4th Training Course on WMO SDS-WAS products (satellite and ground observation and modeling of atmospheric dust)
Casablanca-Morocco, November 17-20, 2014

Ground observations of mineral dust

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Session of practical work (Ground-based observation) WMO SDS-WAS

Long term 1987 - 2012 trends of sulfate, nitrate and dust mixing in the Saharan Air Layer

Sergio Rodríguez (srodriguezg@aemet.es)

Casablanca-Morocco, 17-20 November 2014

Long term aerosols:

Total number concentration	2006
Size distribution 10 – 400 nm SMPS	2008
Size distribution 0.5 – 20 μm APS	2007
Scattering total and back 3 λ TSI neph	2008
Absorption 1 λ MAAP	2007
Aethalometer 7 λ	2012
chemical composition	1987

Izaña, Tenerife Island
2400 m.a.s.l., free troposphere (night)

aerosol chemical composition at Izaña (since 1987): dust (Al, Fe, ...), $SO_4^{=}$, NO_3^{-}, NH_4^{+}, Na, and Cl^{-}

The two data sets were jointed for the firs time

1987-2014
27 years aerosol chemistry in the free troposphere

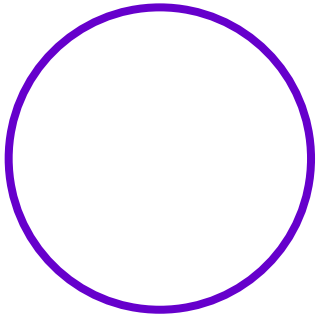
sample collection on filter

cellulose

1987-1999
30 m3/h

Dust: ash method (normalized Al/dust - 8%)
$SO_4^{=}$, NO_3^{-}, NH_4^{+}, Cl^{-}: ion chromatography
Al, Na, Fe: INAA

PM_T: total particulate matter



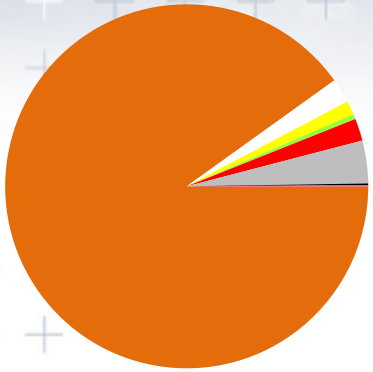
quartz microfibber filter

2002- up to the date
30 m3/h

Dust: elemental composition IPC- AES, ICP-MS (normalized Al/dust - 8%)
$SO_4^{=}$, NO_3^{-}, Cl^{-}: ion chromatography
NH_4^{+}: capillary electrophoresis, specific electrode
OC, EC: TOR

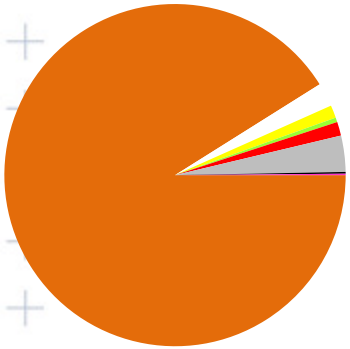
samples collected at night free troposphere

PM_T: total particulate matter
PM_{10}: particulate matter diameter ≤ 10 µm
$PM_{2.5}$: particulate matter diameter ≤ 2.5 µm



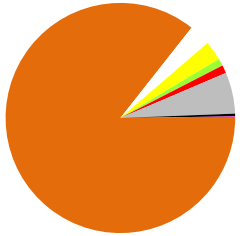
PM_T 47.3 µg/m³

91%	42.6	dust (Al, Fe, Ca, Ti..) Al = 8% dust
2.2%	1.0	none ammonium-sulfate
1.2%	0.5	ammonium-sulfate
0.4%	0.2	ammonium
1.9%	0.9	nitrate
3.8%	1.8	organic matter
0.2%	0.07	elemental carbon



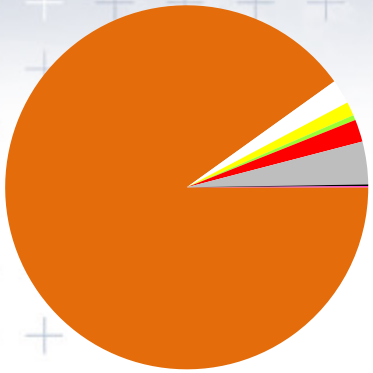
PM_{10} 42.0 µg/m³

91%	38.3	dust
2.2%	0.9	none ammonium-sulfate
1.2%	0.5	ammonium-sulfate
0.4%	0.2	ammonium
1.3%	0.6	nitrate
3.4%	1.4	organic matter
0.2%	0.07	elemental carbon



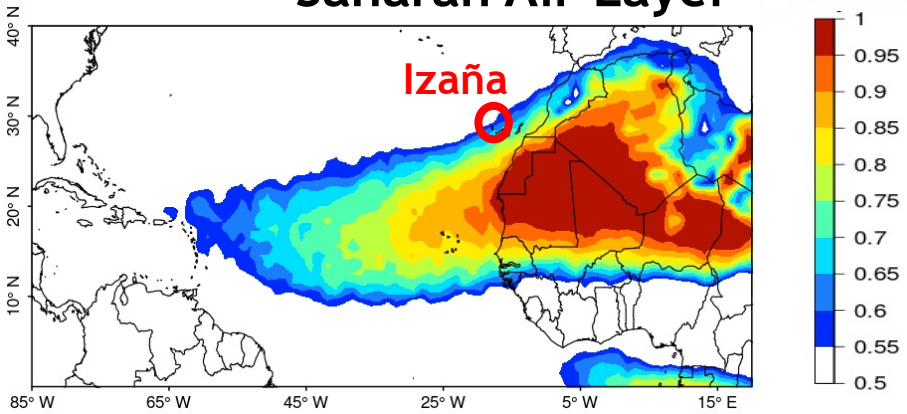
$PM_{2.5}$ 18.5 µg/m³

85%	15.8	dust
3.0%	0.6	none ammonium-sulfate
2.7%	0.5	ammonium-sulfate
1.0%	0.2	ammonium
1.1%	0.2	nitrate
5.8%	1.1	organic matter
0.4%	0.07	elemental carbon



PM_T	47.3 µg/m³
91%	42.6
2.2%	1.0
1.2%	0.5
0.4%	0.2
1.9%	0.9
3.8%	1.8
0.2%	0.07

Saharan Air Layer



MDFA: Major Dust Frequency Activity

UV Absorbing Aerosol Index = sensitive to iron oxides in dust

$$MDFA = \frac{\text{number days UV Absorbing Aerosol Index} > 1}{\text{total number of days in the month}}$$

Satellite (Earth Probe, Nimbus 7, Aura):
Total Ozone Monitor Spectrometer (1987-2001)
Ozone Monitor Instrument (2005-2012)

aerosol chemical composition (since 1987): dust (Al, Fe, ...), $SO_4^{=}$, NO_3^{-}, NH_4^{+}, Na, and Cl^{-}

part-1: long term evolution of dust

part-2: long term evolution of sulfate

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part-1: long term evolution of dust

part-2: long term evolution of sulfate

Atmos. Chem. Phys. Discuss., 14, 26689–26719, 2014
www.atmos-chem-phys-discuss.net/14/26689/2014/
doi:10.5194/acpd-14-26689-2014

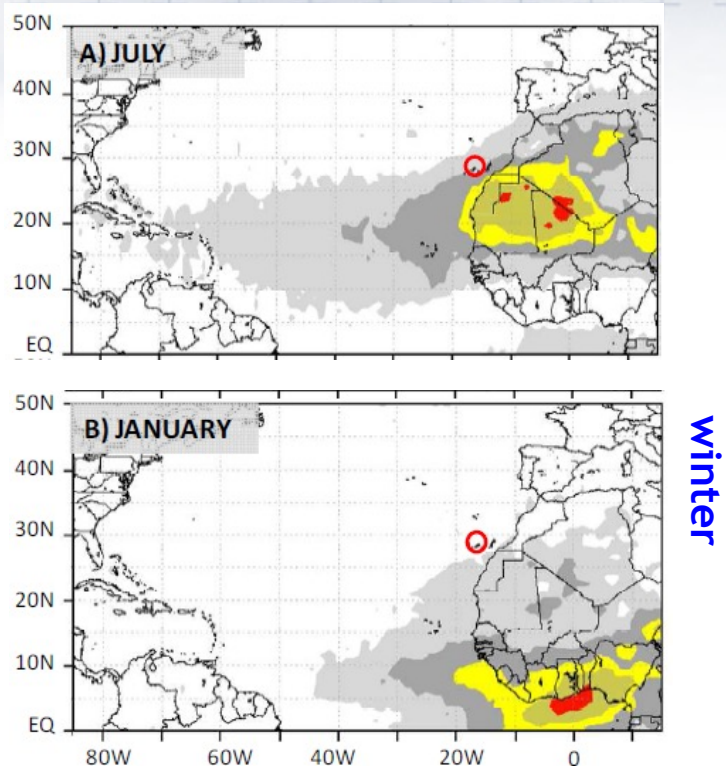
Atmospheric Chemistry and Physics Discussions

