Multiannual study of cold pool situations associated to wet deposition of desert dust in the Sahelian band

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Sahelian measurement sites

Based on **9 years** of **simultaneous** measurements of surface PM10 concentrations, dust wet deposition fluxes and meteorological parameters at **2 Sahelian stations** of the INDAAF network (International Network to study Deposition and Atmospheric chemistry in Africa, Marticorena et al., 2017), 363 and 520 rain events and 288 and 358 wet dust deposition events were recorded and studied in **Banizoumbou** (13.54°N, 2.66°E, Niger, Fig. 1) and **Cinzana** (13.28°N, 5.93°W, Mali), respectively.

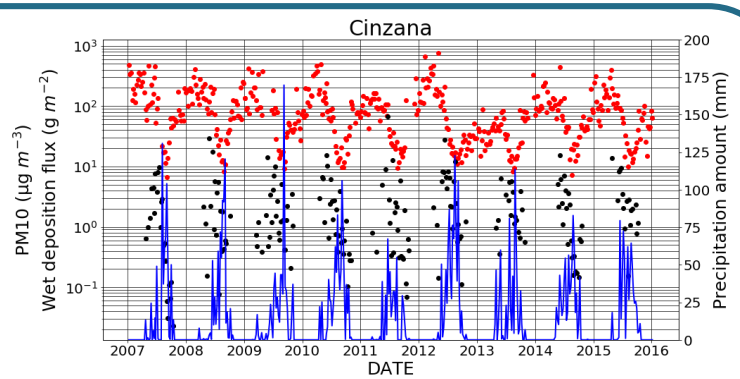


Figure 1. Time series of **PM10 concentration** (µg m^{-3}), **wet deposition fluxes (g m^{-2})** and **precipitation amount** (mm) in Cinzana from 2007 to 2015

Identification of convective Cold Pool events (CP)

Following Provod et al. (2016), each rain event was classified as CP based on simultaneous changes in surface thermodynamic parameters (Fig. 2):

- Wind direction change of at least 30 ° (**ΔDir ≥ 30 °**)
- Decrease of temperature of at least 2 °C (**ΔT ≤ - 2.0 °C**)
- Increase of wind speed (**ΔV ≥ + 0 m s^{-1}**)

This leads to the identification of **281 and 383** rain events associated with **CP** in Banizoumbou and Cinzana, respectively, as well as **79 and 119** rain events not associated with CP situations (hereafter as **NCP**).

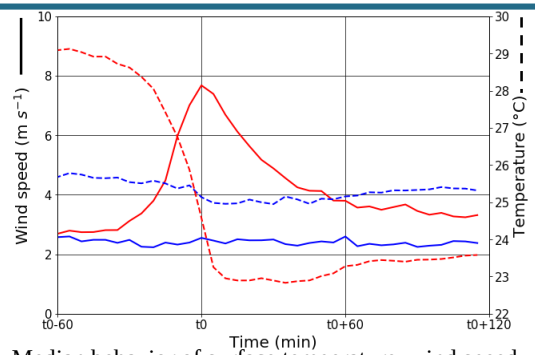


Figure 2. Median behavior of surface temperature, wind speed, rainfall rate and PM10 concentration of **CP** and **NCP** events in **Banizoumbou**

Contribution of CP's and NCP's wet deposition to annual wet deposition

CP events contribute FOR **68 to 72 %** of total annual wet deposition and between **63 and 68 %** of total annual precipitation amount.

NCP events contribute FOR **3 to 8 %** of total annual wet deposition and between **2 to 4 %** of total annual precipitation amount.

The ratios of the deposition fluxes between CP and NCP is similar to that of the rainfall between CP and NCP (Fig. 3) and suggests **no marked difference** between CP and NCP events efficiency.

