Long term dust monitoring in West Africa from AMMA to INDAAF

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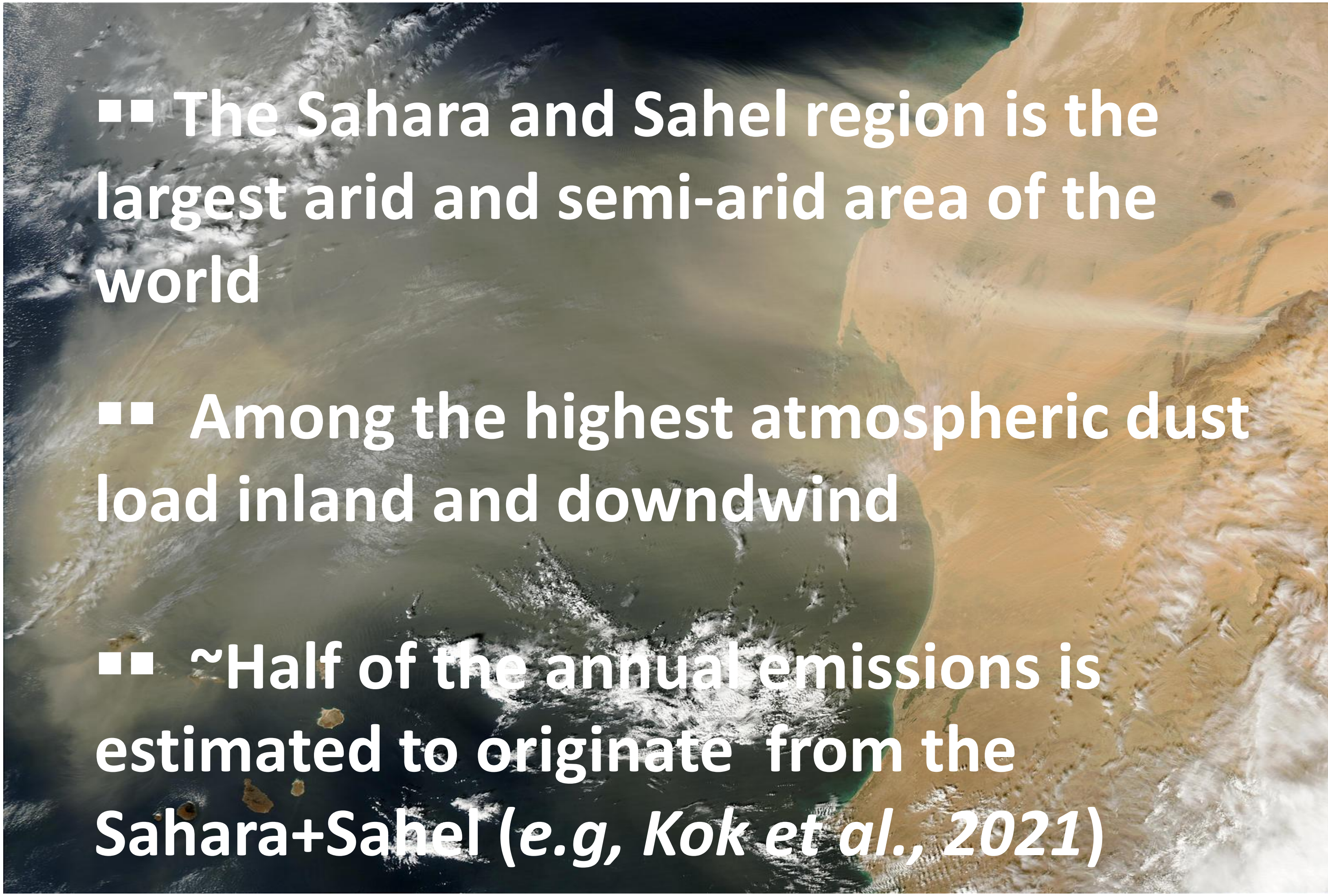
Why monitoring mineral dust in West Africa ?

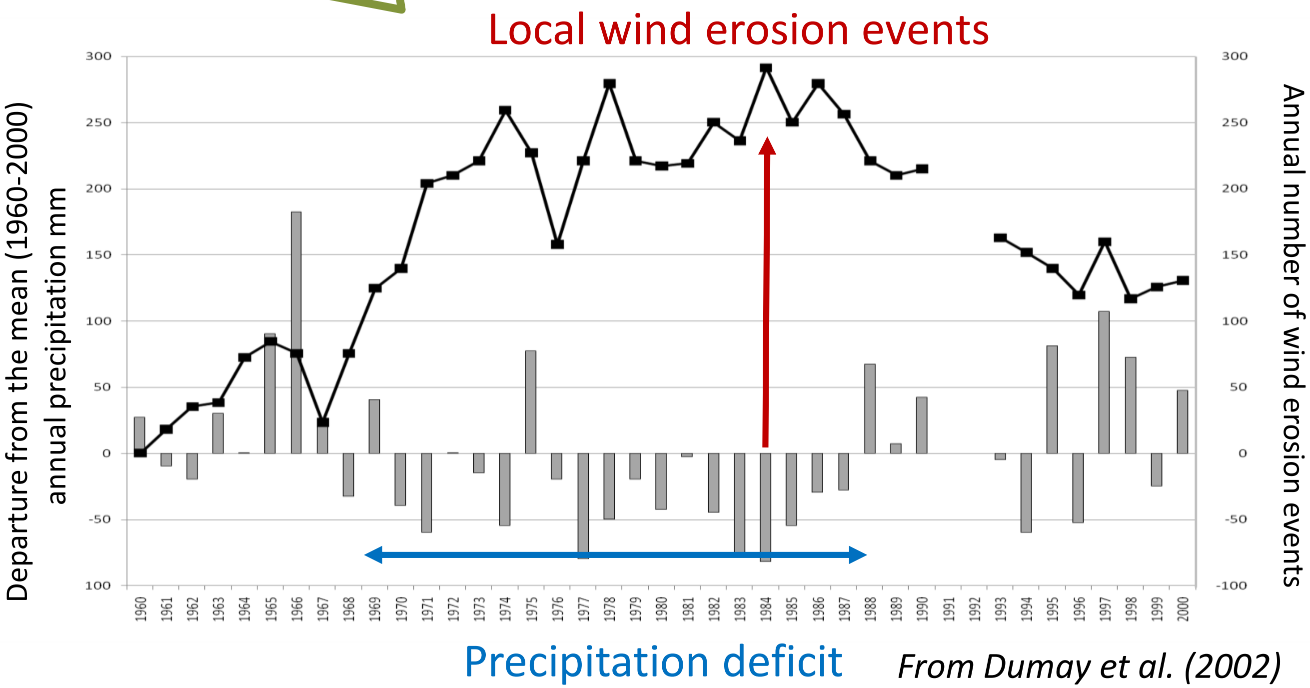


- The Sahara and Sahel region is the largest arid and semi-arid area of the world
- Among the highest atmospheric dust load inland and downwind
- ~Half of the annual emissions is estimated to originate from the Sahara+Sahel (*e.g, Kok et al., 2021*)

Mineral dust and wind erosion in the Sahel

A strong dependence with climate, directly or indirectly via the impact of vegetation

Nouakchott (Mauritania)

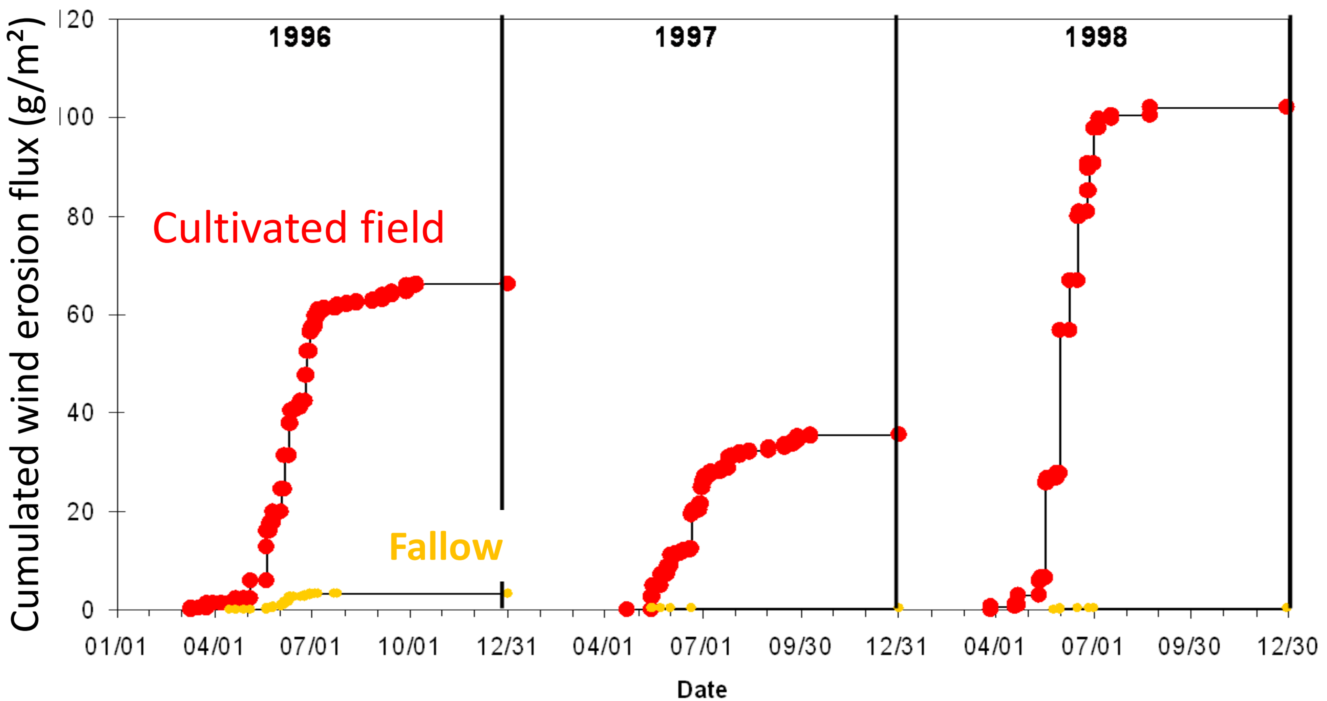


From Dumay et al. (2002)

- **Wind erosion increased during the drought periods**
- **Wind erosion remains higher after the drought than before**

Mineral dust and wind erosion in the Sahel

Land use can have a strong impact on wind erosion



Rajot (2001)

➔ **Wind erosion is measured only on cultivated fields, bare before the wet season and submitted to strong winds associated with convective systems.**

Mineral dust monitoring in the Sahel : the AMMA EOP

African Monsoon Interdisciplinary Analysis
2006-2009

Objectives for the Extended Observing Period

1- Quantify the atmospheric dust content in the Sahel
2- Understand the causes of their variability from the daily to the seasonal and interannual timescales.

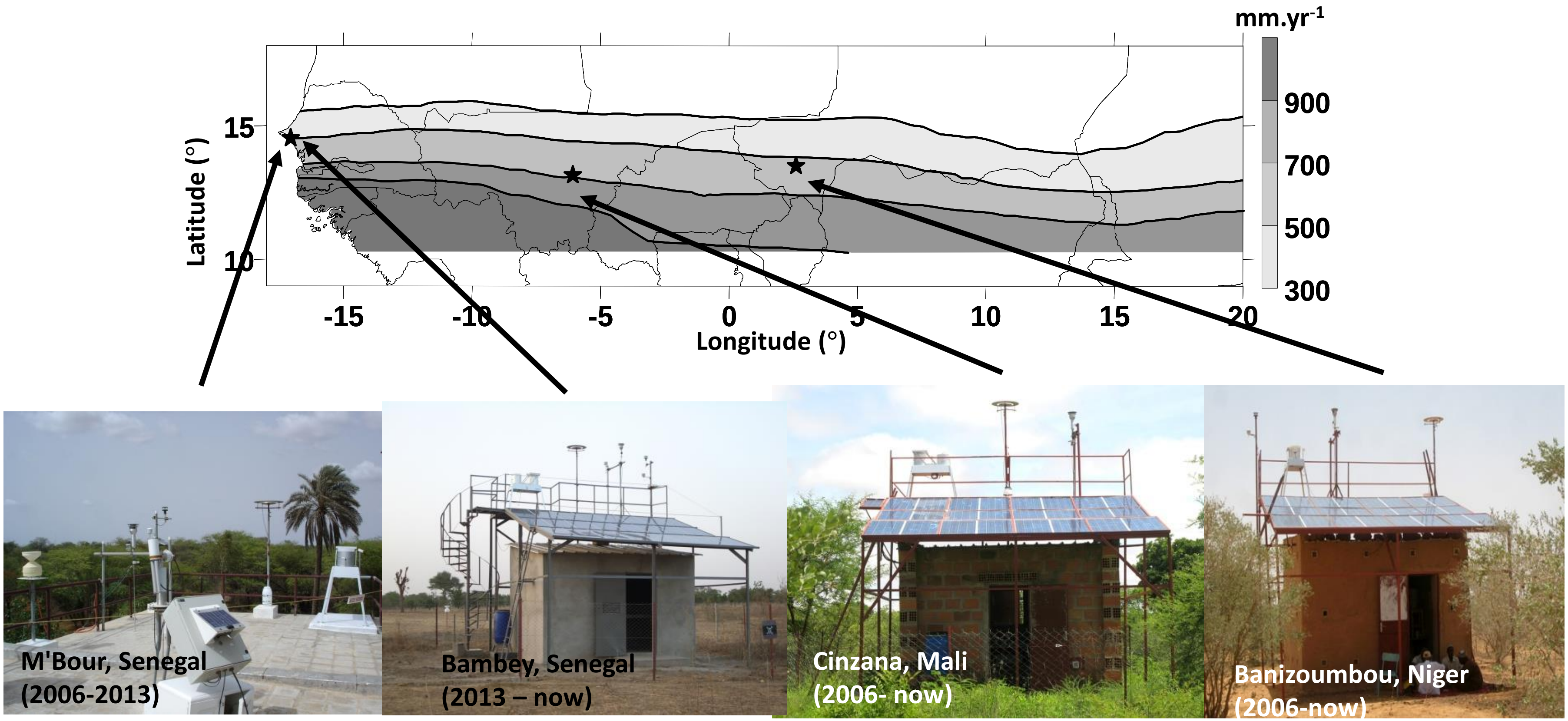
Strategy

Obtain a consistent data set to constrain the dust mass budget at the regional scale :