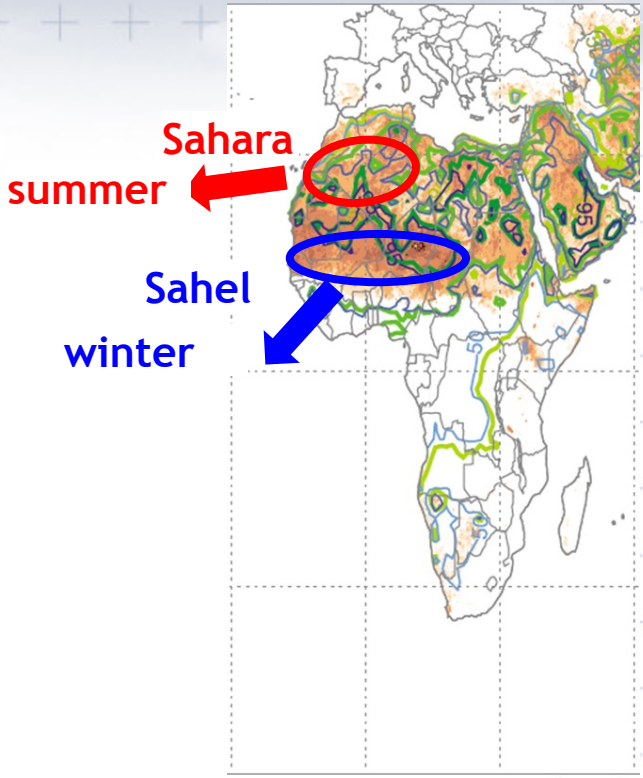
Modulation of Saharan dust export by the North African dipole

S. Rodríguez[1], E. Cuevas[1], J. M. Prospero[2], A. Alastuey[3], X. Querol[3], J. López-Solano[1], M. I. García[1,4], and S. Alonso-Pérez[1,3,5]

[1]Izaña Atmospheric Research Centre, AEMET, Joint Research Unit to CSIC "studies on atmospheric pollution", 38071, Santa Cruz de Tenerife, Canary Islands, Spain
[2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, USA
[3]Institute of Environmental Assessment and Water Research, CSIC, Barcelona, Spain
[4]Department of Chemistry (T.U. Analytical Chemistry), Faculty of Science, University of La Laguna, Tenerife, Spain
[5]European University of the Canaries, Laureate International Universities, La Orotava, Tenerife, Spain

part-1: long term evolution of dust





Winter: dust export modulated by the North Atlantic Oscillation (Ginoux et al., 2004)
Sahel: Monsoon rains (Prospero and Lamb, 2003)

P. Ginoux [a,b,*], J.M. Prospero [c], O. Torres [b,d], M. Chin [b]

Environmental Modelling & Software 19 (2004) 113–128

Long-term simulation of global dust distribution with the GOCART model: correlation with North Atlantic Oscillation

Joseph M. Prospero[1]* and Peter J. Lamb[2]

African Droughts and Dust Transport to the Caribbean: Climate Change Implications

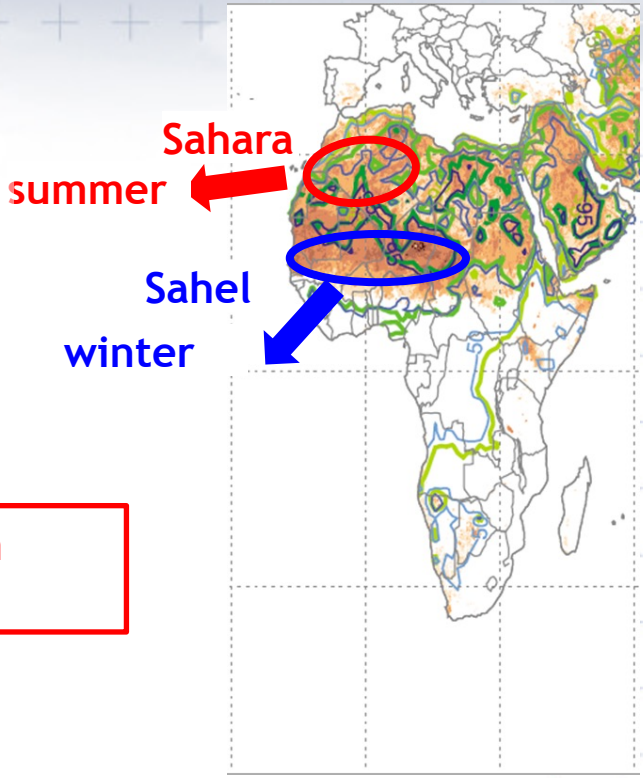
SCIENCE VOL 302 7 NOVEMBER 2003

part-1: long term evolution of dust

We have focused in summer

Why?

- Is the season when maximum dust emissions occurs in North Africa due to the activation of subtropical Saharan sources
- Processes that modulated inter-annual variability in dust export are still unknown



scientific question

Which are the large scale processes that influence on long term inter-annual variability in Saharan dust export in summer?

Winter: dust export modulated by the North Atlantic Oscillation (Ginoux et al., 2004)
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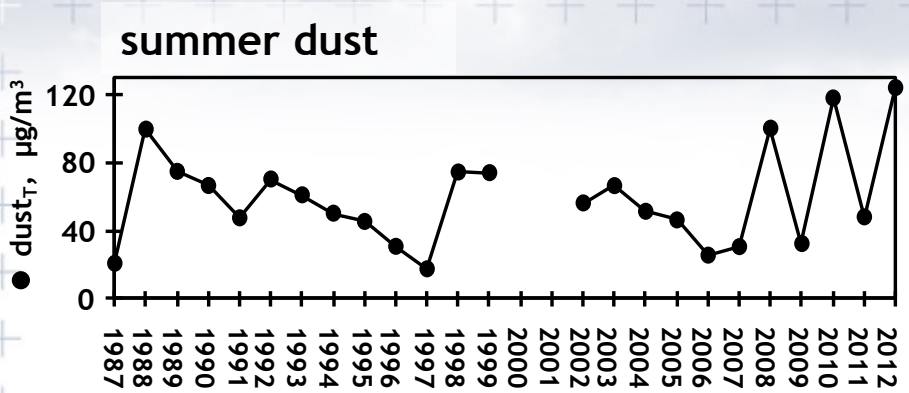
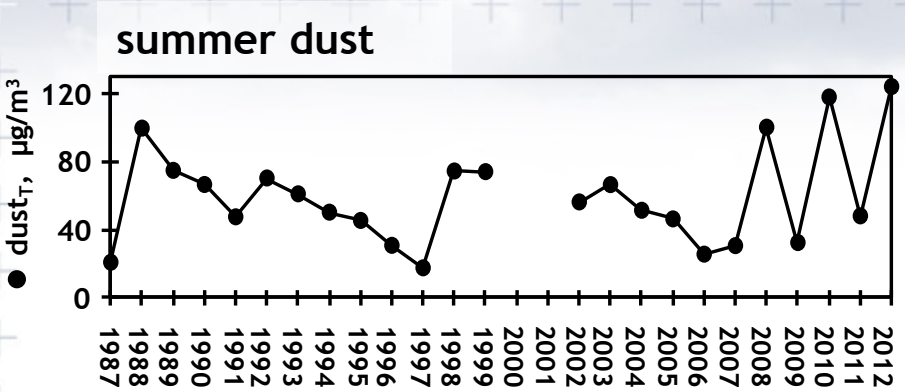
part-1: long term evolution of dust



view from Izaña:

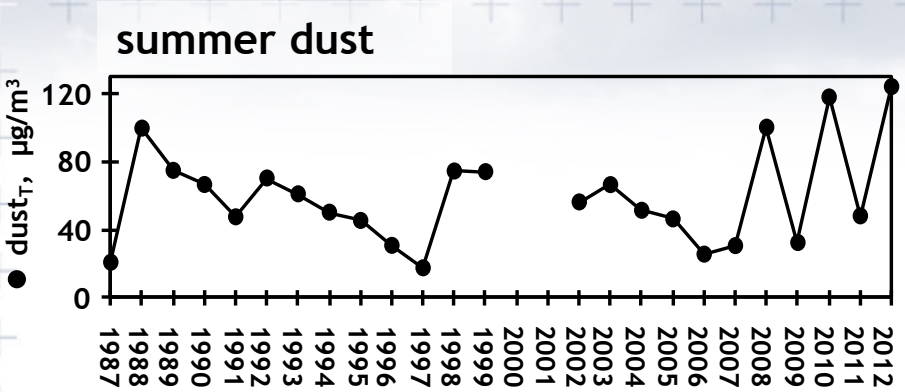
part-1: long term evolution of dust



Methods for data analysis:

