MINERAL DUST EMISSION PROCESSES AND THEIR MODELING: RECENT PROGRESSES AND REMAINING CHALLENGES

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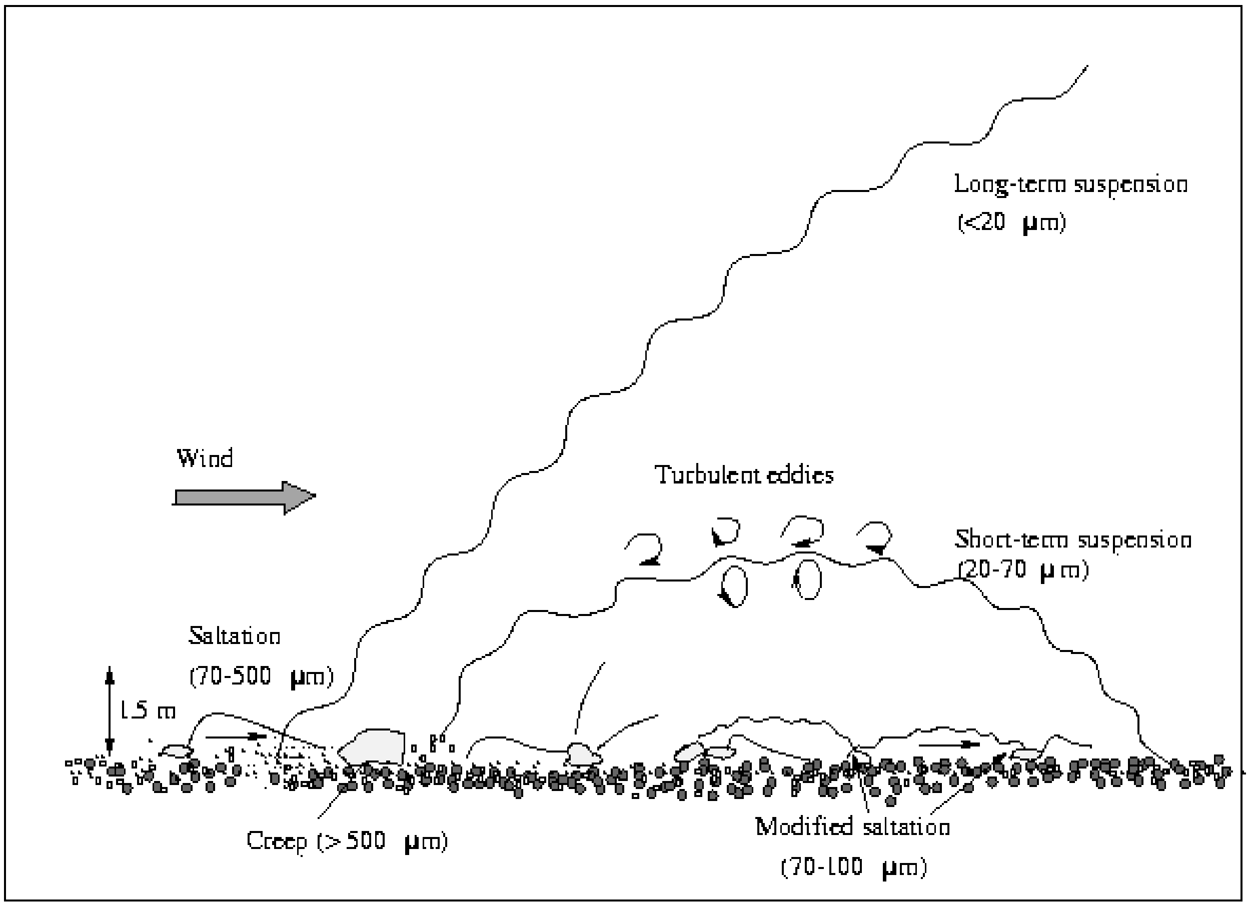
DUST EMISSIONS PROCESSES

General picture



(From Y. Shao)

DUST EMISSIONS PROCESSES

- Dust emission results from mechanical processes involved in wind erosion
  - **Wind is the main driver**
  - There is a wind velocity **threshold**
  - **Saltation** is generally a pre-requisit
  - Dust is released by « **sand-blasting** »

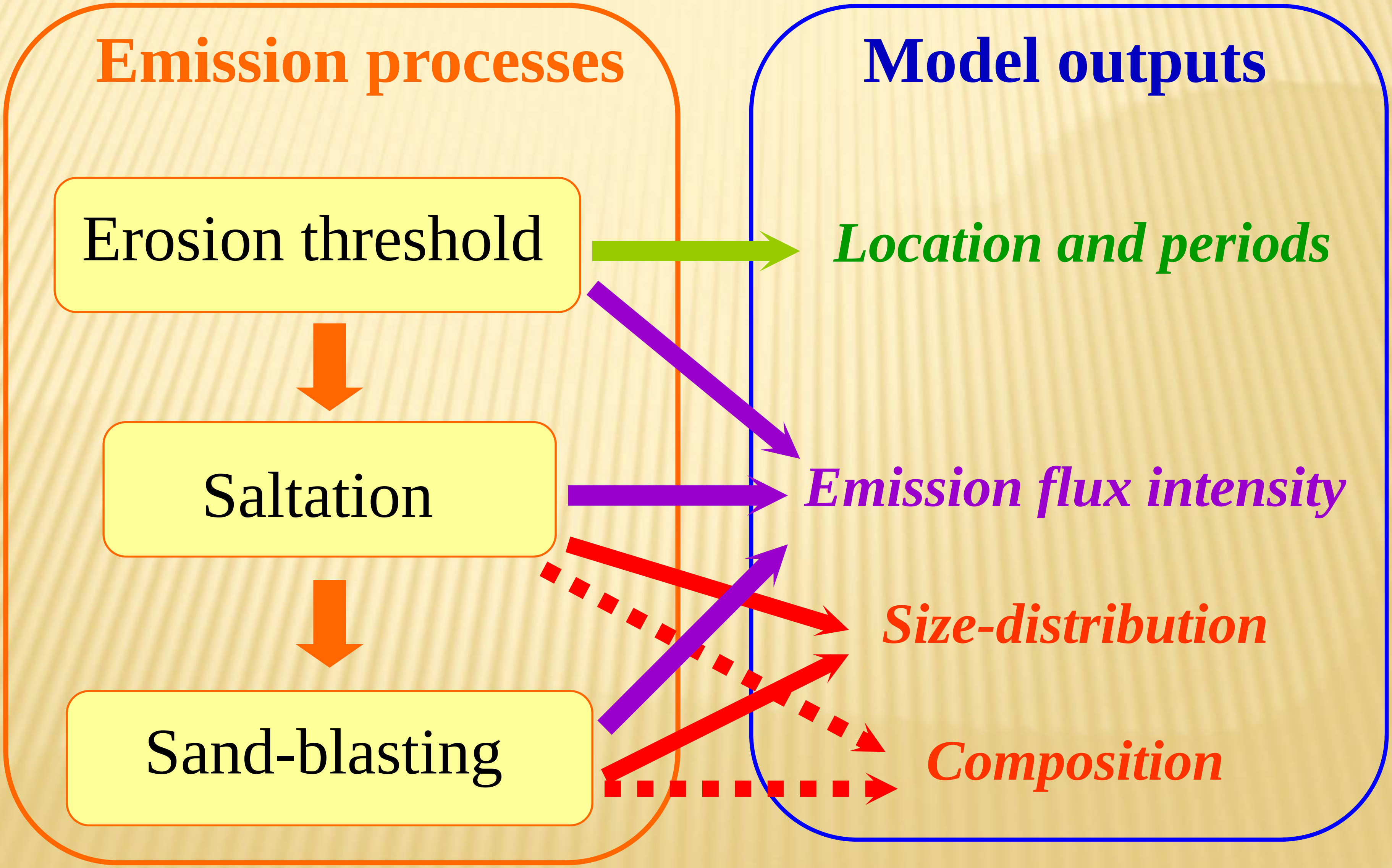
$$F = \alpha \, . \, C. \, U_*^3 \, (U_* - U_{*t})$$

Sand-blasting efficiency (→ α)

Saltation flux ($C. U_*^3 (U_* - U_{*t})$)

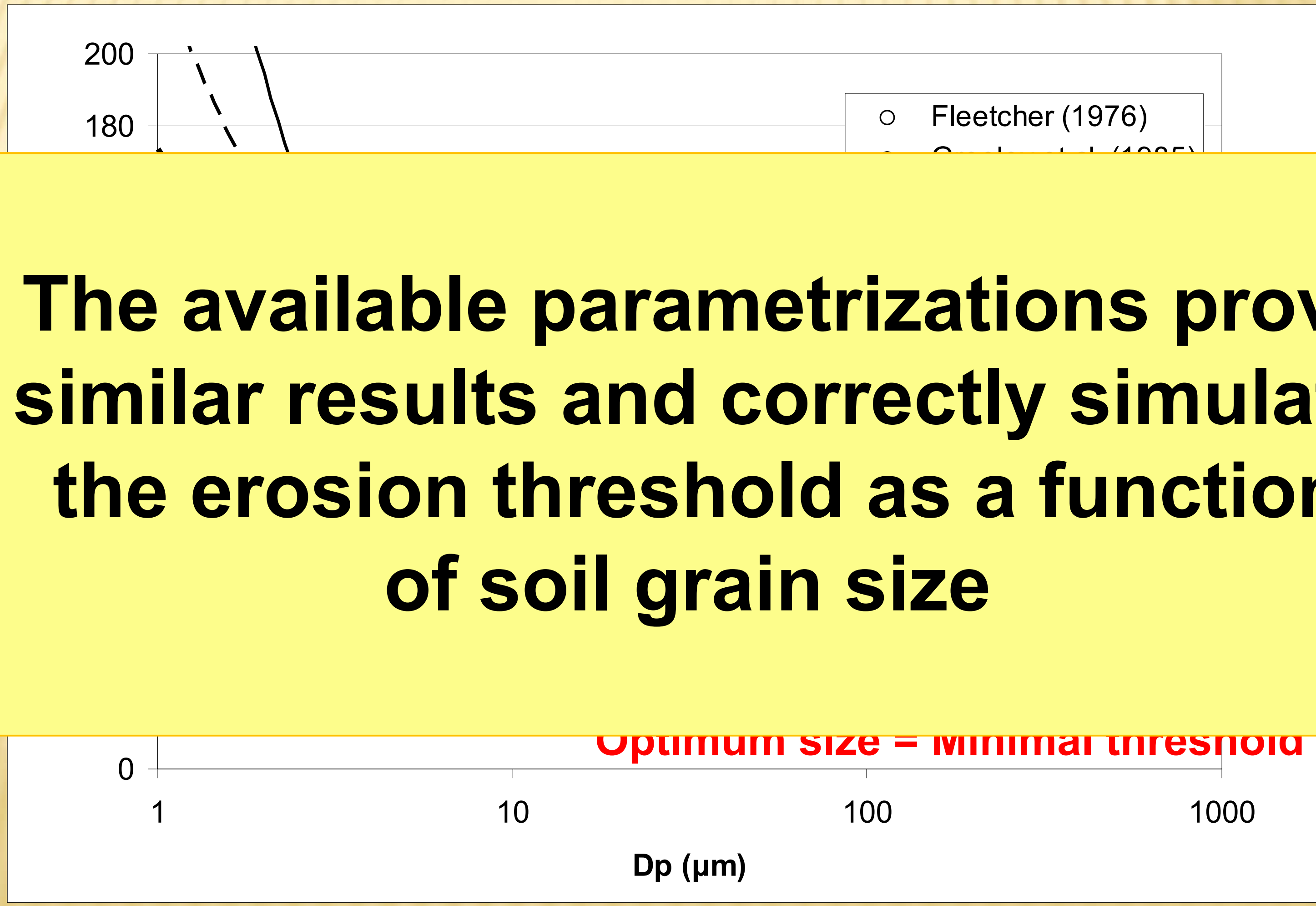
Threshold (→ U_{*t})

