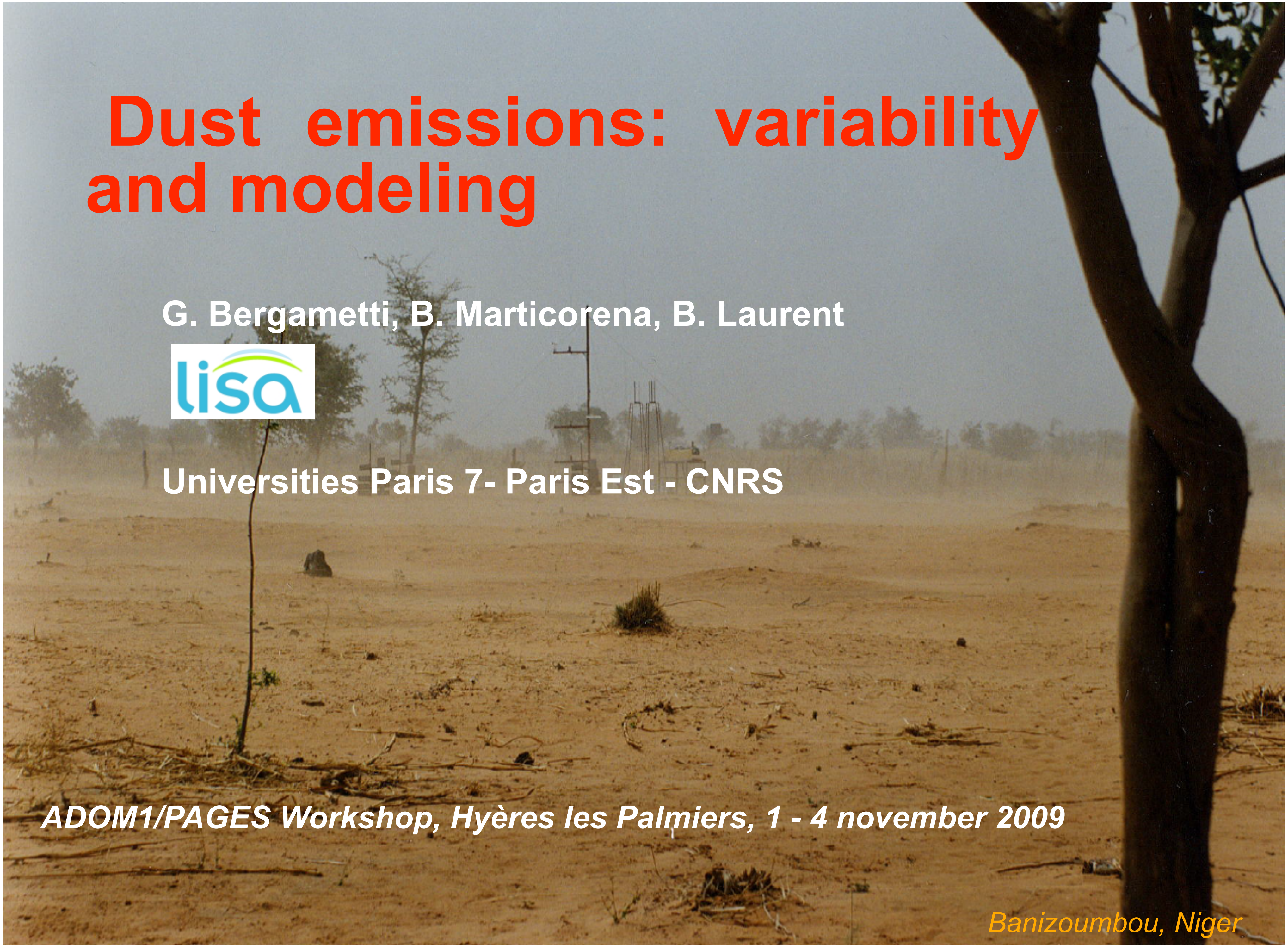


Dust emissions: variability and modeling

G. Bergametti, B. Marticorena, B. Laurent

lisa

Universities Paris 7- Paris Est - CNRS

ADOM1/PAGES Workshop, Hyères les Palmiers, 1 - 4 november 2009

Banizoumbou, Niger

1- The variability of dust emissions, concentrations and deposition

2- Are there some links between the different scales of variability?

3- The basic steps of dust emissions

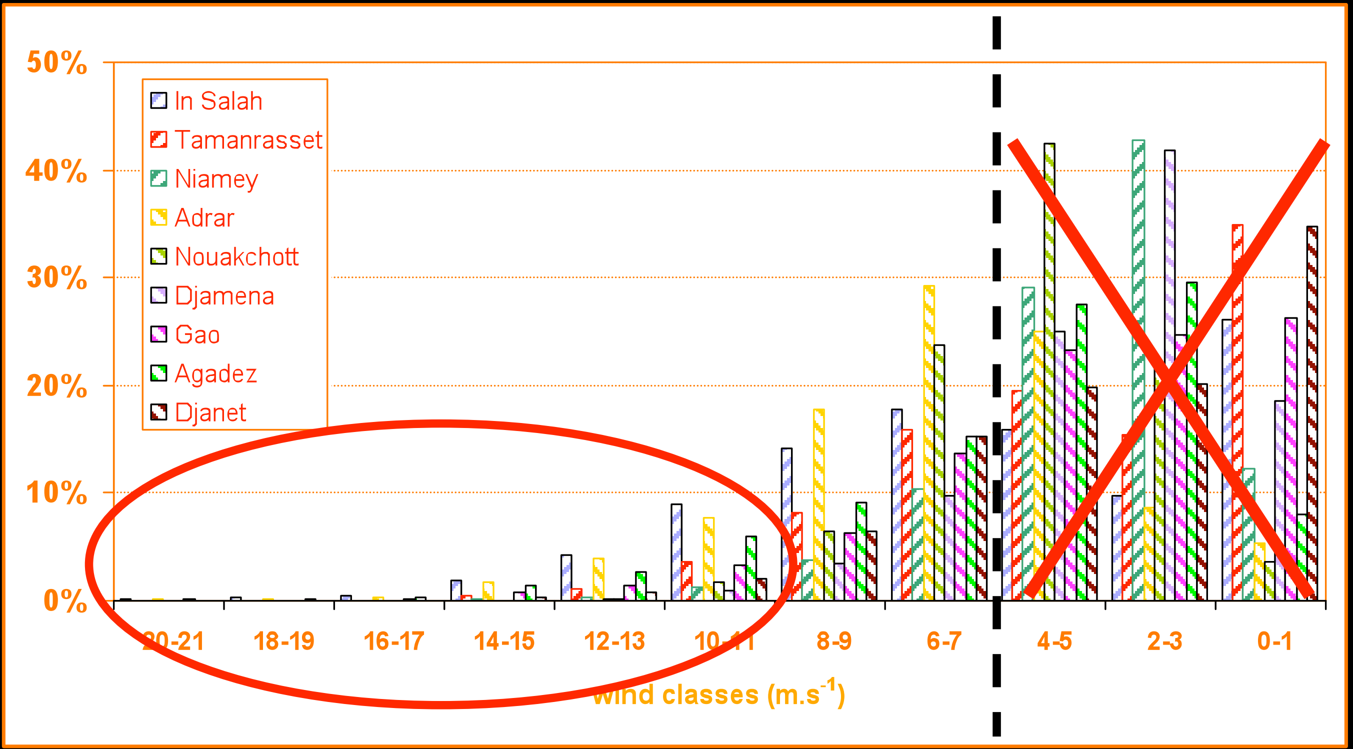
4- Processes and modeling of dust emissions

5- Applications to Asian deserts

VARIABILITY OF DUST EMISSION

- Dust **emissions** are wind-thresholded:
  - *their frequency is controlled by the number of time the wind speed exceed the threshold*
  - *their intensity is controlled by how much this threshold is exceeded*

because high wind speed are unfrequent, intense emissions are sporadic!!!

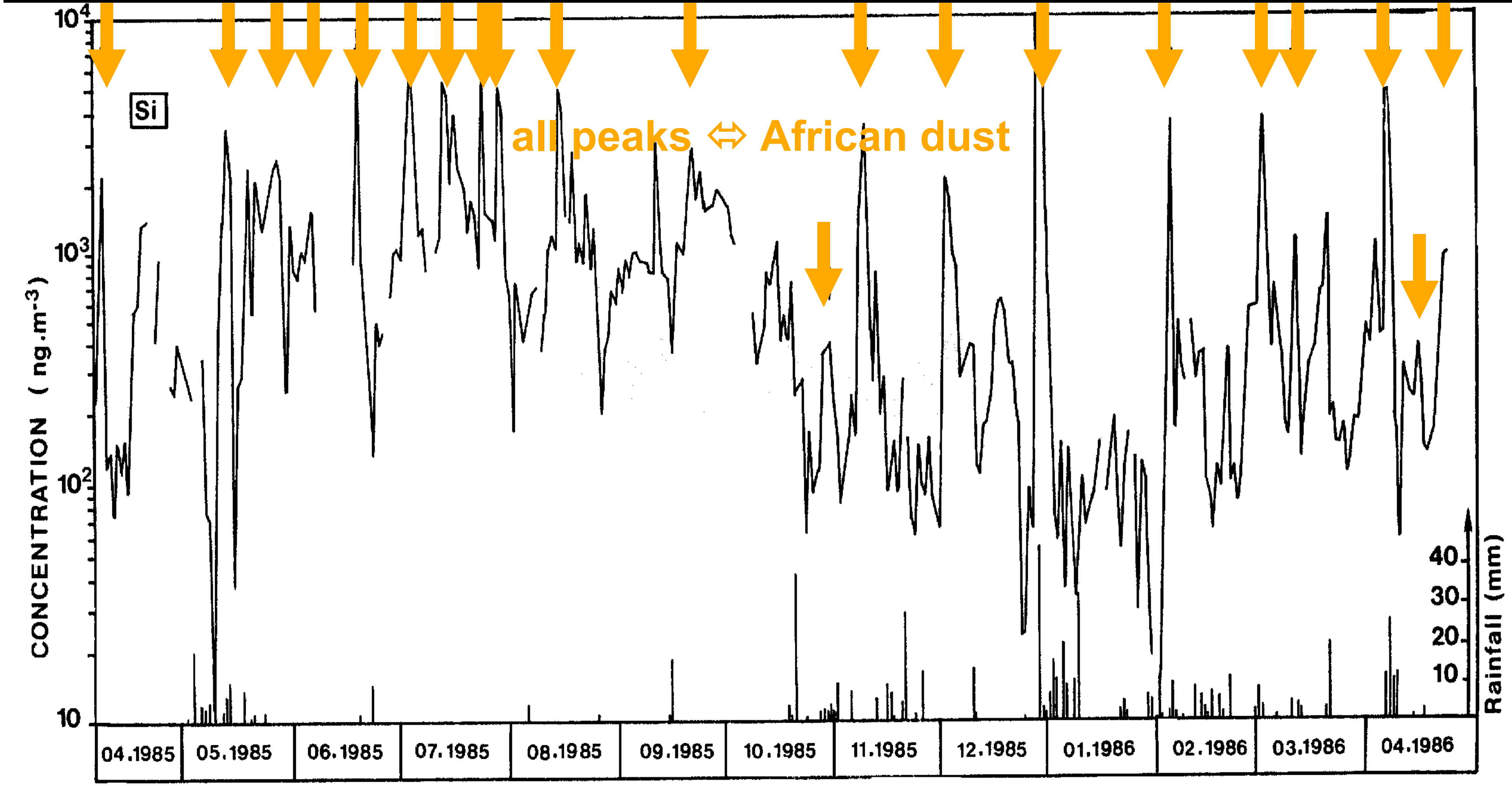


Frequency of wind velocity classes averaged over the period 1986-2005 for different locations in Sahara and Sahel

The daily variability of Mediterranean aerosol surface concentrations: orders of magnitude

Daily atmospheric concentrations in particulate Si (a proxy for mineral dust) at a rural coastal site in Corsica

(Bergametti et al., 1989)



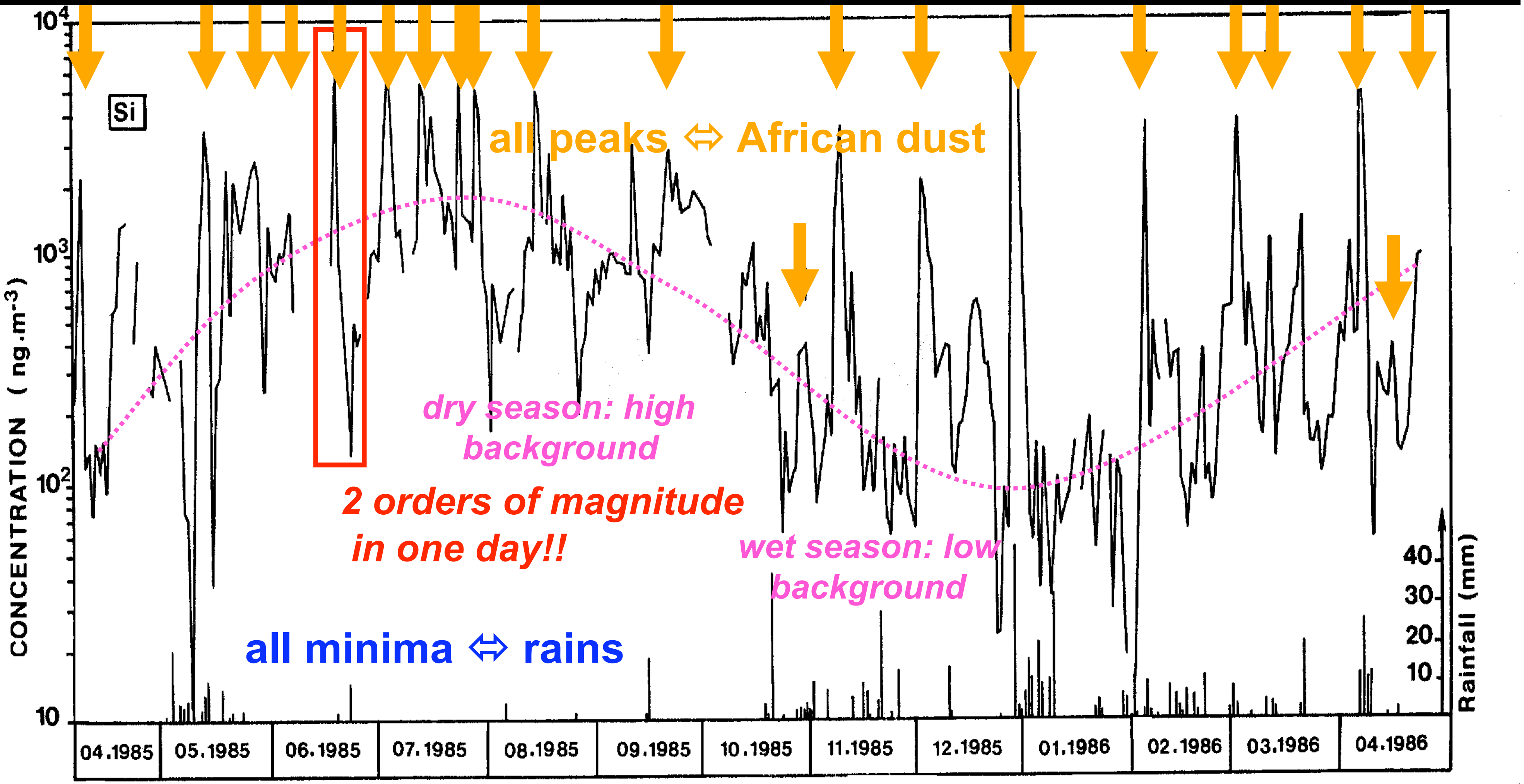
VARIABILITY OF DUST DEPOSITION

- If dust **deposition** by dry processes is a quite continuous process, wet deposition acts almost as a Dirac effect; most of the particles being removed when precipitation occurs…

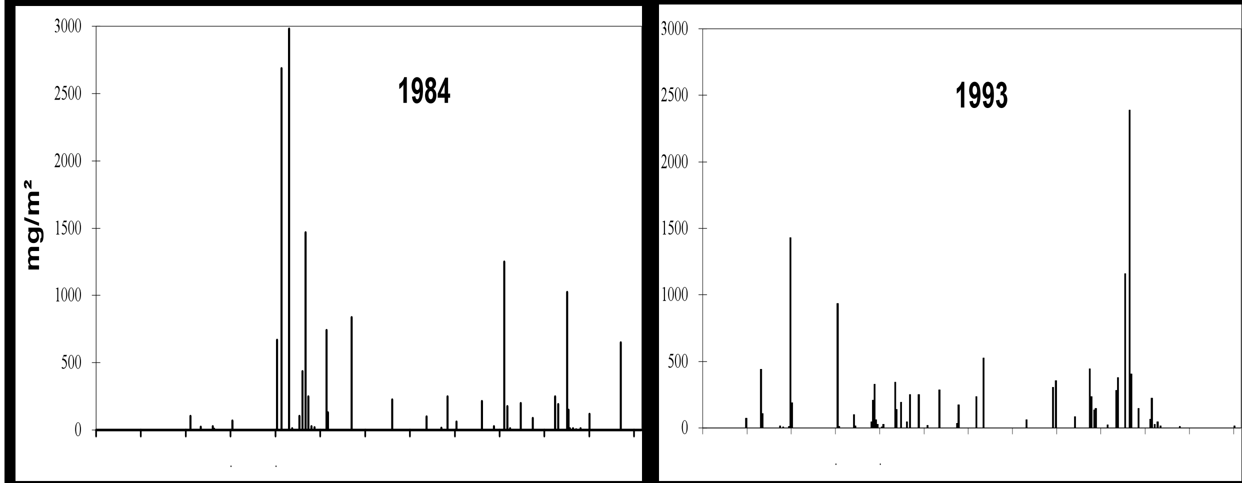
The daily variability of Mediterranean aerosol surface concentrations: orders of magnitude

Daily atmospheric concentrations in particulate Si (mineral dust) at a rural coastal site in Corsica

(Bergametti et al., 1989)