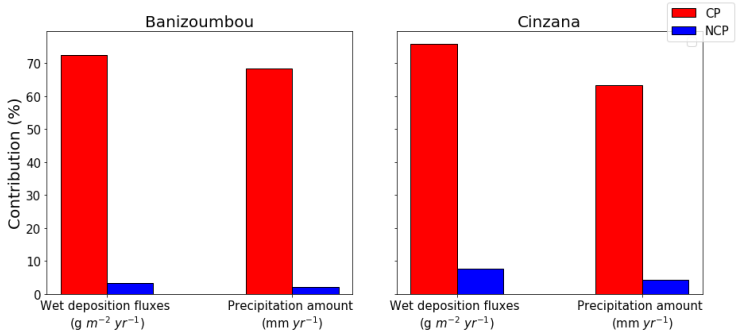


Figure 3. Contribution of rain event types to total studied wet deposition (g m^{-2} yr^{-1}) and annual rainfall amount (mm yr^{-1})

Relationship between rain concentration and surface atmospheric PM10 concentration

Rainfall events can be defined as convective for a mean intensity of 10 mm h^{-1} or more (Leary and Houze, 1979). Linear regressions have been plotted as:

$$C_{rain}(mg\ L^{-1}) = b_0 \times PM10\ (\mu g\ m^{-3})$$

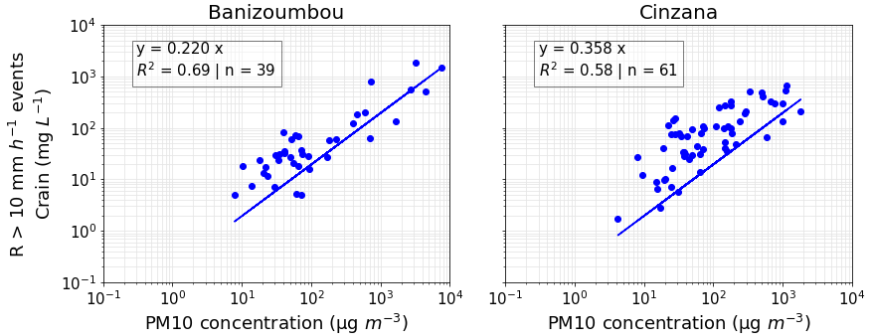


Figure 4. Crain (in mg L^{-1}) vs PM10 concentration (in µg m^{-3}) in Banizoumbou and Cinzana for convective rains

The Washout ratio (WR) is defined as the ratio of the concentration of dust in the rain water (Crain) divided by the mean surface concentration in the air (Cair) during the rain event (Chamberlain, 1960). WR can be computed as:

$$WR = b_0 \cdot \frac{\rho_{air}\ (\mu g\ m^{-3})}{\rho_{rain}(mg\ L^{-1})}$$

From our measurements WR for dust wet deposition associated to intense convective rain in the Sahel have been estimated and range from 264 to 430 in Banizoumbou and Cinzana, respectively.

References

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Acknowledgments

DustClim project
DATSHA project

Background (1)

- Wet deposition is a major removal process for atmospheric dust particles (Jung and Shao, 2006) and a key mechanism regarding the aerosol cycle (Textor et al., 2006).

- Actual measurements and networks do not allow to constrain the dust mass budget (Bergametti and Forêt, 2014).

- Huneeus et al. (2011) underline the deficiencies present in most global climate models to reproduce the fraction of wet deposition by precipitation and the need to study long-term total and wet deposition.

→ Such dust measurements were initiated in Sahelian stations in the vicinity emission sources in the framework of the INDAAF network (Marticorena et al., 2017).

Sahelian measurement sites

- Data collected at two stations of the INDAAF network: Banizoumbou (13.54°N, 2.66°E, Niger) and Cinzana (13.28°N, 5.93°W, Mali).

- 9 years of simultaneous measurement of surface PM10 concentrations, wet deposition fluxes and precipitation amount at high resolution (Fig. 1).