- **Vertically integrated amount (aerosol optical depth, AOD)**
- **Surface concentration**
- **Total and wet deposition fluxes**

Mineral dust monitoring in the Sahel

The "Sahelian Dust Transect "= 3 stations on the main pathway of Saharan and Sahelian dust toward the Atlantic Ocean



(Marticorena et al., ACP, 2010)

Mineral dust monitoring in the Sahel

INSTRUMENTATION : simple and resistant to severe dust and temperature conditions

TEOM

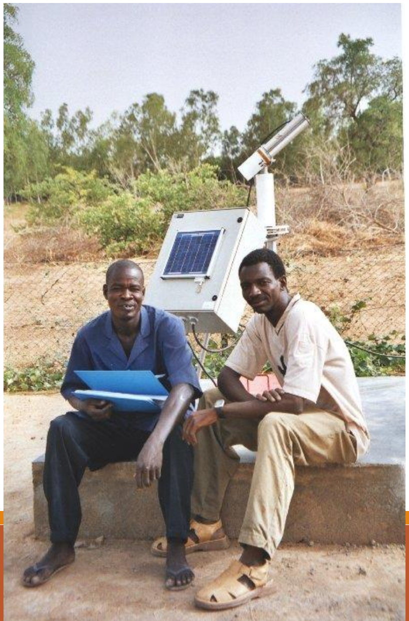
PM10 mass concentration
(5 min)

PM10 inlet

Total and wet deposition
(week and/or rain event)

Aerosol Optical Depth
AERONET/PHOTONS
sunphotometers
(~15 min)

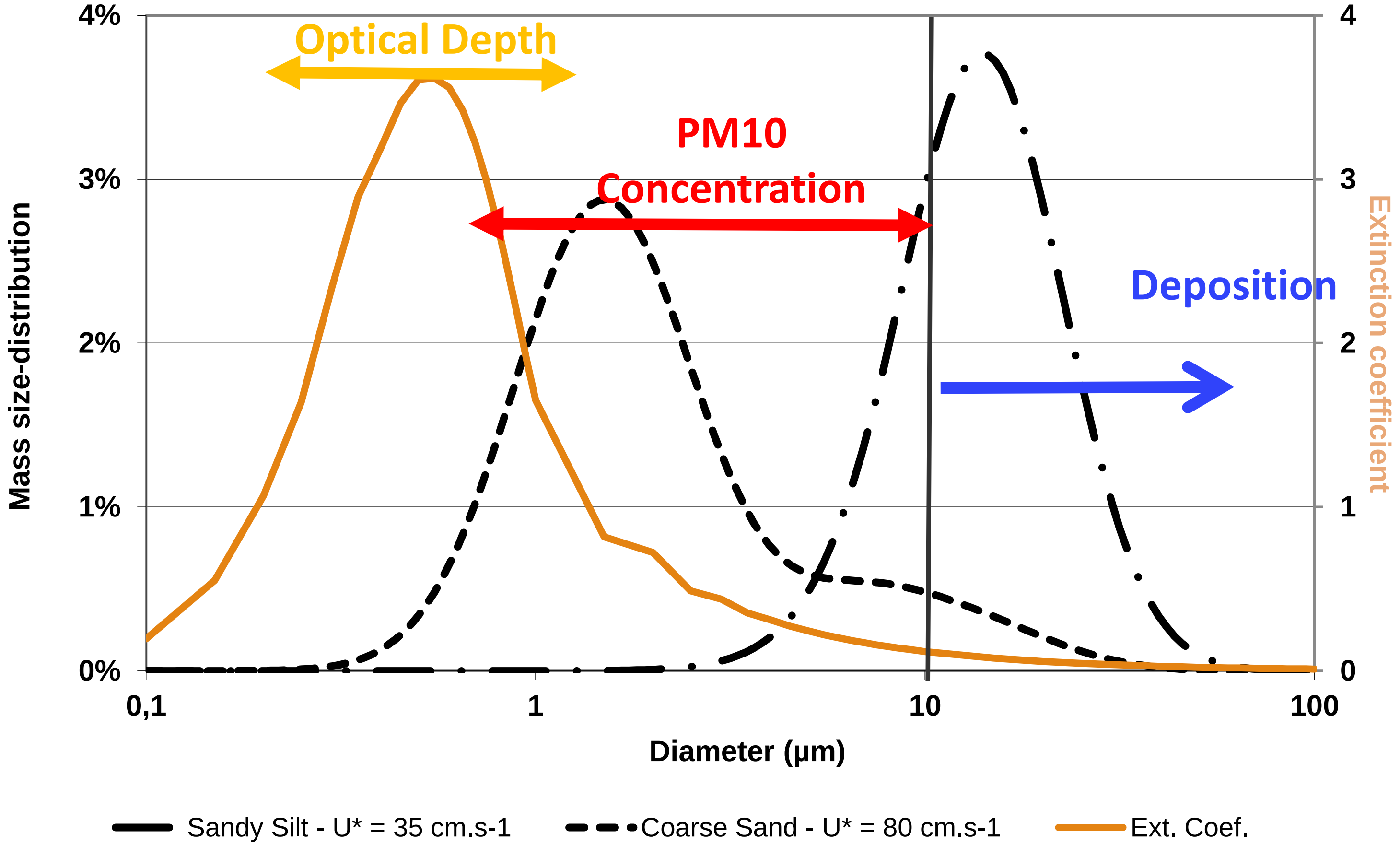
AERONET
AEROSOL ROBOTIC NETWORK



Meteorology (5 min)
- Wind speed
- Wind direction
- Air temperature
- Relative Humidity

Mineral dust monitoring in the Sahel

Monitored parameters and size-distribution

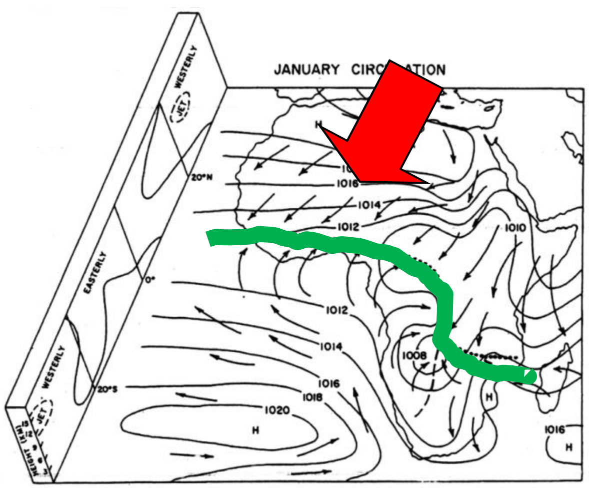


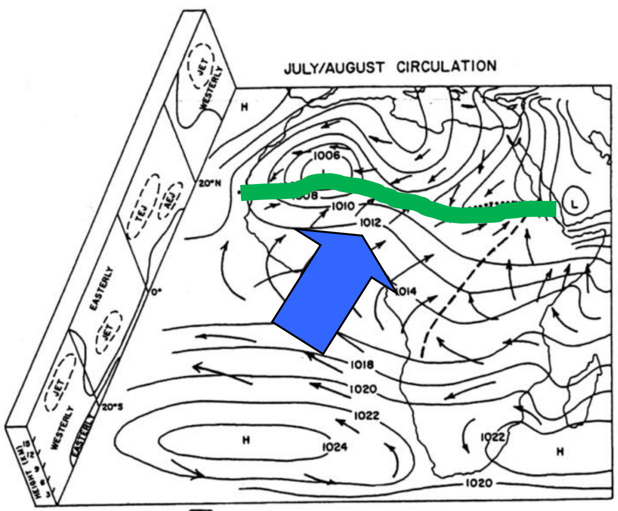
Dust size-distributions derived from a sandblasting model
Alfaro et al. (1996, 1998)

Refractive index @550 nm
(1.5–0.005i)

Seasonal cycle

Mineral dust monitoring in the Sahel





Dry Season = Winter

Harmattan
(Hot and dry)

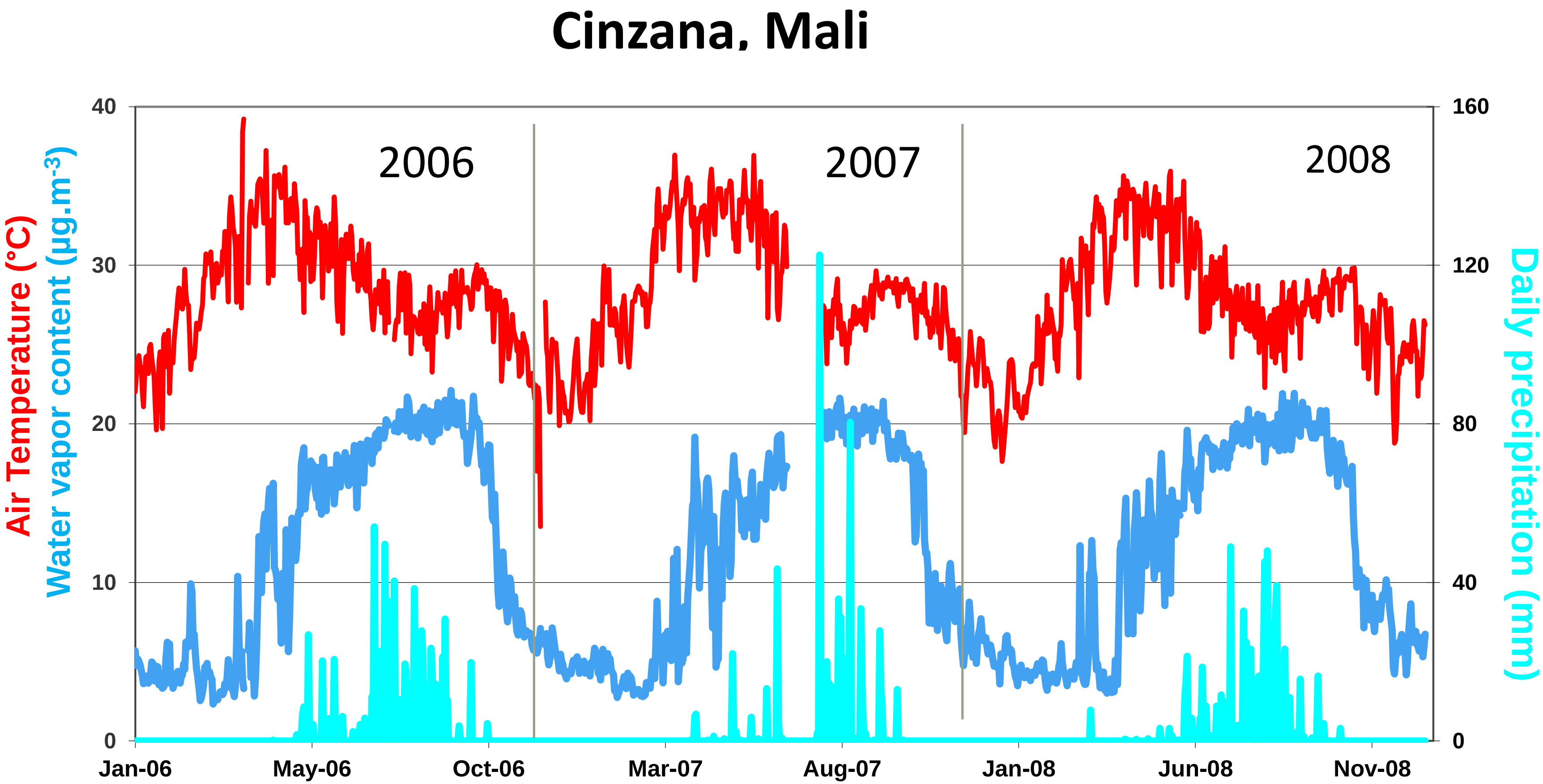
⇨ **2 contrasted seasons**
⇨ **modulated by the displacement of the Intertropical Convergence Zone (ITCZ)**

Wet season = Summer

Monsoon
(Hot and Moist)

(N'Tchayi et al., 1997)