VARIABILITY OF DUST DEPOSITION

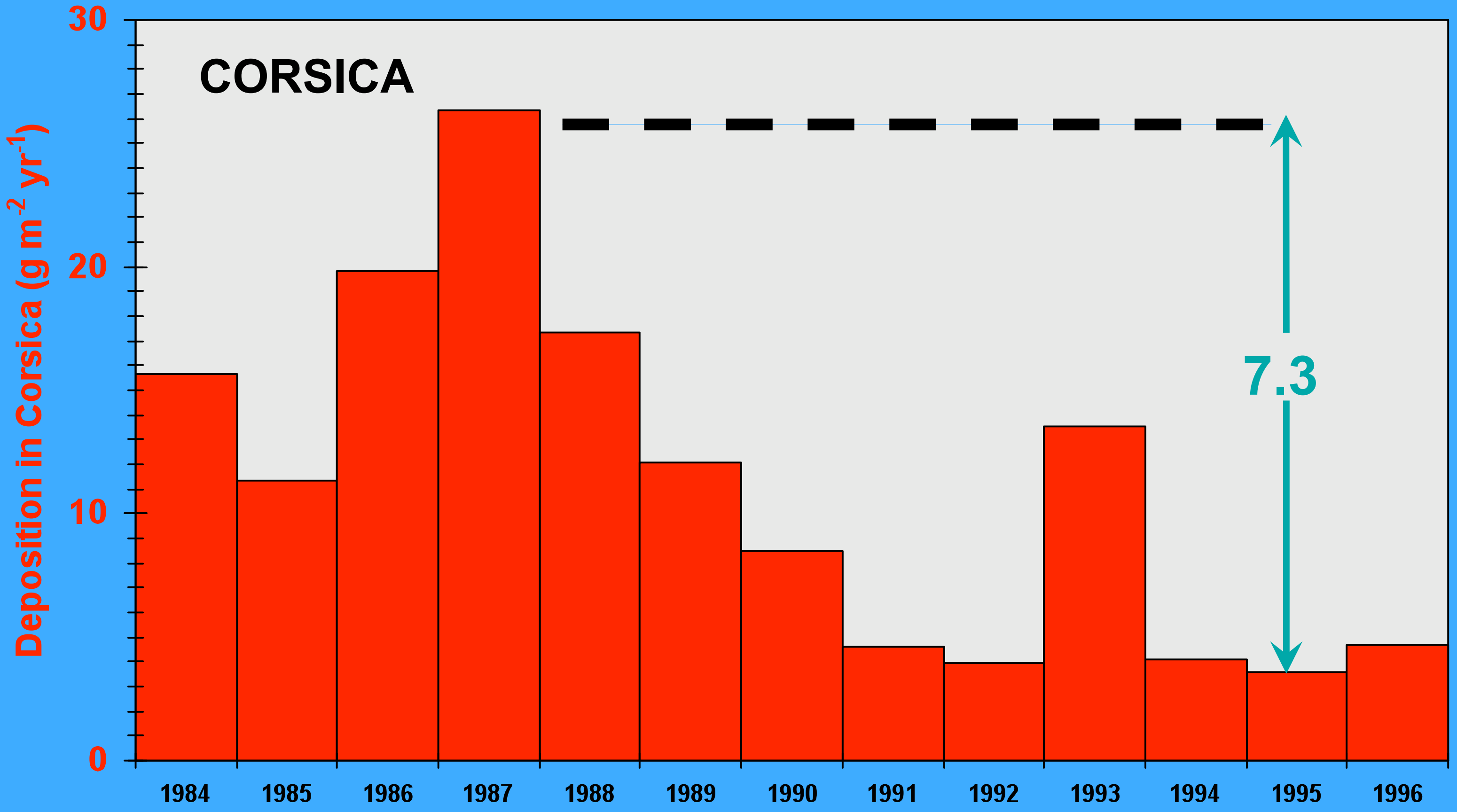


Daily deposition of Saharan dust in Corsica for the years 1984 and 1993.

(from Loÿe-Pilot and Martin, 1996)

1984: 40% of the annual deposited mass in **3 days**
1985: **25%** of the annual deposited mass in **1 day**
1986: **80%** of the annual deposited mass in **3 days**
1988: **55%** of the annual deposited mass in **2 days**

Etc…



Annual (1984-1996) deposition flux of mineral dust

(from Loÿe-Pilot and Martin, 1996)

- The emissions are sporadic and the intense emissions can be considered as extreme events

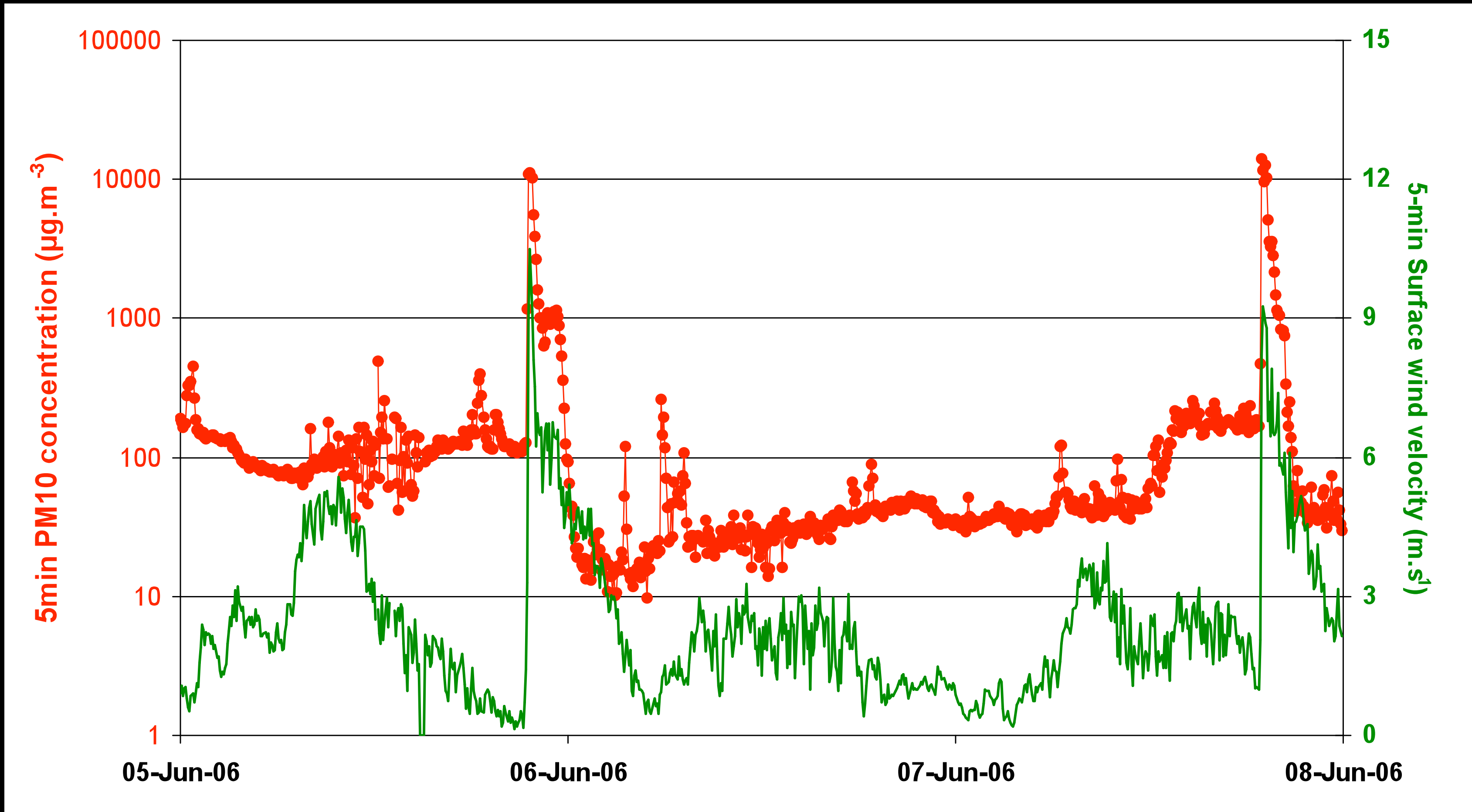
- There are some high deposition events resulting from the combination of high dust concentration and efficient precipitation that can represent a large part of the annual deposition fluxes

- **In transport regions, dust are characterized by a high variability at different time scales, from daily to interannual, of both concentrations and deposition**

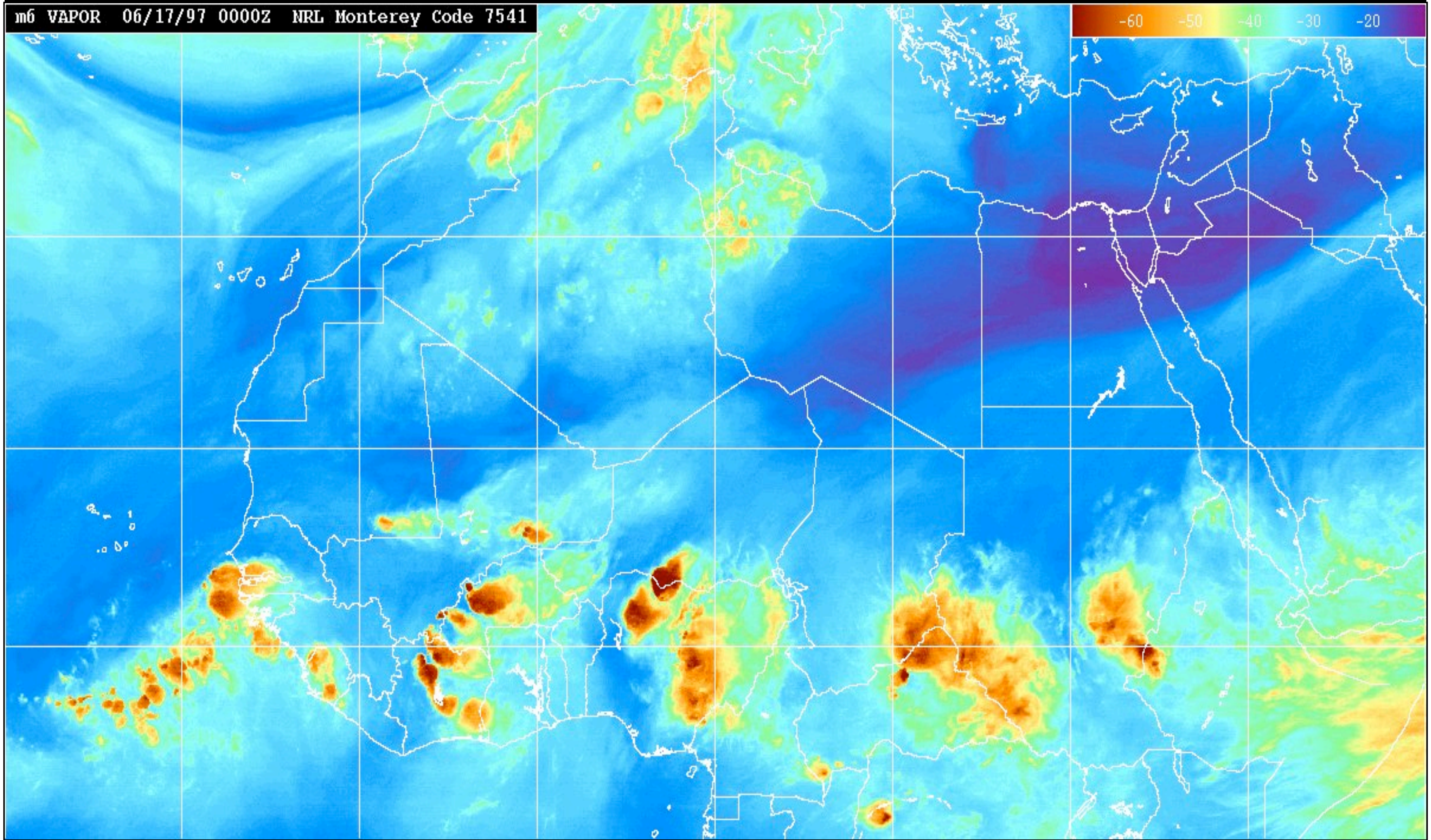
In source regions?

Short time events

Dust concentration and surface winds (Cinzana, Mali)

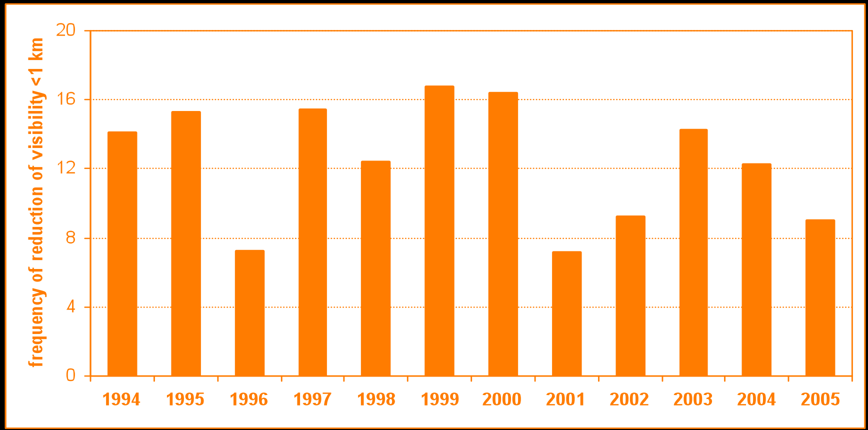


⇨ **Dust concentration increase by two orders of magnitude in 10 min and decrease by three orders of magnitude in 3 hours!!!**



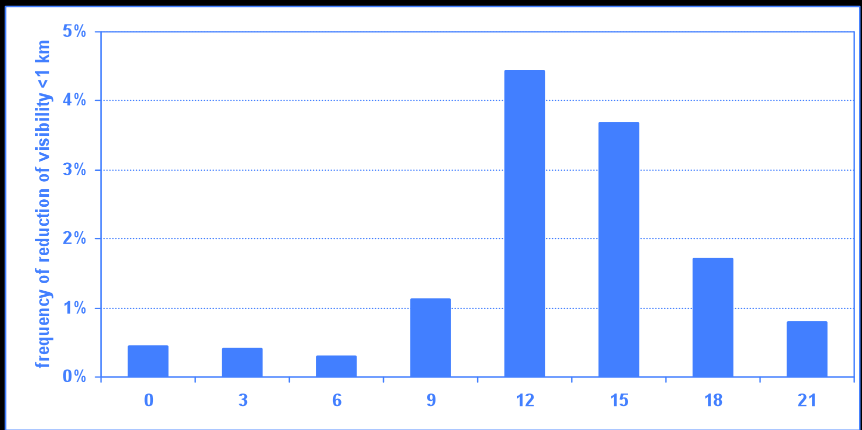
Events of short duration at a given place are not necessary without interest!!!

Nouakchott, Mauritania
1994-2005



Annual frequency of visibility < 1km

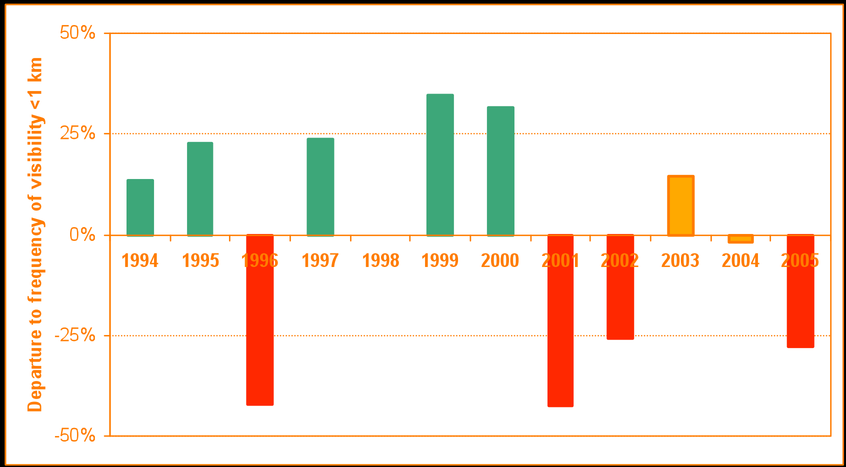
Seasonal cyle of visibility < 1 km



Diurnal cycle of visibility < 1km

Is there a link between these different scales of temporal variability?