DUST EMISSIONS PROCESSES



DUST EMISSIONS PROCESSES : THRESHOLD

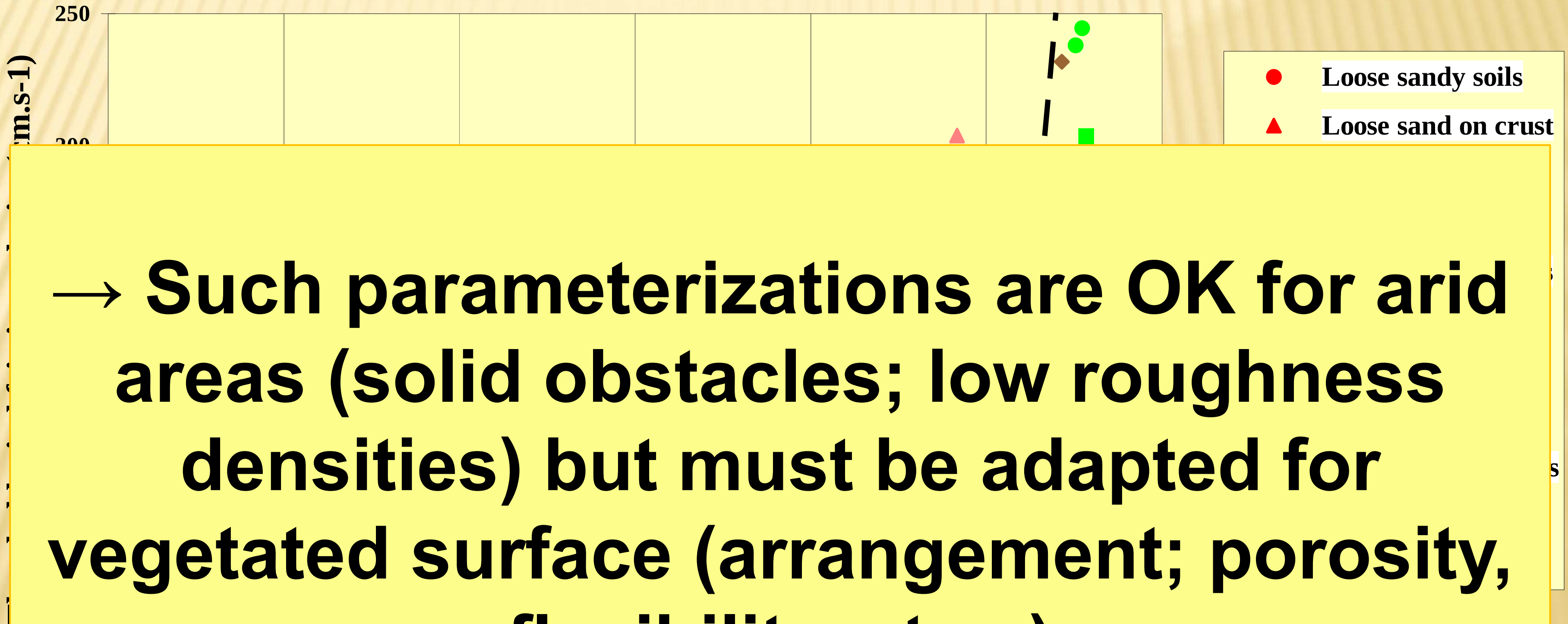
A size-dependent erosion threshold



→ The available parametrizations provide similar results and correctly simulate the erosion threshold as a function of soil grain size

DUST EMISSIONS PROCESSES : THRESHOLD

Influence of surface roughness



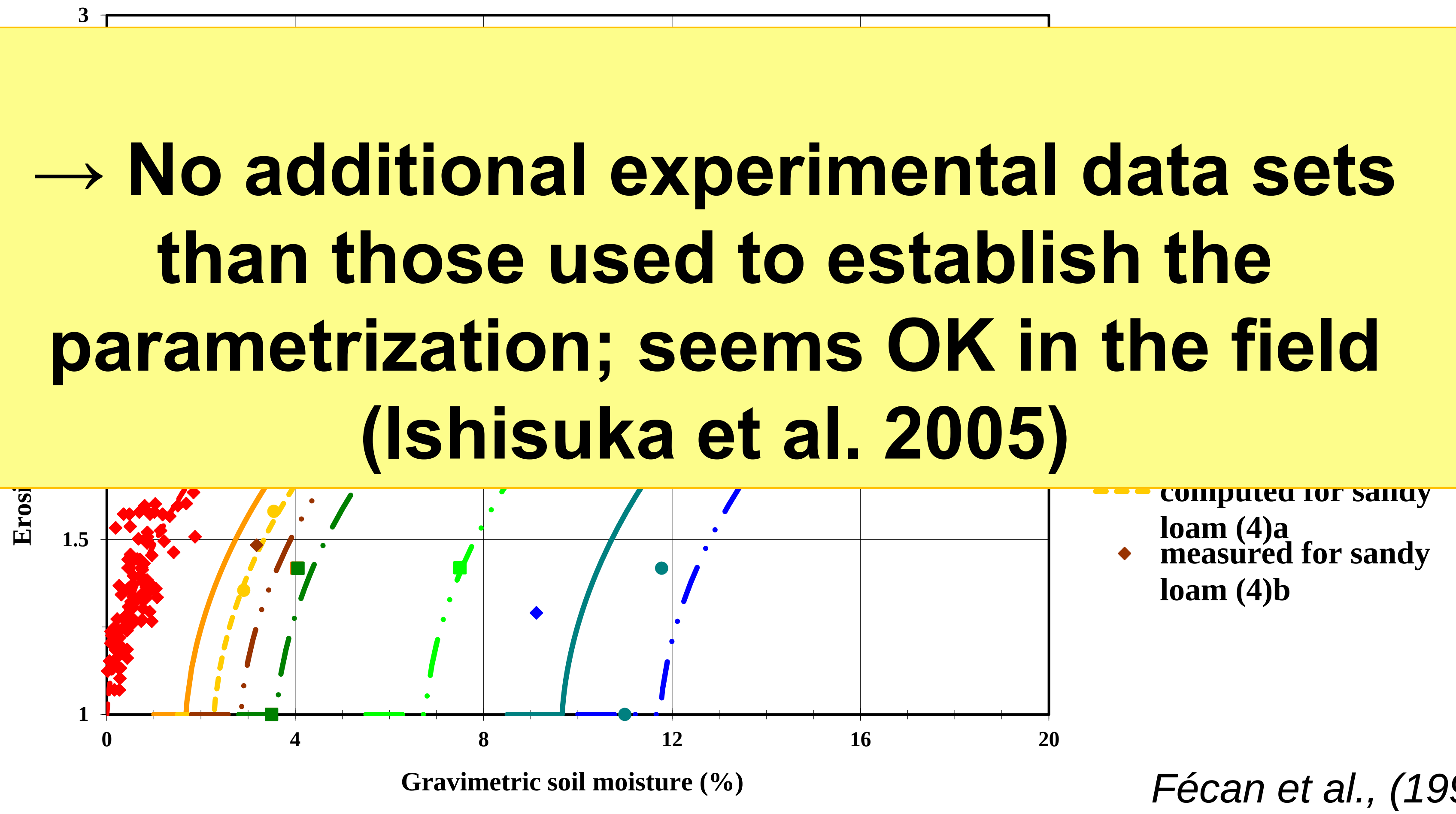
→ Such parameterizations are OK for arid areas (solid obstacles; low roughness densities) but must be adapted for vegetated surface (arrangement; porosity, flexibility, etc ..)

(Mac Kinnon et al., 2004)

(Marticorena and Bergametti, 199

DUST EMISSIONS PROCESSES : THRESHOLD

Influence of soil moisture



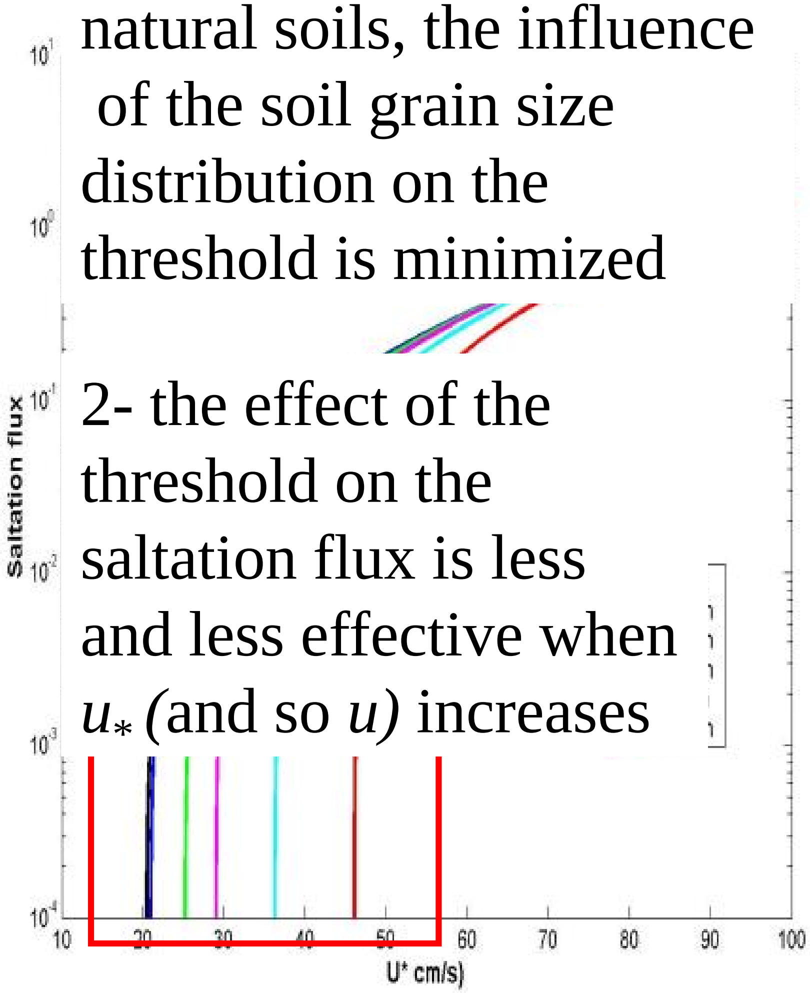
→ No additional experimental data sets than those used to establish the parametrization; seems OK in the field (Ishisuka et al. 2005)