- This represents 288 wet deposition samples for 363 rain events in Banizoumbou and 358 wet deposition samples for 520 rain events in Cinzana for the studied period.

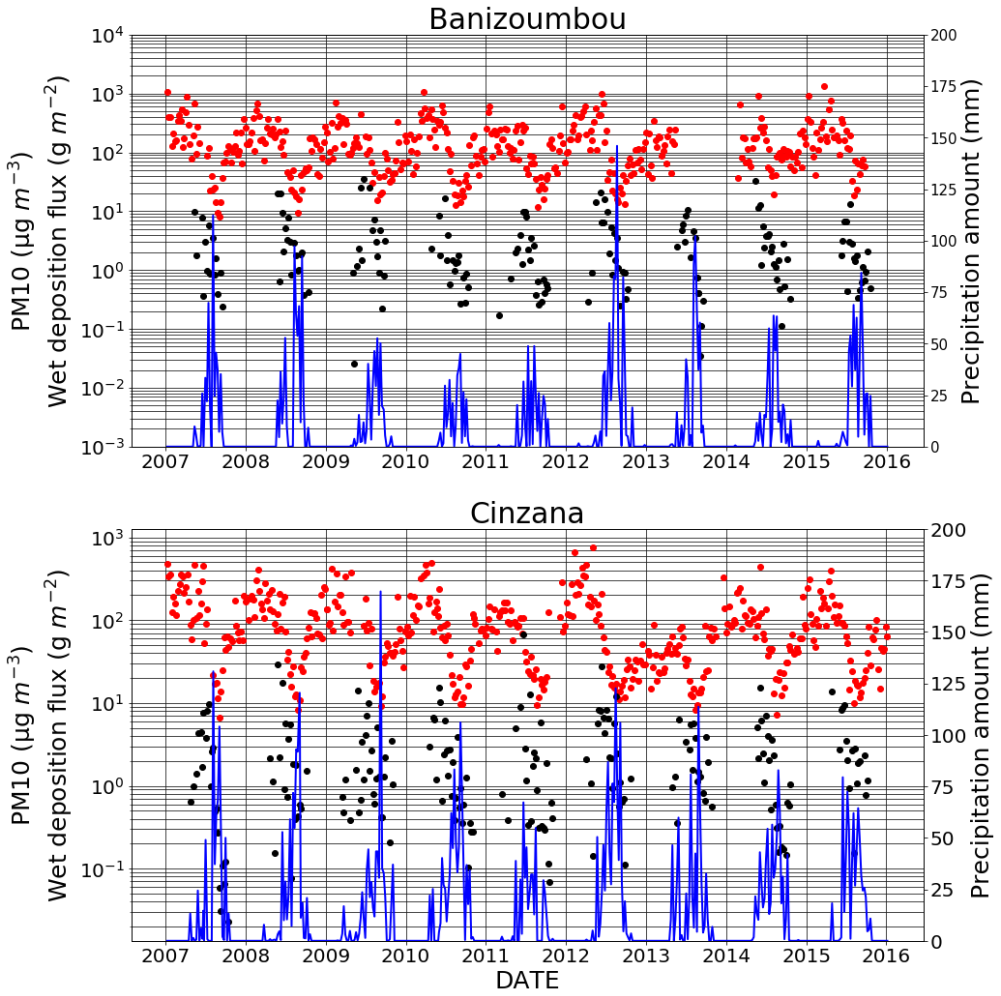


*Figure 1. Time series of **PM10 concentration** (µg m^{-3}), **wet deposition fluxes (g m^{-2})** and **precipitation amount** (mm) in Banizoumbou (top panel) and Cinzana (down panel) from 2007 to 2015*

Background (2)

- Mesoscale Convective Systems (MCSs) are strong convective cells followed by a stratiform region that can produce a contiguous rain area (Houze, 1997).