Nouakchott, Mauritania

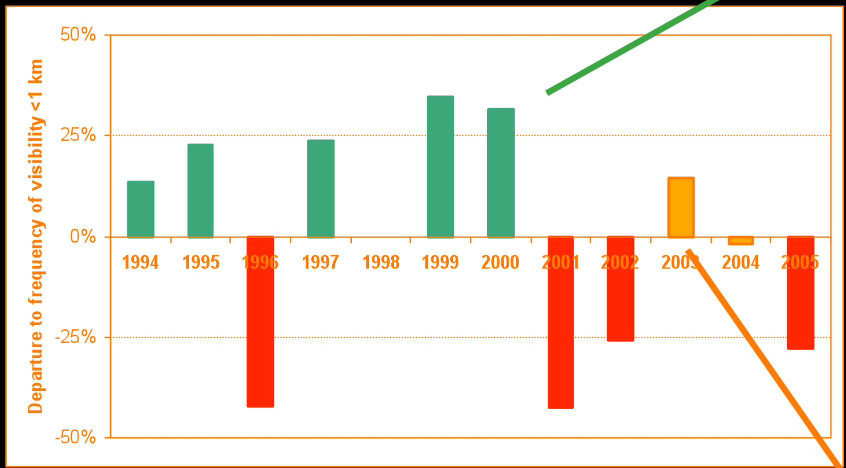


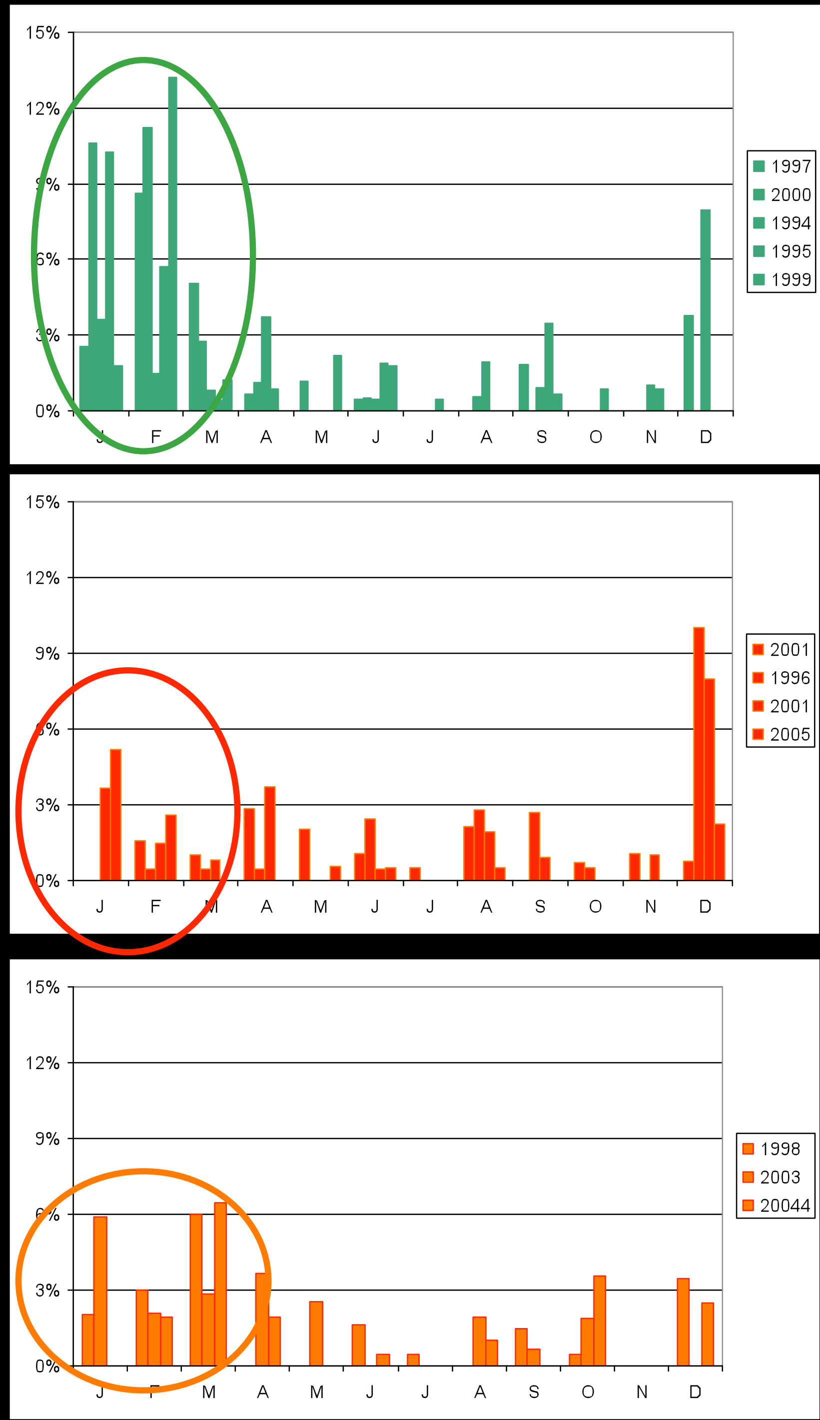
Departure of annual frequency of visibility < 1km for the period 1994-2005

Departure of the visibility < 1km for D, J, F for the period 1994-1995

Departure of the visibility < 1km for 12 and 15 h TU for the period 1994-1995

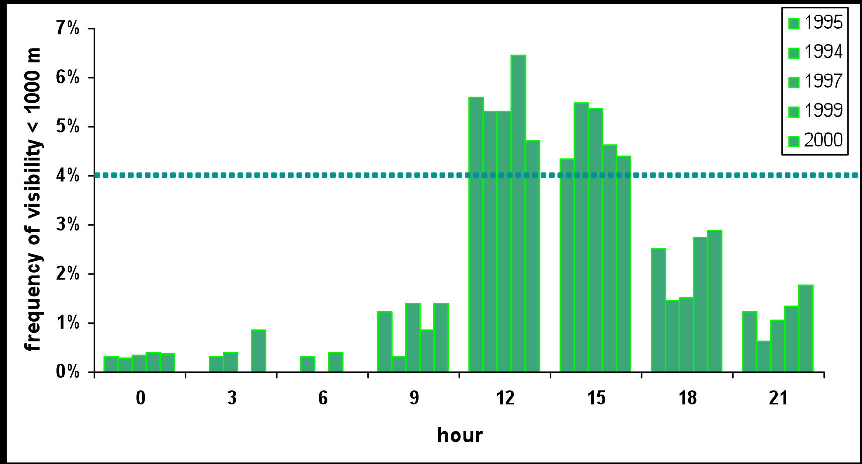
The interannual variability of the frequency of visibility < 1 km is linked to changes in the seasonal cycle of the frequency of visibility < 1 km

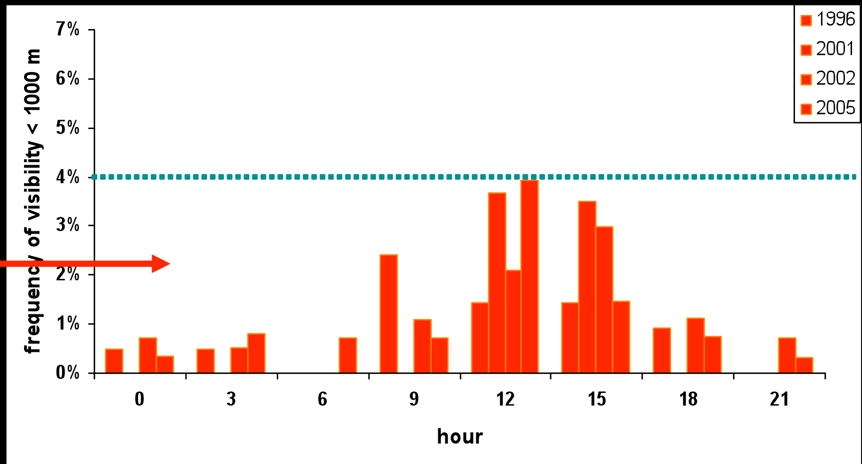


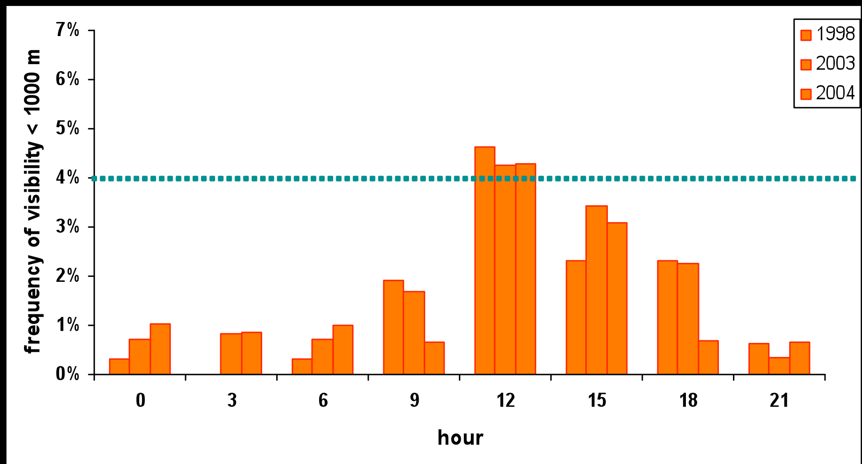


NOUAKCHOTT, Mauritania

The interannual variability of the frequency of visibility < 1 km is linked to changes in the diurnal cycle of the frequency of visibility < 1 km







NOUAKCHOTT, Mauritania

The interannual variability of frequency of visibility less than 1km is strongly linked to the seasonal cycle of frequency of visibility less than 1 km

The seasonal cycle of frequency of visibility less than 1 km is reinforced the years during which the diurnal cycle of reduction of visiblity is reinforced

This suggests that all scales of temporal variability are linked in Nouakchott!!!

WHY?

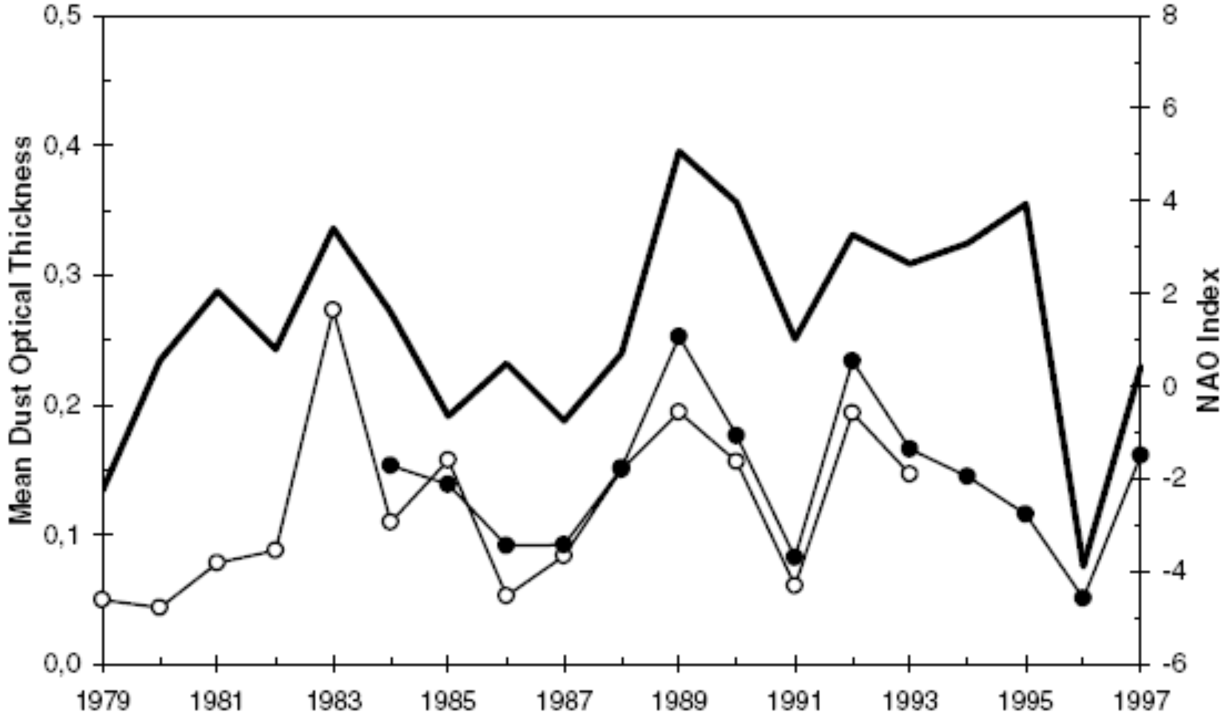


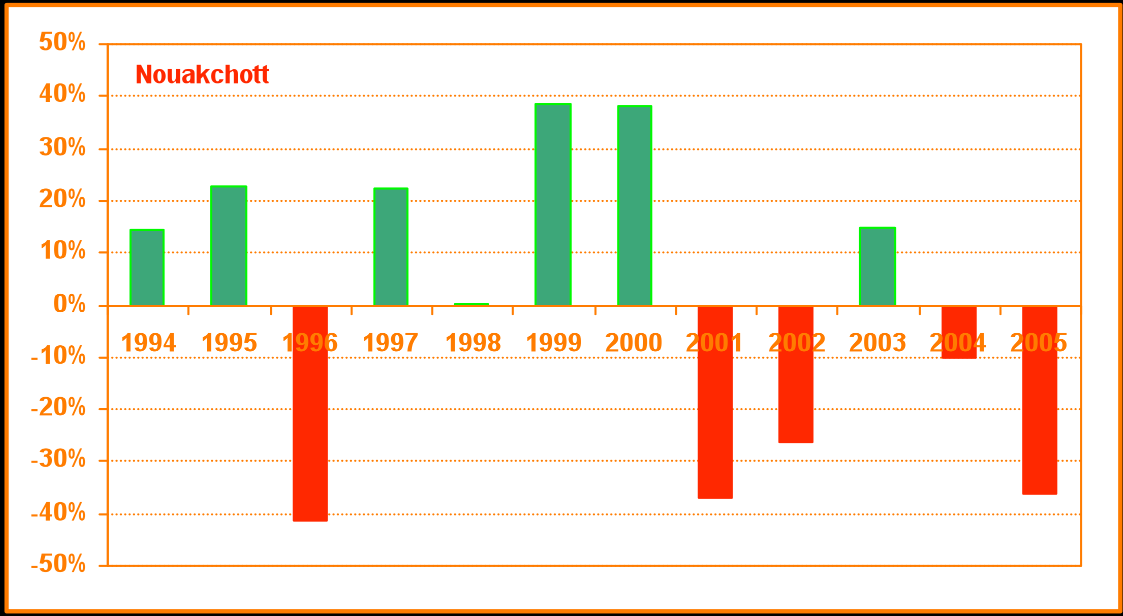
Figure 3. Comparison between the North Atlantic Oscillation (NAO) index (bold continuous line) and the mean dust optical thickness (DOT) in winter (December–March) derived from TOMS Nimbus 7 from 1979 to 1993 (open circles) and from Meteosat from 1984 to 1997 (filled circles) over the northern tropical Atlantic zone.

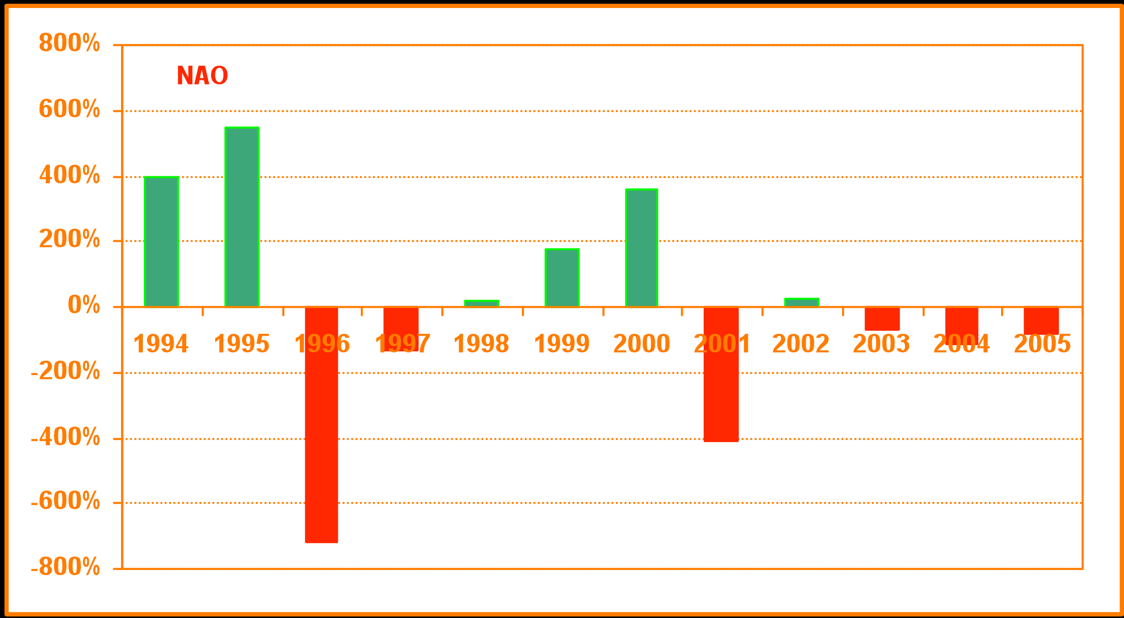
Chiapello et al., JGR, 2005

Is the NAO responsible for the interannual variability of the frequency of visibility less than 1km observed in Nouakchott?

We can say…..

probably YES!!!!





« the NAO acts mostly on the winter transport and is shown to be limited spatially to the northern part of the Atlantic, and possibly to some well identified source regions like the southern Mauritania and the Bodele Depression »

Chiapello et al., JGR, 2005

Let us test!!!

No links with the reduction of visibility in stations close to the Bodélé Depression or on the path of its dust cloud !!!!

- The role of NAO on dust emissions is limited to western Saharan sources…

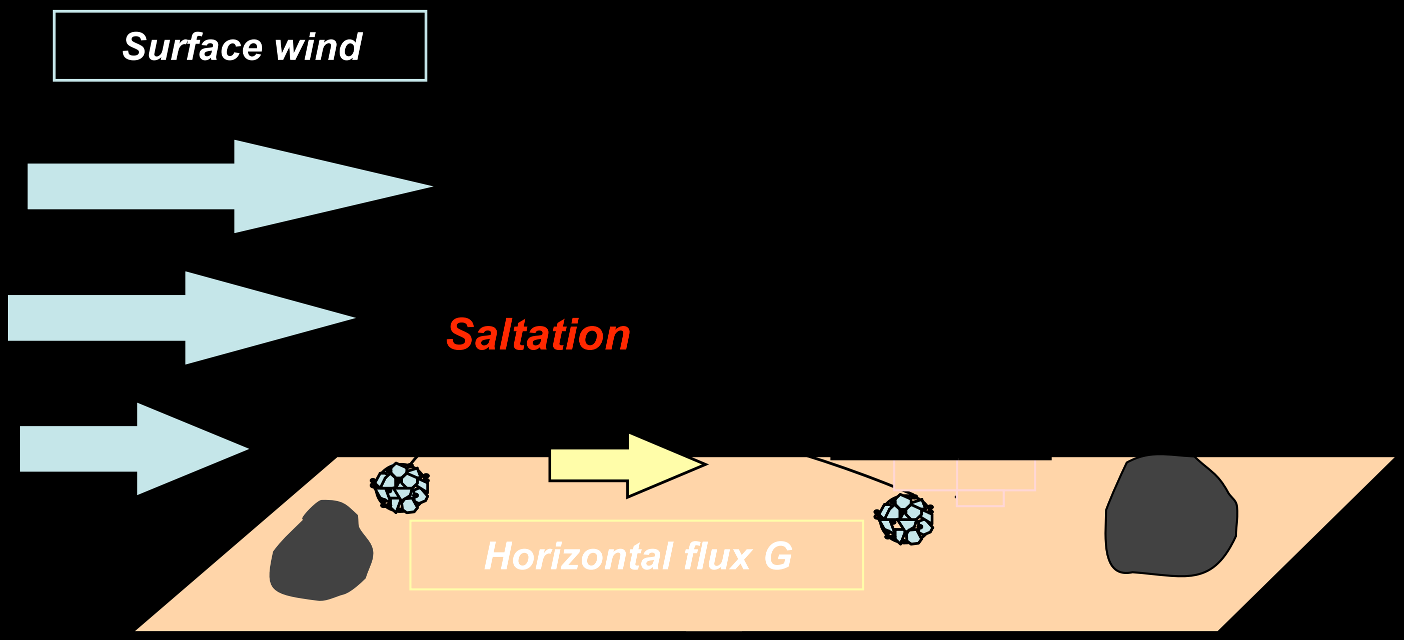
- But, in that area, it appears to be responsible for the link existing between the various temporal scales of variability…

Are they other source regions where the temporal scales of variability are linked and, if yes, why?