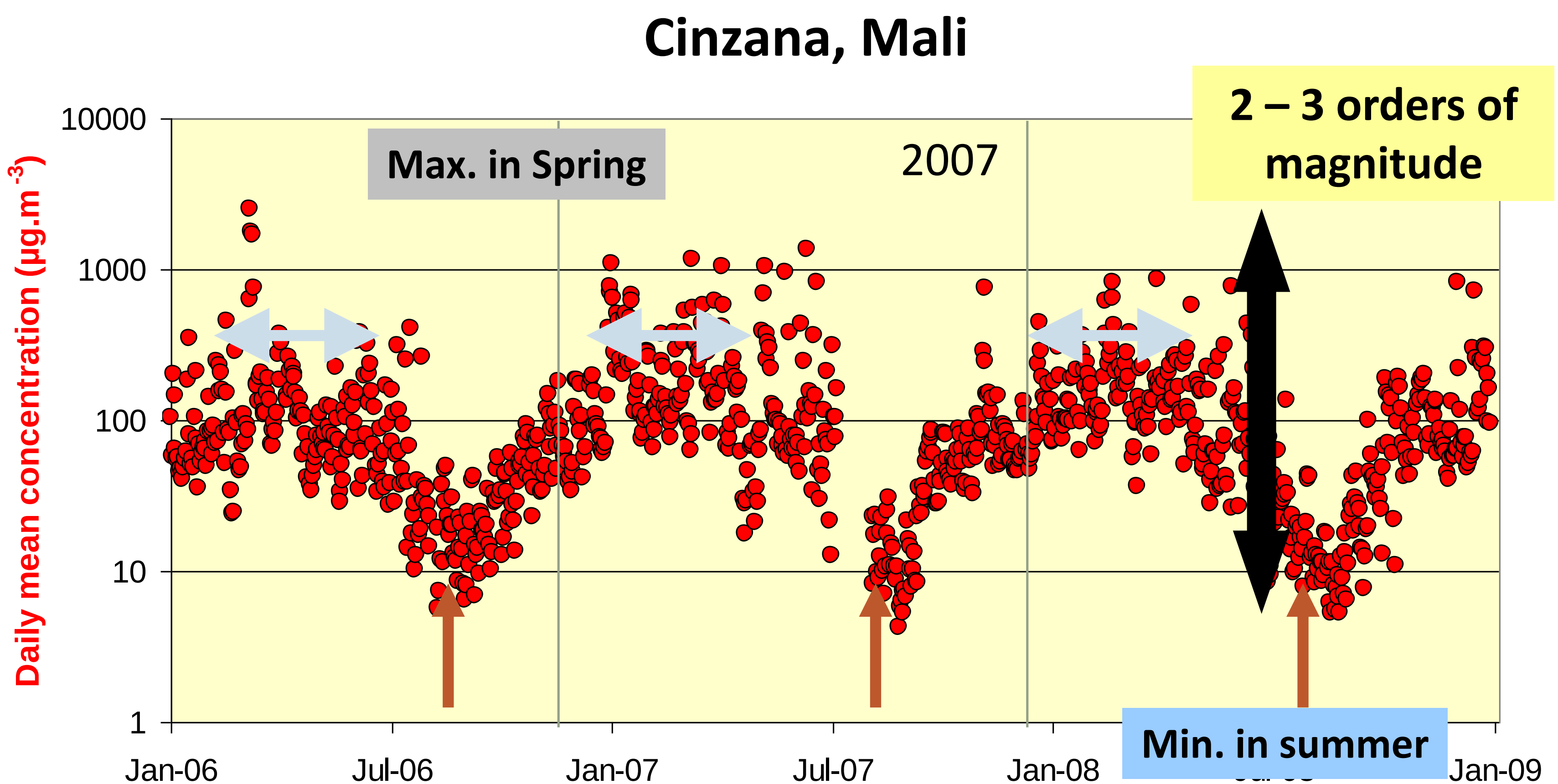
Mineral dust monitoring in the Sahel



⇨ **A typical seasonal cycle : succession of the Harmattan and Monsoon flux**

(Marticorena et al.,ACP, 2010)

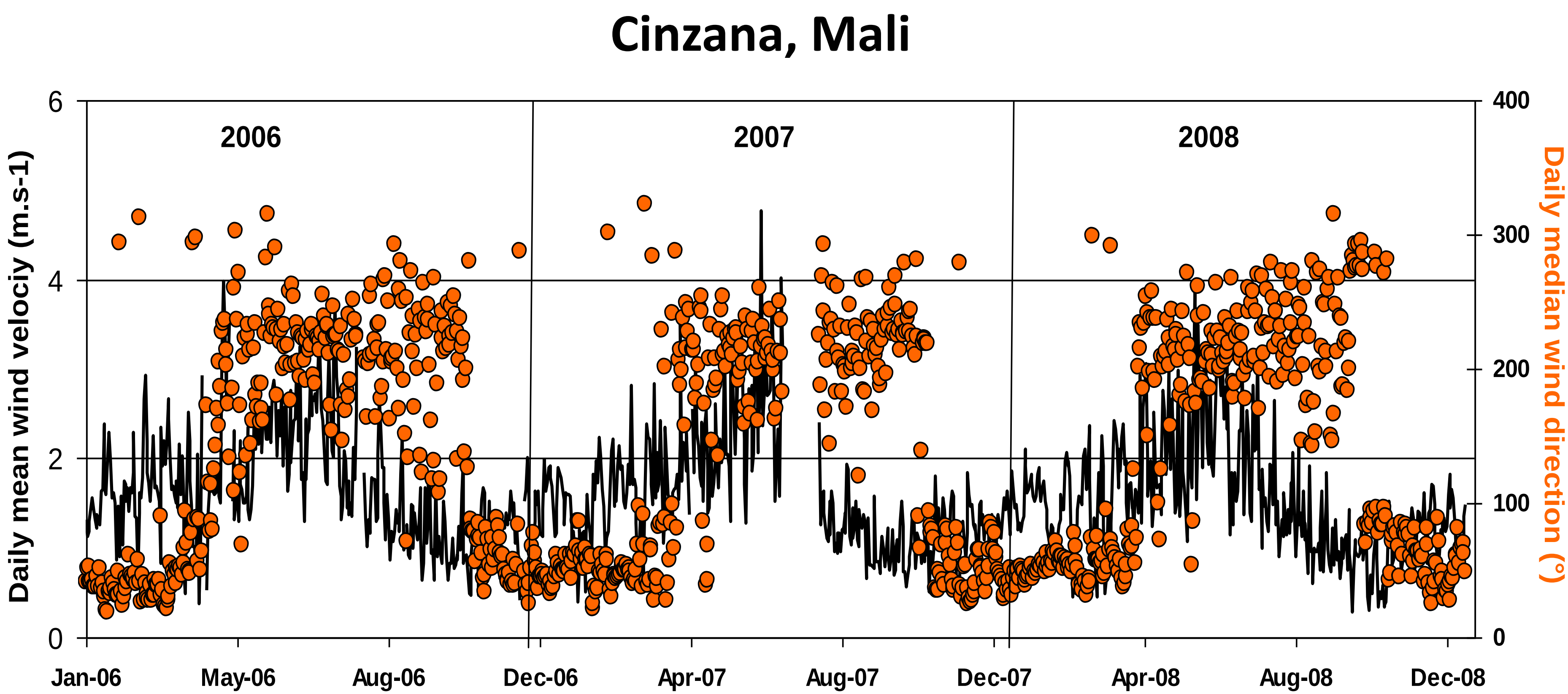
Mineral dust concentration : seasonal cycle



⇨ **A well-marked seasonal cycle, not phased with the two climatological seasons Harmattan/Monsoon**

(Marticorena et al.,ACP, 2010)

Mineral dust concentration : seasonal cycle

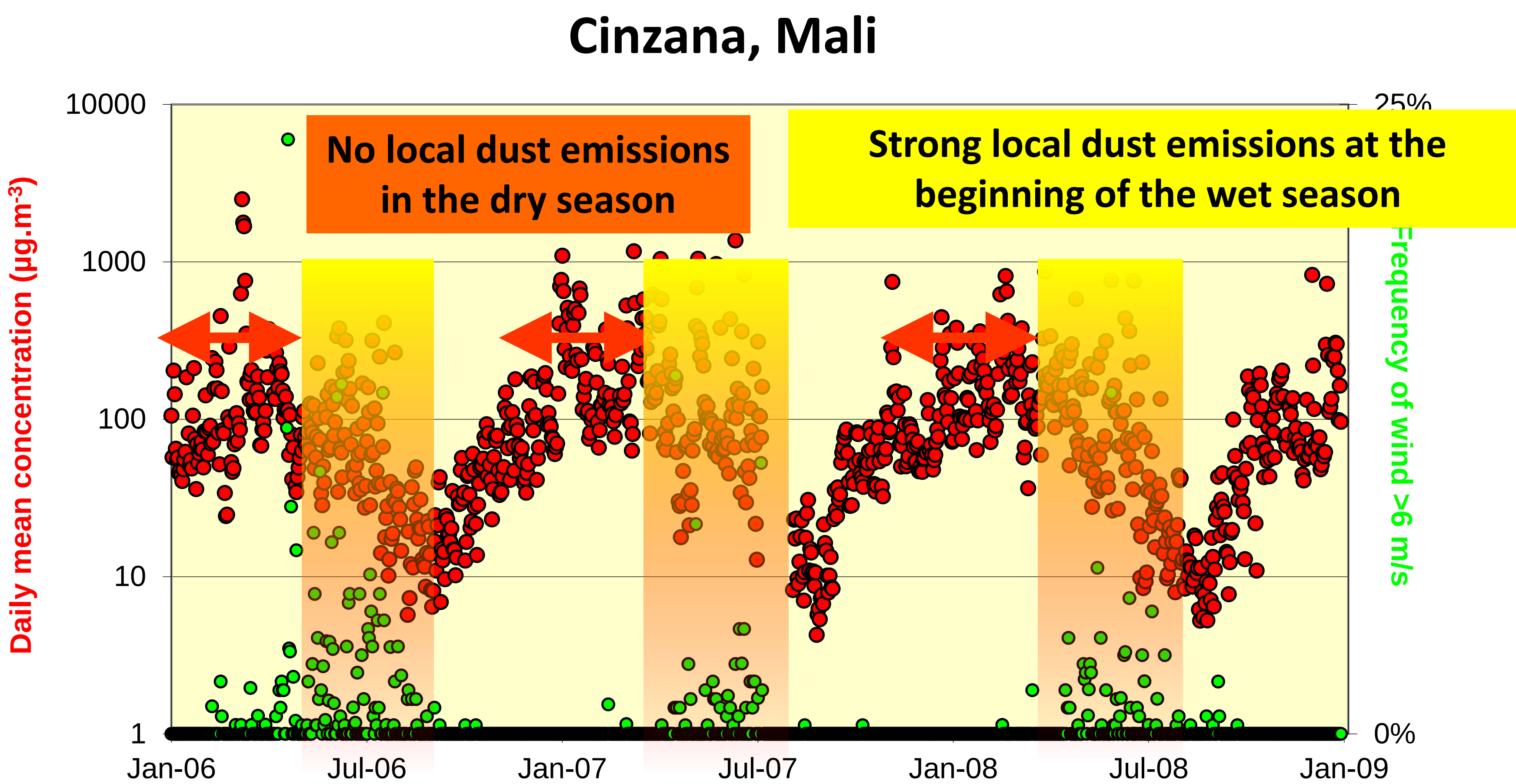


⇨**Wind velocity : max in the beginning of the summer and min in autum**

⇨ **The surface winds are not phased with the dust concentrations**

(Marticorena et al.,ACP, 2010)

Mineral dust concentration : seasonal cycle



⇨ **Local dust emissions are recorded at the beginning of the wet season**

⇨ **The maximum of dust concentrations is due to Saharan dust transport**

(Marticorena et al.,ACP, 2010)

Seasonal cycle

- **Saharan dust transport in the dry season**
  - **Monthly or seasonal average : the highest dust concentration in the year**

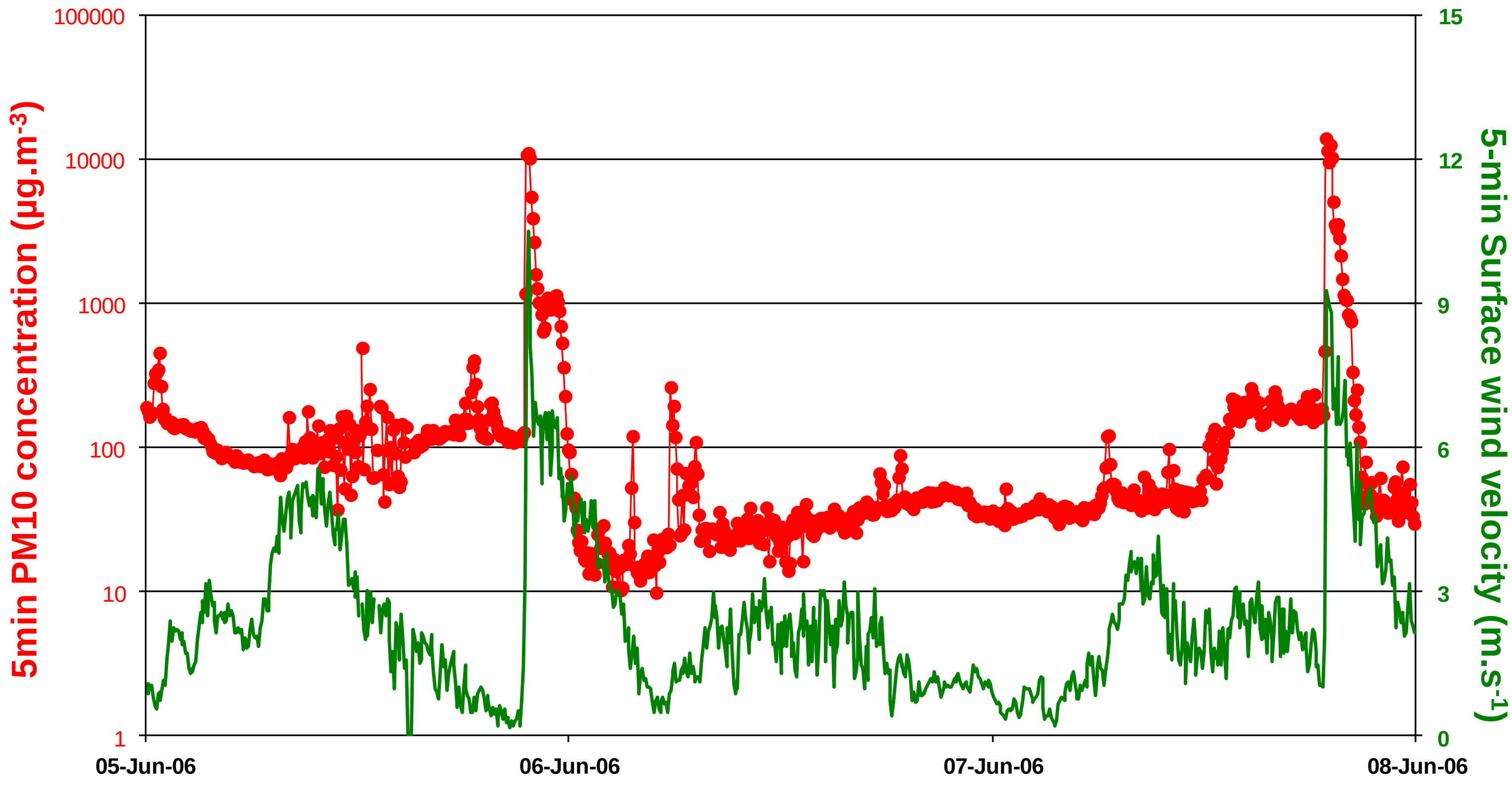
- **Local dust emissions in the wet season**
  - **Extremely high local/ponctual dust concentration**