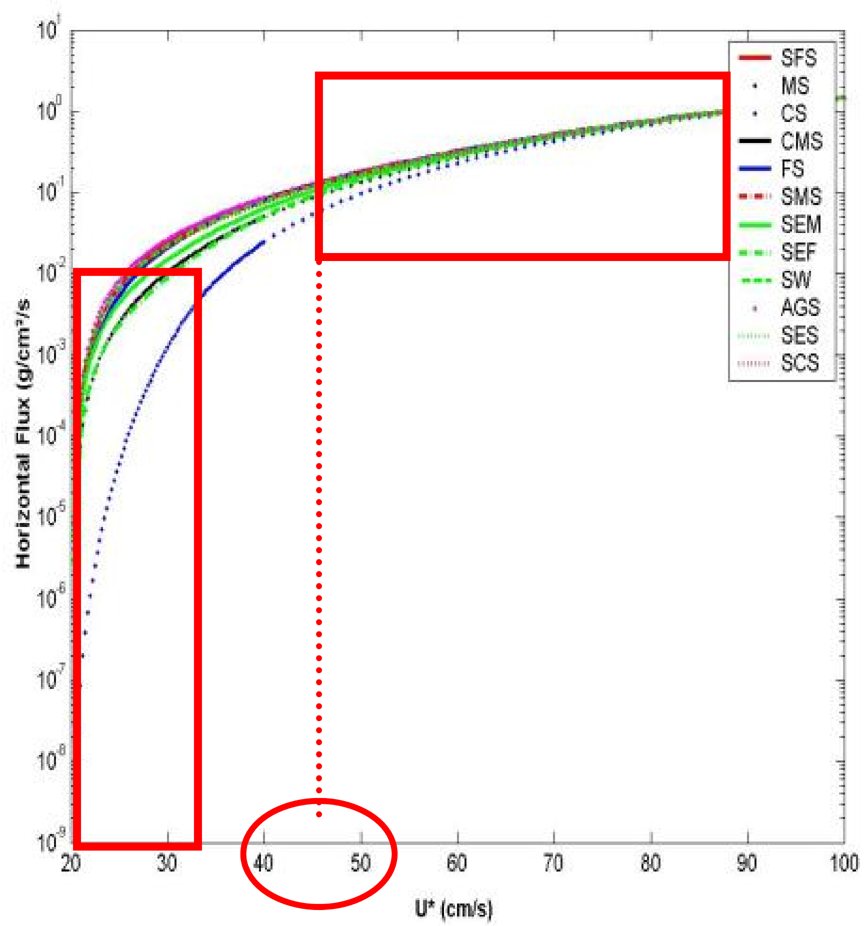
Fécan et al., (1999)

DUST EMISSIONS PROCESSES : SALTATION

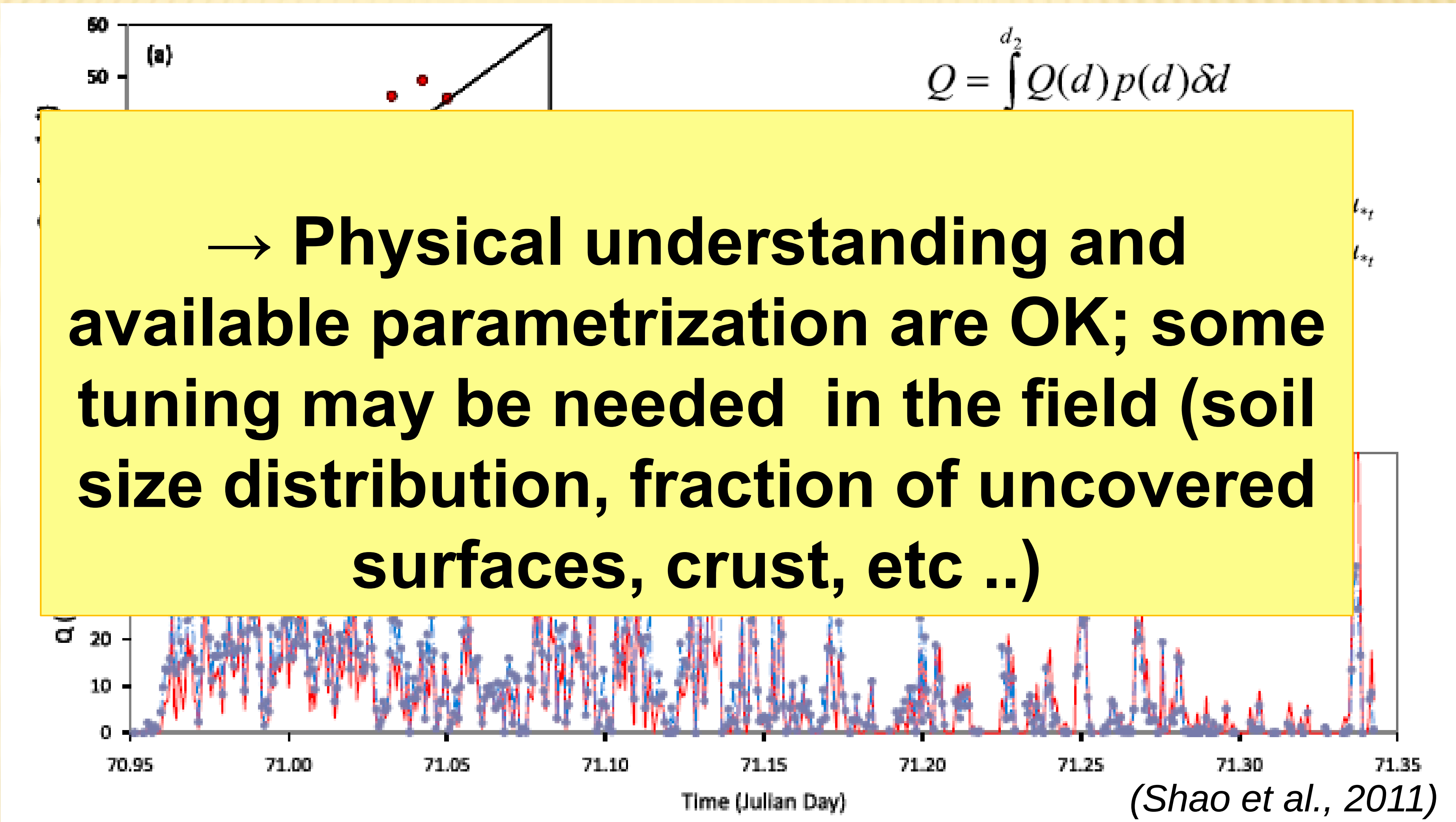
1- When applied to natural soils, the influence of the soil grain size distribution on the threshold is minimized

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





DUST EMISSIONS PROCESSES : SALTATION

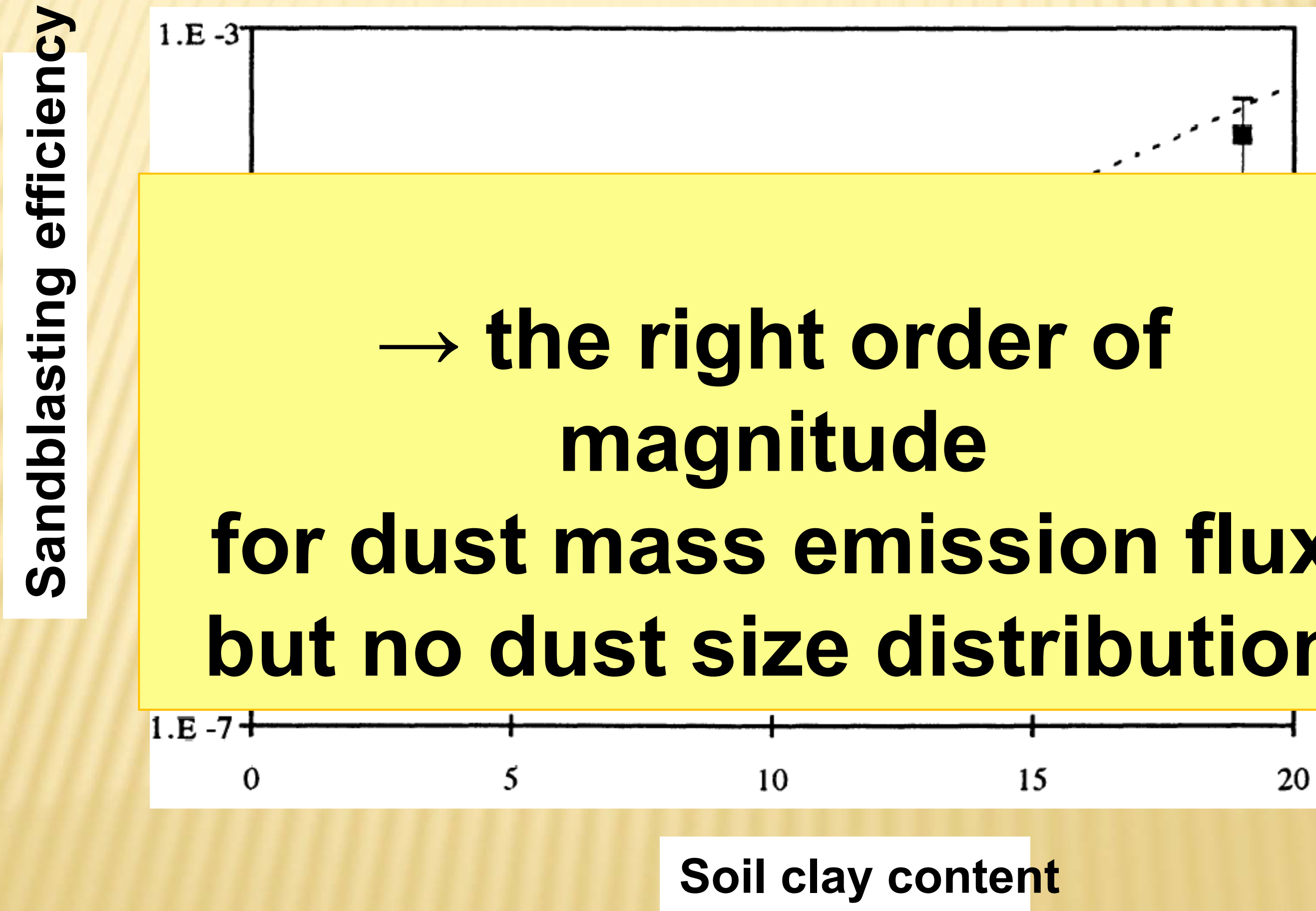


→ Physical understanding and available parametrization are OK; some tuning may be needed in the field (soil size distribution, fraction of uncovered surfaces, crust, etc ..)

(Shao et al., 2011)

DUST EMISSIONS PROCESSES : SANDBLASTING

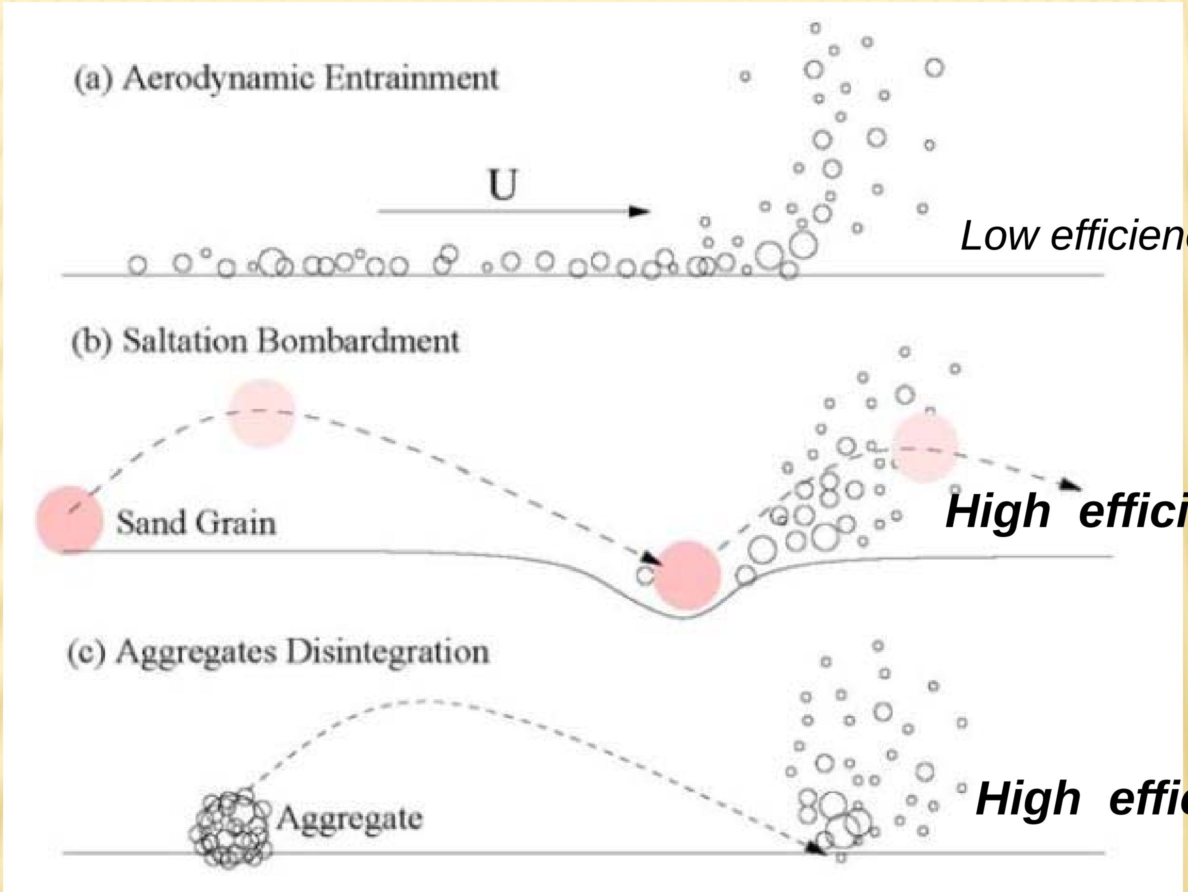
The soil clay content as a proxy of the amount of dust in the s