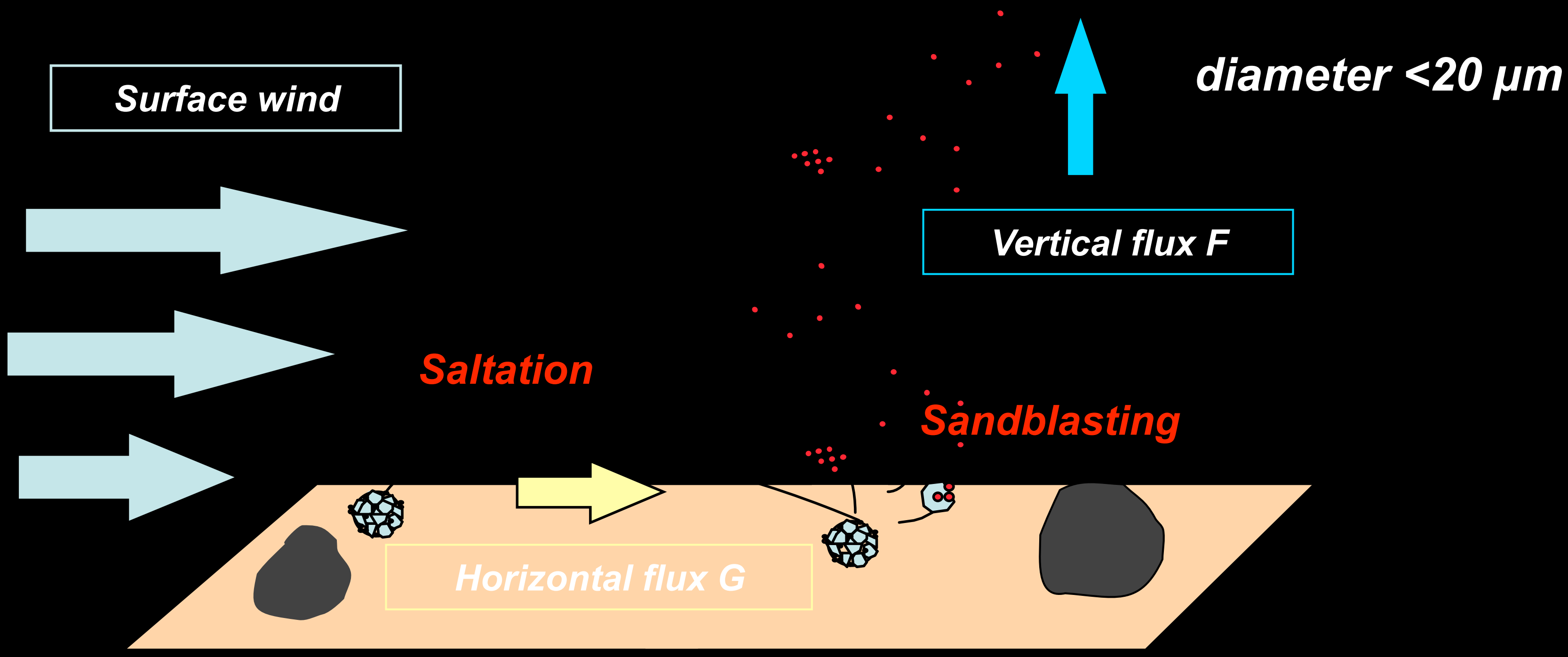
BASIC STEPS OF DUST EMISSIONS

Chihuahan desert, New Mexico

When the wind velocity blows sufficient strongly over a surface not totally protected by vegetation, stones or pebbles, some grains constituting the superficial layer of the soil begin to move

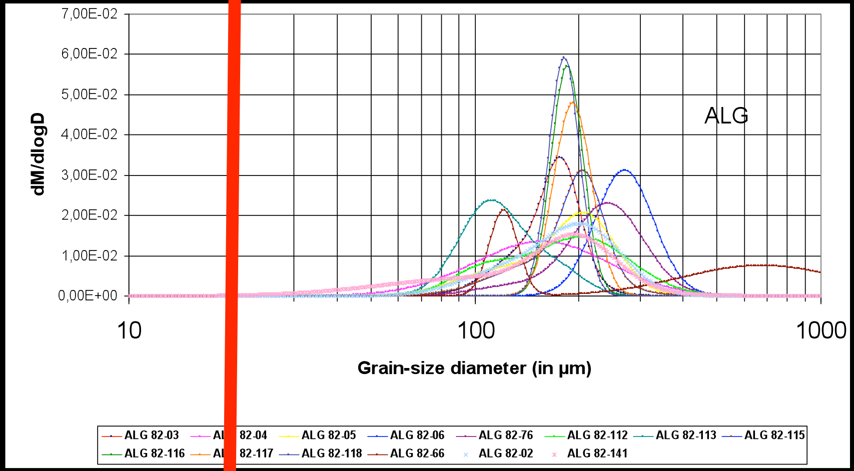


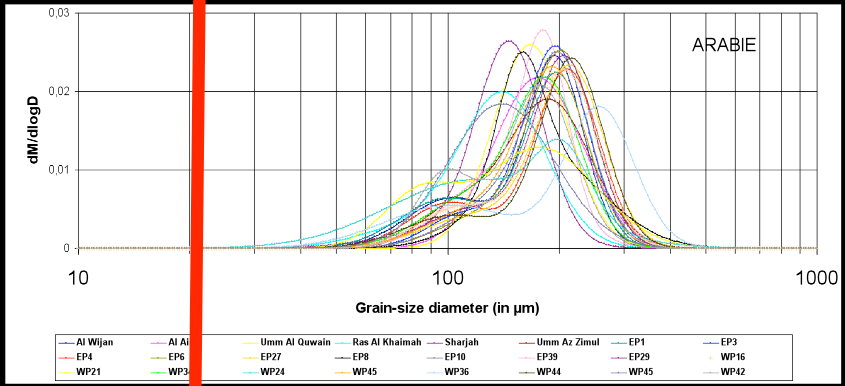
When these saltating grains mobilized by wind fall down the surface, a part of their kinetic energy is transfered to soil aggregates which disrupt, allowing finer particules to be emitted in the atmosphere.

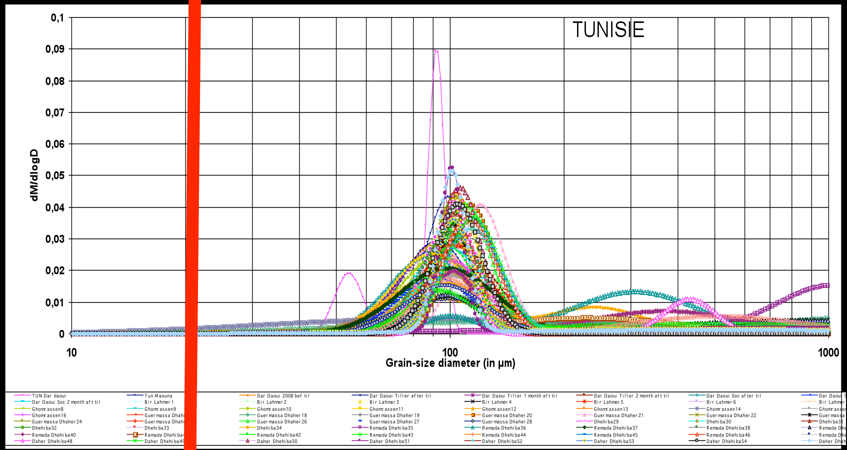


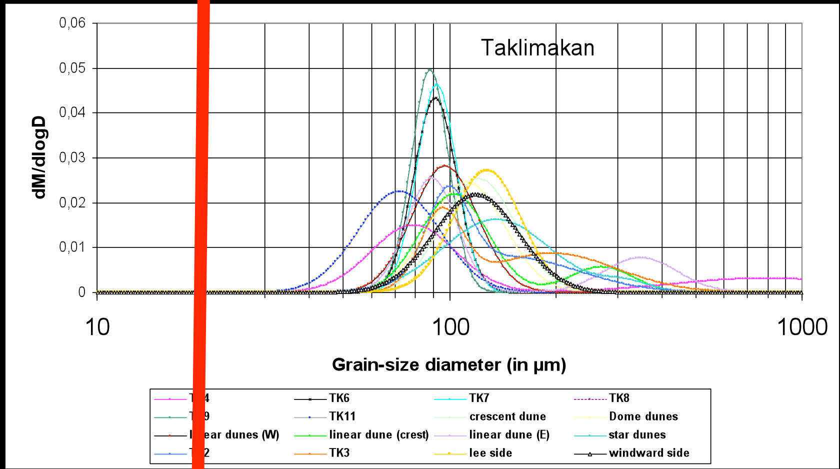
For wind erosion, the size distribution of interest for the soil is that of that of the soil grains in their natural state of aggregation…

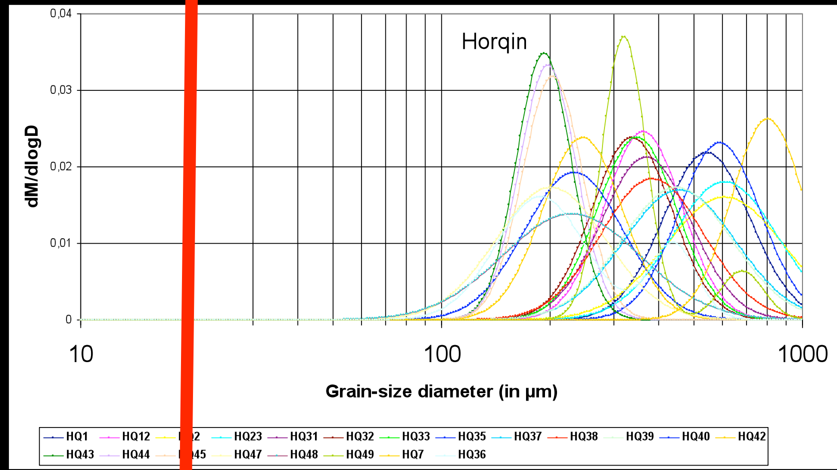
And there is almost no individual particle less than 20 µm in diameter in the soils…

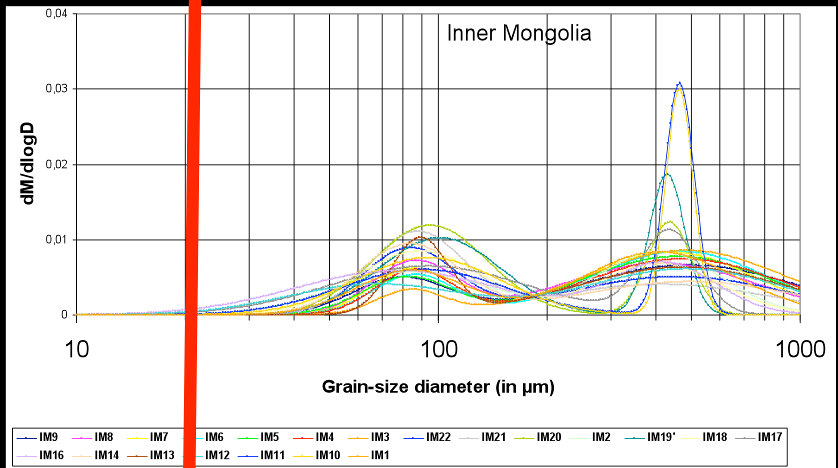


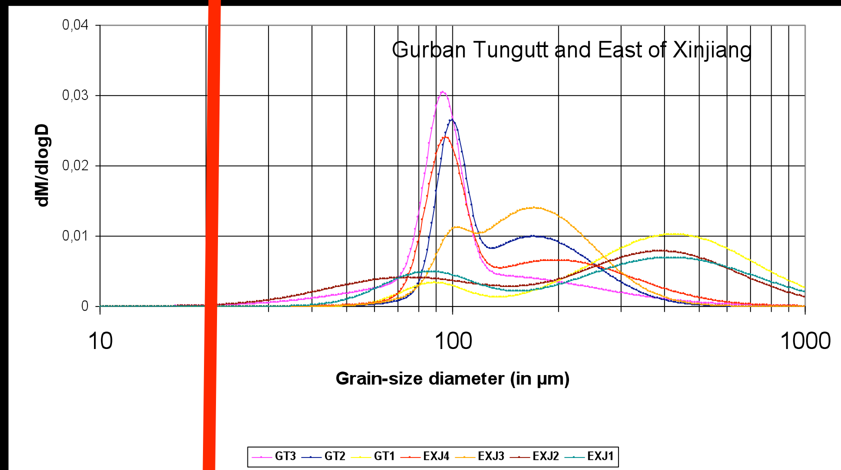


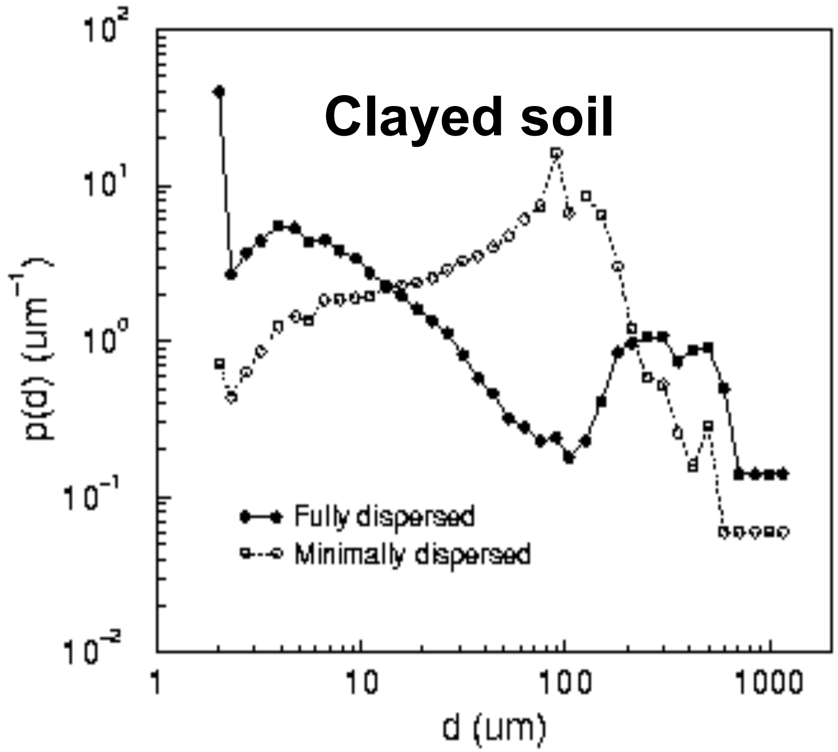



Taklimakan
dM/dlogD
0,06
0,05
0,04
0,03
0,02
0,01
0
10
100
1000
Grain-size diameter (in µm)
TK6
TK7
TK8
TK11
crescent dune
Dome dunes
linear dune (crest)
linear dune (E)
star dunes
TK3
lee side
windward side


Horqin
dM/dlogD
0,04
0,03
0,02
0,01
0
10
100
1000
Grain-size diameter (in µm)
HQ1
HQ12
HQ23
HQ31
HQ32
HQ33
HQ35
HQ37
HQ38
HQ39
HQ40
HQ42
HQ43
HQ44
HQ47
HQ48
HQ49
HQ7
HQ36


Inner Mongolia
dM/dlogD
0,04
0,03
0,02
0,01
0
10
100
1000
Grain-size diameter (in µm)
IM9
IM8
IM7
IM6
IM5
IM4
IM3
IM22
IM21
IM20
IM2
IM19'
IM18
IM17
IM16
IM14
IM13
IM12
IM11
IM10
IM1


Gurban Tunguttt and East of Xinjiang
dM/dlogD
0,04
0,03
0,02
0,01
0
10
100
1000
Grain-size diameter (in µm)
GT3
GT2
GT1
EXJ4
EXJ3
EXJ2
EXJ1



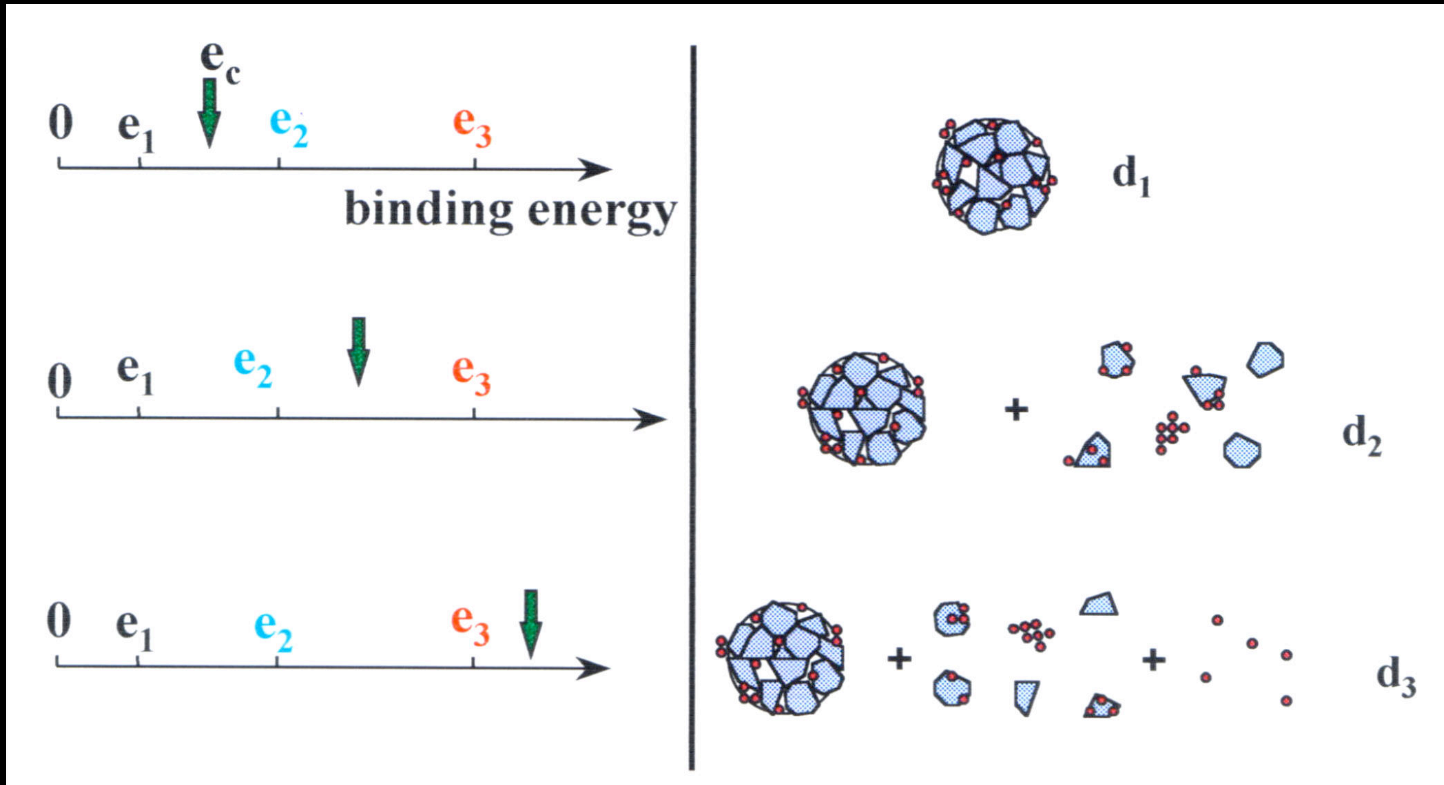
From Shao, 2002

The dust size particles are included in larger soil aggregates : thus, the dust size particles have to be produced during the wind erosion : it is the sandblasting process