1. Meteorological re-analysis data
2. Satellite data

part-1: long term evolution of dust



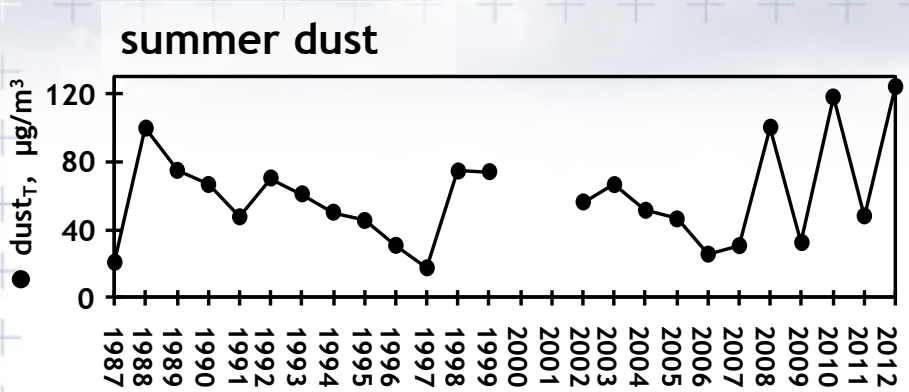
Methods for data analysis:

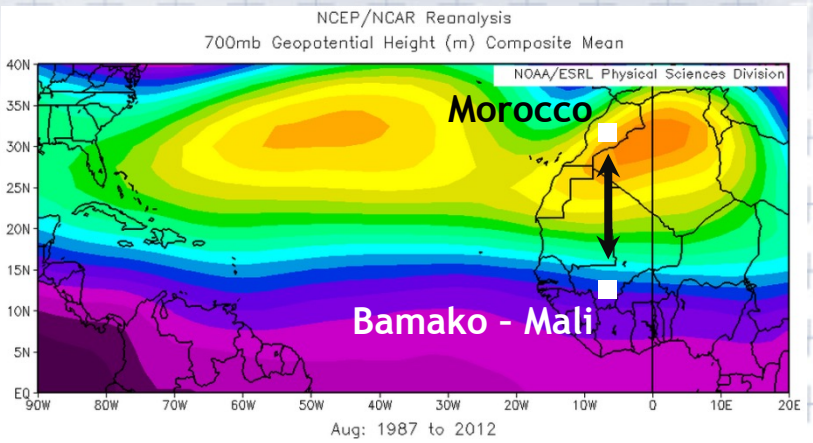
1.Meteorological re-analysis data

National Center for Environmental Prediction (NCEP)
National Center for Atmospheric Research (NCAR)

2.Satellite data

part-1: long term evolution of dust





dust export occurs at altitudes between 1 to 5km above sea level:

700hPa geopotential level

North AFrican Dipole Intensity:

Difference of the anomalies of the geopotential between sub-tropic (Morocco) and the tropic (Bamako-Malí)

North AFrican Dipole Intensity

$$NAFDI = \frac{1}{10}\left(\left(\Phi^{y}_{Mo} - <\Phi>_{Mo}\right) - \left(\Phi^{y}_{Ba} - <\Phi>_{Ba}\right)\right)$$

700 hPa: relevant level for dust export

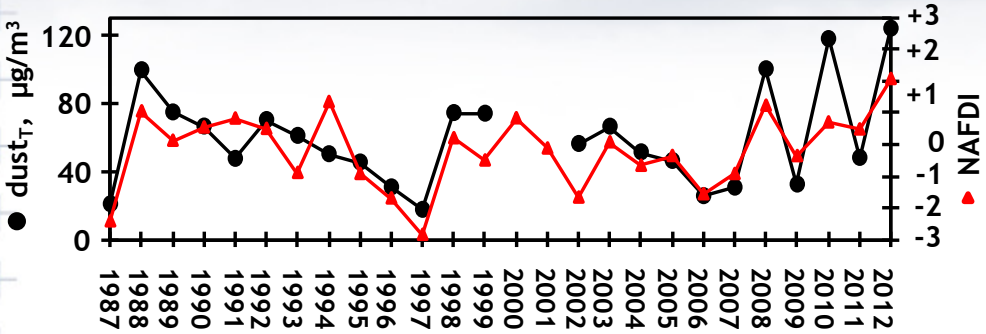
Φ^{y}_{Mo} mean geopotential height at 700hPa averaged in central Morocco region (30-32°N, 5-7°W) in August of year 'y'.

$<\Phi>_{Mo}$ mean geopotential height at 700hPa averaged in central Morocco region (30-32°N, 5-7°W) averaged in August months from 1948 to 2012.

Φ^{y}_{Ba} is the mean geopotential height at 700hPa averaged in Bamako region (10-13°N, 6-8°W) in August of year 'y'.

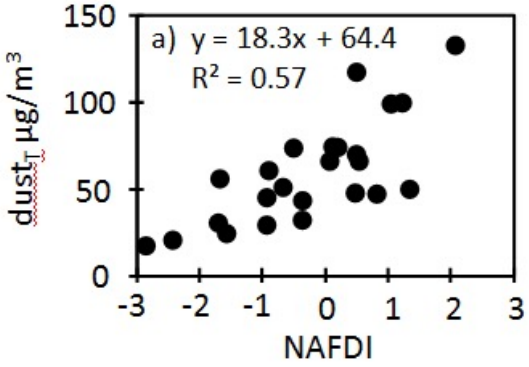
$<\Phi>_{Ba}$ mean geopotential height at 700hPa averaged in Bamako region (10-13°N, 6-8°W) averaged in all August months from 1948 to 2012.

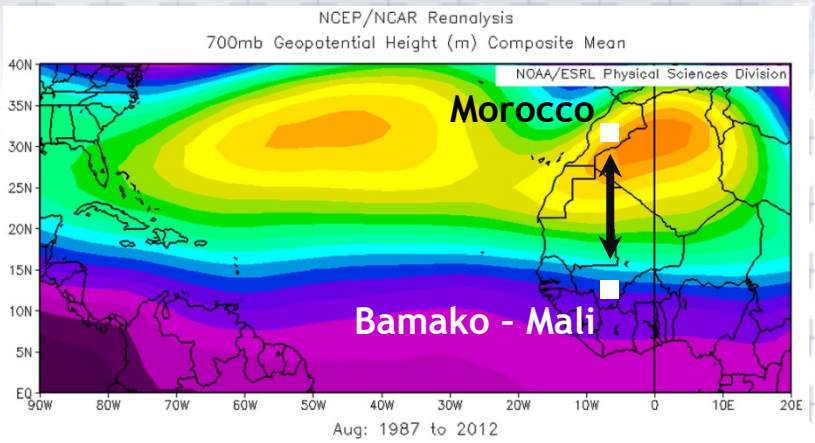
part-1: long term evolution of dust



Pearson correlation between NAFDI and the dust at Izaña = +0.75

R1: Variability in NAFDI influence on dust export
geostrophic wind influence on dust export





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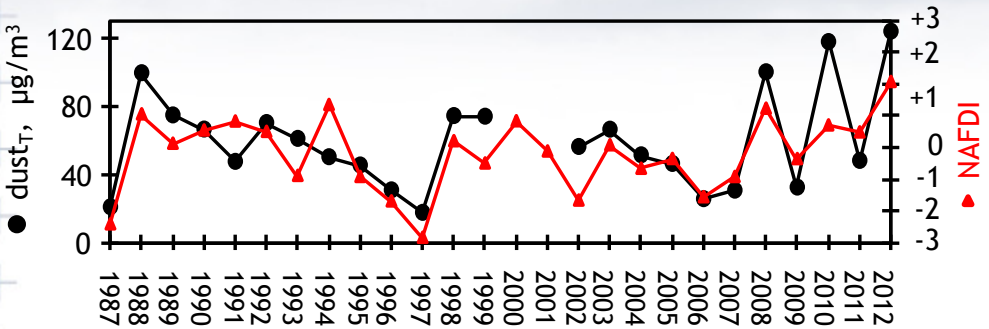
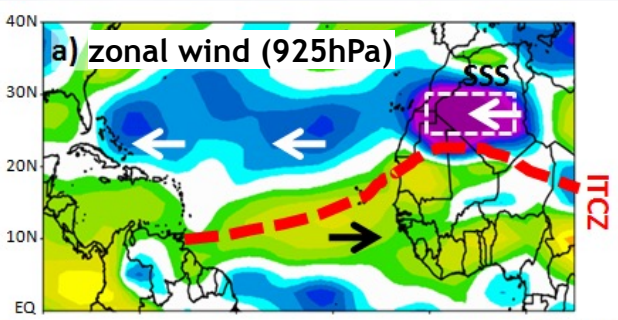
$<\Phi>_{Ba}$ mean geopotential height at 700hPa averaged in Bamako region (10-13°N, 6-8°W) averaged in all August months from 1948 to 2012.