→ the right order of magnitude
for dust mass emission flux
but no dust size distribution

(Marticorena and Bergametti, 199

DUST EMISSIONS PROCESSES : SANDBLASTING



Low efficiency

High efficiency

High efficiency

(Shao et al., 2004)

= A balance between the kinetic energy of saltating grains and the cohesion of fine particles

DUST EMISSIONS PROCESSES : SANDBLASTING

➯ Conceptual understanding

→ **all these models require input parameters that are difficult/impossible to measure**

→ **Measurements of the size distribution of the emission fluxes could be used as a constrain**

DUST EMISSIONS PROCESSES : SANDBLASTING

Simulated dust size distribution **(Alfaro and Gomes, 2001)**

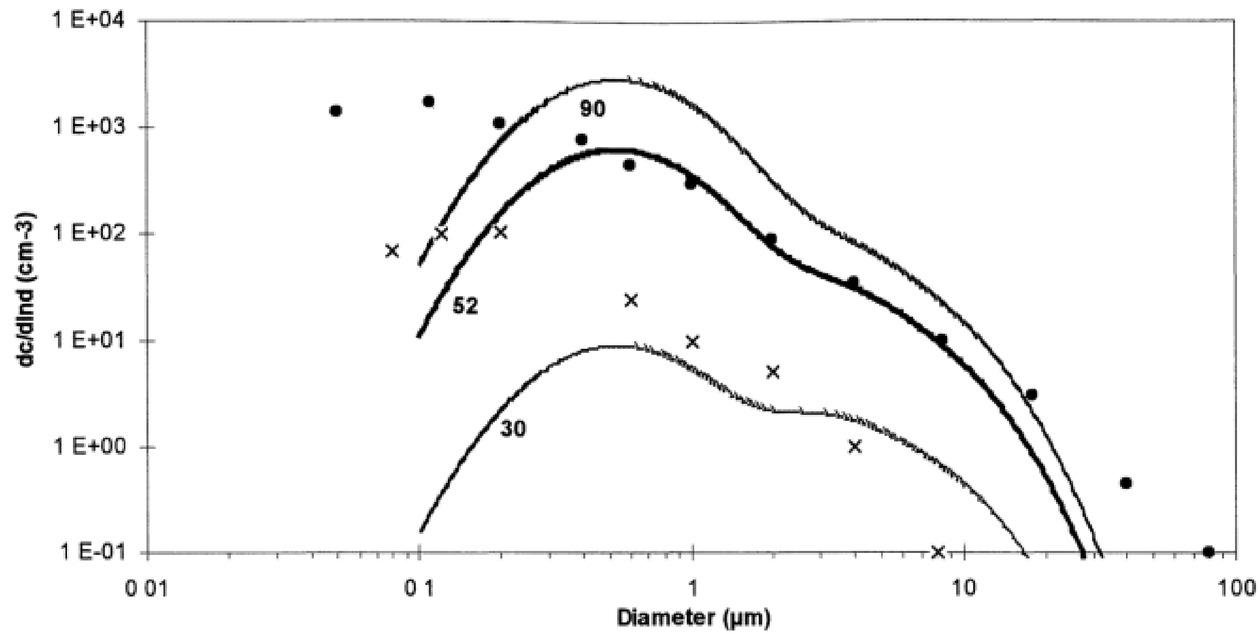


Figure 5. Comparison of the (concentration) size distributions of the aerosols released by a smooth FS soil at three different u^* (30, 52, and 90 cm/s) with field measurements in 'background' (crosses) and 'dust storm' (circles) conditions [after *d'Almeida*, 1986]

-The proportion of the finest modes increases as wind friction velocity increases because of higher kinetic energy flux

DUST EMISSIONS PROCESSES : SANDBLASTING

Size-resolved dust emission fluxes (Sow et al., 200

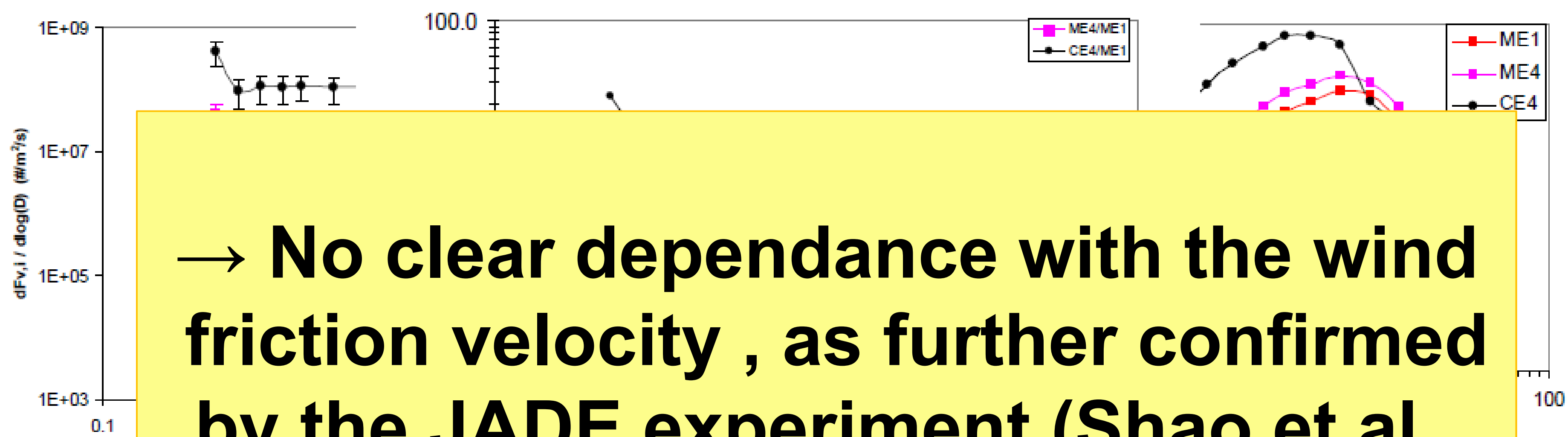


Fig. 9. Aver
(CE4) and M
bars corresponds to the standar

measured during the monsoon event chosen as a reference case (ME1).

tudy.
tes of
distribution towards smaller sizes
(CE4).

→ No clear dependance with the wind friction velocity , as further confirmed by the JADE experiment (Shao et al., 2011)

DUST EMISSIONS PROCESSES : SANDBLASTING

Size-distribution of the dust emission fluxes (Sow et al., 200
(log normal modes; gmd, = geometric mean diameter in µm)

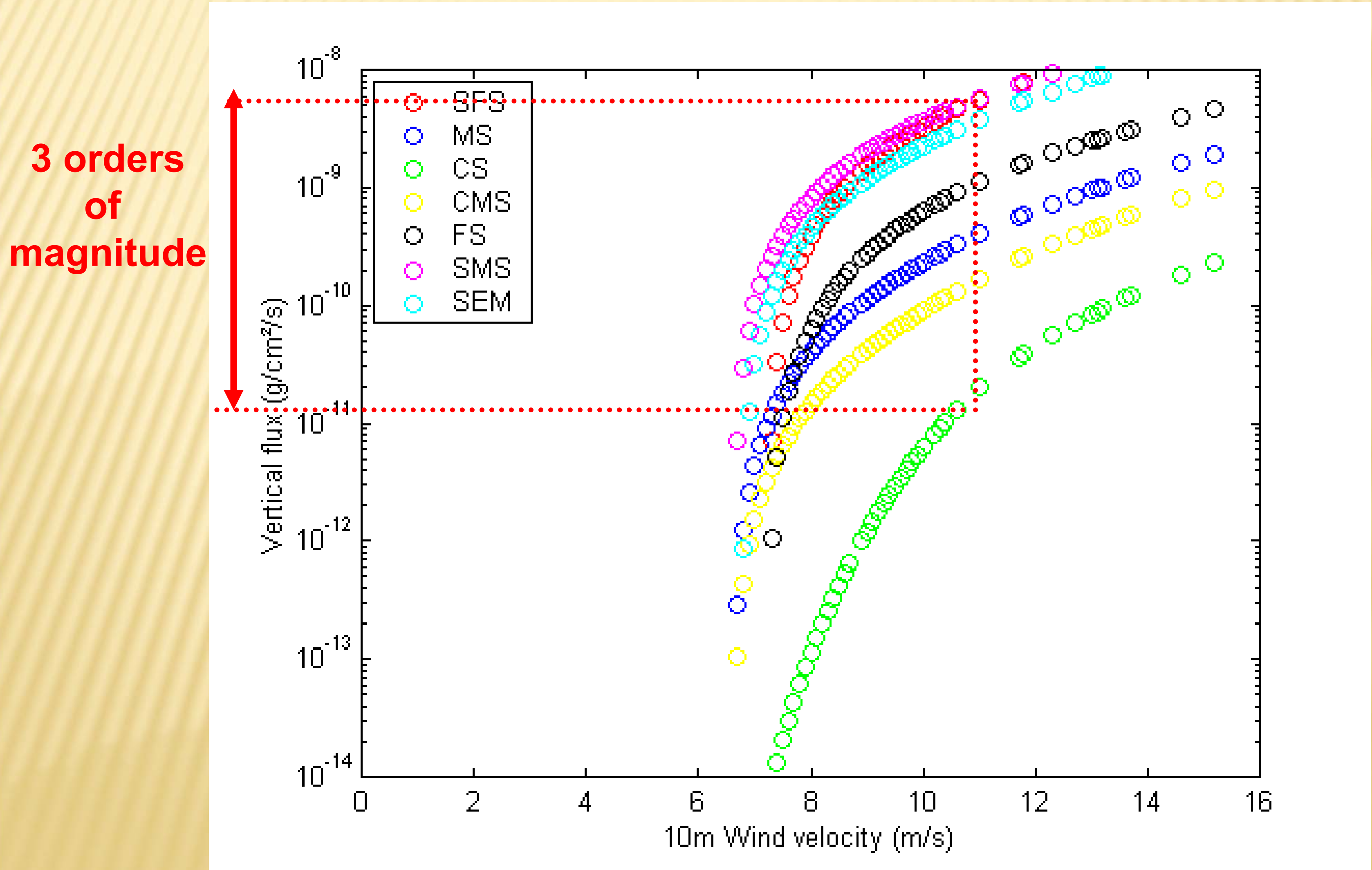
	mode1			mode2			mode3		
	σ	gmd	%	σ	gmd	%	σ	gmd	%
ME1				1,7	4,9	42%	1,5	10,4	58
ME4				1,8	5,1	43%	1,5	10,4	57%
CE4	1,50	1,70	11%	1,7	5,1	77%	1,5	10,0	12%
Wind tunnel	1.7	1.5		1.6	6.7		1.5	14.2	