« sand-blasting »

Kinetic energy of saltating particles
$e_c = f(D_p, U^*)$

Cohesive forces of aggregates
$e_d = f(d)$



From Alfaro and Gomes, JGR, 2001

Processes and modeling of dust emissions

Dust storm in Mali

- Three phases in dust emissions modeling:
  - 1- modeling the threshold wind velocity
  - 2- modeling the saltation (also called « horizontal ») flux
  - 3 modeling the sandblasting process to simulate the dust (also called the « vertical ») flux

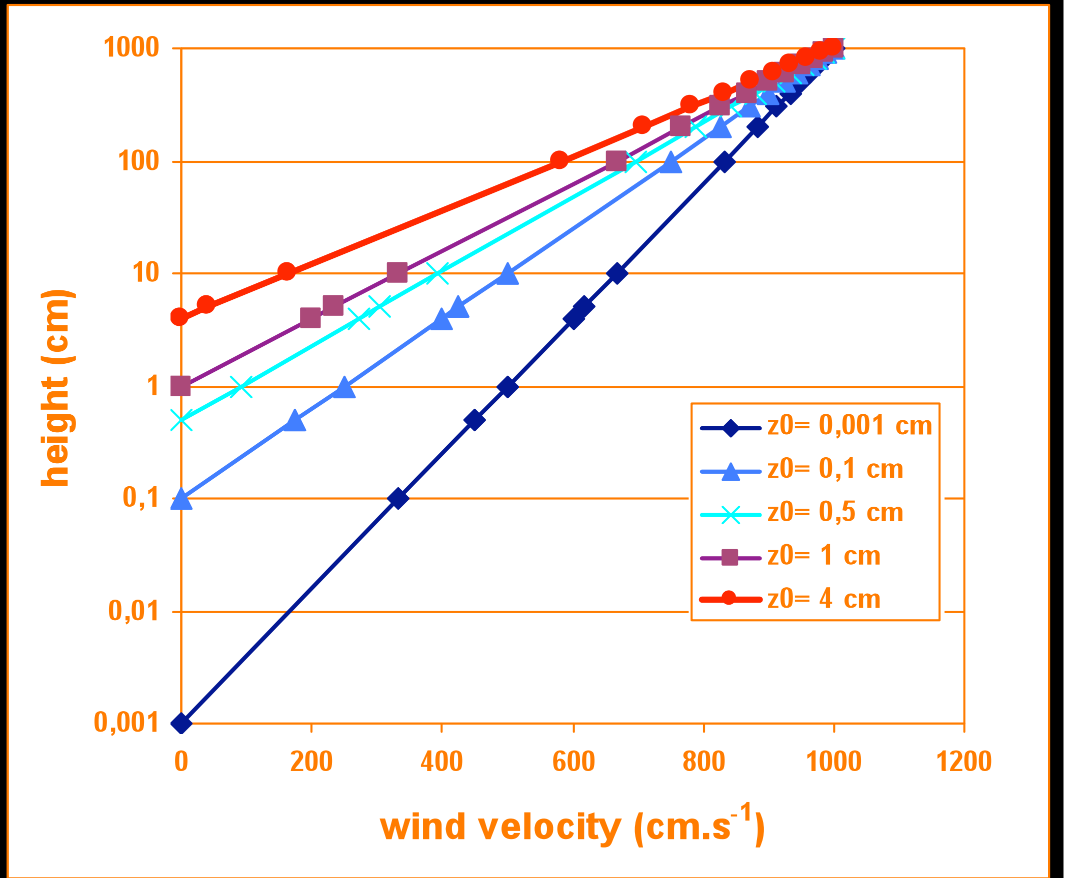
The energy provided by wind to move a soil grain:

$$\tau = \rho_a \,.\, u_*^2$$

τ : wind shear stress

ρ_a : air density

u_* : wind friction velocity



$$u_* = u_{(z)} \,.k \,/\, \ln(z/z_0)$$

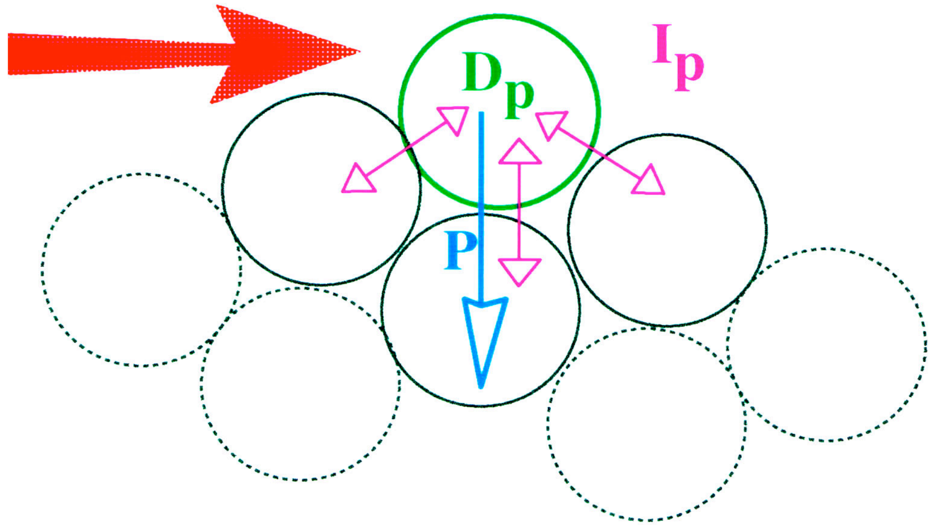
$u_{(z)}$: wind velocity at height z

k : Von Karman constant ($\approx$ 0.4)

z_0 : roughness height

Erosion threshold on a smooth surface

$$\tau = \rho_a u_*^2$$



D_p : particle diameter

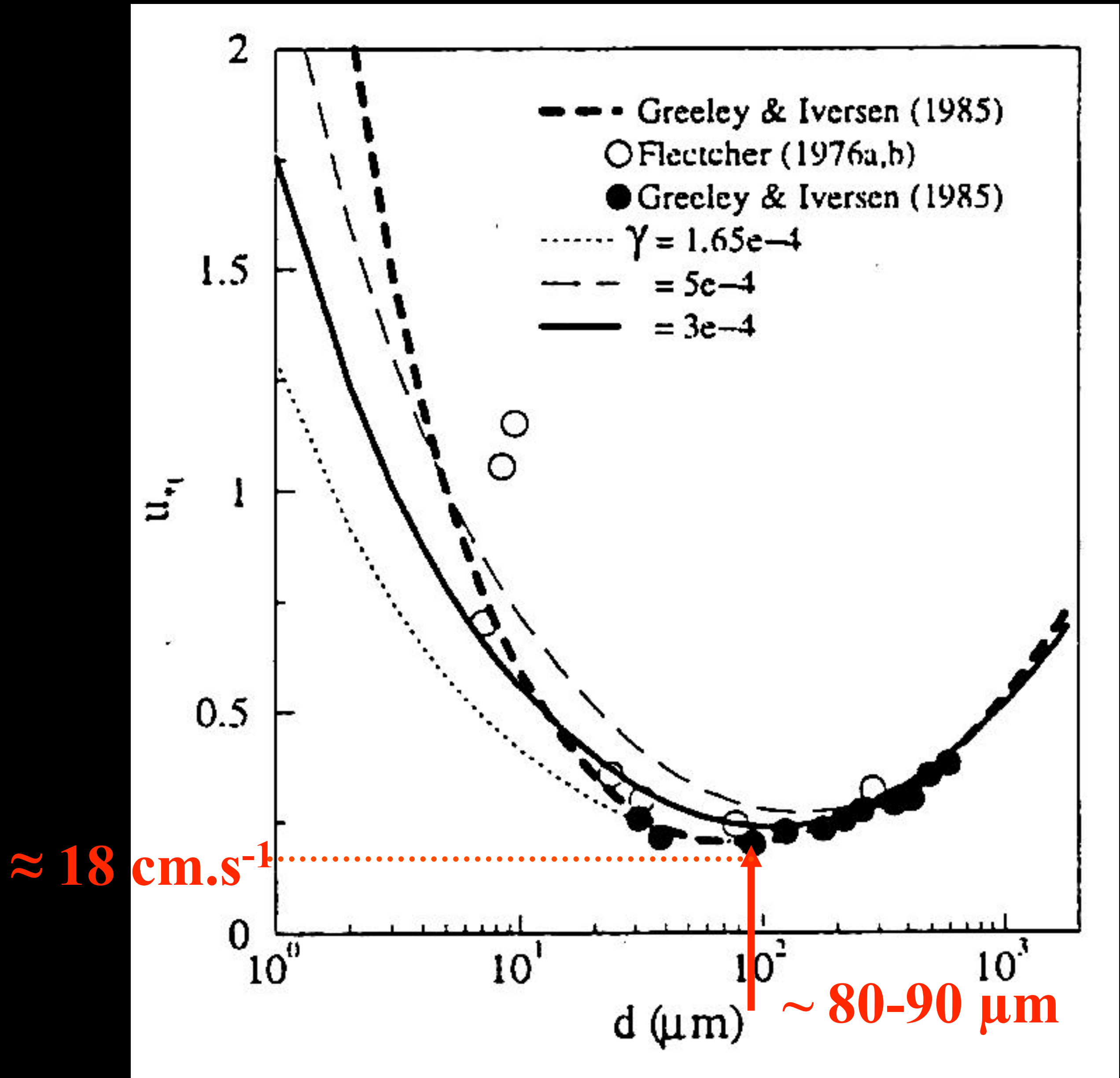
P Gravity force

I_p : interparticles cohesive force

Wind erosion starts only

when $\tau > P + I_p$

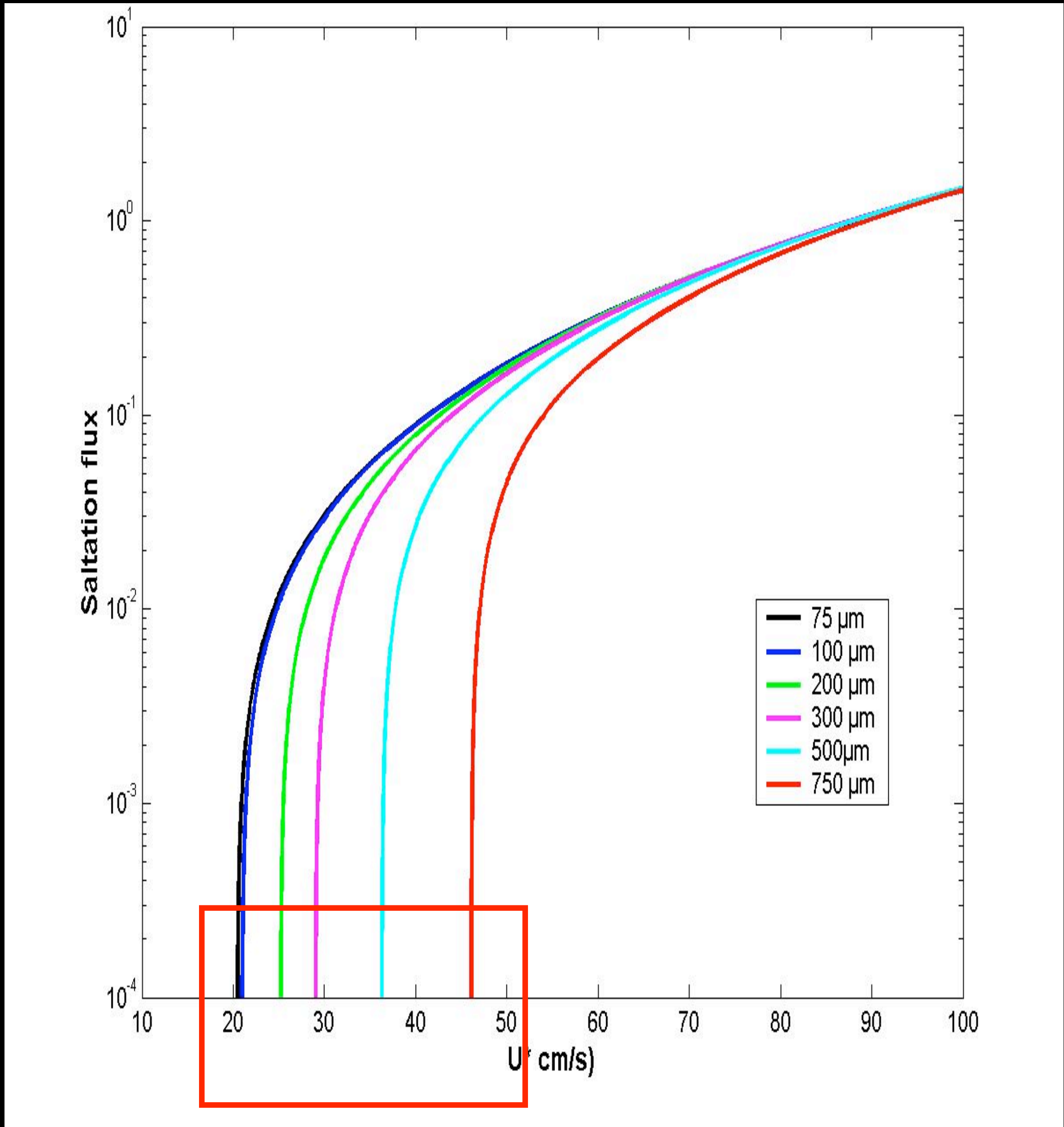
Minimal threshold wind friction velocity versus soil particle size



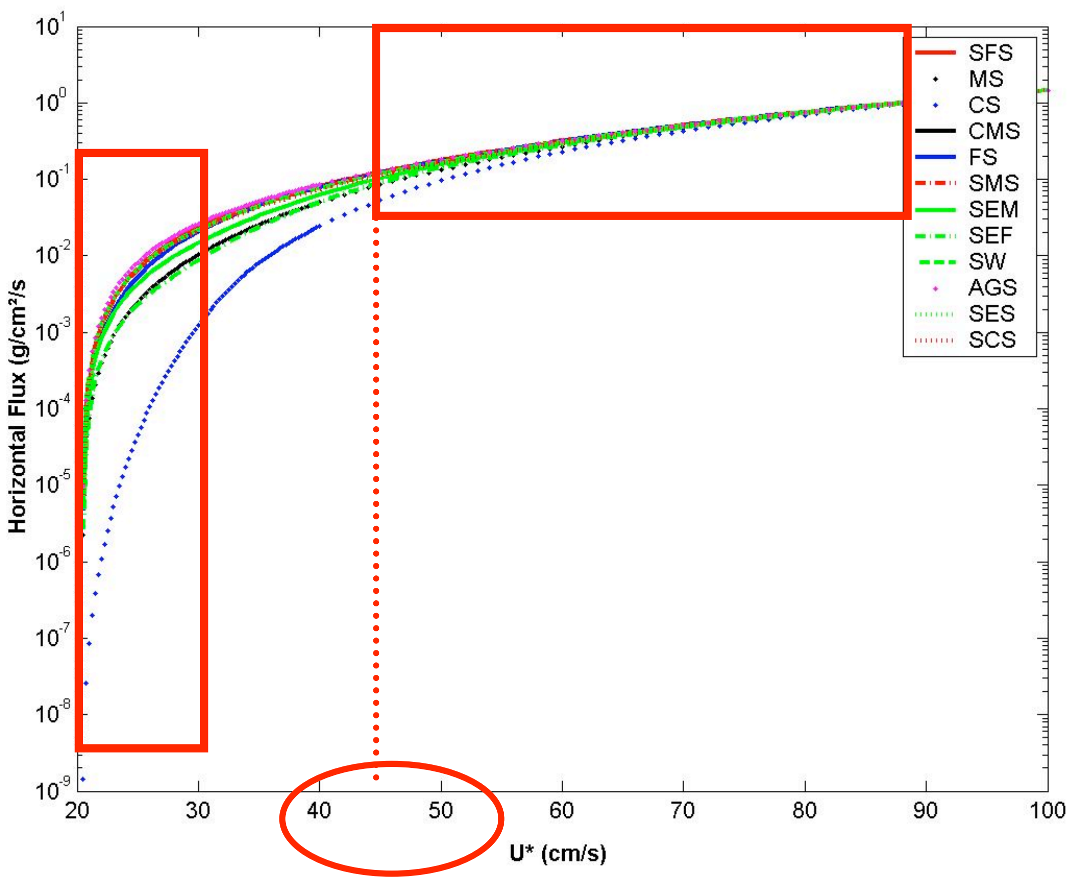
smooth surfaces with loose dry soils

From Shao and Lu, 2000

Erosion Threshold friction velocities for smooth surfaces



1- from a theoritical point of view, the aeolian erosion should begin at different wind friction velocities depending on the size of the soil grain



1- When applied to natural soils, the influence of the soil grain size distribution on the threshold is limited

2- the effect of the threshold on the saltation flux is less and less effective when u_* *(*and so *u)* increases