- In the Sahel, MCSs are not only a major source of dust lifting during the rainy season (Marsham et al., 2008) but also the main cause of total rainfall production and its variability. Indeed, 12% of MCSs are responsible for 90% of the rainfall amount during the wet season (Lebel et al., 2003; Nicholson, 2013).

- Cold pools (CP) are mesoscale areas of cold and dense air beneath precipitating clouds that participate in the development of new convective cells, being therefore a key mechanisms of MCSs (Provod et al., 2016; Wilson and Schreiber, 1986).

→ Based on the measurements of the INDAAF network, we proposed to study CP situation and wet deposition events.

Identification of convective Cold Pool events (CP)

- Rain events associated with CP situations can be identified based on thermodynamic surface parameters: the variation in wind speed, temperature as well as the change in wind direction are computed for each rainfall event (Provod et al., 2016).

- We consider the variations of the wind speed and temperature before the beginning [t0-1h; t0] and during the rain [t0; t0+2h] as illustrated in Fig. 2, and wind direction changes occurring within 30 min.

- This leads to the identification of 281 and 383 rain events associated with CP in Banizoumbou and Cinzana, respectively, as well as 79 and 119 rain events not associated with CP situations (hereafter as NCP).

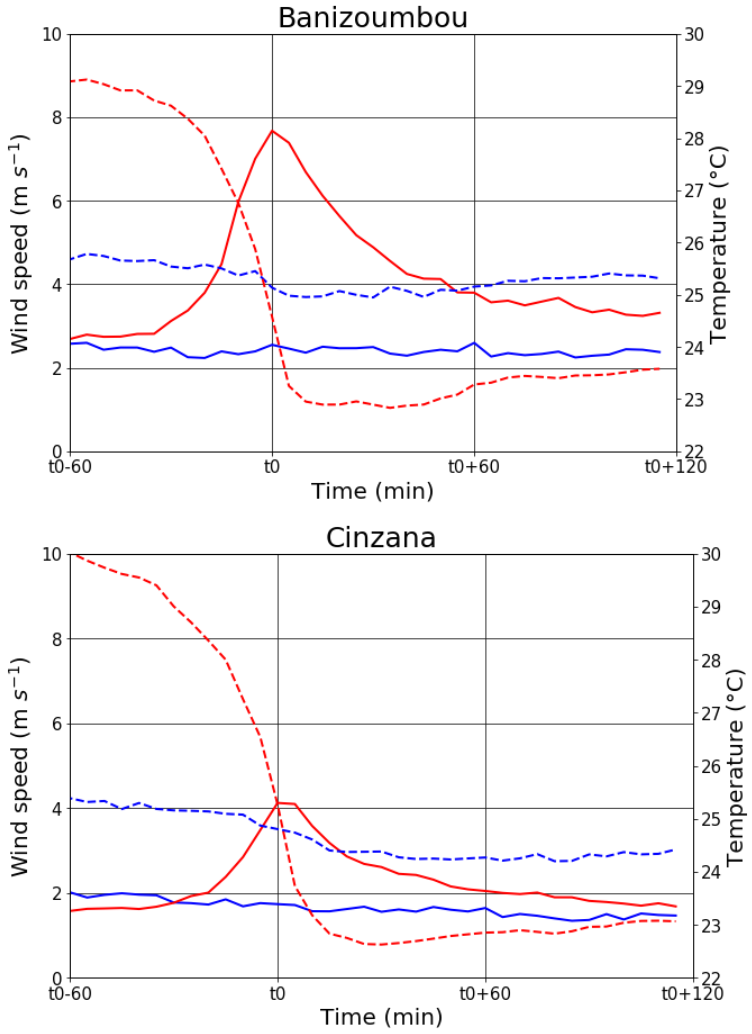


*Figure 2. Median behavior of surface temperature, wind speed, rainfall rate and PM10 concentration of **CP** and **NCP** events in **Banizoumbou** (top panel) **and Cinzana** (down panel). Solid lines correspond to left-hand axis and dashed lines correspond to right-hand axes. t0 corresponds to the first time step where the rain is measured.*

Contribution of CP's and NCP's wet deposition to annual wet deposition

- CP events contribute to 72 ± 16% of the annual wet deposition fluxes is and to 68 ± 15% of the annual precipitation amount in Banizoumbou. In Cinzana, CP events contribute to 76 ± 18% of the annual wet deposition fluxes and to 63 ± 17% of the annual precipitation amount (Fig. 3).

