therefore, at the
316 later stage of a rain event, the below-cloud air is devoid of aerosols and scavenging occurs mostly
317 by rainout. Although the decreasing trends in washout ratios resemble each other for
318 concentrations above or below the $100 \mu\text{g m}^{-3}$ threshold, the WR is always significantly higher for
319 CP events with concentrations below that threshold.

320 Regarding CP events with $R \geq 10 \text{ mm h}^{-1}$, it can be seen that for the same rainfall amount, the WR
321 is greater for CP events under low concentrations regime and, unlike the latter, there is no dilution
322 effect for CP events under high concentrations regime (figure 2-d).

323
324 To estimate dust deposition over oceanic surfaces, Duce et al. (1991) used for dust particles a $\text{WR} =$
325 200 for the North Atlantic Ocean, based on measurements done at Bermuda and Miami (Church
326 et al., 1984; Prospero et al., 1987) and 1000 for other oceans using data obtained in the Pacific
327 Ocean region from Japanese network (e.g., Tsunogai and Kondo, 1982), and from Sea-Air
328 Exchange (SEAREX) Program and related project (e.g., Arimoto et al., 1987; Uematsu et al.,
329 1985).

330 According to an event-based study of nearly 240 wet deposition events collected over almost a
331 decade in two Sahelian sites, our results suggest that the assumption of a single WR value is not
332 valid in a Sahelian environment. Indeed, it is necessary to take into account the dilution effect for
333 some categories of events, i.e., CP events associated with low concentrations regime ($< 100 \mu\text{g m}^{-3}$)
334 as well as CP events associated with high concentrations and low rainfall rates ($R < 10 \text{ mm h}^{-1}$).
335 However, for the most convective events (i.e., CP with $R \geq 10 \text{ mm h}^{-1}$) under a high dust
336 concentrations regime, the use of a WR between 319 and 766 seems reasonable considering the
337 absent dilution effect and the lower dispersion of values. This range of value is in the lower range
338 of values reported by Duce et al. (1991) and slightly higher than the washout ratios reported in the
339 literature for crustal elements as Al, Si or Fe (250–375) (Cheng et al., 2021). Since these WRs are
340 calculated from PM_{10} concentrations, their application in global climate models must be applied
341 with precaution. For example, models that simulate the size spectrum up to $100 \mu\text{m}$ (e.g., Balkanski
342 et al., 2021; Di Biagio et al., 2020; Lu & Shao, 2001), can recalculate a WR considering the
343 proportion $\text{PM}_{10}/\text{TSP}$ and those that only simulate particles $< 20 \mu\text{m}$ (e.g., Huneeus et al., 2011;
344 Tegen & Lacis, 1996), for example, could apply this range of WR knowing that this could probably
345 lead to an overestimation of the wet deposition fluxes.

346

347 **4 Conclusions**

348 Wet deposition fluxes, meteorological parameters and PM_{10} concentrations have been analysed at
349 the event scale using a 9-year data set (2007–2015). Annual wet deposition ranged from 38.0 to
350 $117.6 \text{ g m}^{-2} \text{ yr}^{-1}$ and from 43.2 to $116.2 \text{ g m}^{-2} \text{ yr}^{-1}$ in Banizoumbou and Cinzana, respectively, for
351 complete years with continuous measurements.

352

353 We used meteorological criteria to distinguish rain events associated with Cold Pools (CP). 273
354 and 399 rain events were associated with CP characterized by $\Delta T \geq 2.0^\circ\text{C}$, $\Delta V < 0 \text{ m s}^{-1}$ and ΔDir
355 $\geq 30^\circ$, while 89 and 121 rain events were not associated with cold pools (NCP) in Banizoumbou
356 and Cinzana, respectively. We found that CP and NCP events contribute to 66 to 81% and 1 to 7%
357 respectively of total studied wet deposition while they account for between 91 to 93% and 7 to 9%
358 respectively of total studied precipitation amount.

359
360 Relationships between concentrations of particles in rain and surface PM_{10} concentrations have
361 been studied for CP events associated to rainfall higher and lower than 10 mm h^{-1} . Significant
362 correlations have been found and allowed us to calculate washout ratios (WR). Since the
363 assumptions of representativeness of surface concentrations and homogeneity of the column under
364 the cloud are not fulfilled for NCP events, we focus here on the determination of WR for CP events.
365 Our results suggest that, for the same amount of precipitation, the WR is higher for CPs under a
366 low concentration regime, regardless of the rain intensity.

367
368 This study allowed us to determine a range of value of WR between 319 and 766 for the Sahel
369 during convective rain events under a high dust concentrations regime ($C_{\text{air}} \geq 100 \mu\text{g m}^{-3}$), i.e. CP
370 events associated to rainfall rate higher than 10 mm h^{-1} . Regarding other type of events, a single
371 value for the WR of dusts is not sufficient, the dilution effect must be taken into account.
372

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386

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