Erosion Threshold friction velocities for smooth surfaces

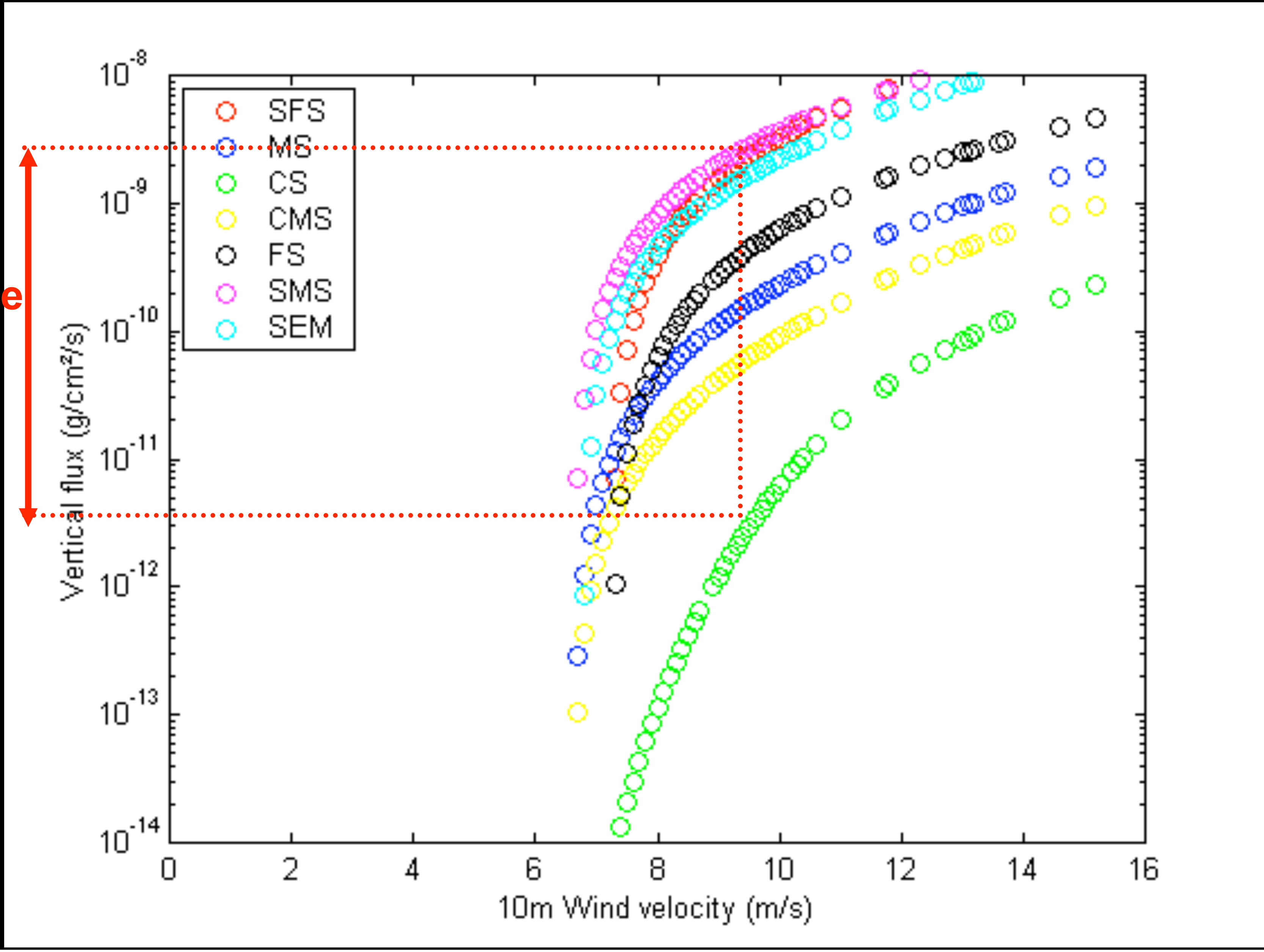
These results suggest that the dust emissions are not very sensitive to the soil grain size distribution…

But!

The soil grain size distribution also controls both the abundance of aggregates and the distribution of the kinetic energy provided by the saltating grains for sandblasting

Sensitivity of the vertical (dust) flux to the soil grain size

3 orders of magnitude

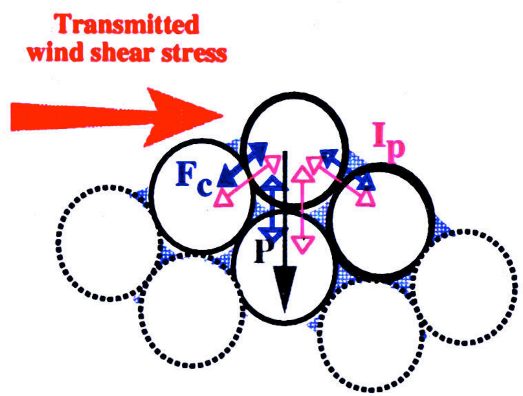


The soil grain size distribution is a key parameter to retrieve the dust flux (and its size distribution)

Erosion threshold and soil moisture

Minimal required energy

Arid regions



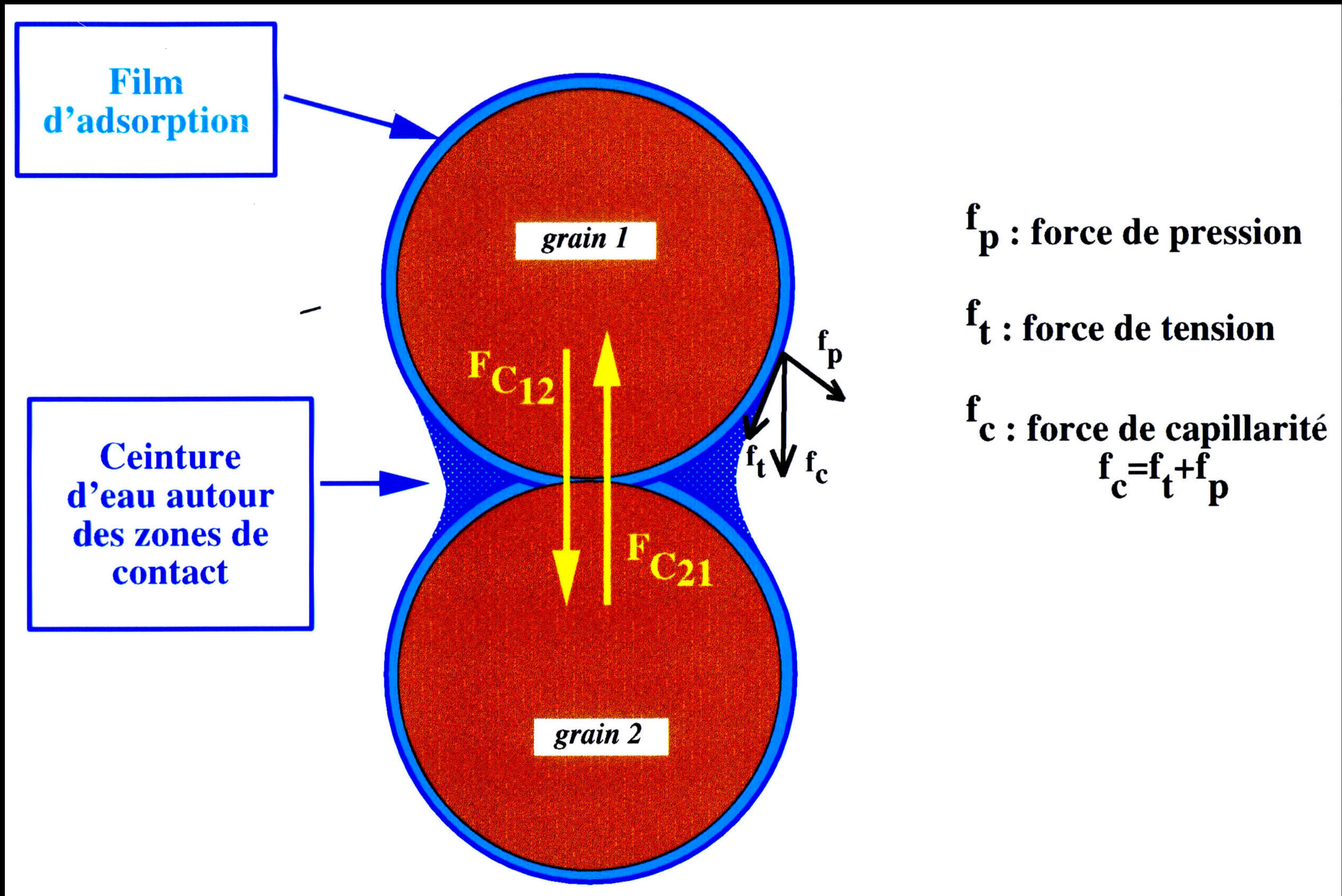
☛ **Forces maintaining the soil grains :**
Particle weight, P
Interparticle cohesion forces I_p

Semi–arid regions

☛ **Soil Moisture :**
Capillary forces F_c

PRECIPITATION

Erosion threshold and soil moisture



Fécan et al., 1999

Erosion threshold and soil moisture

$$U^*_{tw}/U^*_{td} = f\,(\%H, \%clay)$$

(Fécan et al, Annales Geophysicae, 1999)

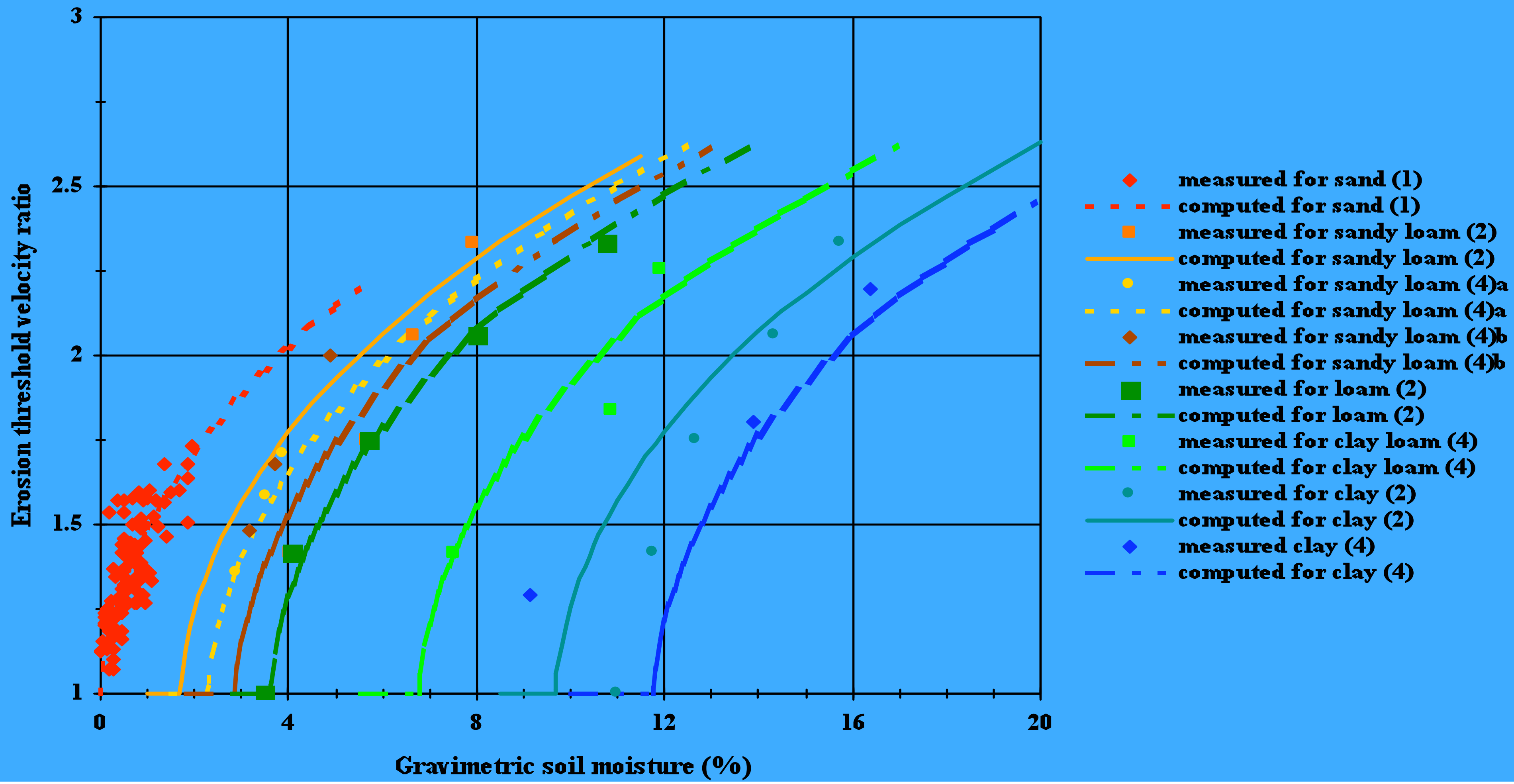
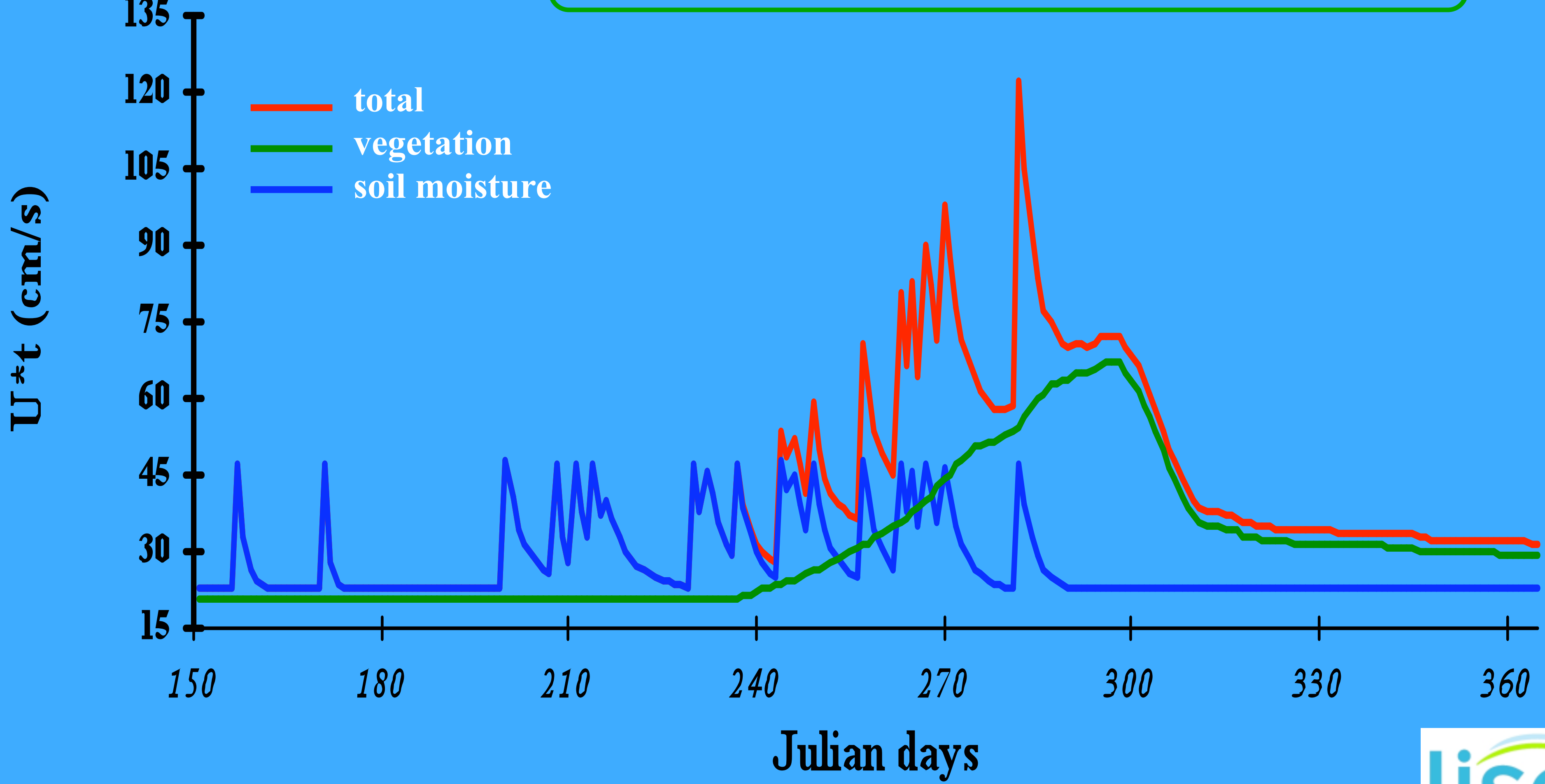


Fig. 8. Measured and computed erosion threshold ratio as a function of the gravimetric soil moisture. Data from (*2*): Bisal and Hsieh (1966); (*3*): McKenna-Neuman and Nickling (1989); (*4*): Saleh and Fryrear (1995)

Erosion threshold and seasonal precipitation

Simulation of the changes in erosion threshold during the wet season for a smooth sandy soil (Dahra, Senegal)

U^*_t = f (vegetation, soil moisture)



- **The effect of the soil moisture on the increase of the threshold wind friction velocity is limited in time in most of the arid and semi-arid areas**