(Alfaro et al., 1998)

The two coarse modes are finer than in the wind tunnel expe

DUST EMISSIONS PROCESSES : SANDBLASTING

Sensitivity of the dust flux (Alfaro and Gomes, 2001) **to the soil grai**



DUST EMISSIONS PROCESSES : SANDBLASTING

Simulation of the size-distribution of emitted dust with a brittle fragmentation theory (Kok, 2011)

<u>Input parameters</u>

Propagation length

λ= 12±1 µm

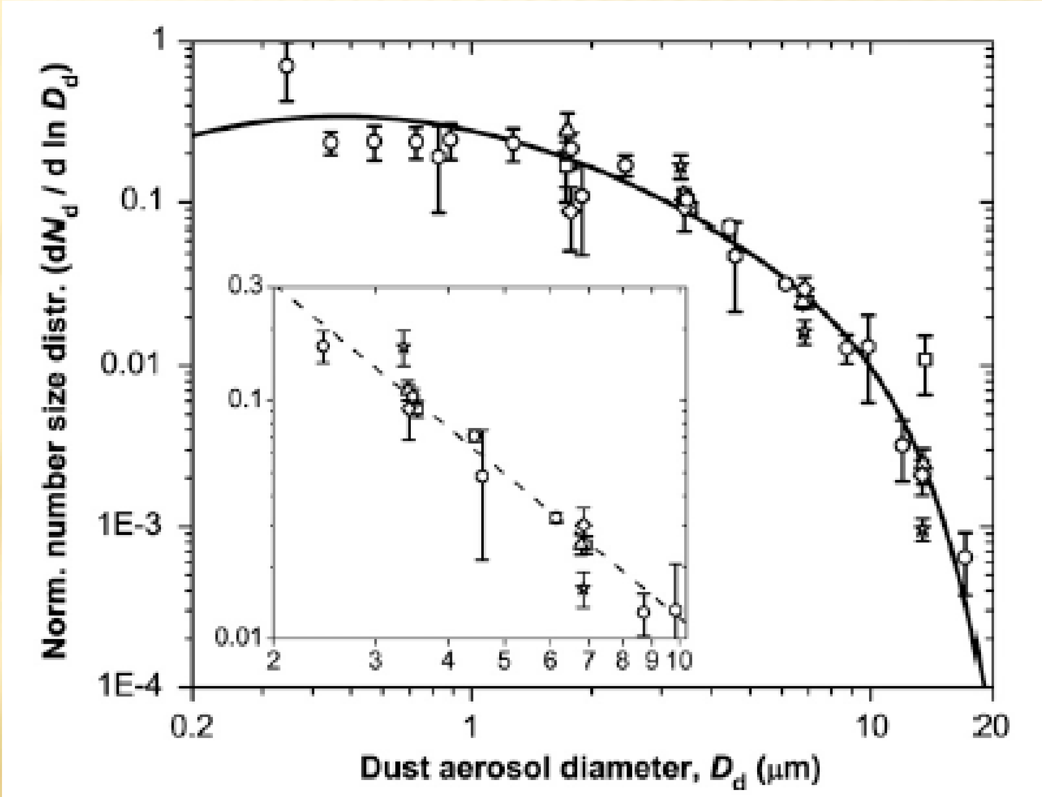
Soil texture

D_s =3.6 µm

σ_s =3

C_N =0.9539

C_v =12.62



Dust size distribution = power law

DUST EMISSIONS PROCESSES : SANDBLASTING

→ Soil properties seems to play a critical role in the sandblasting models ; to be further investigated (wind tunnel; in the field)

→ Soil size distributions is not homogeneously measured (no standard)

→ Measured dust size distribution must be enlarged (<0.3 µm; >10µm)

(Kok et al., 2011)

DUST EMISSIONS PROCESSES

→ **Dust emission fluxes can be reasonably well predicted if surface parameters (soils properties, surface roughness, vegetation/litter cover), surface winds and soil moisture are correctly measured/estimated**

→ **Sand blasting models cannot predicted the size distribution of the emitted dust with a good confidence level.**

- Too few emission experiments

DUST EMISSIONS PARAMETERIZATIONS

- Formally, dust emission parameterizations used in 3-D models are in the form :

$$F \approx C.\ U^3\ (U - U_t)$$

- Simplifications : Prescribed preferential sources, erodability index ($C = \sum c_i$) , …

- Input parameters
  - Surface properties: aeolian roughness; soil size-distribution
  - Meteorological parameters : Wind velocity ; soil moisture or precipitation

INPUT PARAMETER : SURFACE ROUGHNESS

- Mapping from satellite surface products

(La

→ Surface satellite products (BRDF, radar backscatter coefficient) provides very good estimation of the aeolian roughness length and thus of the erosion threshold

→ Today d ifferent maps are available at the global scale *(i.e., Prigent et al.,submitted to AMT-D; MODIS BRDF, E. Vermote))*

M

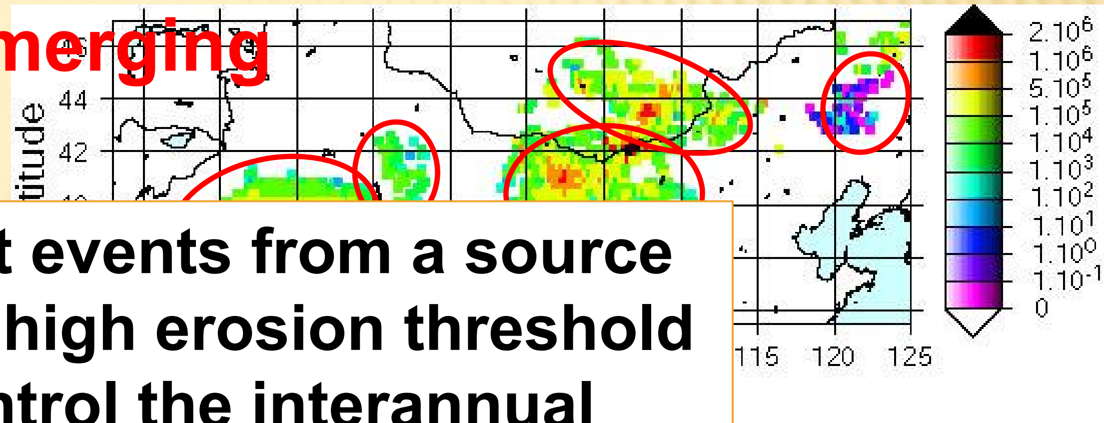
m

INPUT PARAMETER : SURFACE ROUGHNESS

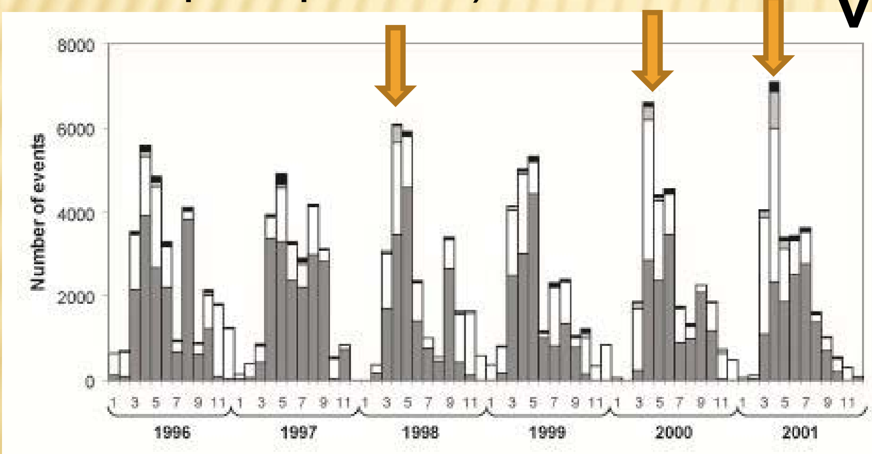
Dust sources are clearly emerging

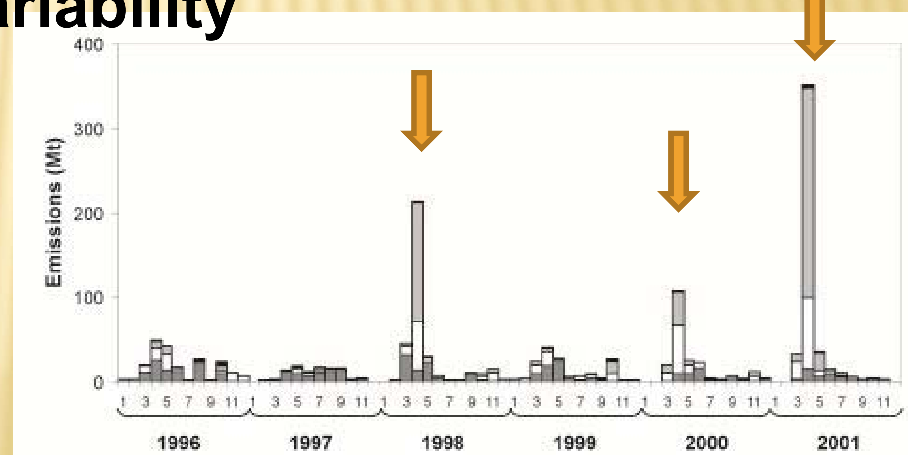
Simulated dust emissions 242±131 Mt - 1996-2001

(ERA40 surface win
precipitation)



3 dust events from a source with a high erosion threshold control the interannual variability





Taklimakan desert | Northern deserts | Gobi desert | Other arid areas

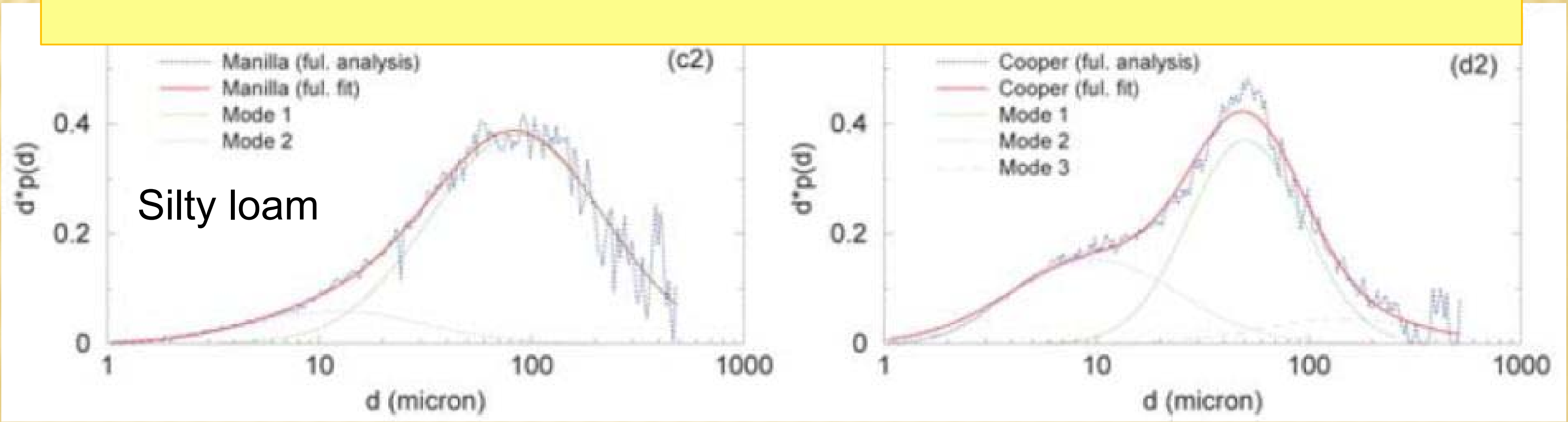
(Laurent et al., 2006)