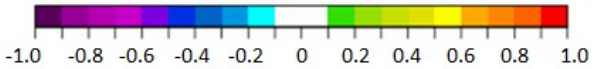
part-1: long term evolution of dust



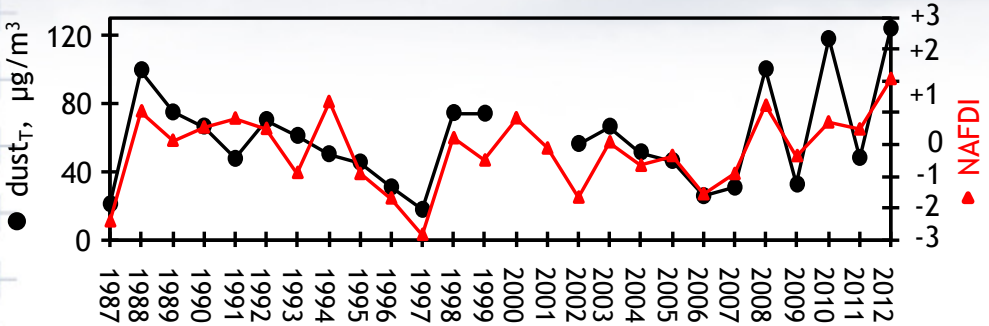
Correlation coefficient (1987-2012) between NAFDI and



SSS: Subtropical Saharan Stripe



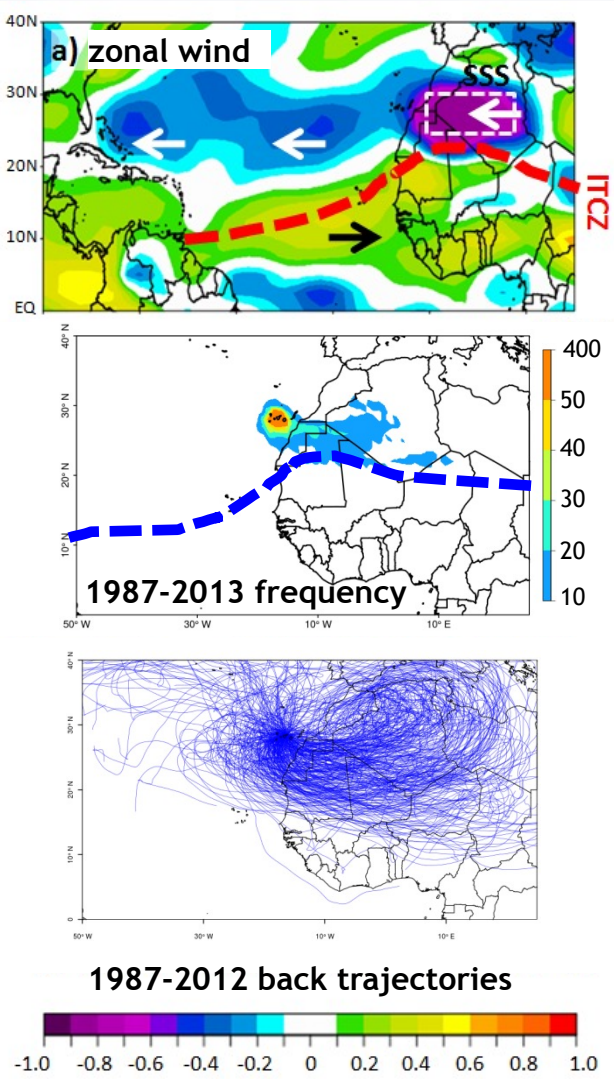
part-1: long term evolution of dust



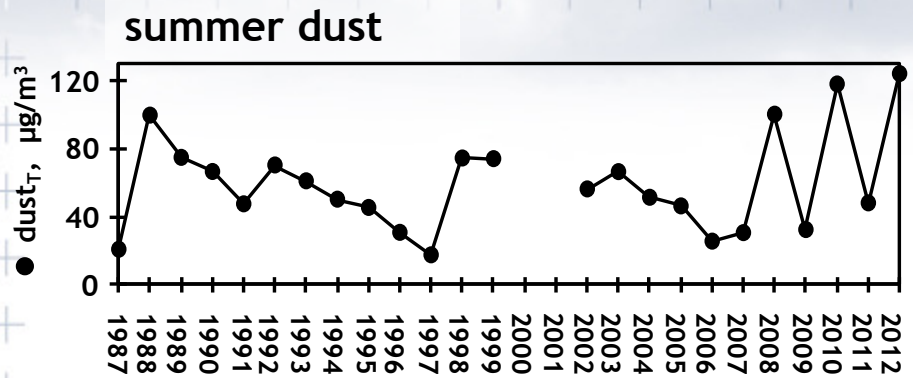
R1: Variability in NAFDI influence on trade winds at the north of the ITCZ (surface-925hPa Harmattan)

➔ dust export (1-5 km)

Correlation coefficient between NAFDI and



part-1: long term evolution of dust



Methods for data analysis:

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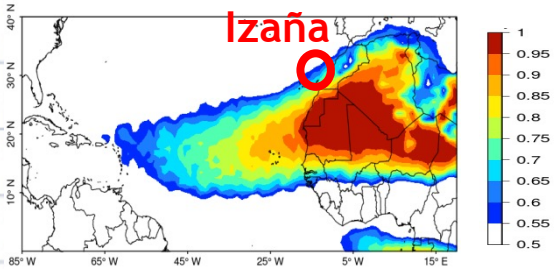
Location of the Saharan Air layer for every summer:

1987



1988..... 1990

....2012

MDFA: Major Dust Frequency Activity

UV Absorbing Aerosol Index = sensitive to iron oxides in dust

$$\text{MDFA} = \frac{\text{number days UV Absorbing Aerosol Index} > 1}{\text{total number of days in the month}}$$

Satellite (Earth Probe, Nimbus 7, Aura):
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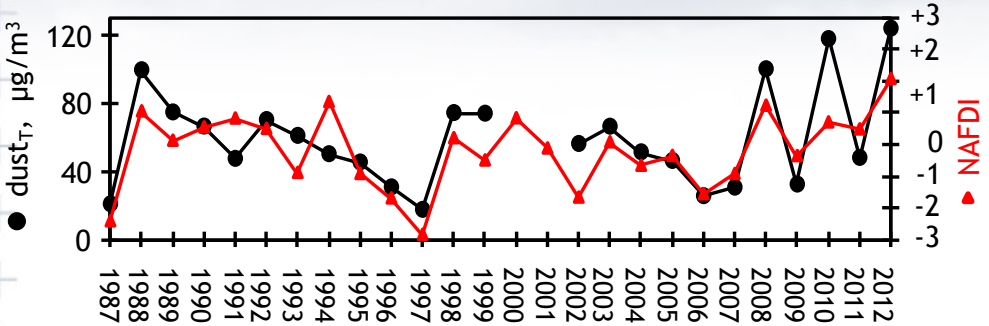
Ozone Monitor Instrument (2005-2012)

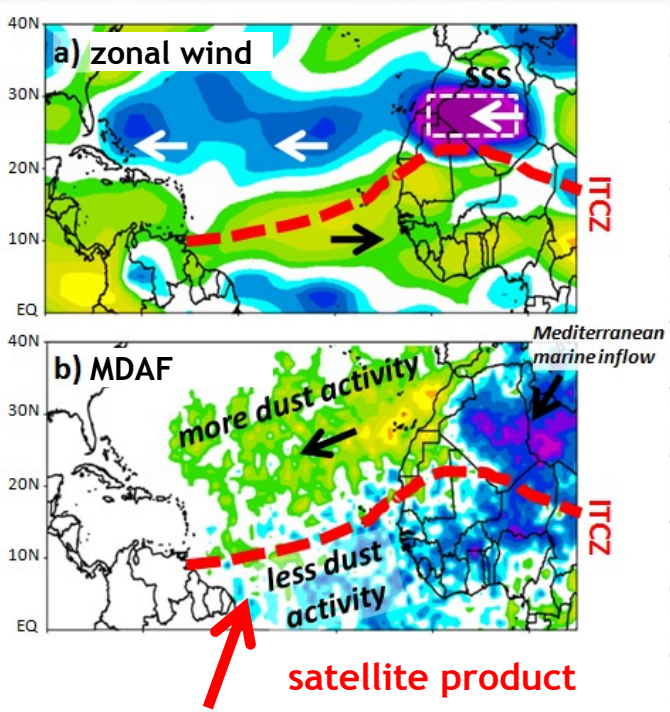
part-1: long term evolution of dust



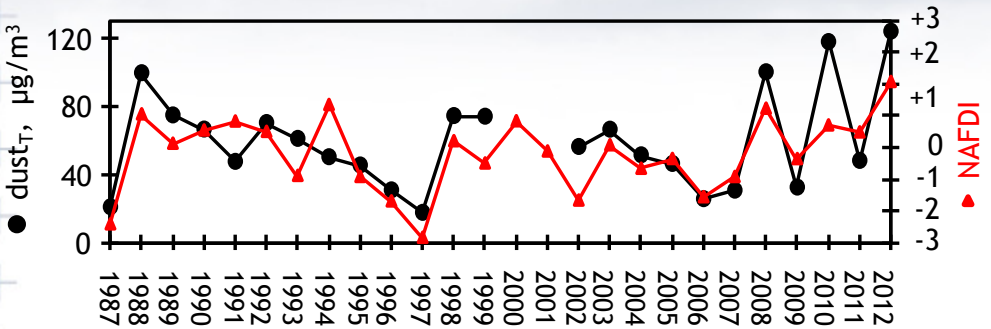
Correlation coefficient between NAFDI and the MDAF (location of the Saharan Air Layer)