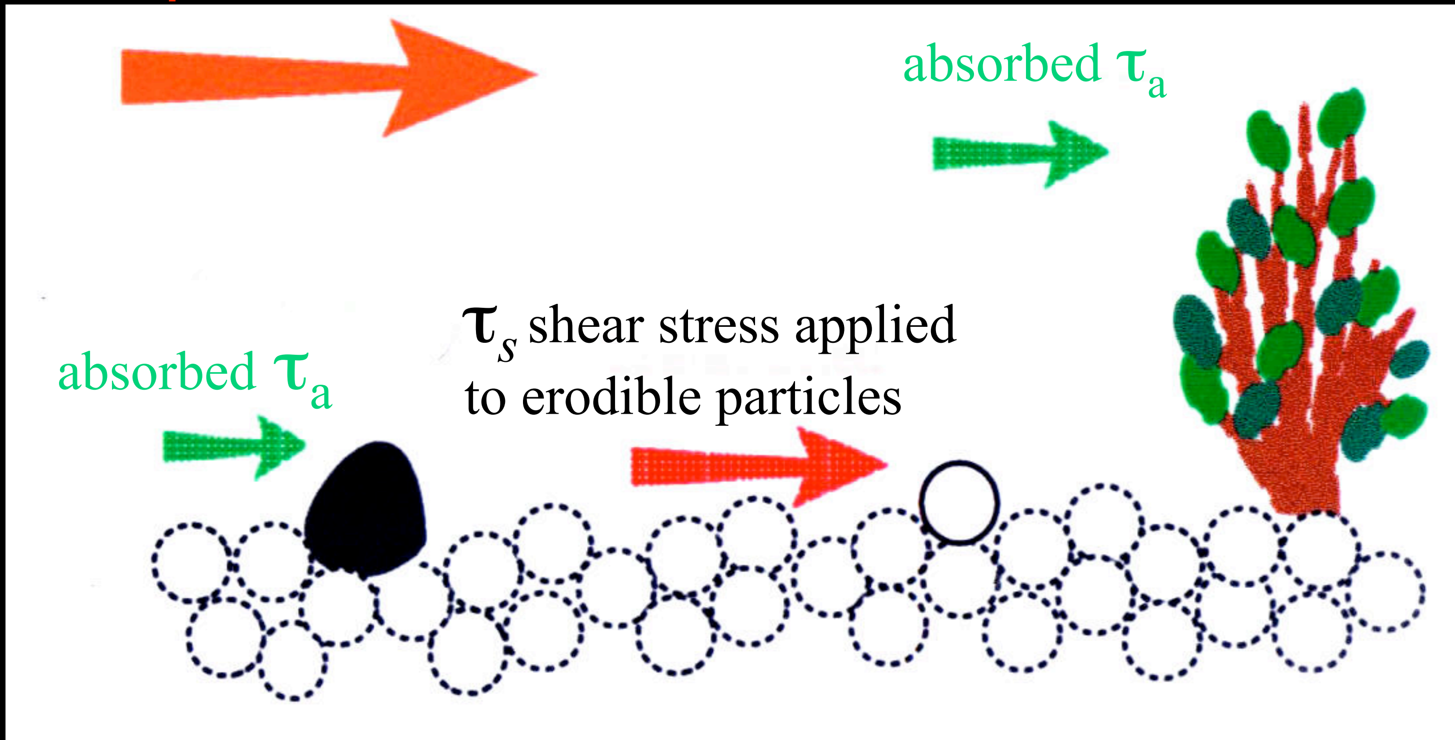
- **The soil moisture is a key parameter to correctly simulate the growth and death of the seasonal vegetation**

- **A correct soil moisture requires precise profile of the soil texture (and obviously correct precipitation)**

Erosion threshold on a rough surface

Total shear stress

$\tau = \rho\, u_*^2$



Drag partition scheme : $\tau = \tau_a + \tau_s$

$$\frac{\tau_s}{\tau} = \left(\frac{U_s^*}{U^*}\right)^2 = \left(\frac{\ln\left(\frac{\delta}{Z_0}\right)}{\ln\left(\frac{\delta}{z_{0s}}\right)}\right)^2$$

Marticorena and Bergametti, JGR, 1995

Validation against wind tunnel measurements

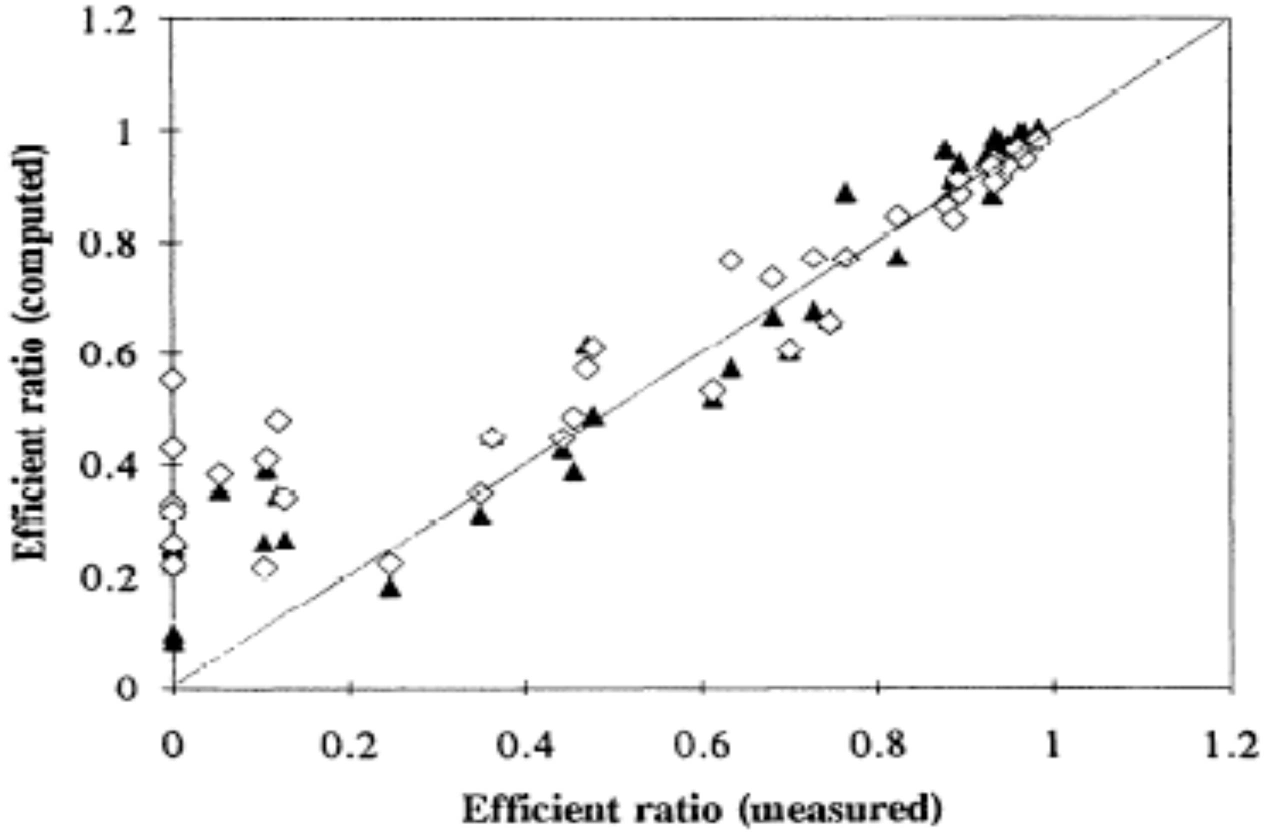


Figure 3. Predicted efficient ratios versus *Marshall*'s [1971] measurements; diamonds: equation (10) [*Raupach*, 1992]; triangles, equation (18).

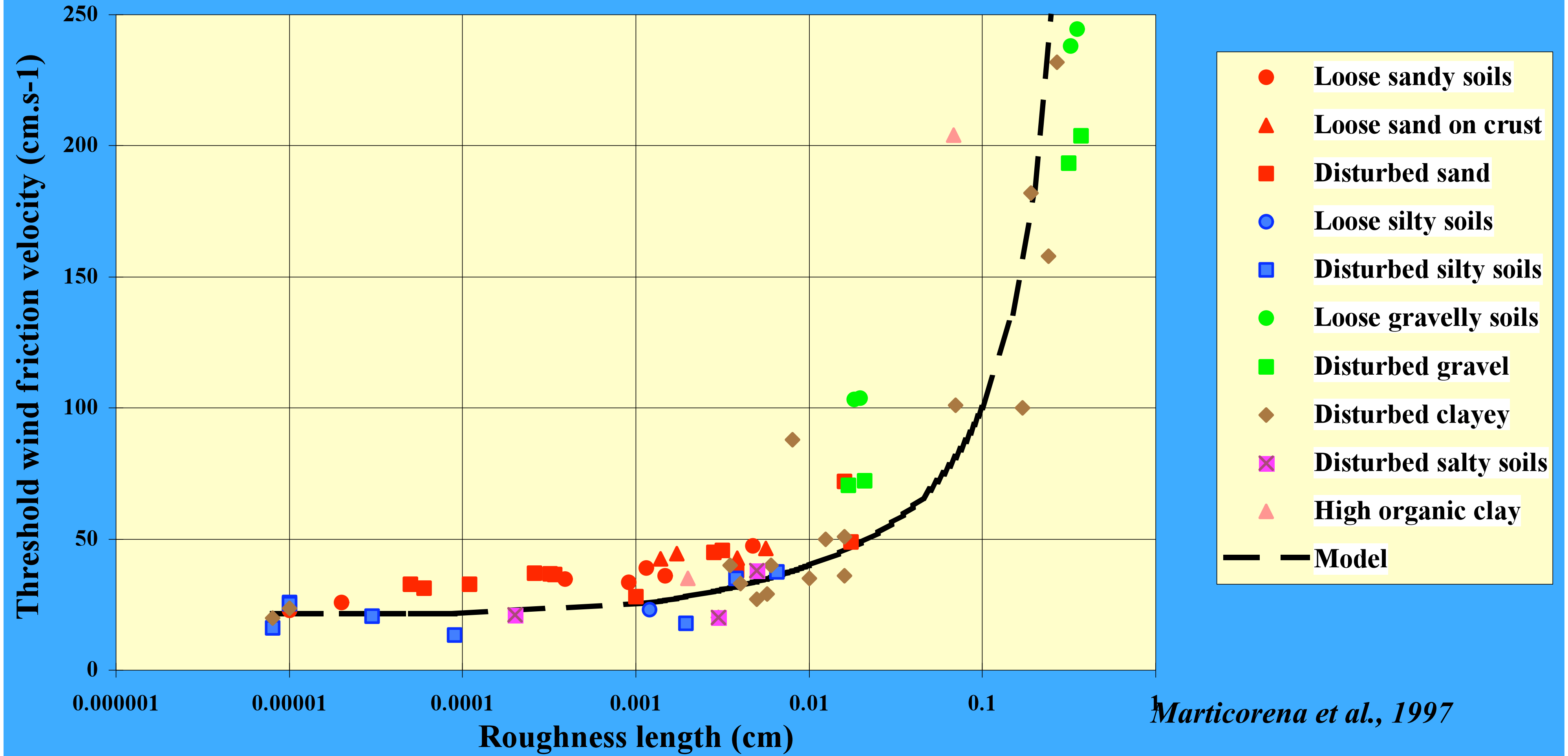
Marticorena and Bergametti, 1995

Threshold wind friction velocity over rough surfaces

Validation against in situ measurements

(data from Gillette, JGR, 1981)

$U^*_t = f(Z_0, D_p)$



Marticorena et al., 1997

- **The roughness height is a key parameter required for precisely reproducing the threshold wind friction velocities over most of the arid and semi-arid surfaces.**

- **It is, with wind velocity, one of the parameters contributing the most to the spatial and temporal variability of dust emissions**

Dust emission processes / saltation

$$G(D_p) = E\,\frac{\rho_a}{g}\,U^{*3}\left(1+R\right)\left(1-R^2\right)$$

with

$$R = \frac{U_t^*\left(D_p, Z_0, z_{0s}\right)}{U^*}$$

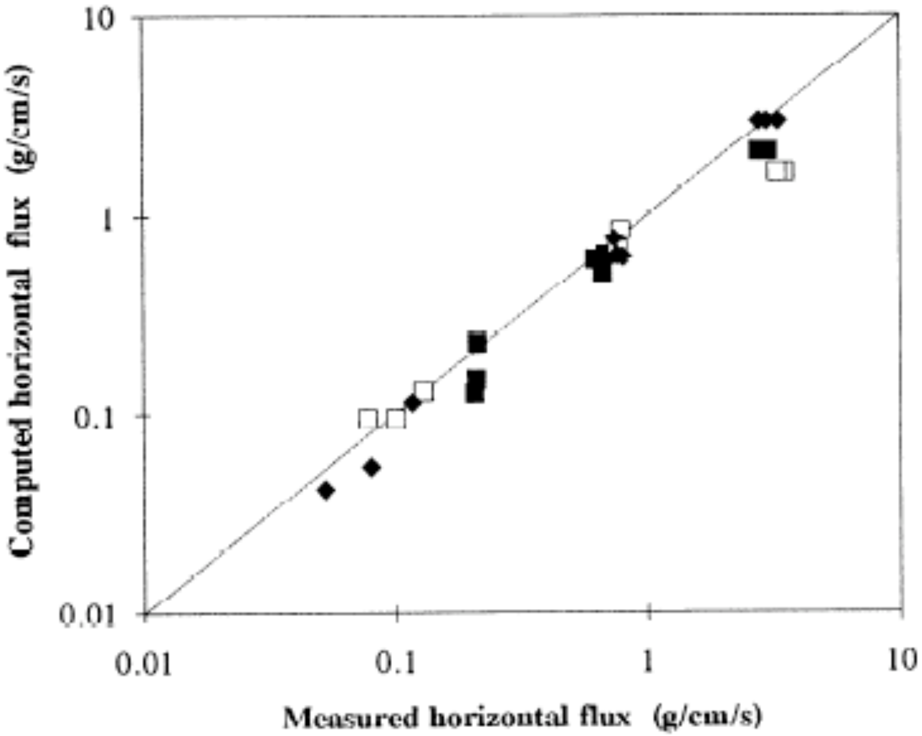
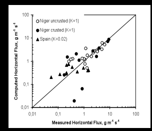


Figure 6. Predicted (equation (34), with C=1) versus measured [*Williams*, 1964] horizontal fluxes; solid squares, symmetrical sand size distribution; open squares, truncated sand size distribution; diamonds, uniform sand size distribution.

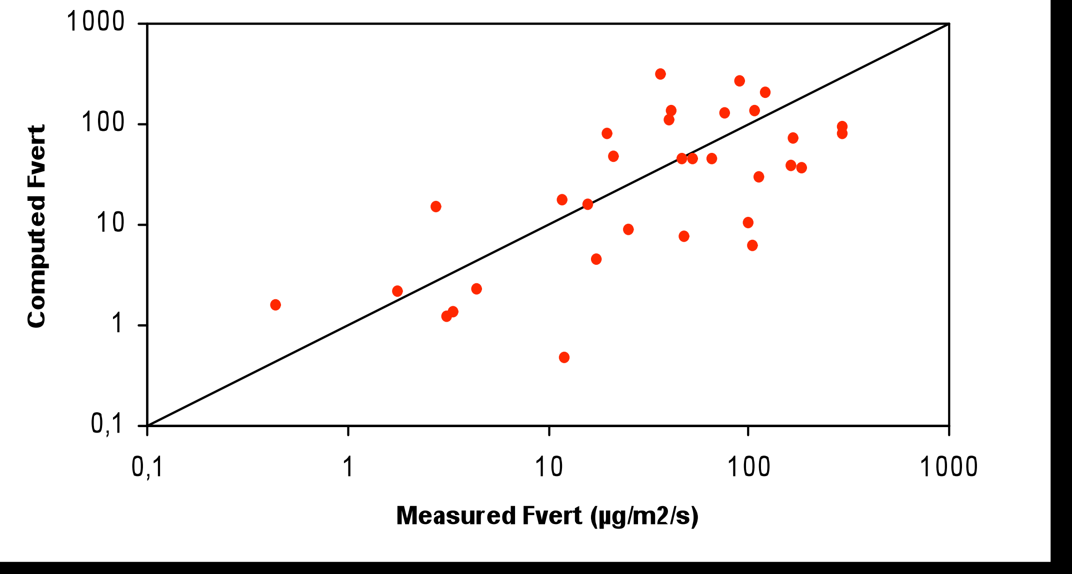


Alfaro and Gomes, JGR, 2002

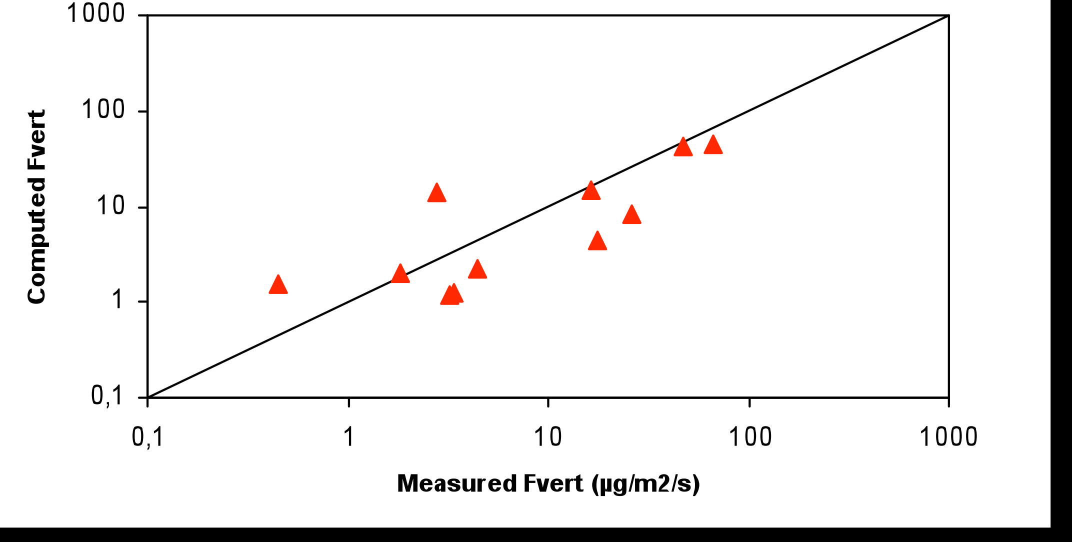
Marticorena and Bergametti, JGR, 1995

Modeled dust emissions fluxes vs fluxes measurements

Niger



Spain



Alfaro (2003)

- **When relevant data are available, physical models work satisfyingly at small and local scale**