INPUT PARAMETER : SOIL SIZE DISTRIBUTION

- Input for saltation flux computation =

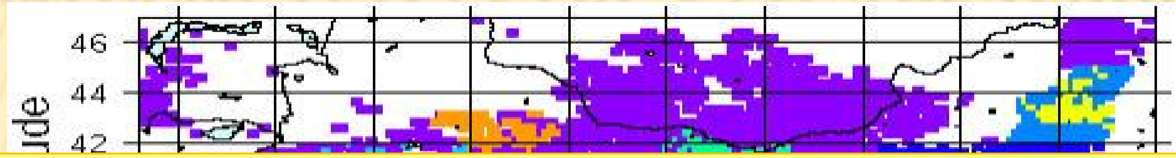
→ Undisturbed size distribution significantly differs from the disturbed one

- ... er



(Courtesy of Y. Shao)

INPUT PARAMETER : SOIL SIZE DISTRIBUTION

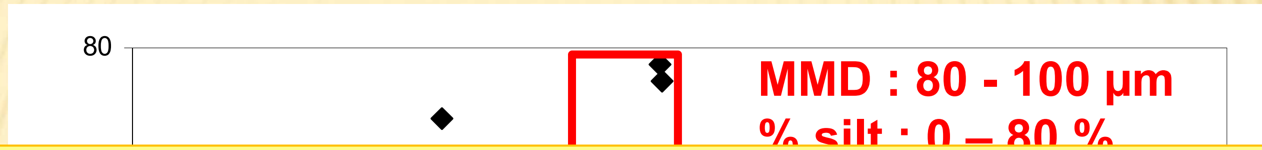


→ In East Asia,undisturbed soil size are significantly different from one desert to the other and relatively homogeneous in a given desert

Ulan Buh and Badain Jaran (N=10)		97	1.30	52	316	1.59	48	3.4	8.6	88.2
Tengger and Kubqi (N=9)		120	1.48	72	322	1.29	28	2.6	7.3	90.7
Mu Us (N=8)		99	1.17	35	330	1.37	65	1.6	7.7	90.2
Horqin (N=23)		315	1.29	100	-	-	-	1.6	7.7	90.2
East of Xinjiang area (N=4)		90	1.24	29	293	1.66	71	9.9	34.7	55.3
Hexi Corridor (N=10)		97	1.26	40	386	1.59	60	4.8	14.8	80.6
Gurban Tunggut (n=3)		94	1.12	36	170	1.69	64	3.6	13.5	82.0

[*Laurent et al.*, GPC, 2006]

INPUT PARAMETER : SOIL SIZE DISTRIBUTION



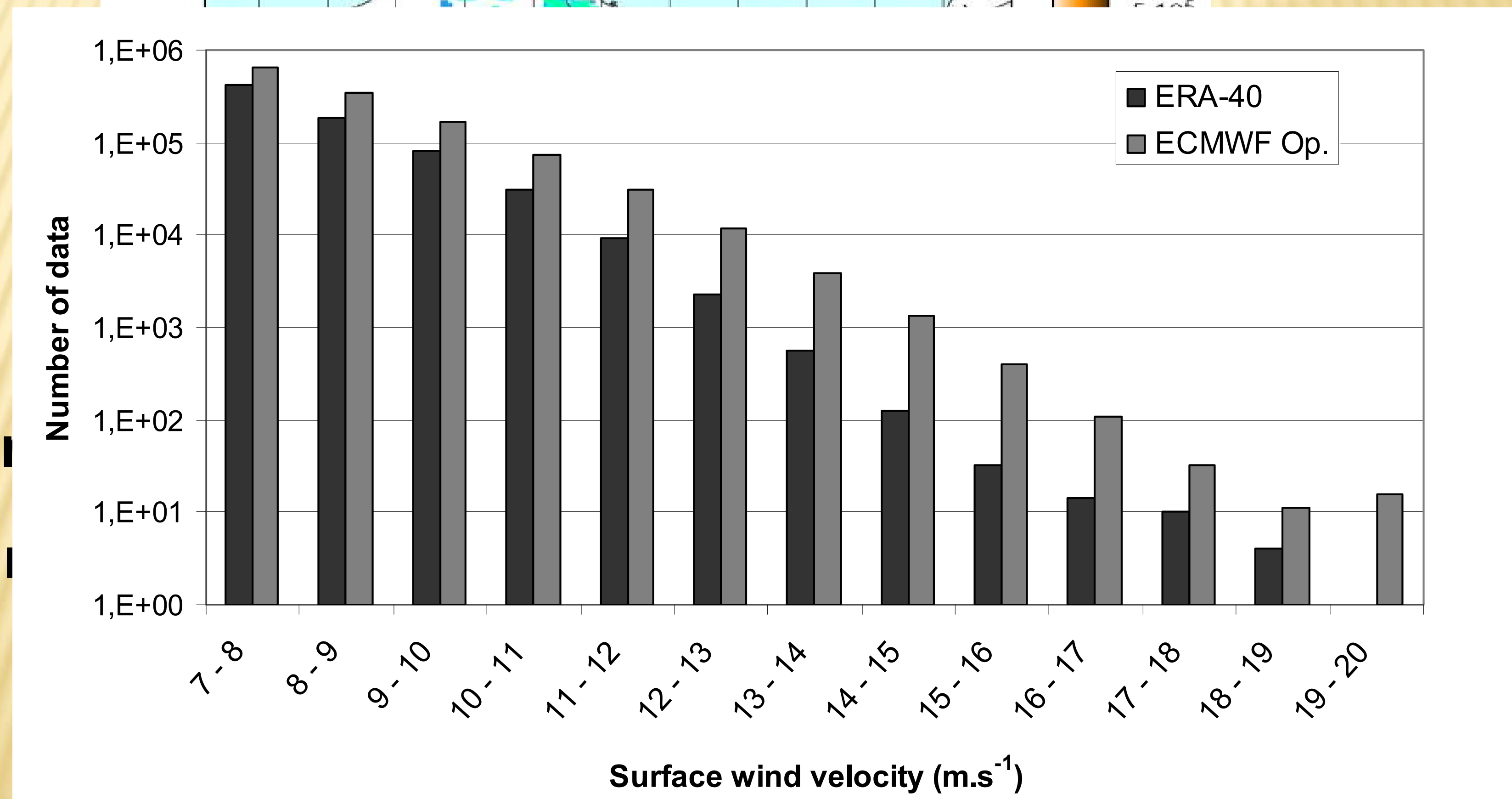
→ No unambiguous relationship between soil texture and undisturbed soil size distribution

→ Additional samples/analyses are needed for other deserts to establish links with soil texture (available at global scale)

(Laurent et al., 2006)

INPUT PARAMETER : WIND VELOCITY

Annual mean emissions



DUST SOURCES SIMULATION : VALIDATION ?

→ Difficult to validate simulated dust emissions due to uncertainties on aerosol satellite products over bright surfaces

→ In some regions horizontal visibility from meteorological stations can be used

(when a sufficient number of stations and data is available)

→ Quantification of the relevance of the dust emissions through results of 3-D regional simulations ?

REGIONAL SIMULATIONS WITH CHIMERE-DUST

Dust Emission :

⇒ Dust emissions fluxes (Marticorena and Bergametti, 1995); Surface data base (Marticorena et al., 1997)

⇒ Associated size-distribution (Alfaro and Gomes, 2001)

⇒ distributed on 20 log. bins

Domain : 10S-60N, 90W-90E

North Atlantic, North Africa, Arabian Peninsula

Model outputs

-Dust 4D fields in µg/m3 for each bin
-Optical thickness, deposition fluxes

Simulation domains:

- Horizontally: (1x1 degrees)
-Vertical mesh 15 to levels (up to 200hPa)

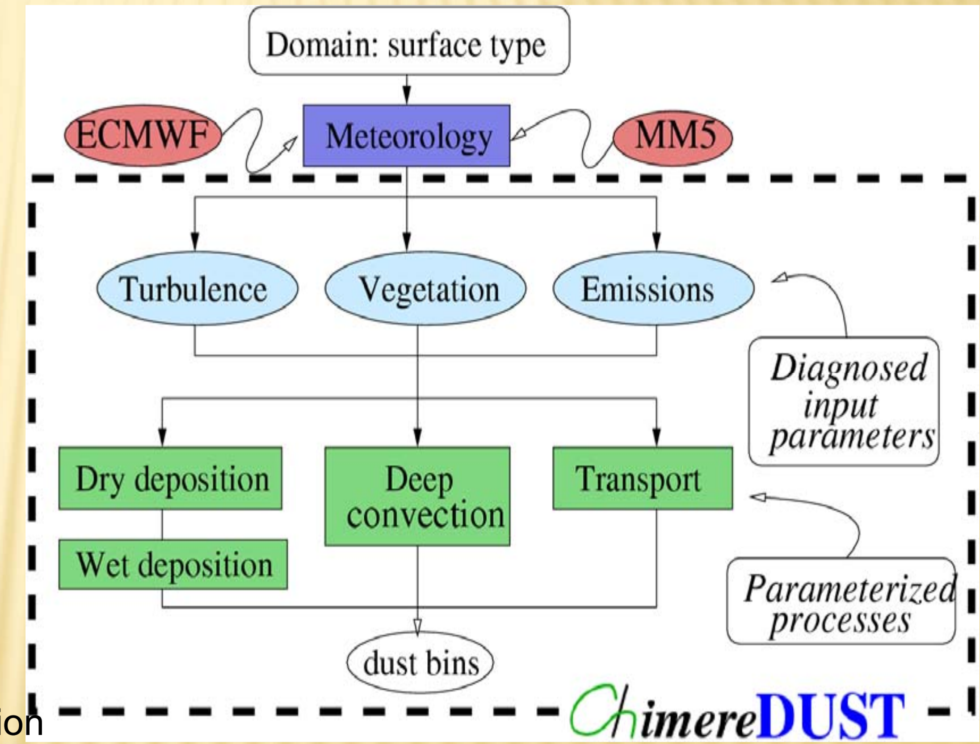
Meteorological forcing

-ECMWF forecast (Fist guess) + empirical correction of surface winds in the Bodélé Depression

Aerosol Optical Depth @550nm

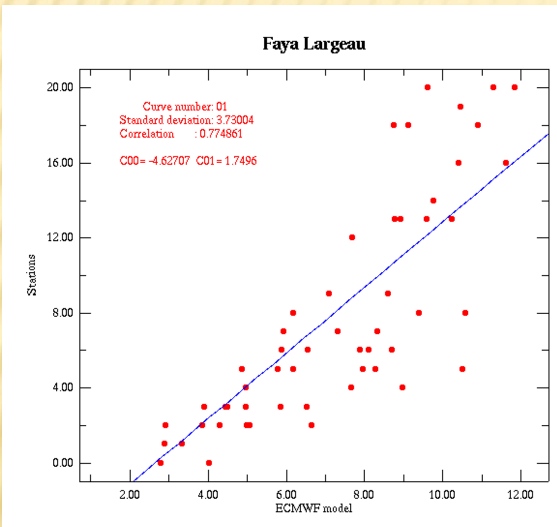
Refractive Index =1.5 - 0.005i ; (Moulin et al., 2001)