1. More dust activity at the north of the ITCZ
2. Less dust activity at the south of the ICTZ reason ?

Correlation coefficient between NAFDI and



part-1: long term evolution of dust



Correlation coefficient between NAFDI and

The MDAF (location of the Saharan Air Layer)

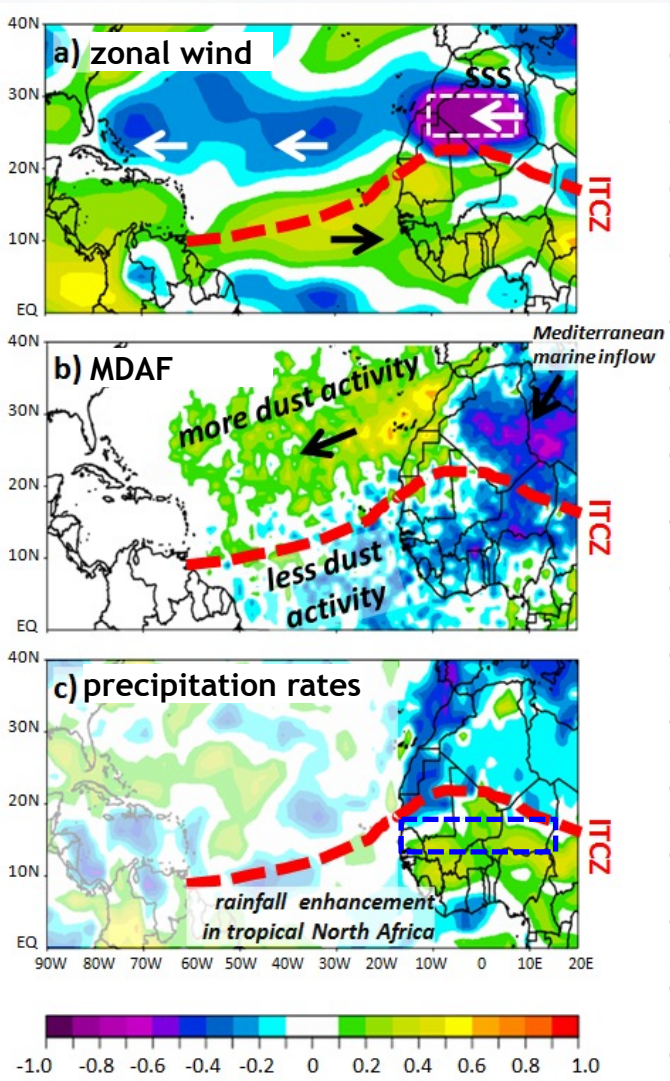
1. More dust activity at the north of the ITCZ
2. Less dust activity at the south of the ICTZ reason ?

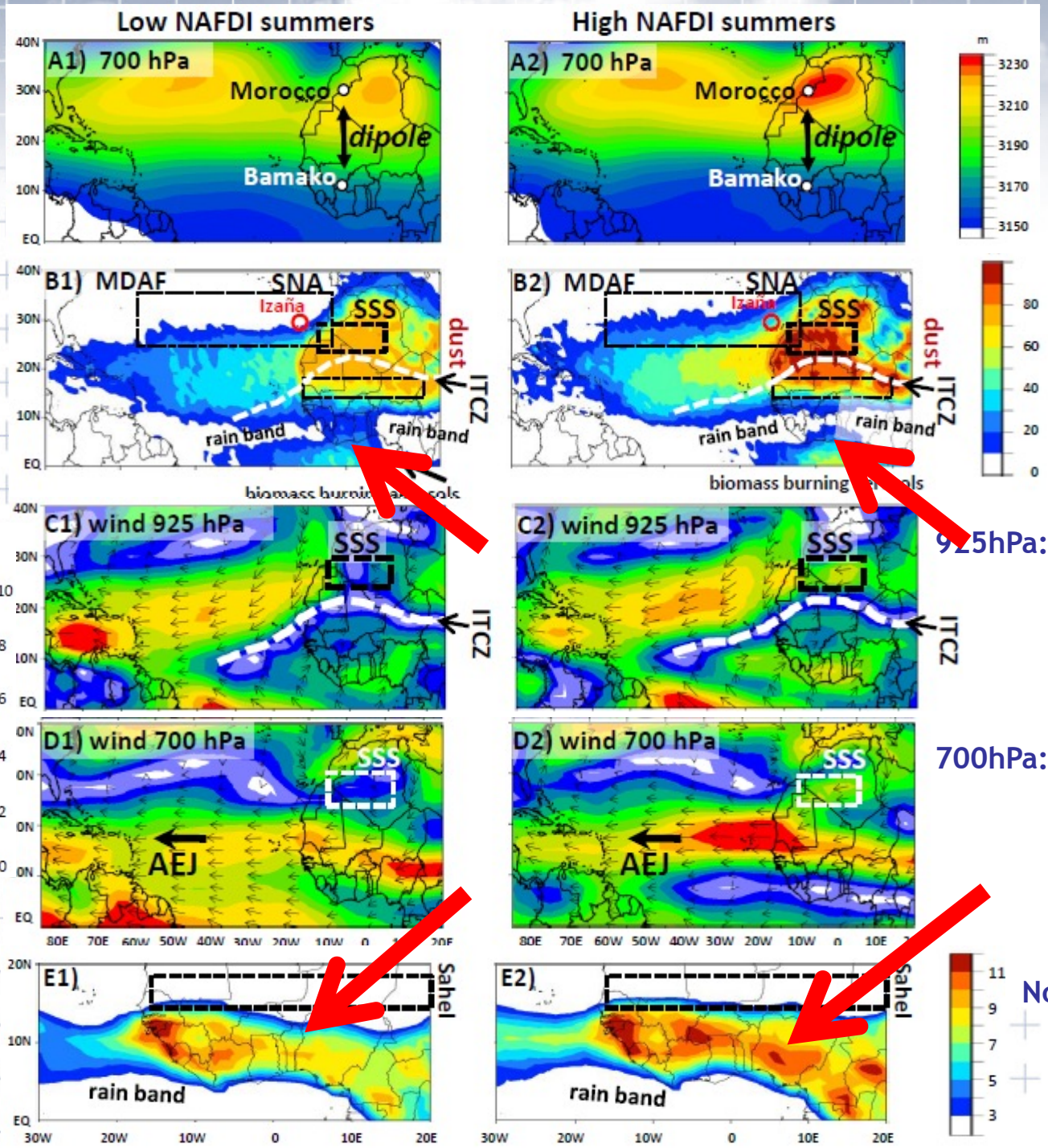
NAFDI also connected with monsoon rainfalls (Sahel)

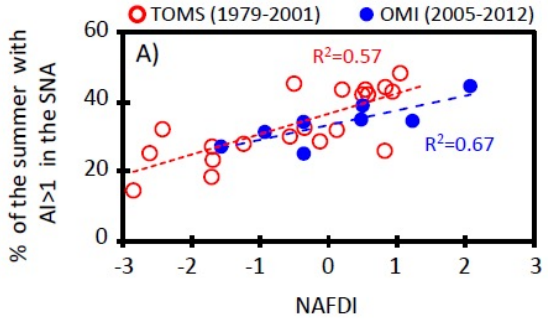
R: Variability in NAFDI influence on:

1. trade winds at the north of the ITCZ (Harmattan)
   ➔ dust export
2. monsoon rainfalls, including the Sahel
3. latitudinal shifts of the Saharan Air Layer