Dust emissions in the wet season

Mineral dust concentration : wet season events

An extreme wet season event

PM10 Concentrations and wind velocity (Cinzana, Mali)

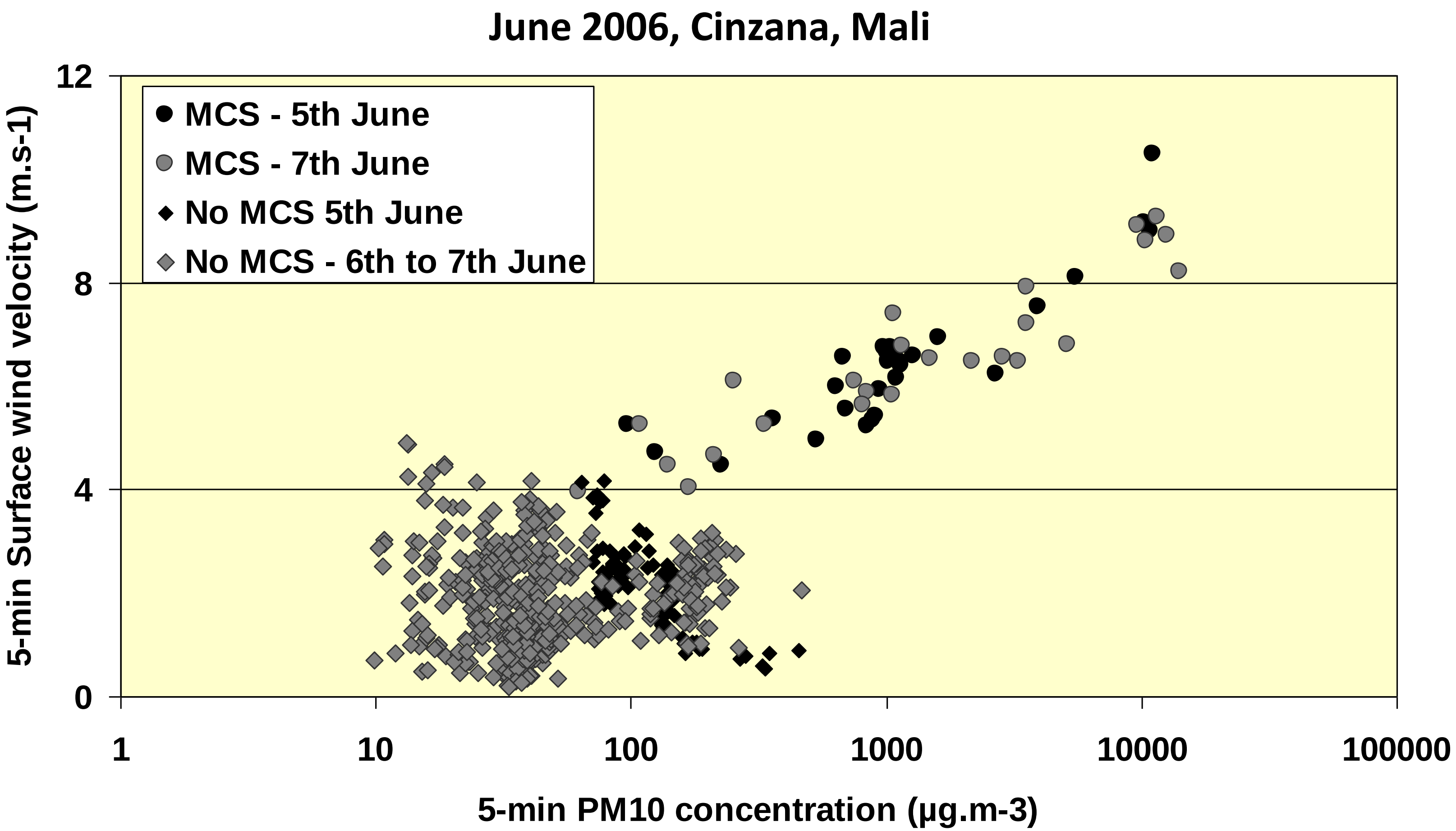


⇨ **The PM10 concentration increases by two orders of magnitude in ~ 10 min**

⇨ **The dust concentration and the wind velocity increase simultaneously**

(Marticorena et al., 2010)

Mineral dust concentration : wet season events



⇨ **Correlation between concentration and wind velocity**

= local wind erosion and dust emissions due to the high wind associated with Mesoscale Convective systems (MCS)

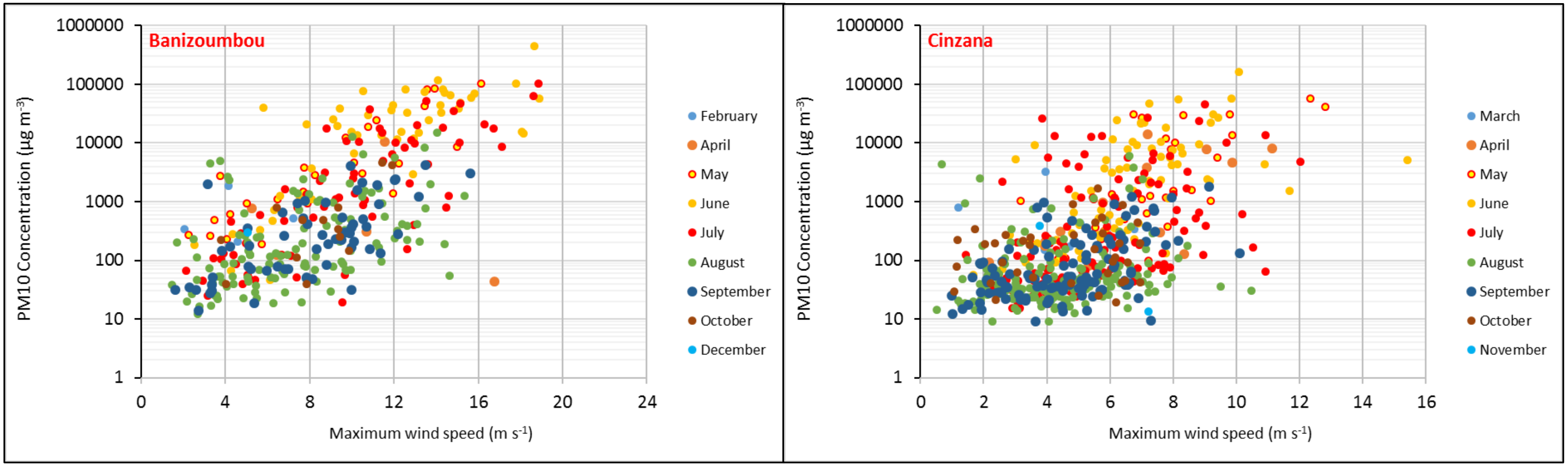
(Marticorena et al., 2010)

Mineral dust concentration : wet season event

View of a dust front associated with a Mesoscale Convective System (MCS)

Mineral dust concentration : wet season events

Relationship between dust concentration and maximum wind speed (2006-2016)



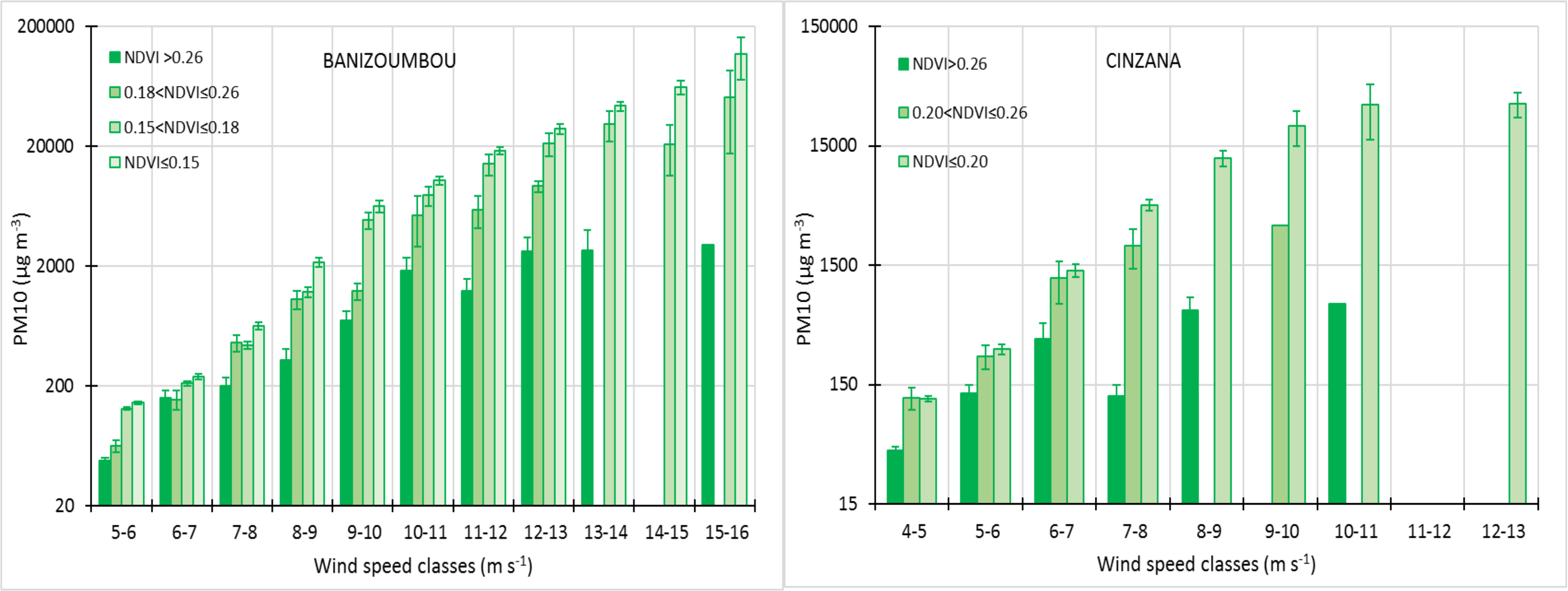
- **Correlation between dust concentration and maximum wind speed = local wind erosion and dust emissions**

- **From may to october, the relation is shifted because of an increase of the erosion threshold due to the growing vegetation**

Mineral dust concentration intraseasonal pattern

Relationship between dust concentration and vegetation

PM10 concentration distribution by wind speed classes for different vegetation cover (NDVI)



-> PM10 concentrations are significantly lowered (up to 80%) when vegetation develops during the wet season.

(Bergametti et al., GRL, 2020)

Dust emissions in the wet season

- **Dust emission decreases along the wet season due to :**
  - **(1) the decrease of the wind speed associated with the changes in the convective activity**
  - **(2) the increase of the erosion threshold due to vegetation growth**

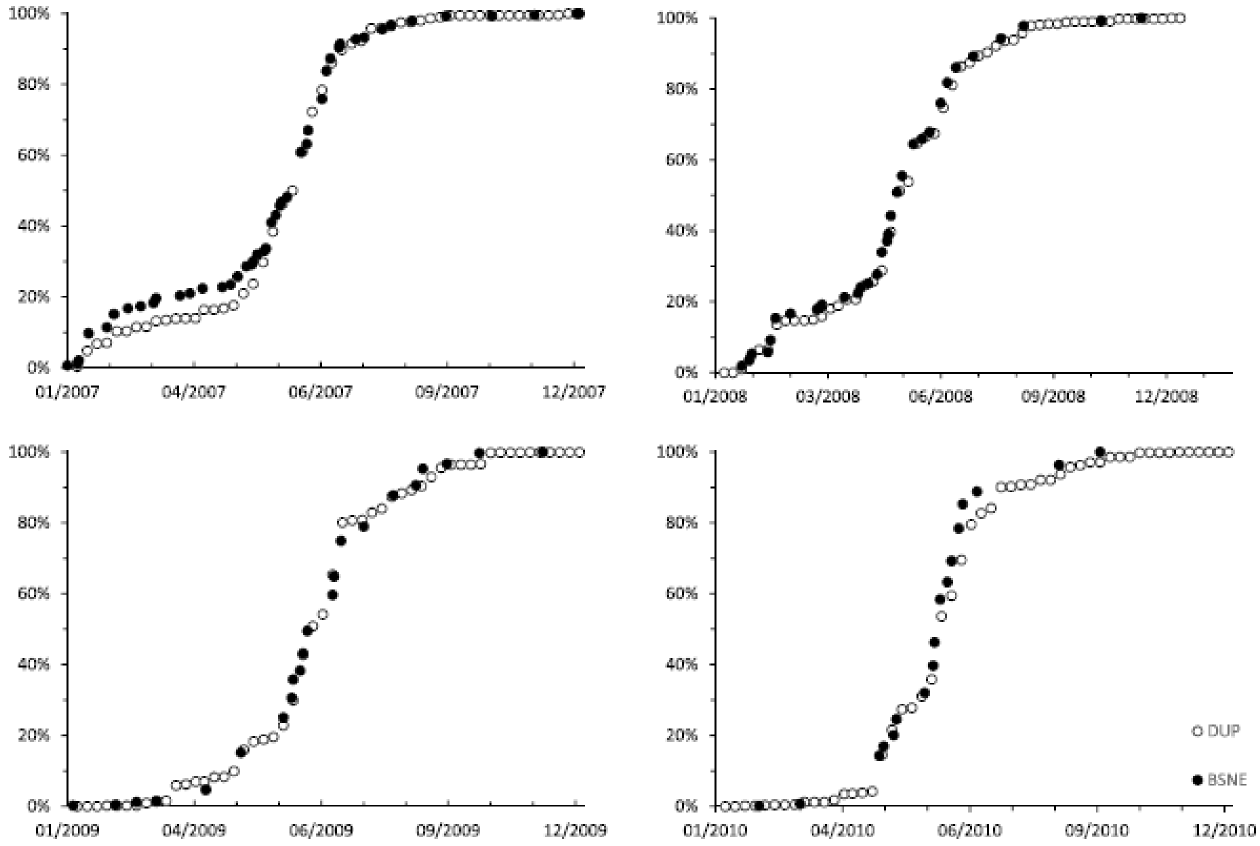
Seasonality of Potential Wind Erosion

Dust Uplift Potential and local wind erosion

Cumulative weekly DUP and cumulative horizontal sediment fluxes measured using BSNE catchers in Banizoumbou from 2007 to 2010.