A Chemistry and Transport Model with no chemistry but dust …

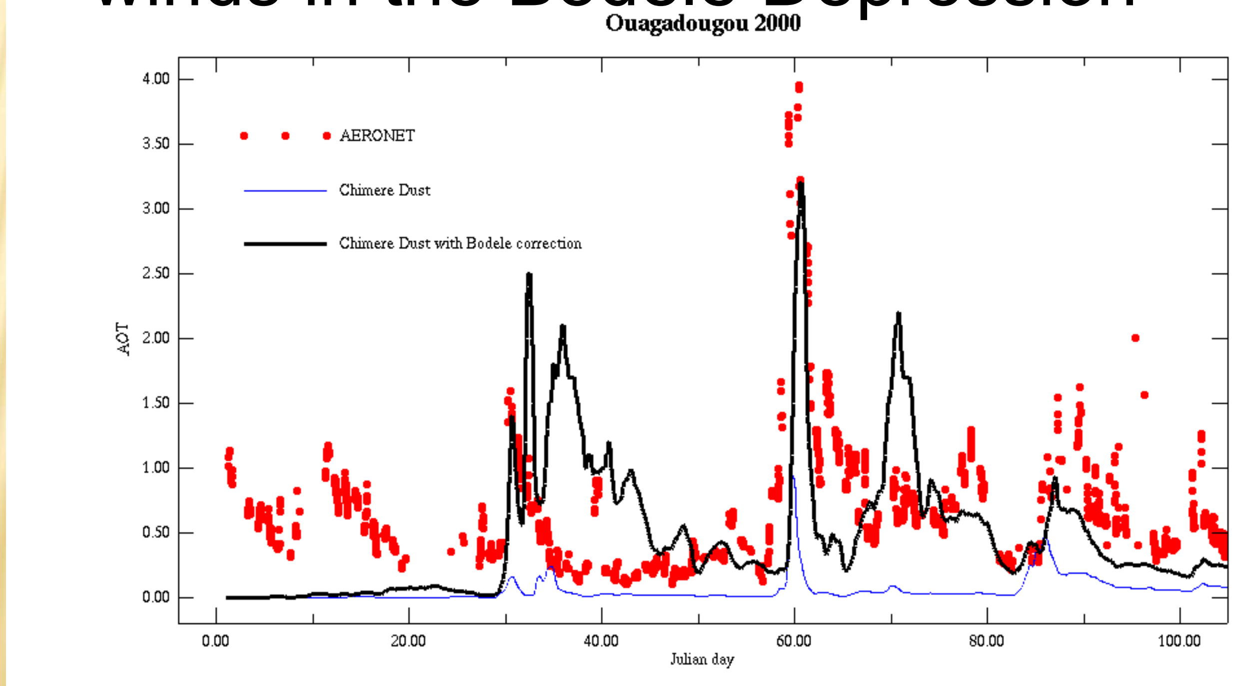


INPUT PARAMETER : WIND VELOCITY

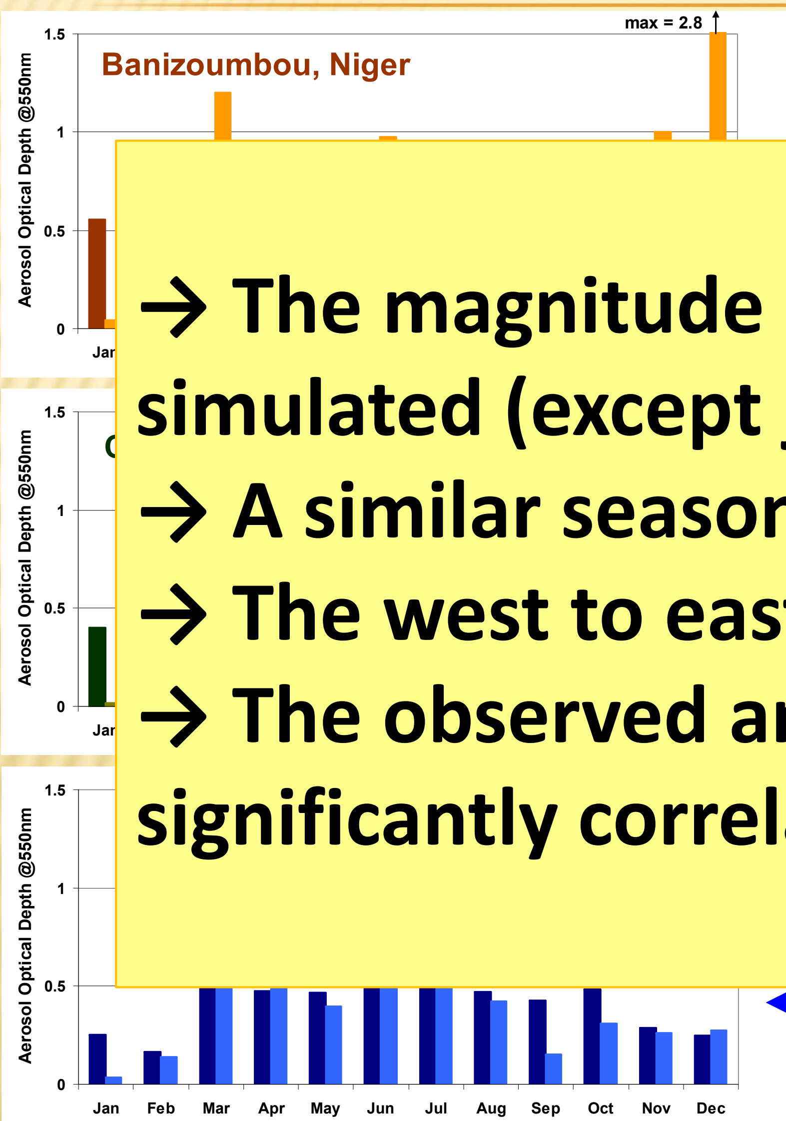
Simulation of the dust content over the Sahel with CHIMERE-Dust
:
Impact of the correction of surface winds in the Bodele Depression



Correction based on measurements in Faya-Largeau 15N-19N and 15E-20E



REGIONAL SIMULATIONS WITH CHIMERE-DUST

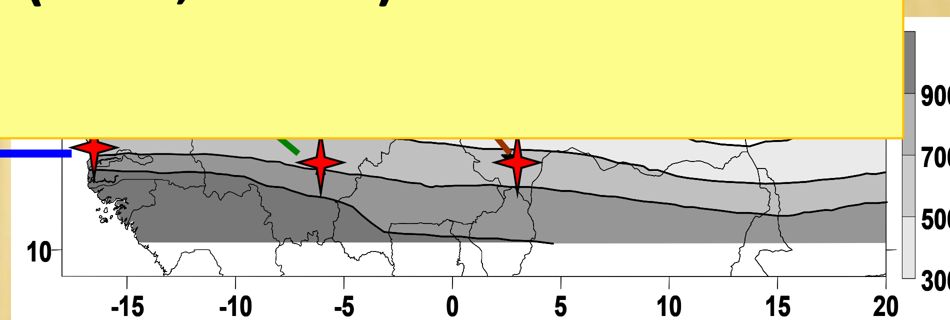


→ The magnitude of the observed AOD is well simulated (except jan, dec)

→ A similar seasonal cycle at the three stations

→ The west to east gradient is retrieved

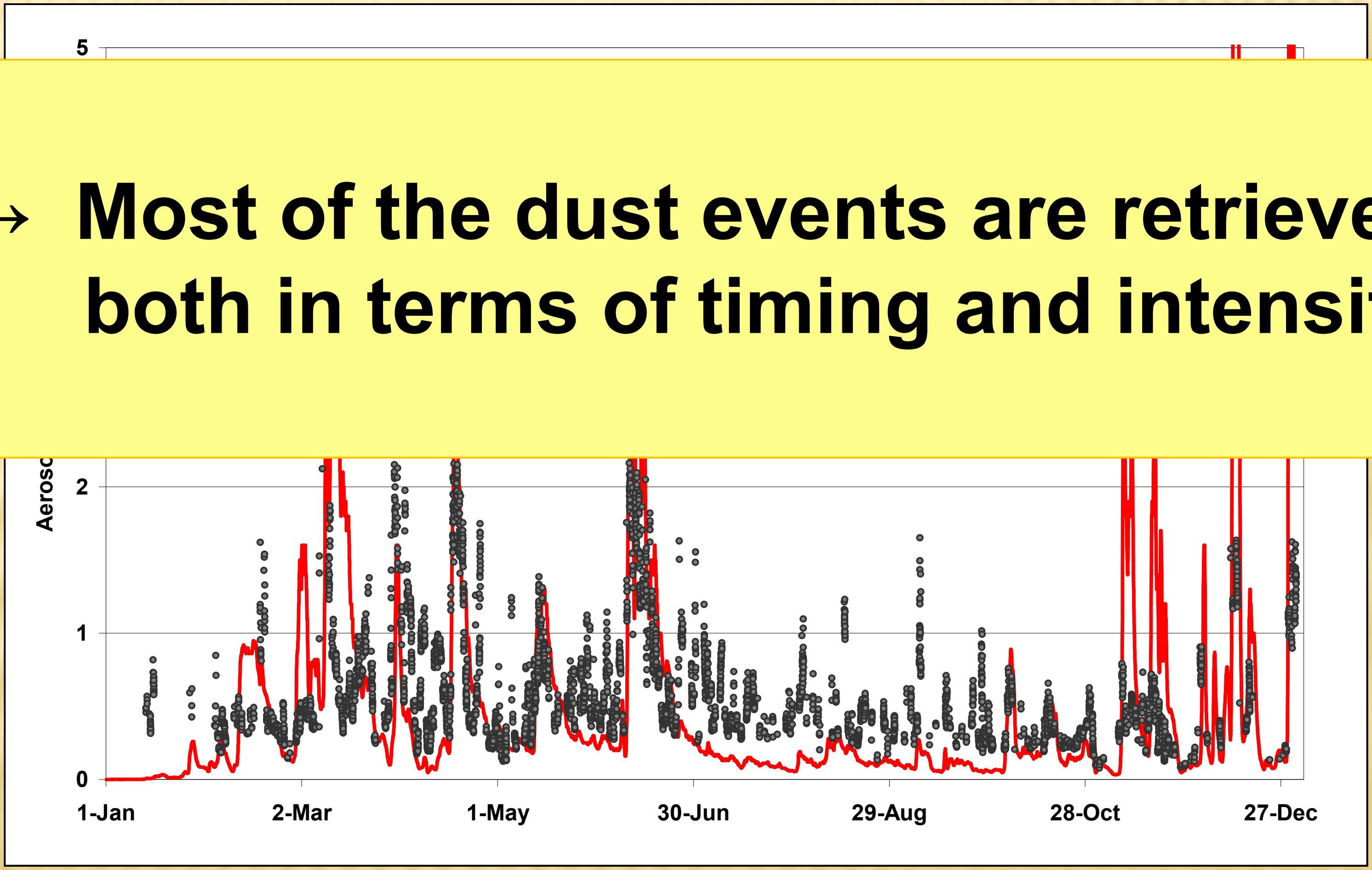
→ The observed and simulated AODs are significantly correlated (n=36; r=0.53)