- NCP events contribute to 2 ± 3% and 4 ± 4% of the annual wet deposition fluxes in Banizoumbou and Cinzana, respectively, and to 4 ± 2% and 8 ± 7% of the total precipitation amount (Fig. 3).

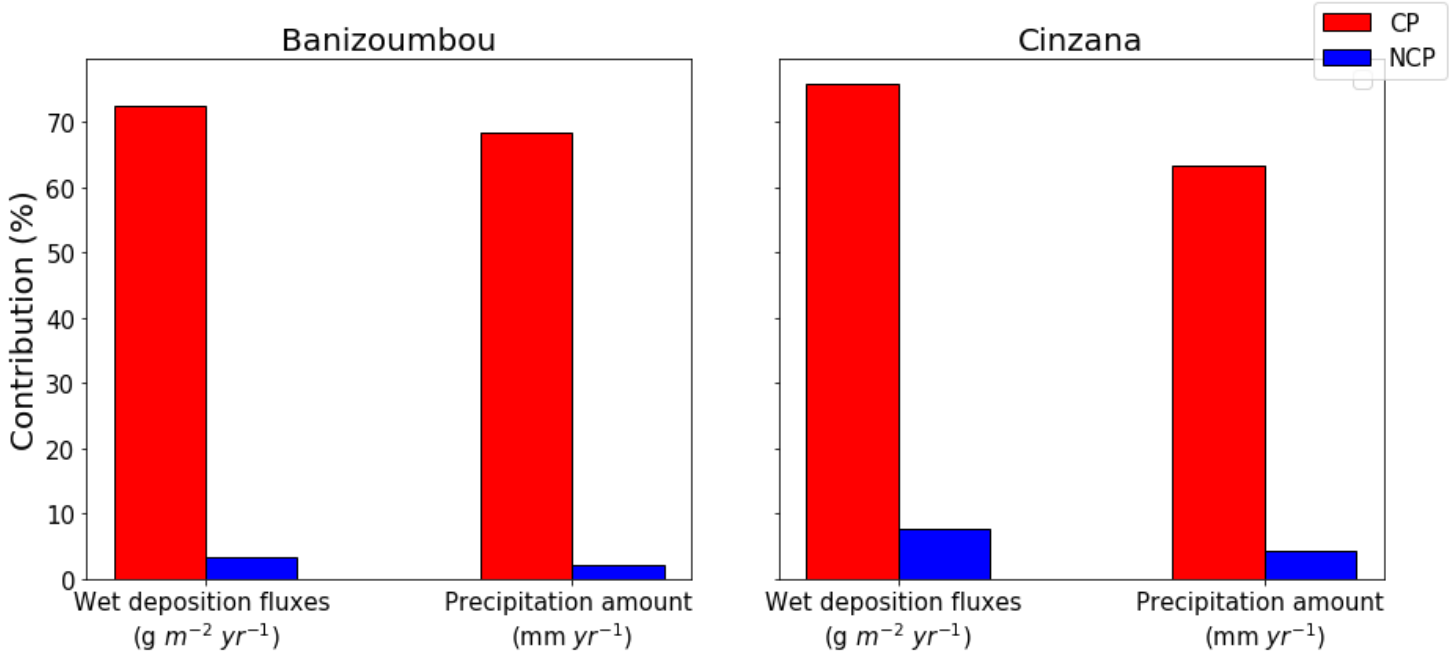


Figure 3. Contribution of CP and NCP events to total studied wet deposition (g m^{-2} yr^{-1}) and annual rainfall amount (mm yr^{-1}) for Banizoumbou (left panels) and Cinzana (right panels)

→ Even though CP events are associated to the majority of the rain events, they are not more efficient regarding the deposition fluxes.