Correlation coefficient between NAFDI and





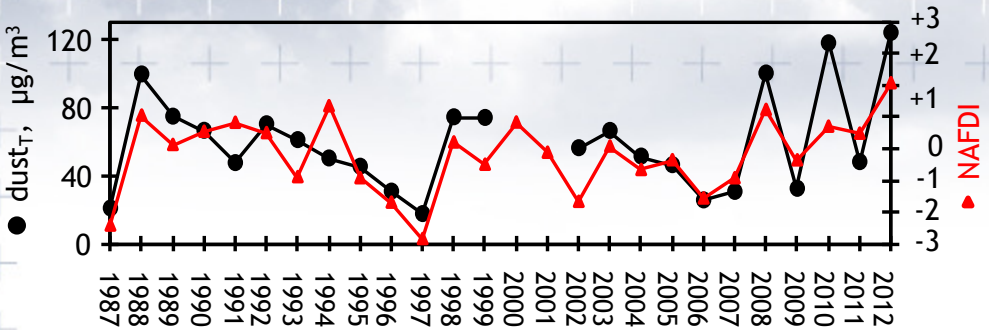


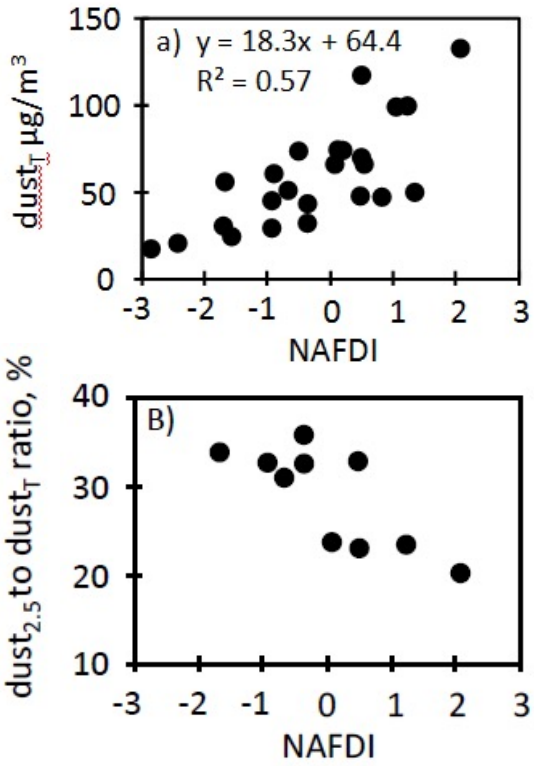
925hPa: related to potential dust emissions

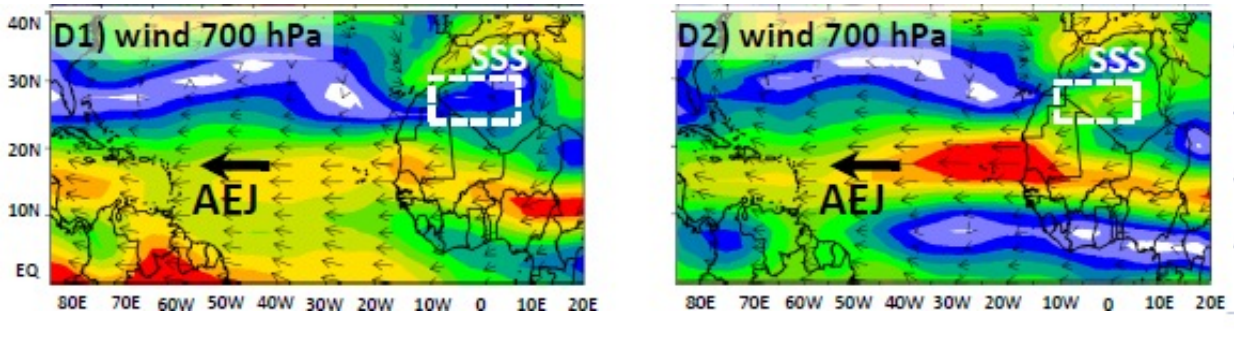
SSS: Subtropical Saharan Stripe

700hPa: related to dust export

Northern shift in the monsoon rains







Dust particles size ?
2002-2012

Low NAFDI
Low Wind
Coarse particles (65%)
Enhanced effects
of dry deposition

High NAFDI
Windy
Coarse particles (80%)
More dry deposition

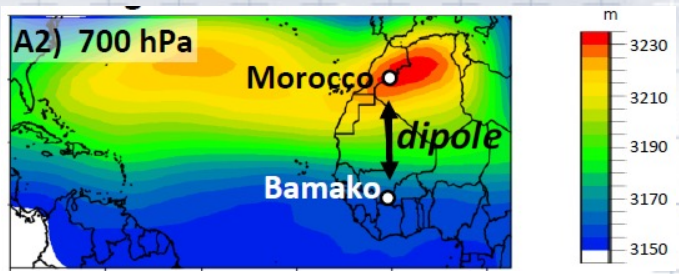
part-1: long term evolution of dust

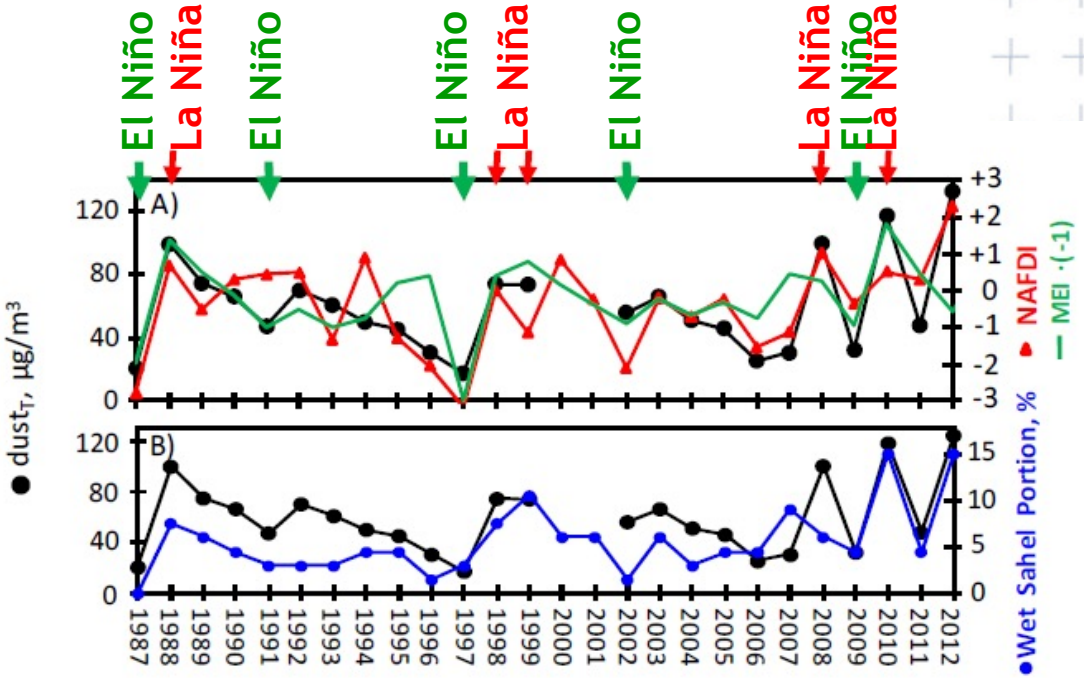
Variability in NAFDI influence on Saharan dust export during 25-y

1. trade winds at the north of the ITCZ (Harmattan)
   ➔ dust export
2. monsoon rainfalls, including on the Sahel
3. latitudinal shifts of the Saharan Air Layer

4. Dust particle size
5. Connection global to climate (?)

   NAFDI and ENSO connected to variability in subtropical and tropical climate





Low dust years tend to be associated with El Niño - low (negative) MEI values

Atmos. Chem. Phys. Discuss., 14, 26689–26719, 2014
www.atmos-chem-phys-discuss.net/14/26689/2014/
doi:10.5194/acpd-14-26689-2014

Atmospheric Chemistry and Physics Discussions

Modulation of Saharan dust export by the North African dipole

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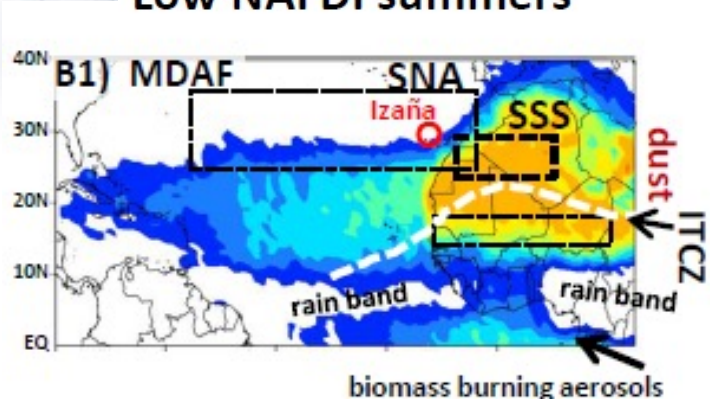
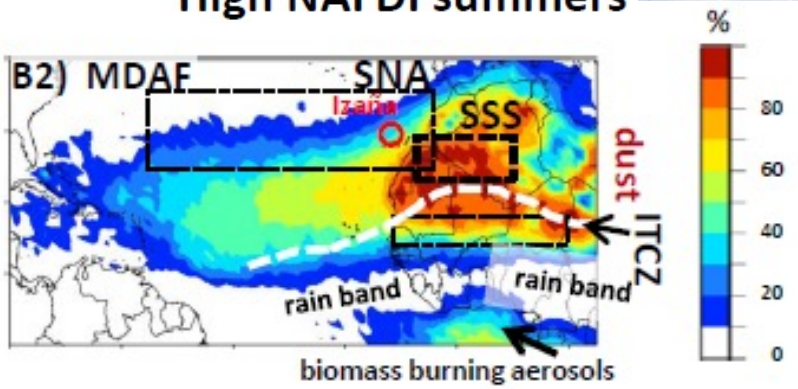
Multivariate ENSO (El Niño Southern Oscillation) Index (MEI), - calculated with sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature and total cloudiness fraction of the sky over the 20 tropical Pacific Ocean