(Observed : dark color; Simulated : light color)

REGIONAL SIMULATIONS WITH CHIMERE-DUST

Hourly measured and simulated aerosol optical depth



→ Most of the dust events are retrieved both in terms of timing and intensity

(Level 2 AODs with α>0.4)

(Schmechtig et al., 2011)

REGIONAL SIMULATIONS WITH CHIMERE-DUST

Daily measured and simulated surface concentrati

→ The order of magnitude of the surface concentrations is retrieved

→ The seasonal cycle is well reproduced

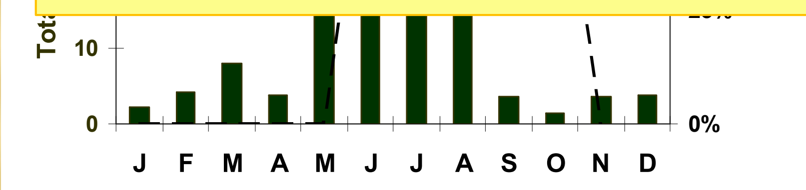
→ The level of agreement with observations is similar than PM concentration in air quality models (NME = 75%; NMB = -36 %)

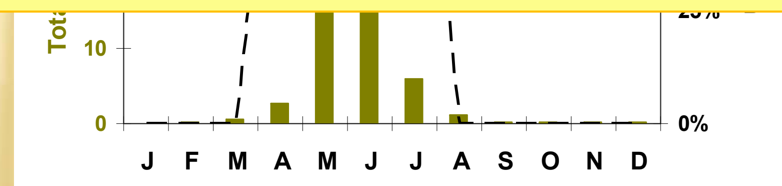
REGIONAL SIMULATIONS WITH CHIMERE-DUST

Year 2006	Total deposition (µg.m^{-2})	
	Measured	Simulated

⇨ **Annual total deposition fluxes are reasonable but underestimated**

→ Underestimation of the dry deposition ?
→ Bias in the size distribution ?
→ Significant bias due to precipitation spatial and temporal distribution



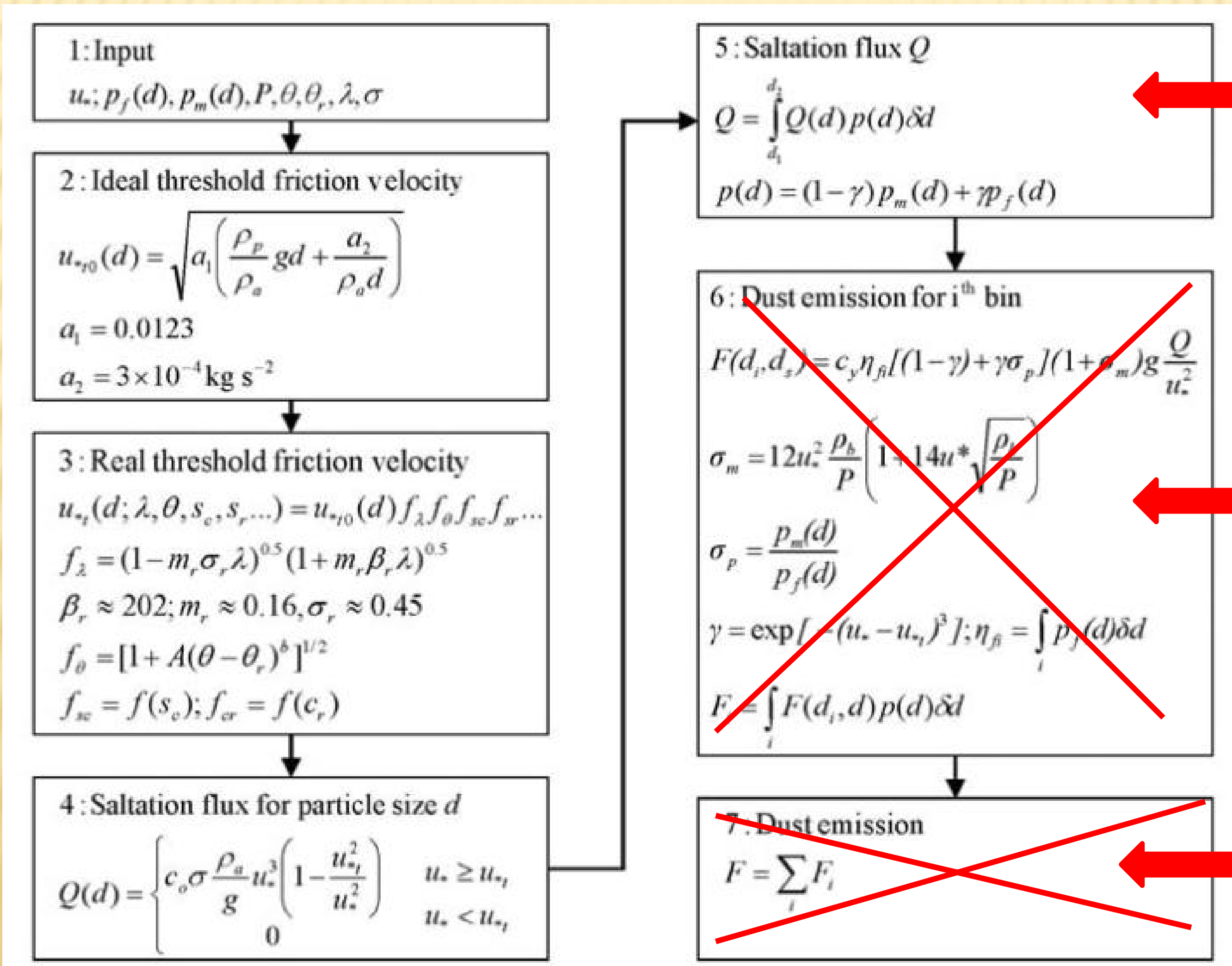


CONCLUSION (1/3)

- Dust emission fluxes can be reasonably well predicted based on available parameterizations provided surface parameters are correctly estimated
  - Surface roughness can be mapped based on satellite products
  - Soil properties must be derived/calibrated from measurements
- Emitted dust size distribution of the emitted dust cannot be modelled today with a good confidence level.
  - Additional process studies and field measurements are needed
  - It can be assigned from available field measurements (AMMA; JADE)

SIMPLIFIED DUST EMISSION SCHEME

Structure of the dust emission model Shao et al., 2004



Simplified Soil types

(Marticorena and Bergametti, 1995)

A = F/Q = f(clay content)

(Sow et al., 2009; Shao et aL, 2011)

Prescribed updated size-distribution at emission

CONCLUSION (2/3)

- **Surface wind velocity is the most critical parameter for dust emission simulations**
- The capability of meteorological models to provide **realistic surface winds** must be **questioned and evaluated**
- **Bias** in the simulated surface wind must be **corrected** ; it **cannot be compensated** by a tuning of the surface properties
- **Soil moisture** is also important in defining source regions and suffers from even larger uncertainties

CONCLUSION (3/3)

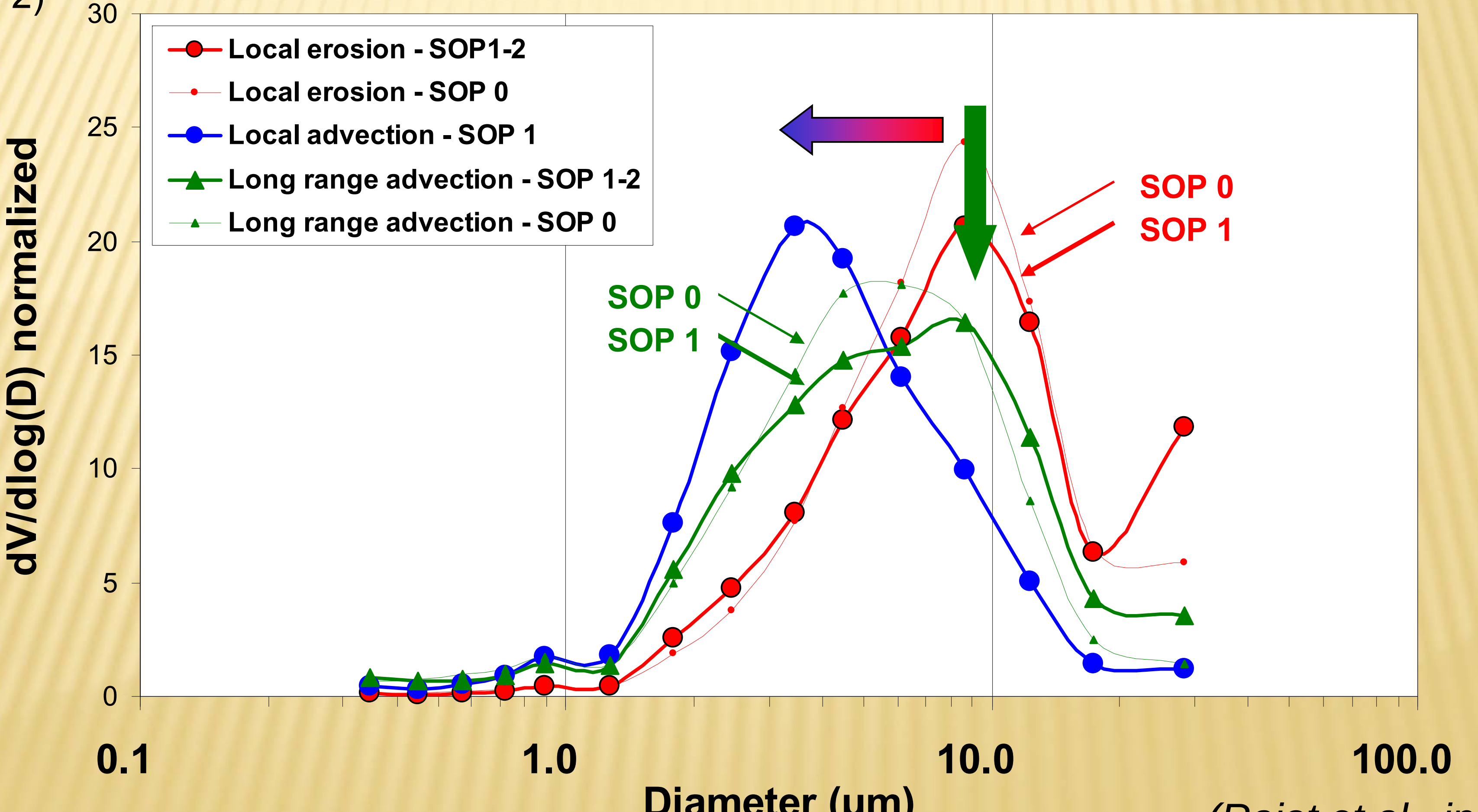
- Satellite aerosol products should be used to constrain the dust events frequency separatly from the dust content (a constrain on the erosion threshold/modelled wind velocity)

- Other uses of satellite products should be investigated (evaluation displacement velocities of dust plumes; gradient of deposition using angstrom coefficients, …)

- **The only way to reduce the uncertainties on the dust emissions is to close the mass budget**
  - **Deposition** networks are needed
  - **Data on dust size distribution** from the recent intensive field campaign (large size range) must be compiled to extract trends and patterns to test the 3-Dmodels

DUST SIZE DISTRIBUTION MEASURED IN THE SAHEL

- ✓ Shift between local erosion and local advection (decrease of coarse modes)
- ✓ Coarse mode within the long range transport
- ✓ Local erosion and Long range advection similar within dry (SOP 0) and wet season (SO 1-2)



(Rajot et al., in

Thank you for your attention !