$$DUP = u^3(1 + {}^{u_t}/_{u})\left(1 - {}^{u_t^2}/_{u^2}\right) \quad \text{for } u > u_t \text{ and 0 otherwise;}$$

(Marsham et al., 2011)

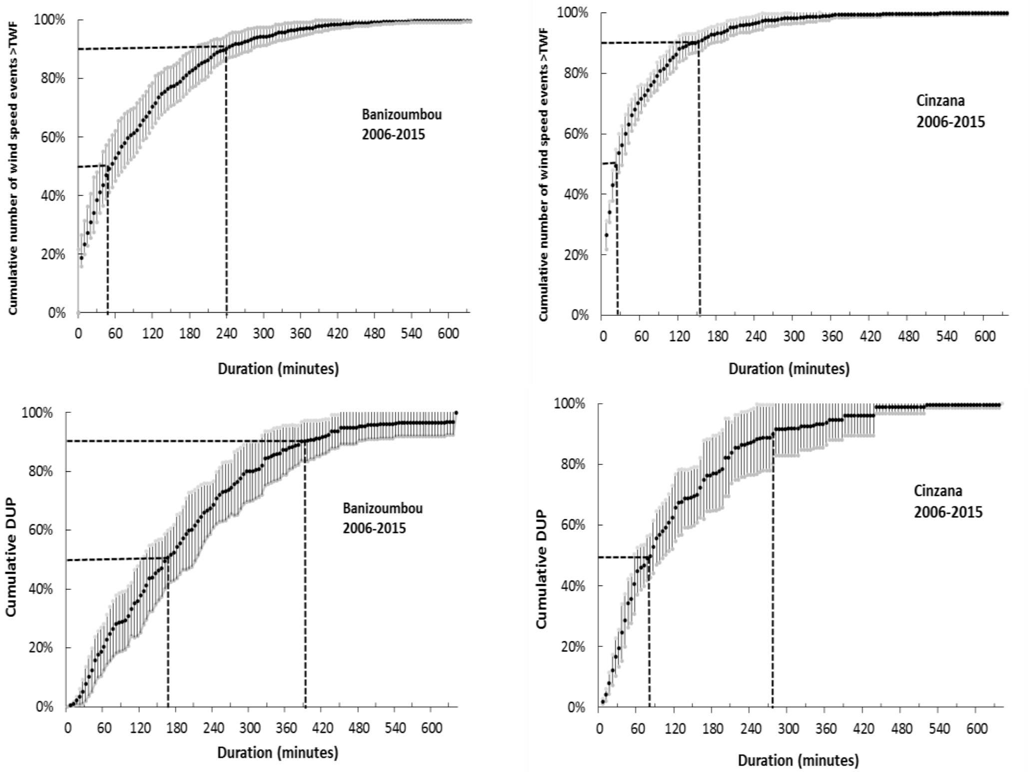


⇨ **The 5-min DUP is a good proxy of the dynamic of wind erosion over a bare surface = the maximum wind erosion for a given wind regime**

(Bergametti et al., JGR, 2017)

Dust Uplift Potential and local wind erosion

Cumulative distributions of the duration of wind speed events > TWV (top) and of DUP (bottom) for Banizoumbou (left) and Cinzana (right) averaged over the period 2006-2015.



- ❑ 50% of the periods having wind speeds higher than the threshold wind velocity have duration less than 60 minutes

- ❑ 50% of the DUP is due to events of wind speed higher than threshold wind velocity having duration less than 2h45 in Banizoumbou and 1h20 in Cinzana

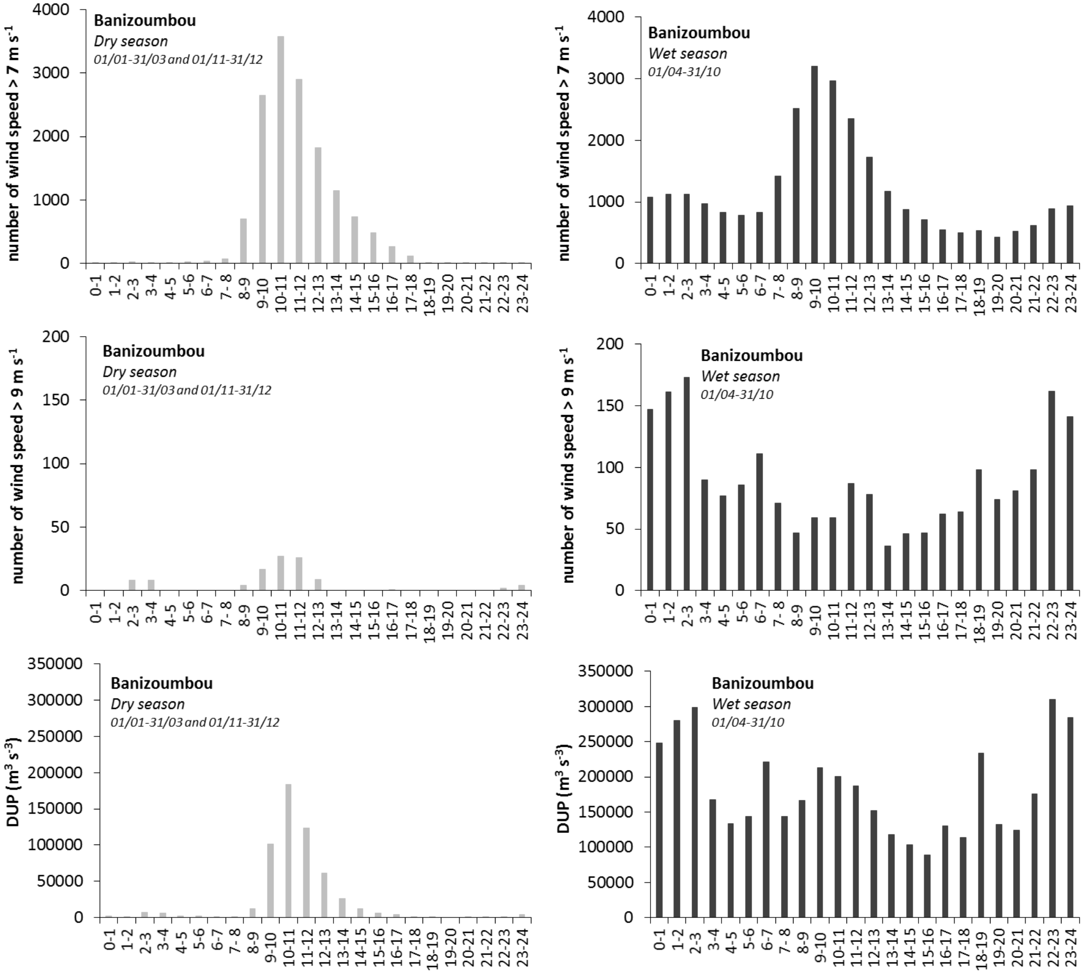
⇨ Most of the DUP is due to short duration events

⇨It cannot be properly estimated with a low time resolution sampling

(Bergametti et al., JGR, 2017)

Dust Uplift Potential : diurnal and seasonal pattern

Diurnal cycle of the number of 5-min wind speeds > 7 m s^{-1} (top), > 9 m s^{-1} (middle) and DUP (bottom) in Banizoumbou (Niger). Left: dry season, right: wet season.



⇨ The DUP in the dry season is only due to the LLJ

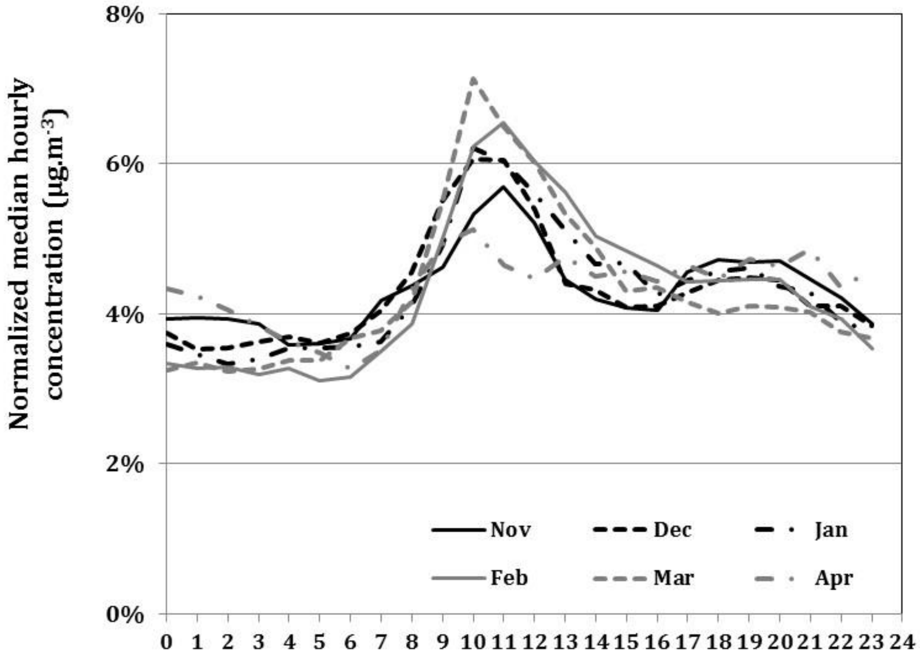
⇨In the wet season, the DUP it is mainly driven by convective winds associated with MCS

(Bergametti et al., JGR, 2017)

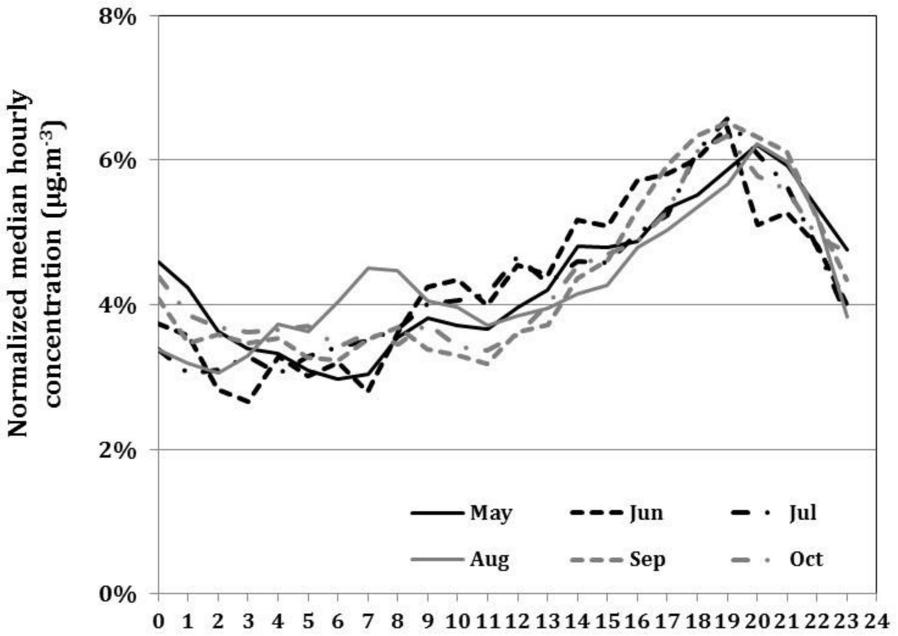
Mineral dust : diurnal cycle and seasonal pattern

Diurnal cycle of the PM10 concentrations
Banizoumbou (Niger) (2006-2011)

Dry season



Wet season



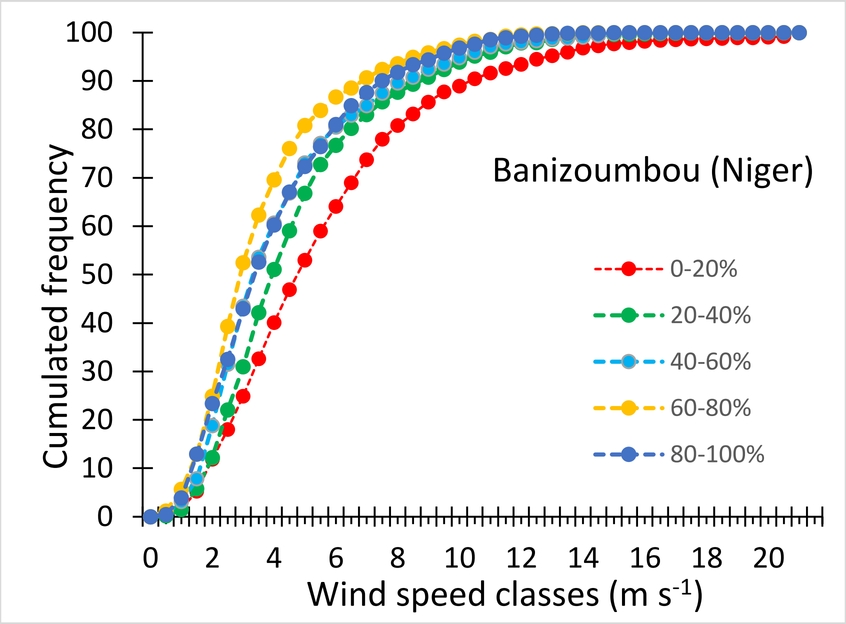
⇨ The diurnal cycles of the concentrations highlight the dynamical processes responsible of dust transport and emissions