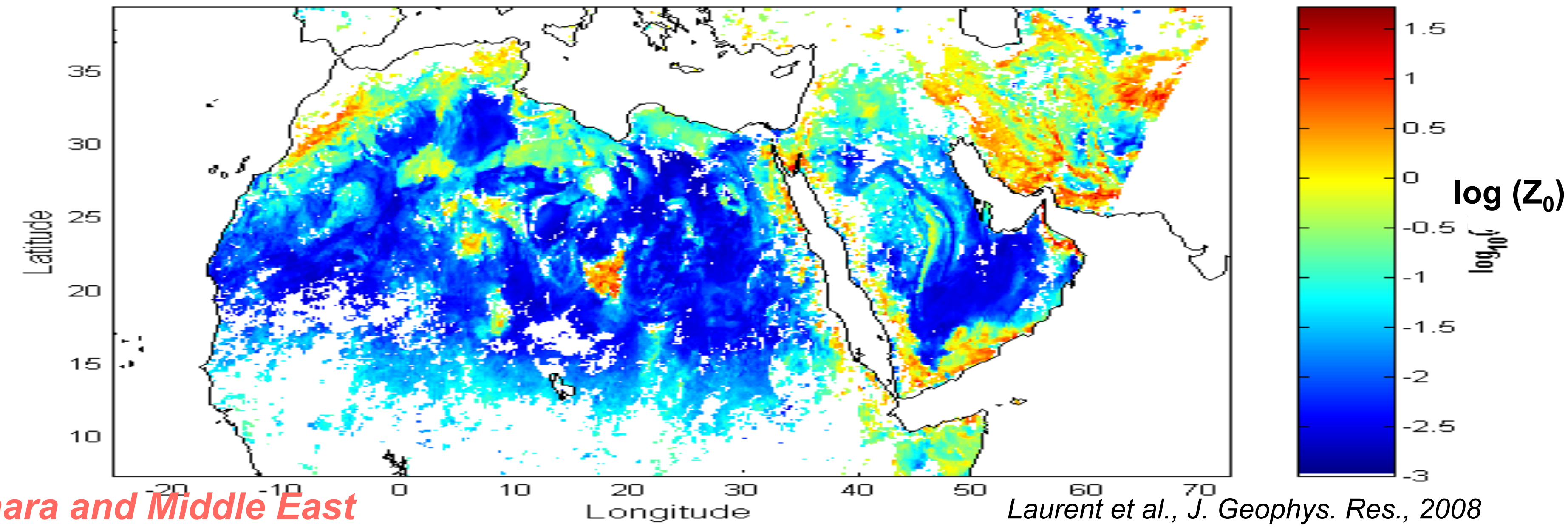
- **Most of the key processes of the aeolian erosion are quite well known and correctly parameterized**

- **The remaining not well constrained processes mainly concern the semi-arid surfaces (crusting, interactions between the vegetated and bare parts of the surface…)**

Applications to Asian deserts

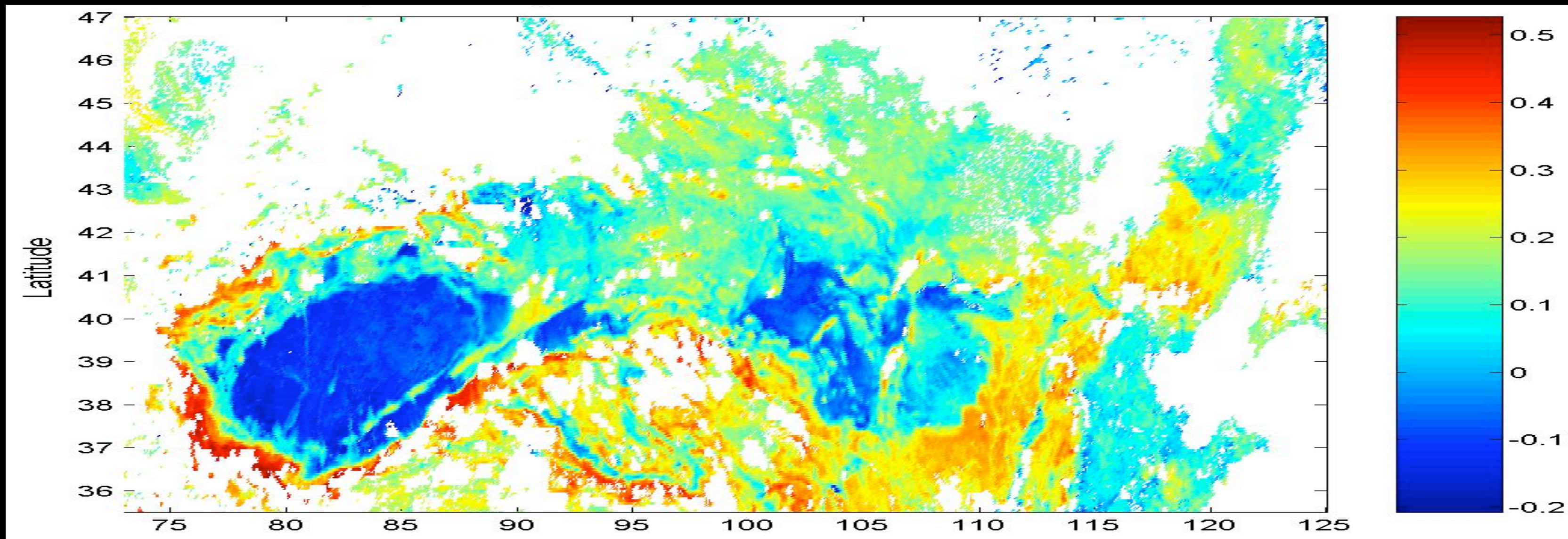
Owens Lake (USA)
Crédit photo: M. Sabre, LISA

Map of the roughness height in arid regions



Sahara and Middle East

Laurent et al., J. Geophys. Res., 2008



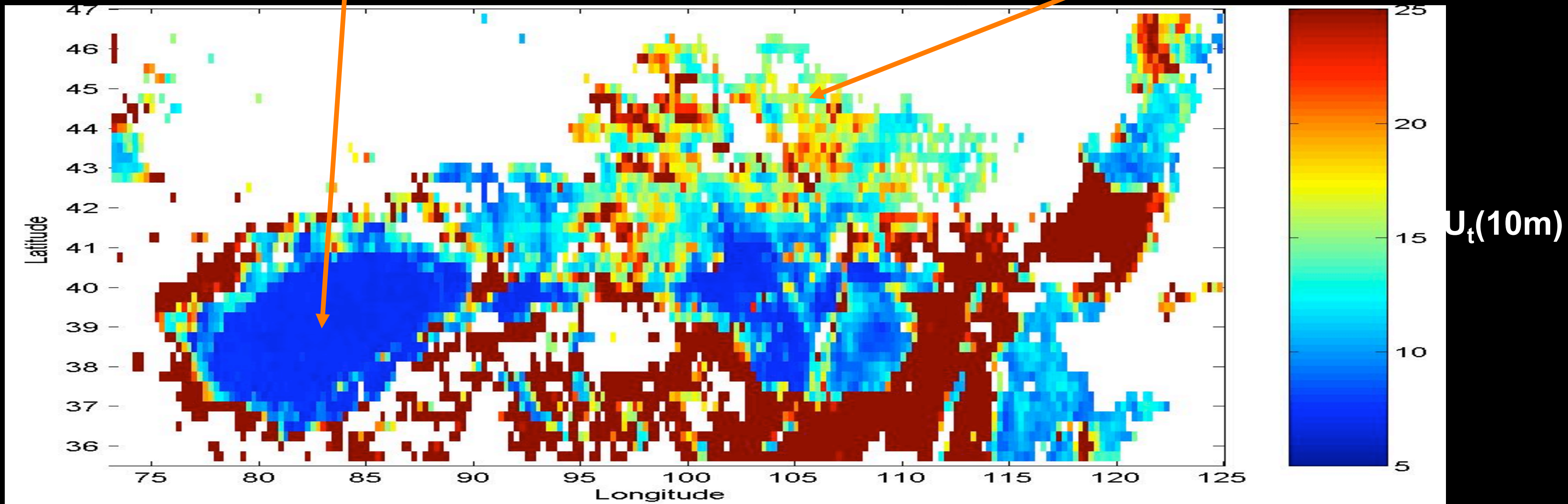
Chinese and Mongolian deserts

Laurent et al., J. Geophys. Res., 2005

10 m erosion threshold wind velocities

Taklimakan
median ~**7 m.s^{-1}**
● Wind velocities associated with dust storms: **6-8 m.s^{-1}** [*Wang et al.,* Water, Air, and Soil Poll., 2003]

Gobi:
median ~**15 m.s^{-1}**
● Wind velocities associated with dust storms: **11-20 m.s^{-1}** [*Natsagdorj et al.,* Atmos. E., 2003]
● Wind tunnel and field studies: **10-12 m.s^{-1}** *Murayama,* Met. Satell. Cent. Tech. Note, 1988; *Hu and Qu,* Chin. Met. Press, 1997]



Laurent et al., J. Geophys..Res., 2005

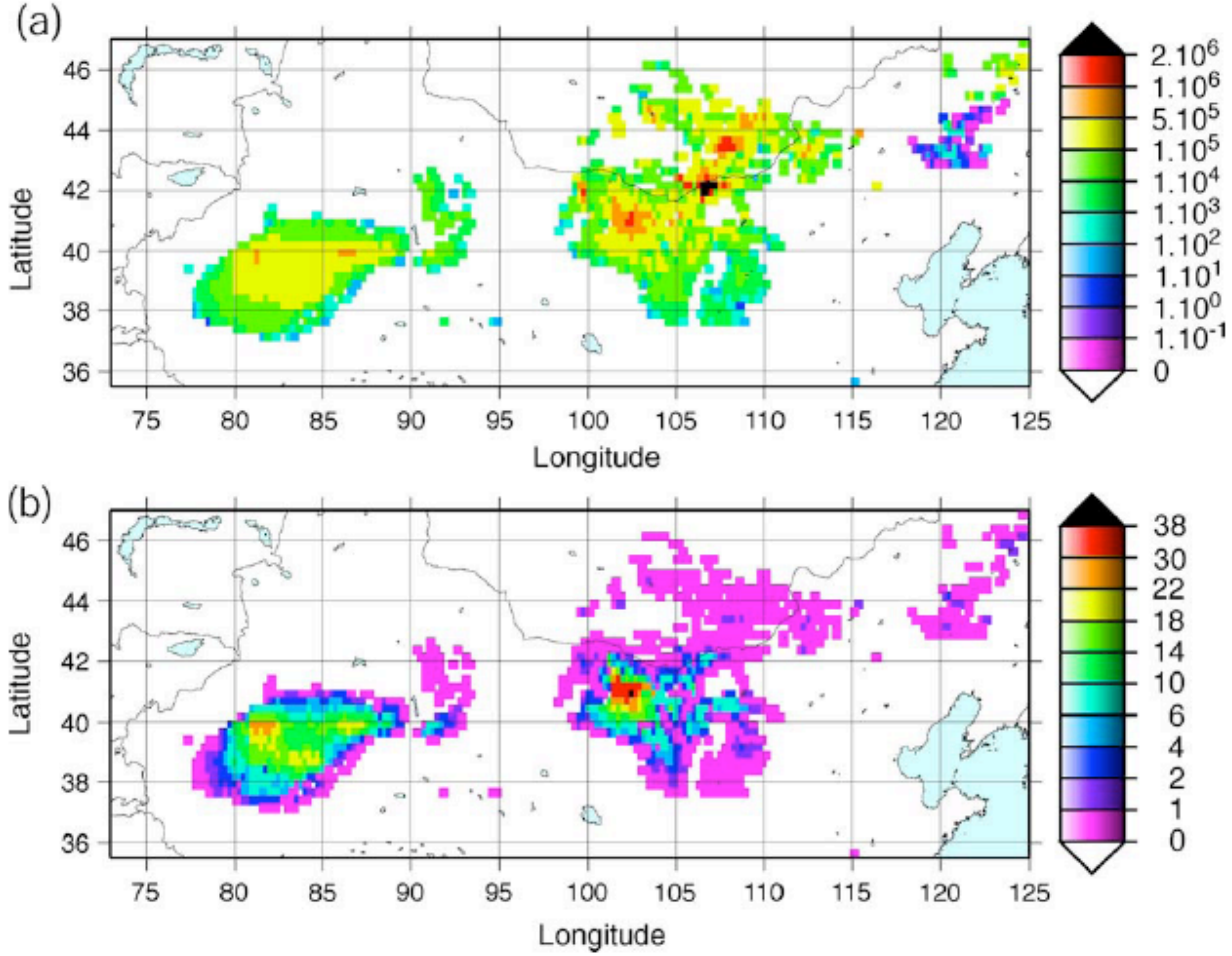


Fig. 9. Annual dust emissions averaged (in t yr^{-1}) over the period 1996–2001 (a); annual number of dust event days averaged over the period 1996–2001 (b).

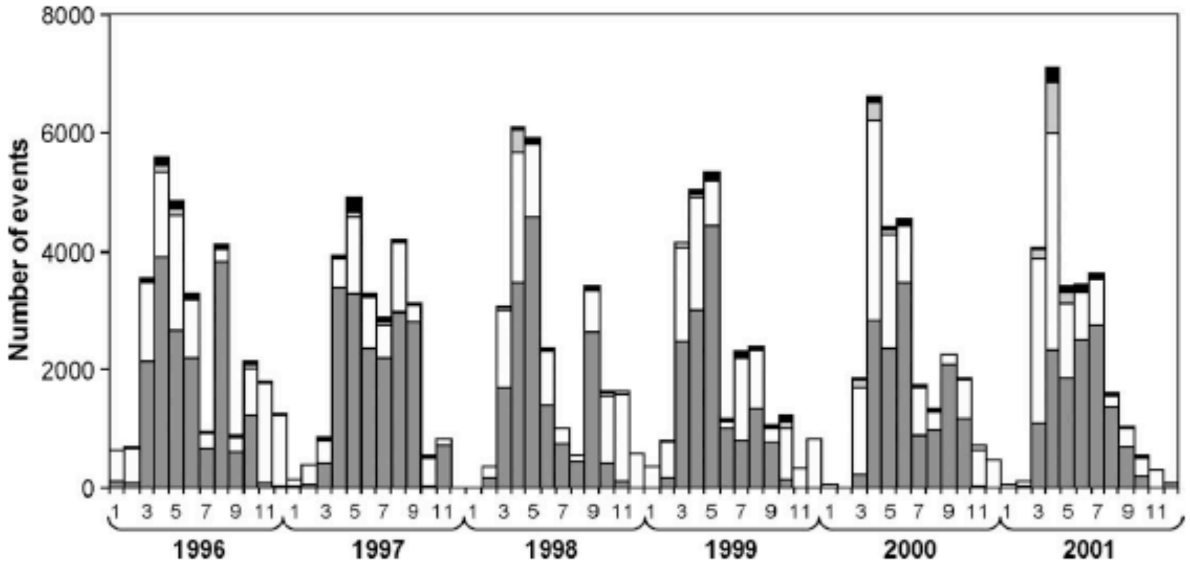


Fig. 13. Monthly number of dust events simulated with a 6-h time step for the Taklimakan desert (dark grey), the northern deserts of China (white), the Gobi desert (light grey) and the other arid areas (black) from January 1996 to December 2001.

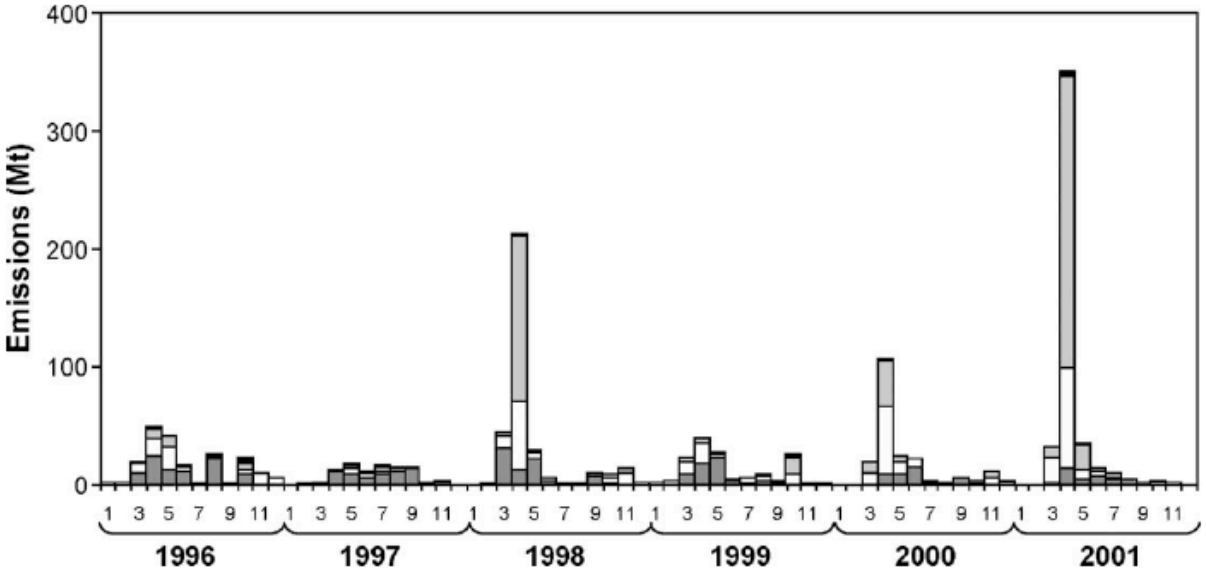


Fig. 12. Monthly dust emissions simulated for the Taklimakan desert (dark grey), the northern deserts of China (white), the Gobi desert (light grey) and the other arid areas (black) from January 1996 to December 2001.

(Laurent et al., Global Planetary Changes, 2006)

Table 4
Annual emissions from 1996 to 2001 for the whole studied area (total), the Taklimakan desert (TK), the northern deserts of China (ND), the Gobi desert (GB) and the other arid areas of China and Mongolia (other)

	Mineral dust emissions (10^6 t)				
	TK	ND	GB	Other	Total
1996	94	72	26	12	204
1997	68	19	10	4	100
1998	80	99	149	3	332
1999	62	59	27	4	151
2000	46	96	61	2	205
2001	41	126	285	7	459
Mean	65	79	93	5	242
σ	20	37	107	4	131

Conclusions

- ***Dust emissions and deposition are controlled by sporadic processes leading to a very high variability of the atmospheric dust load***
- ***Short but intense emission or deposition events can represent a large part of the annual budget***
- ***The possible links between the different temporal scales of variability need to be more systematically investigated***
- ***The emission models have significantly progressed towards more physical consistency and they better account for the variability of the surface properties***
- ***In terms of processes, the remaining cavits (for present times!) concern mainly the sandblasting process, the role of the seasonal vegetation, and the crusted surfaces***
- ***In terms of input data, wind is the key problem***
- ***There are no quantitative validation of the simulations at large scale***