Washout Ratio (WR)

- WR is defined as the ratio of the concentration of a species in the rain water (C_{rain}) divided to the mean surface concentration in the air (Cair) during the rain event (Chamberlain, 1960).

$$WR = \frac{C_{rain}\ (\mu g\ kg^{-1})}{C_{air}\ (\mu g\ kg^{-1})} = \frac{C_{rain}\ (mg\ L^{-1})}{C_{air}\ (\mu g\ m^{-3})} \times \frac{\rho_{air}\ (\mu g\ m^{-3})}{\rho_{rain}(mg\ L^{-1})}$$

- WR can be used to quantify the integrated efficiency of wet deposition mechanisms for a rain event. WR values for dust particles are ranging from 100 to 2000 in the literature (*e.g.,* Duce et al., 1991).

- Our results suggest a narrower range for dust particles with WR values between 264 and 430 for convective rains (R > 10 mm h^{-1}) in the Sahel.

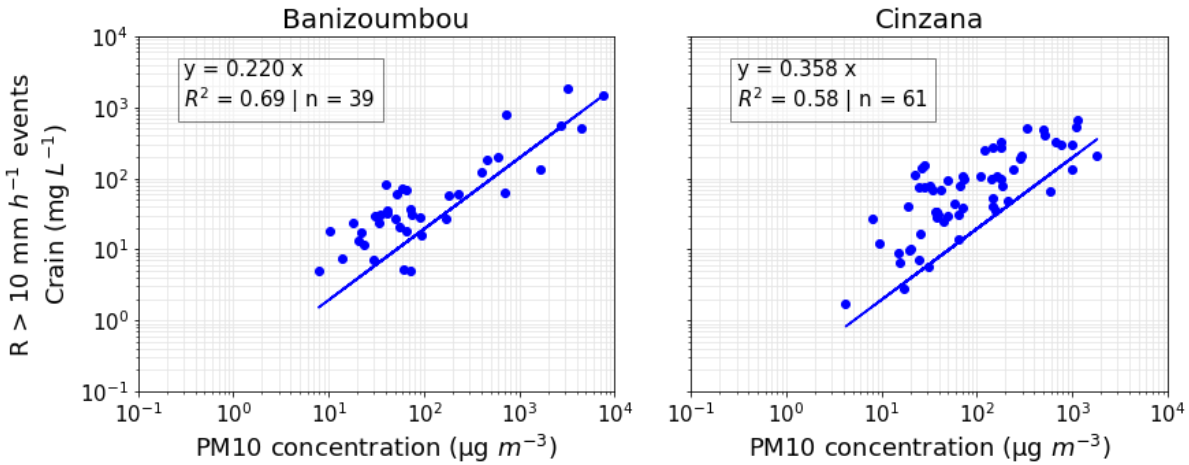


Figure 4. Crain (in mg L^{-1}) vs PM10 concentration (in µg m^{-3}) in Banizoumbou and Cinzana for convective rains

$$WR = b_0 \cdot \frac{\rho_{air}\ (\mu g\ m^{-3})}{\rho_{rain}(mg\ L^{-1})}$$

Washout ratios obtained for convective rain events for Banizoumbou and Cinzana and all the data together.

WR	R > 10 mm h^{-1} (R10)	
Banizoumbou	264 ± 69	N = 39
Cinzana	430 ± 113	N = 61
Banizoumbou + Cinzana	280 ± 49	N = 100

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Acknowledgment

This work was performed thanks to the INDAAF measurements (CNRS INSU), and supported by the LEFE-CHAT and the Fondation Air Liquide (DATSHA project). This work is part of the ERA4CS DustClim project.