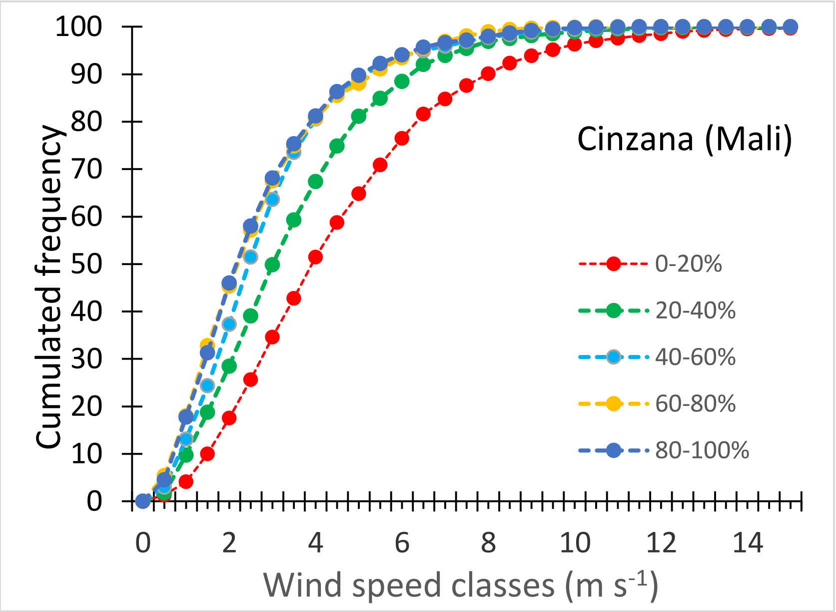
- Low level jet in the dry season = mainly transport
- Convection in the wet season = local wind erosion and dust emissions

(Kaly et al., Amos. Res, 2015)

Wind speed distribution and precipitation

Wind speed distribution associated with the different cumulative fractions of precipitation

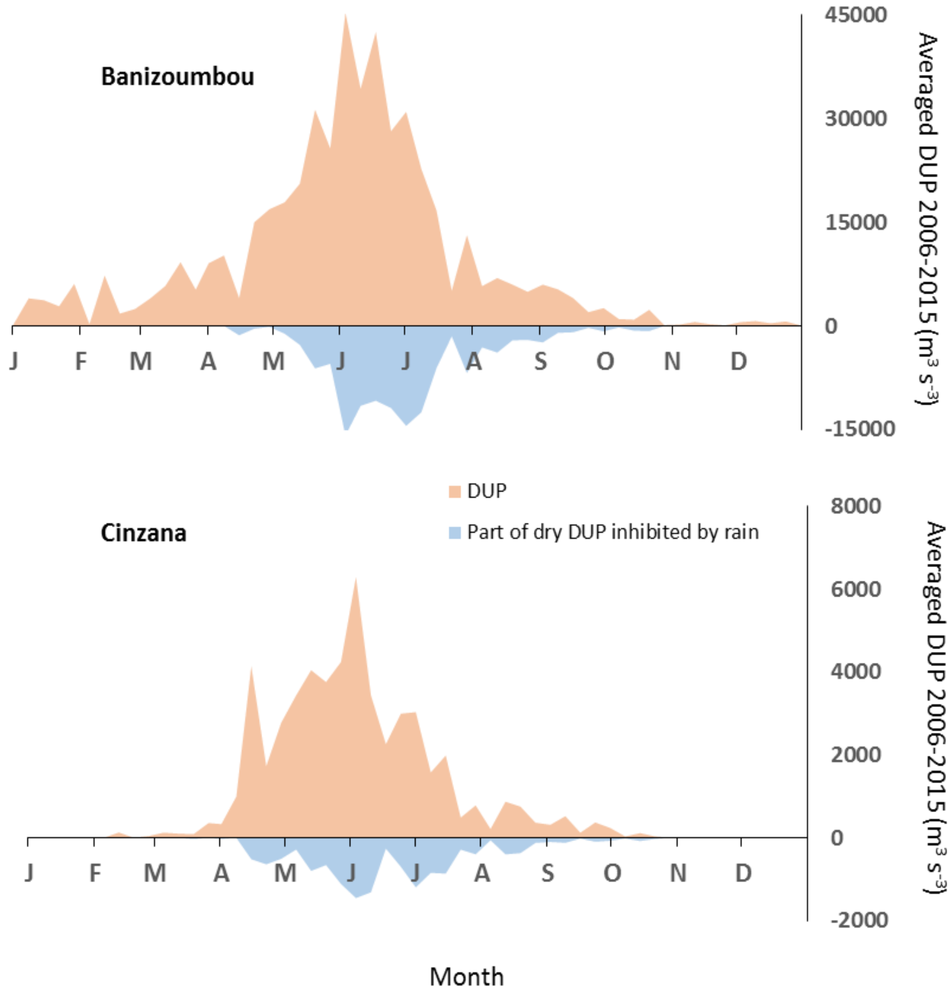




- **The highest wind speeds correspond to the beginning of the wet season**
- **Their intensity decrease during the wet season**

(Bergametti et al., JGR, 2017)

Dust Uplift potential and precipitation



Impact of precipitation on the annual DUP

-26% in Banizoumbou (-18 to -34%)
-25% in Cinzana (-12 to -36%)

⇨ The impact of precipitation is significant but it is not a major driver

(Bergametti et al., JGR, 2017)

Seasonality of potential wind erosion

- **The DUP is a good proxy of local wind erosion (and local dust emission)** if computed with the relevant resolution since periods of wind > erosion threshold are less than a few hours
- Both the descend of the **NLLJ and MCS produce significant DUP,** but in Banizoumbou (Niger) and Cinzana (Mali), **MCS contribution largelly dominates**
- **Precipitation affects wind erosion but is not a major factor since it occurs when wind speeds are lower**
  - **the change in the surface wind speed is the main driver !**

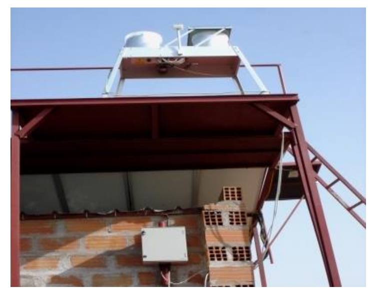
Dust deposition

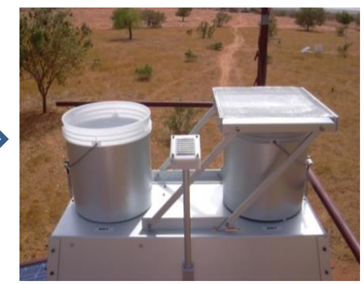
Mineral dust deposition

DEPOSITION FLUX MEASUREMENTS

Total deposition collector (Inverted frisbee + aerodynamic disc + marbles)

Wet deposition automatic collector (MTX)





Collection with water

Decantation

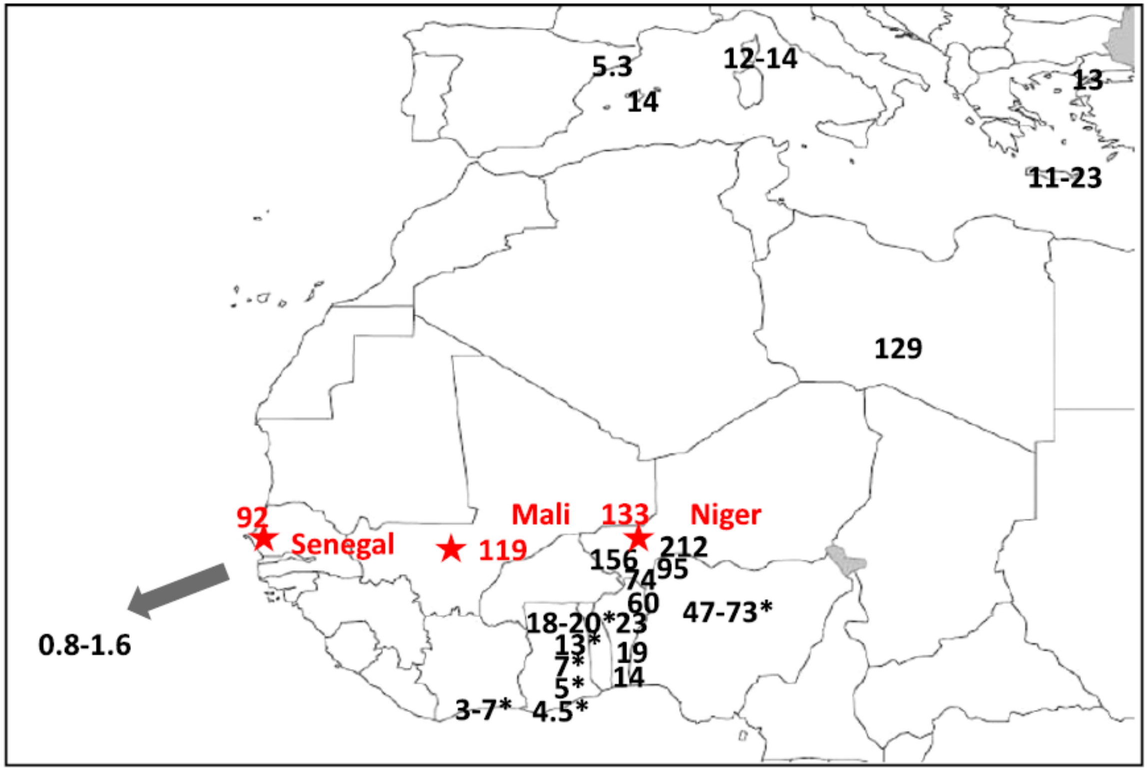
Drying

Weighing

Total and wet deposition mass flux (insoluble)

Mineral dust deposition : annual fluxes and spatial pattern

Annual mean deposition flux 2006-2012



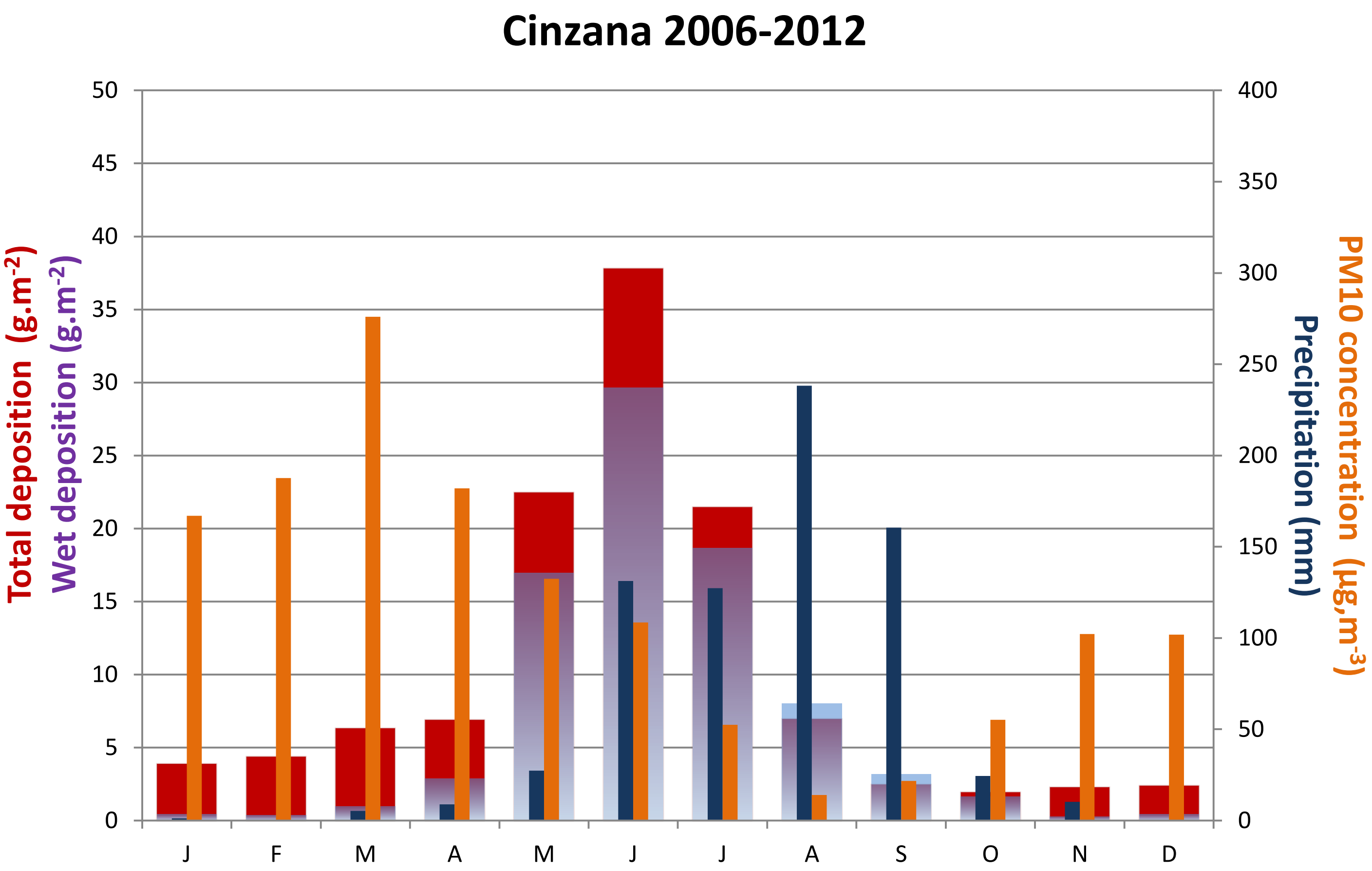
Senegal, Mali and Niger (this work);
Niger [*Drees et al.,* 1993; *Herrmann*, 1996; *Rajot*, 2001];
Libya [*O'Hara et al*., 2006], Ghana [*Breuning-Madsen et al*., 2015],
Nigeria [*Møberg et al*., 1991],
Ivory Coast [*Stoorvogel et al*., 1997],
Spain [*Avila et al.,* 1997];
Balearic Islands [*Fiol et al*., 2005];
Corsica [*Bergametti et al*., 1989; *Löye-Pilot et al*., 1986];
Turkey [*Kubilay et al*., 2000];
Kriti [*Mattson and Nihlén*, 1996];
Barbados [*Prospero et al*., 2010].
*Dry season only