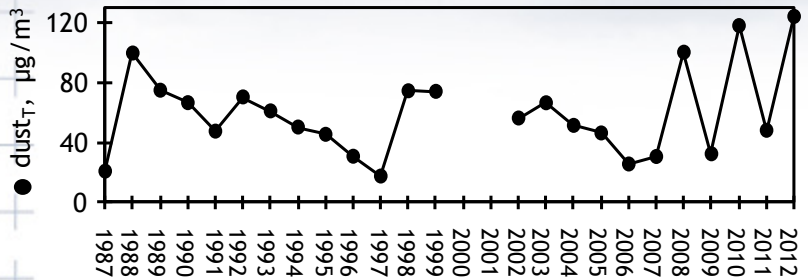
	Low NAFDI summers	High NAFDI summers
		
Sahara Air Layer:	shifted to south	shifted to north
Dust impacts:	Less impacts in Morocco	More impacts in Morocco
Tropical Africa: Benin, Togo, Ghana, Malí, Burkina Faso, Côte d'Ivore, Liberia, Sierre Leone, Guiné Bissau, Senegal	More impacts of dust+biomass burning from Central Africa	Less impacts of dust+biomass burning from Central Africa
	Less monsoon rainfalls	More monsoon rainfalls

aerosol chemical composition (since 1987): dust (Al, Fe, ...), $SO_4^{=}$, NO_3^{-}, NH_4^{+}, Na, and Cl^{-}

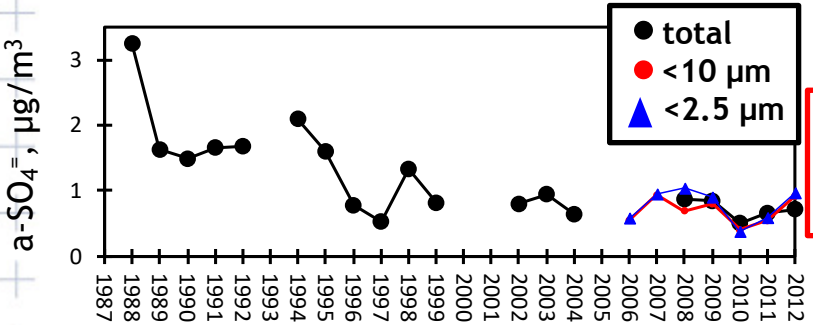
part-1: long term evolution of dust

part-2: long term evolution of sulfate

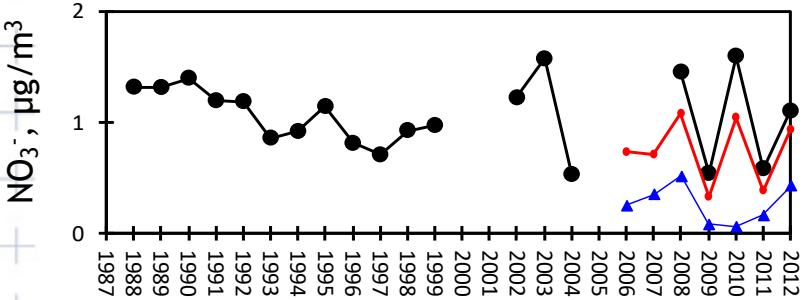
trend of sulfate in the Saharan Air Layer



sulfate present as ammonium sulfate (a-$SO_4^=$) during dust condition in Izaña



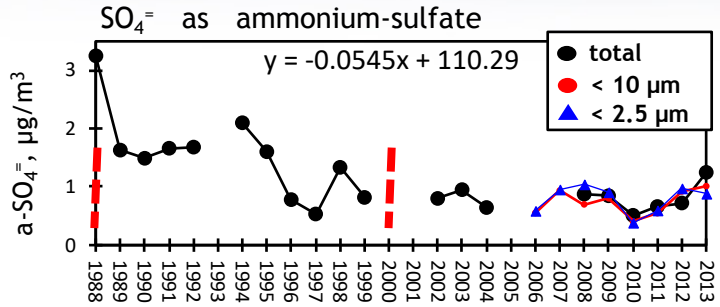
nitrate

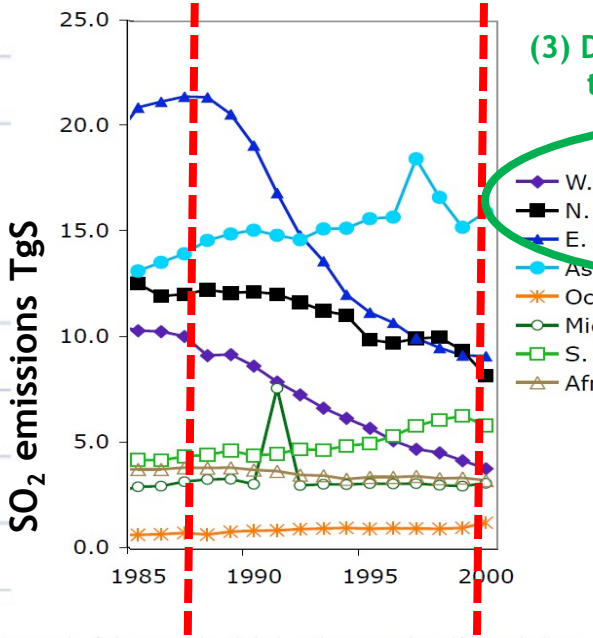


concentrations of ammonium-sulfate in the Saharan Air Layer decreased through the 1990s

view from Izaña:

trend of sulfate in the Saharan Air Layer





Reversal of the trend in global anthropogenic sulfur emissions

David I. Stern*

Global Environmental Change 16 (2006) 207–220

(3) Decrease in a-sulfate in the SAL is correlated with the decrease in European SO2 emissions

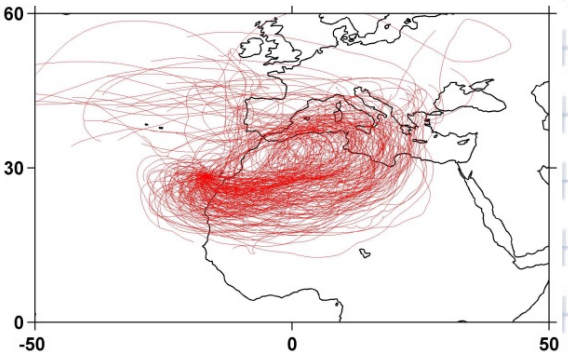
55% decrease

55% decrease

no significant change

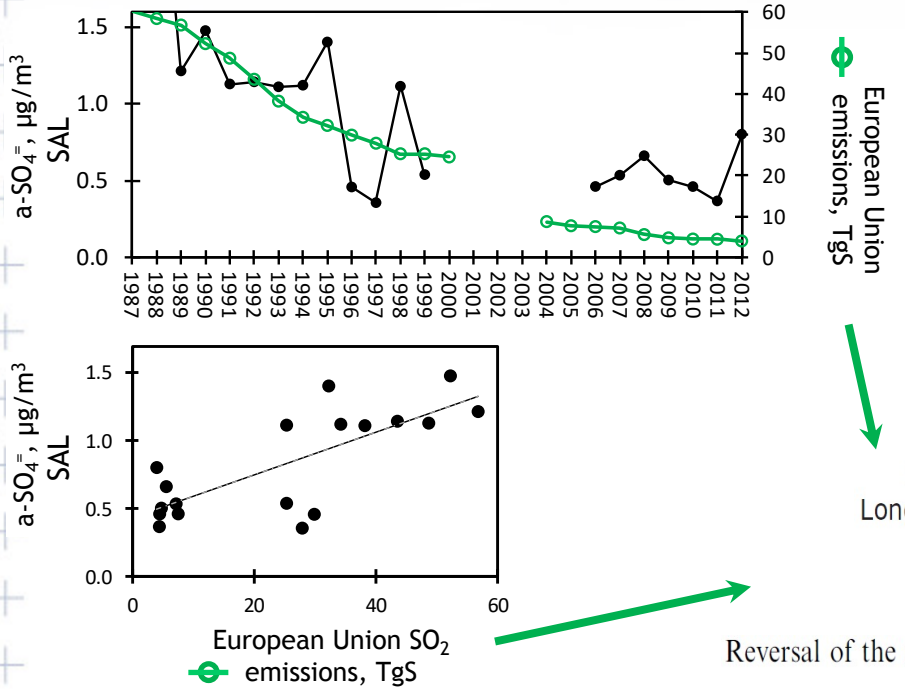
(2) North African emissions of SO_2 did not changed significantly during the 1990s

(1) air laden in Saharan dust has previously passed over the Mediterranean and Europe



August 1987-2012, dust days

trend of sulfate in the Saharan Air Layer



decrease in a-sulfate in the Saharan Air Layer is correlated with the decrease in European SO_2 emissions

EEA Technical report | No 12/2014

European Union emission inventory report 1990–2012 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP)