⇨ **Our data are consistent with the litterature**

⇨ **Deposition fluxes decrease from the sources to the transport regions in all directions**

(Marticorena et al., JGR, 2017)

Mineral dust deposition



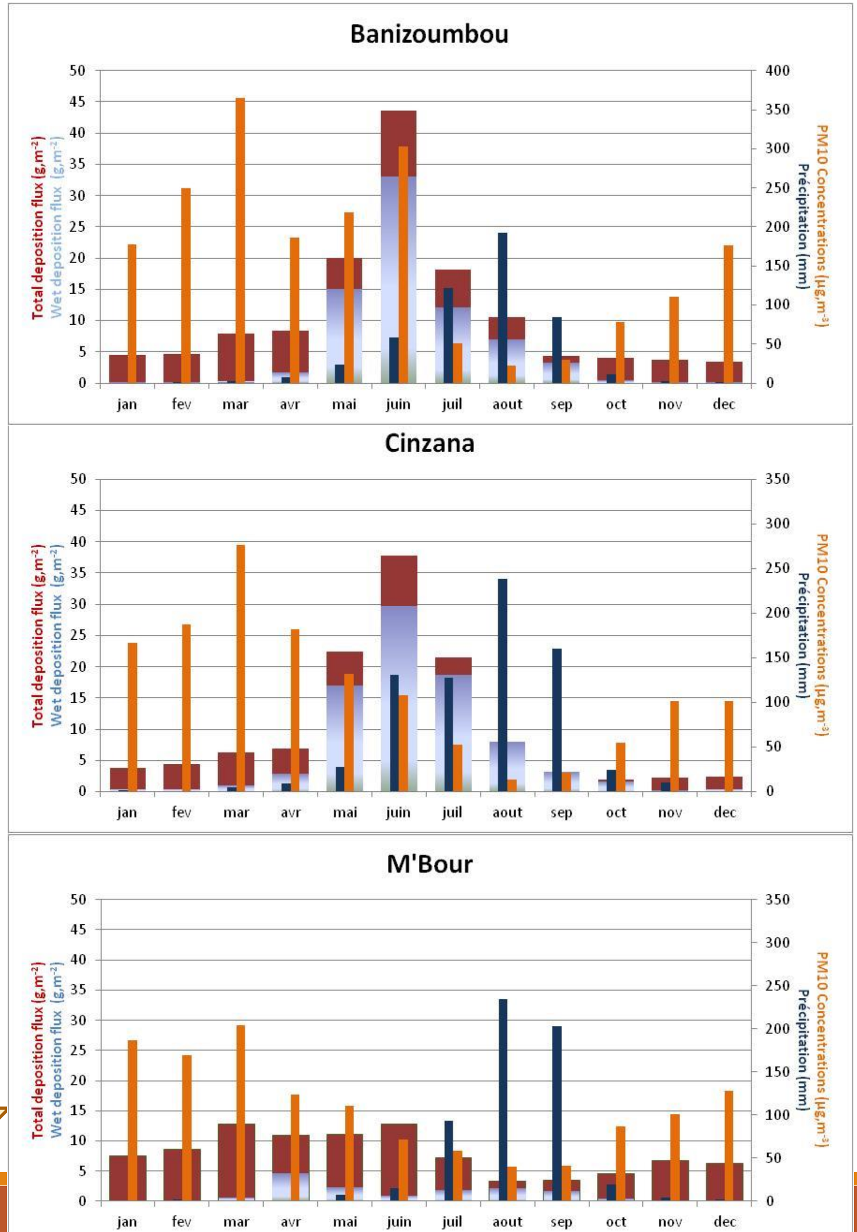
- ➢ **PM10 concentrations are maximum in March**
- ➢ **Précipitation are maximum in August ↔ minimum concentration**
- ➢ **High concentrations + précipitation ↔ wet deposition maximum in June**

(Marticorena et al., JGR, 2017)

Mineral dust deposition

East

West



Higher [PM10]
Lower precipitation : 505 mm
-> wet deposition
= **52%** of total deposition

Precipitation 735 mm
-> wet deposition
= **62%** of total deposition

Lower [PM10]
Lower precipitation : 594 mm
-> wet deposition
= **8 %** of total deposition

(Marticorena et al., JGR, 2017)

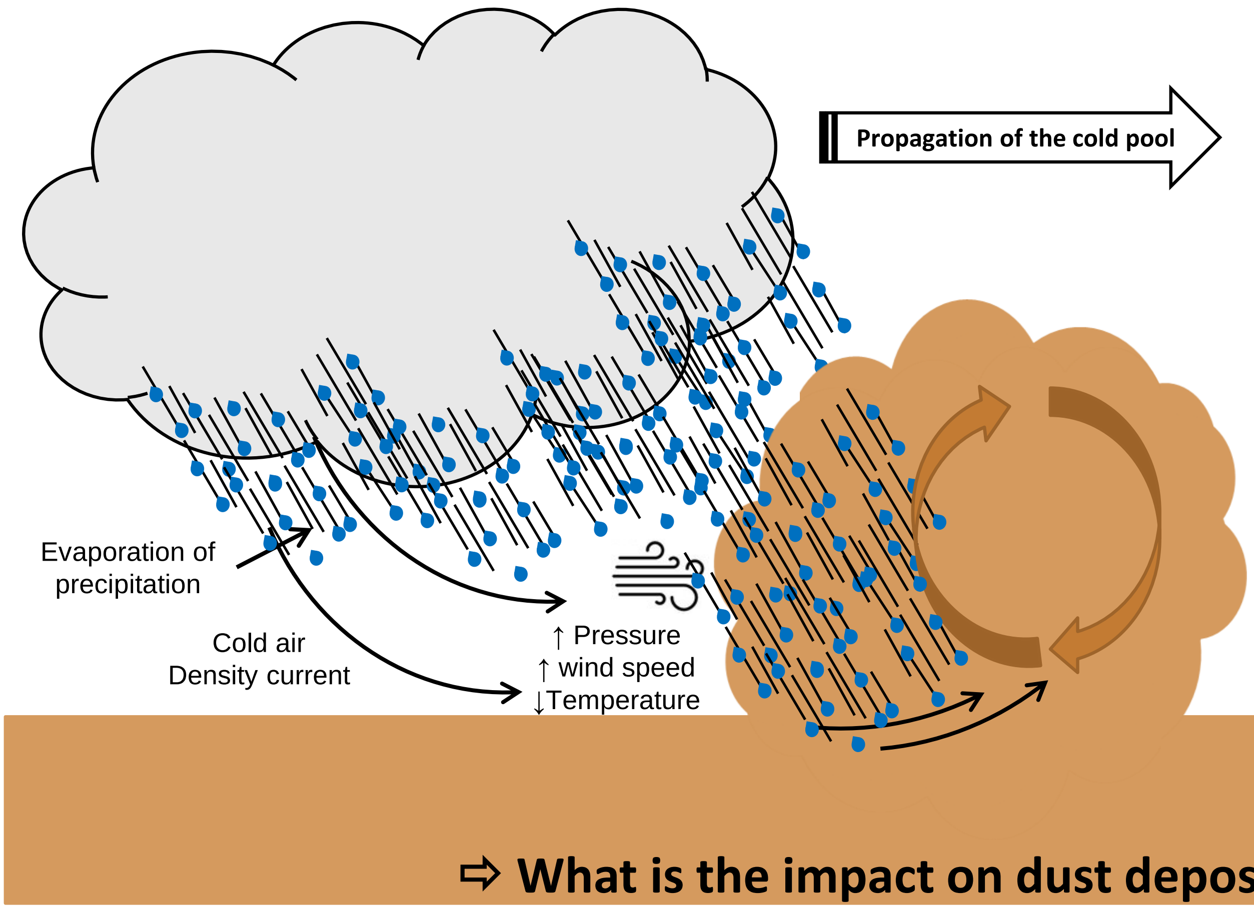
Dust deposition

- **Annual dust deposition is ~100 $g.m^{-2}$**
- **Wet deposition represents up to 60% of total deposition in Mali and ~50% in Niger but only 8% in Senegal**
- **The timing of the precipitation is a major factor of variability**
- **The highest deposition fluxes are wet and are related to the highest dust concentration due to local dust emissions by convective systems**

Convection and deposition

MCS « detection » based on local meteorological monitoring

MCS and cold pool



Adapted from Bukowski *et al.*, 2021
and Knippertz et al., 2007

⇨ **What is the impact on dust deposition ?**

(Audoux, 2022)

MCS « detection » based on local meteorological monitoring

➢ **Try and detect the « cold pools » and « gust fronts » from the INDAAF meteorological data in Banizoumbou (Niger) et Cinzana (Mali) from 2006 to 2016**

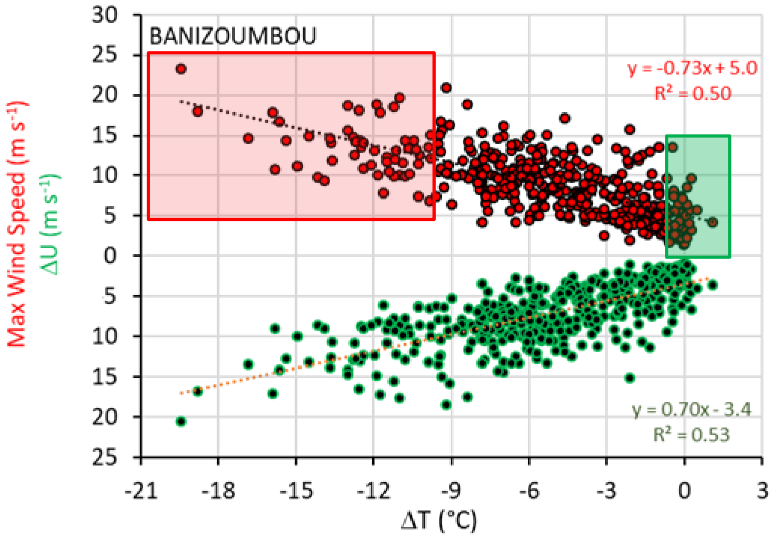
- **Indicator of convection =** Precipitation occurrence
  - A precipitation event = P>0,2 mm
- **Computation of the change in temperature, wind speed and relative humidity** : ΔT, ΔV, ΔRH
  - Period of computation = +/- 90 min before and after precipitation starts
- **Detection of the maximum wind speed**

From Provod et al., 2016,

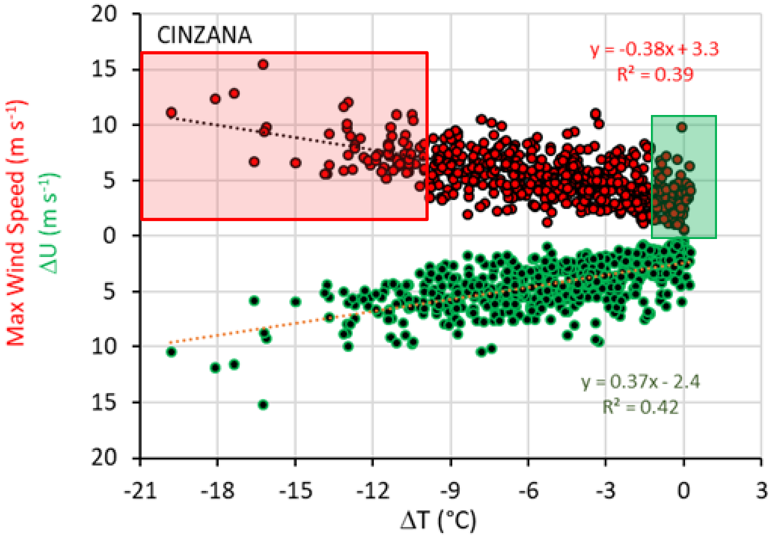
MCS detection based on local meteorological monitoring

Relationship between wind and temperature (2006-2016)

432 precipitation events



586 precipitation events



Convective ← Stratiforme

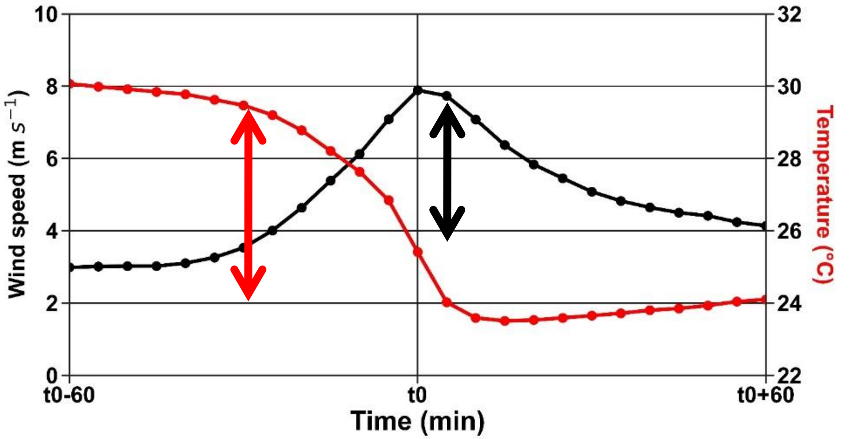
Convective ← Stratiforme

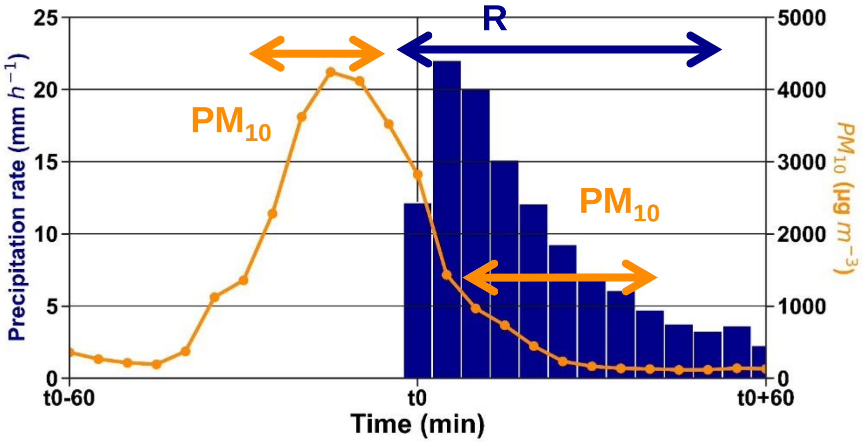
(Bergametti et al., JGR 2022)

Cold pool characteristics

Meteorological criteria
(Provod *et al*., 2016)
$\Delta V > 0$ m s^{-1}
$\Delta T < -2°C$
ΔDirection > 30°

Banizoumbou (Niger) 2007-2015





ΔV = 7,3 ± 3,6 m s^{-1}

ΔT = -7,7 ± 3,5°C

R = 11,4 ± 8,7 mm h^{-1}

PM_{10} before = 3 750 µg m^{-3}

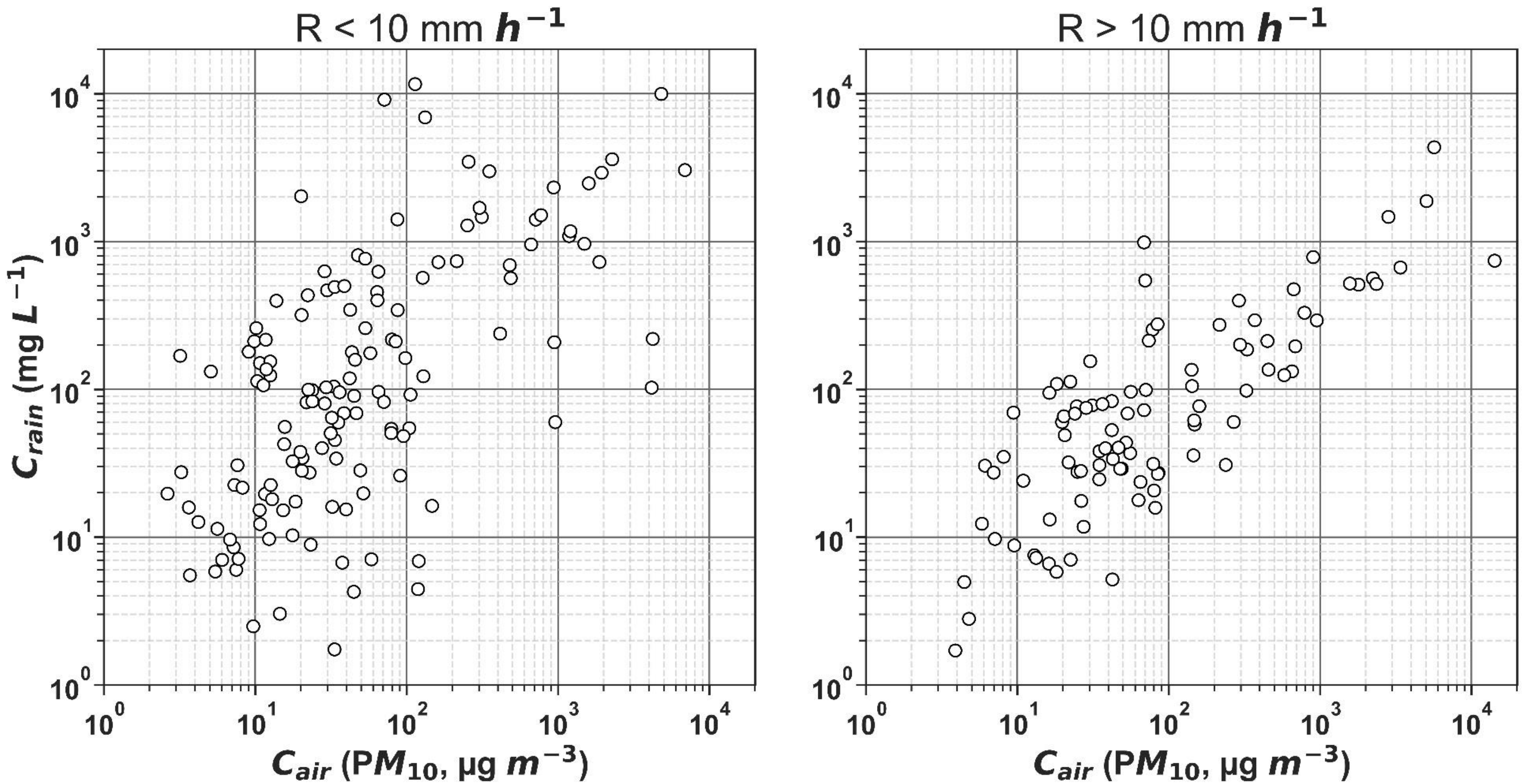
PM_{10} after = 132 µg m^{-3}

⇨ **in Banizoumbou 274 events are associated with cold pools**
= 90% of total precipitation
= 65 % of wet deposition fluxes

(Audoux et al., GRL, 2022)

Cold pool and deposition

Dust concentration and precipitation rates



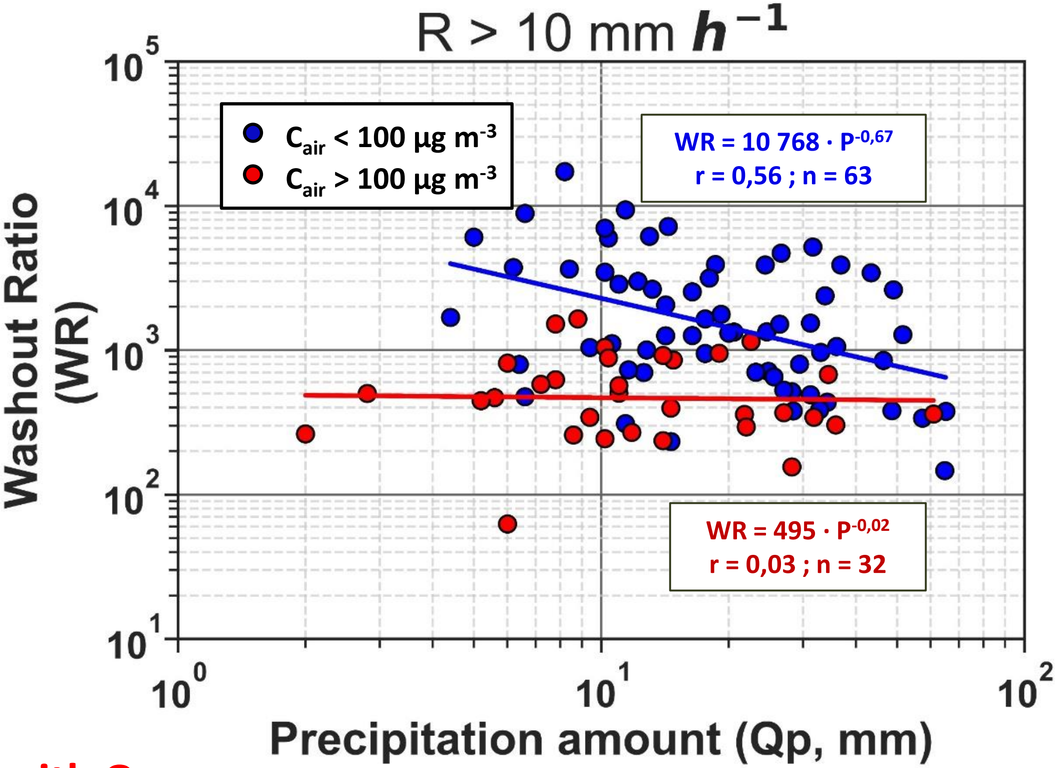
⇨A relationship between C_{rain} and C_{air} for the most intense rainfall

(Audoux et al., GRL, 2022)

Cold pool and deposition : Washout ratio

$$WR = \frac{[X]_{rain}}{[X]_{air}}$$

WR decreases as Qp increases
= dilution effect



WR does not vary with Qp
No aerosol limitation

(Audoux et al., GRL, 2022)

Convection and deposition

- **Cold pools (and thus) MCS can be detected with basic meteorological measurements**
- **Washout ratio have been estimated for dust deposition in convective rains that can be used in dust models**

CONCLUSION (1/2)

- Because they have been carefully selected (from a scientific and a technical point of view) and continuously monitored, **the measured parameters, despite their simplicity, have brought robust and reliable information on many aspect of the dust cycle**

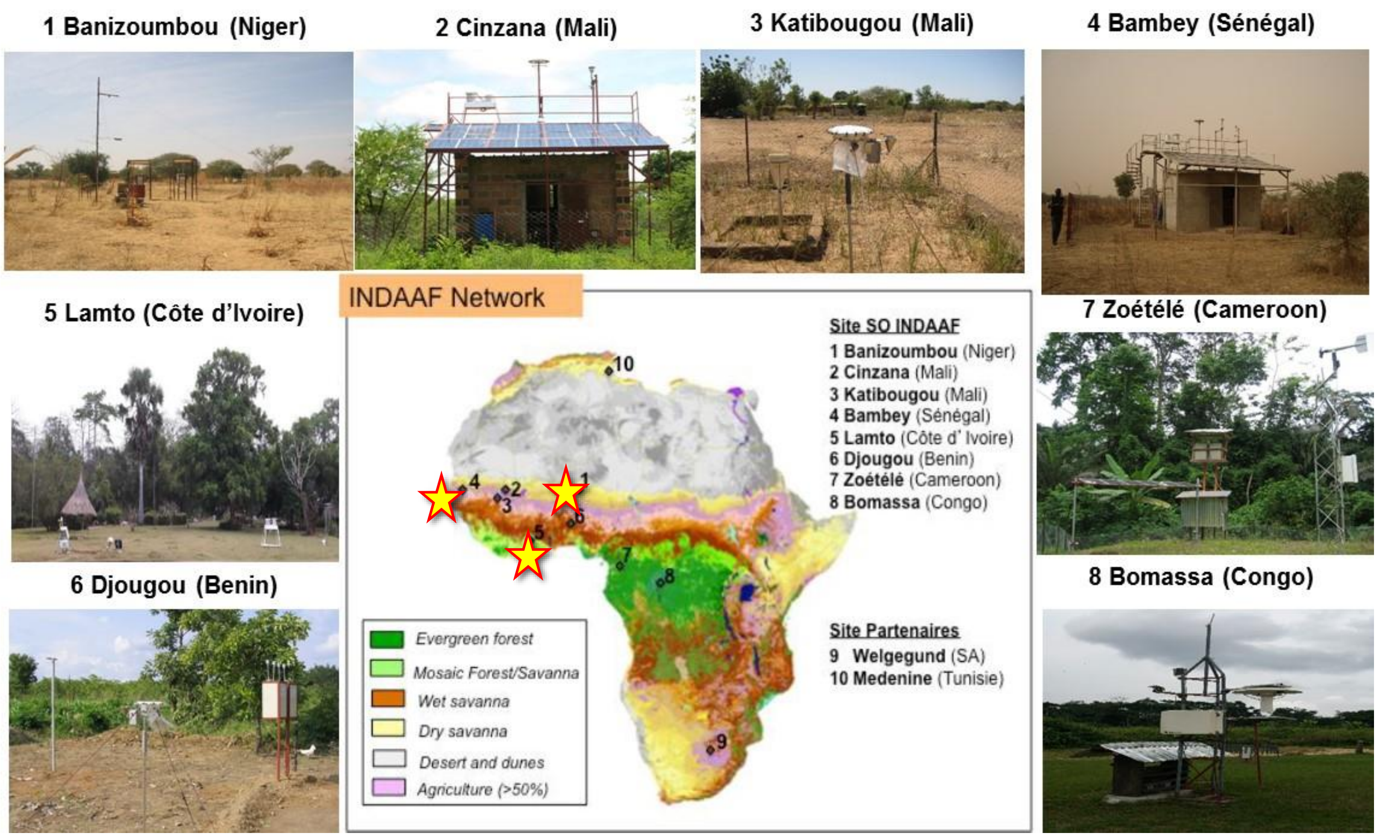
- This requires a lot of effort and organization, especially for the stations located in non-accessible places (Niger, Mali).

- A **unique data set** on concentration, AOD, total and wet deposition and local meteorological conditions close to Saharan dust sources from 2006 to now

The INDAAF Network

" International Network to study Deposition and Atmospheric composition in AFrica"

Corinne Galy Lacaux (LAERO, Toulouse), Béatrice Marticorena (LISA, Créteil)



- **8 stations**
- **7 countries**
- **3 Super-sites**

https://indaaf.obs-mip.fr/

CONCLUSION (2/2)

- **The concentrations and deposition fluxes have been investigated from the event to the seasonal and interannual times-scale and at the regional scale**

- **The main dynamical drivers have been identified the major dynamical features**
  - **LLJ plays a role for dust emission and transport all along the year**
  - **Convection plays a major role for dust emission and deposition**

- **A challenge for regional and global 3-D models of the mineral dust cycle but an opportunity to better constrain the dust mass budget**

ON GOING ACTIVITIES AND NEXT CHALLENGES

- **Try and detect the impact of global changes**
  - **Changes in wind and precipitation regimes**
  - **Changes in land-use and agricultural practices**

- **Dust size distribution for aerosol and deposition (on-going project)**

- **Composition of dust deposition (C, N and nutrients of interest for soils: P, Ca) (on-going project)**

Thank you for your attention !!