European Environment Agency

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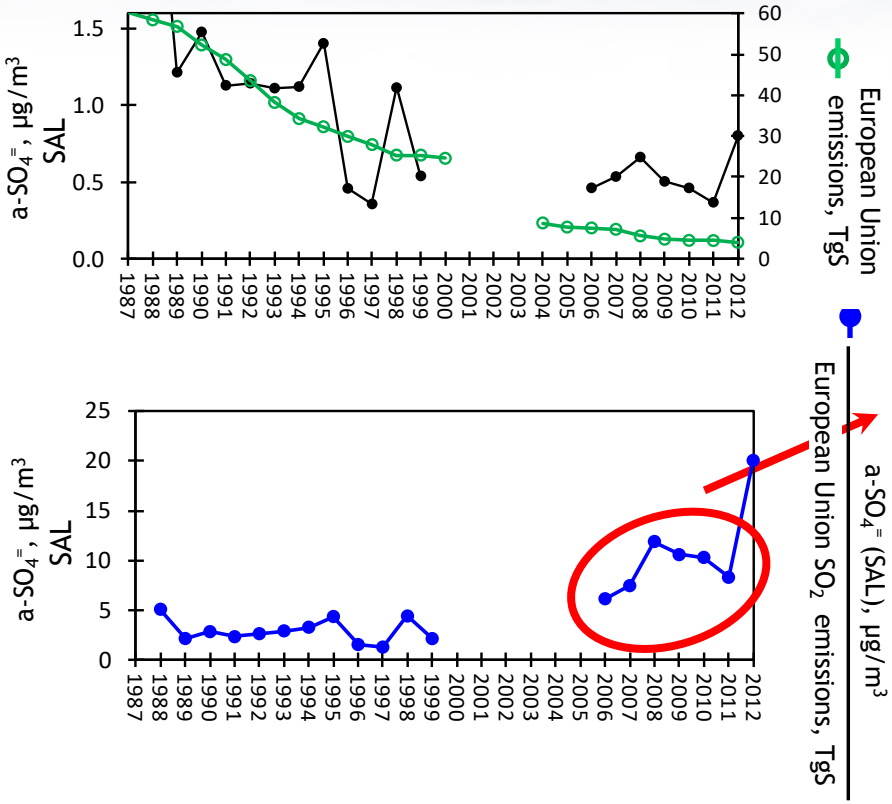
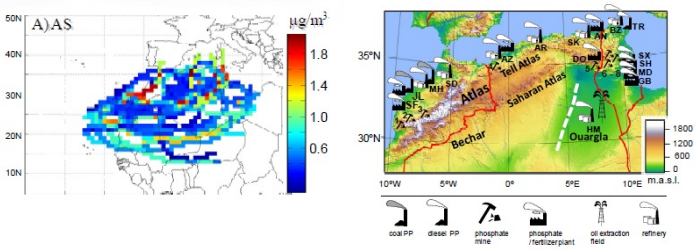


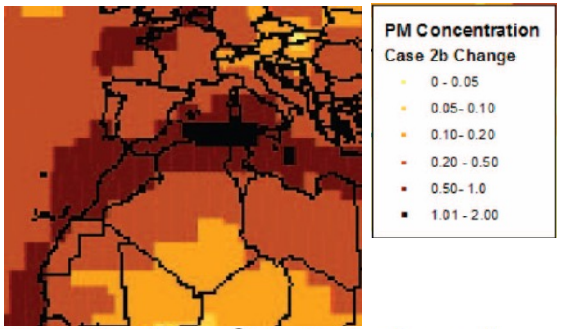
other sources contributing

north African emissions (?)

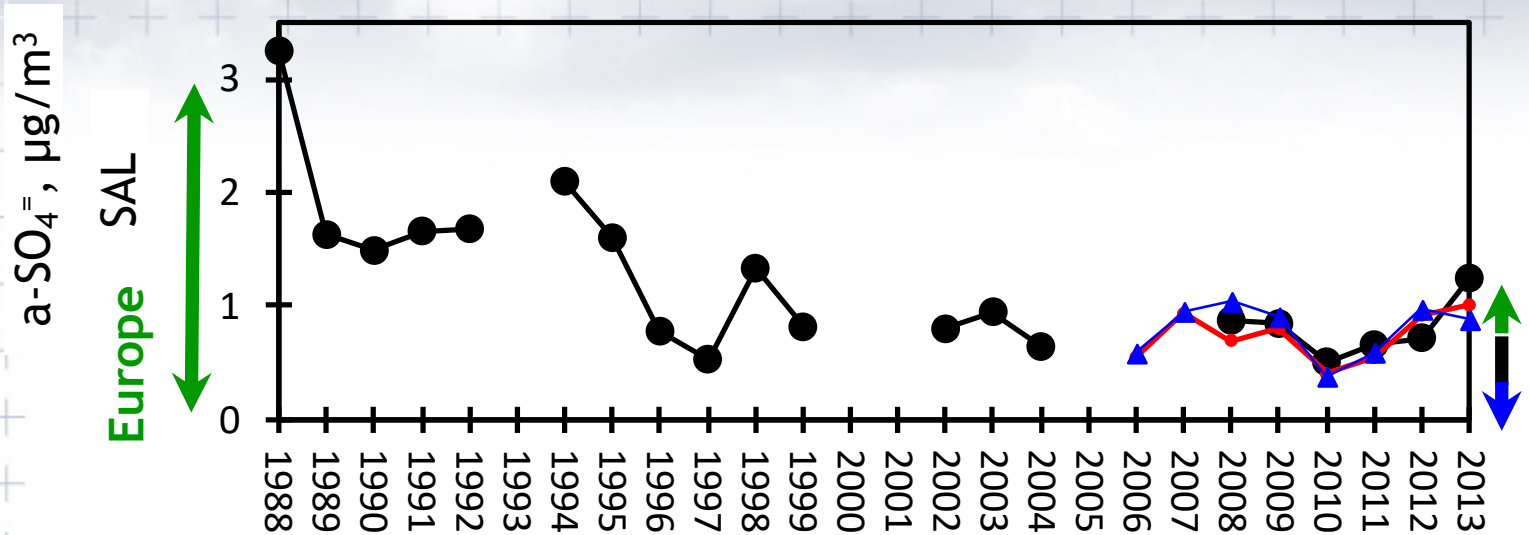


Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer
Rodríguez et al., 2011
Atmos. Chem. Phys., 11, 6663–6685, 2011

ship emissions in the Mediterranean (?)



Mortality from Ship Emissions: A Global Assessment
Environ. Sci. Technol. **2007**, *41*, 8512–8518
Cobett et al., 2007



Europe
North Africa
Ships
Mediterranean

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IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 9 (2014) 035003 (10pp)
doi:10.1088/1748-9326/9/3/035003

Explosive growth in African combustion emissions from 2005 to 2030

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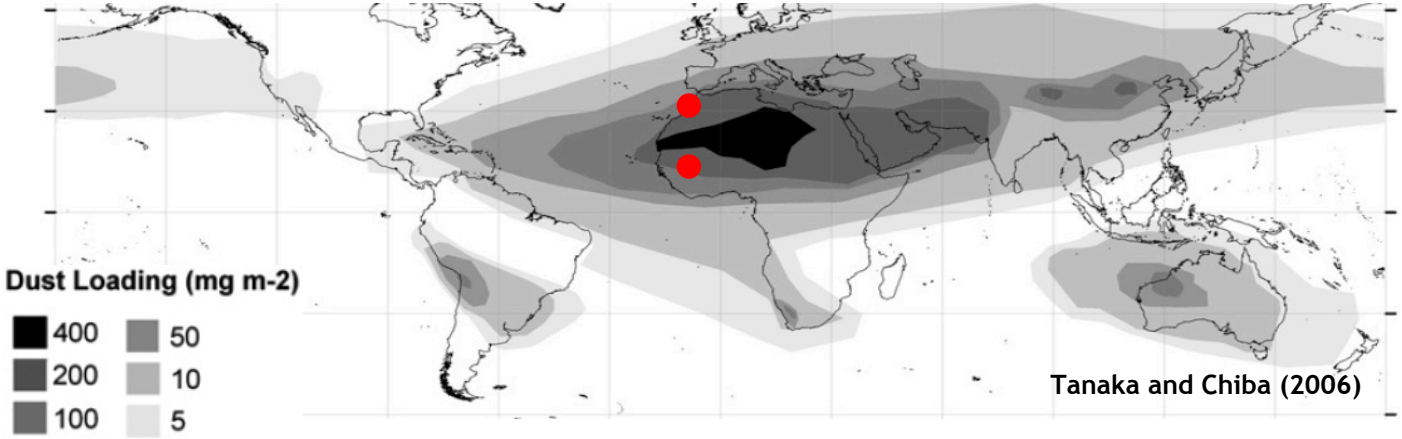
[6] Max-Planck Institute for Meteorology, Hamburg, Germany

➔Need to develop regional emission inventories



Tanaka and Chiba (2006)

dust belt

4th Training Course on WMO SDS-WAS products (satellite and ground observation and modeling of atmospheric dust)
Casablanca-Morocco, November 17-20, 2014

Ground observations of mineral dust

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