



Izaña: 1916-2016

Trends in the Saharan Air Layer Composition Observed at Izaña - Tenerife

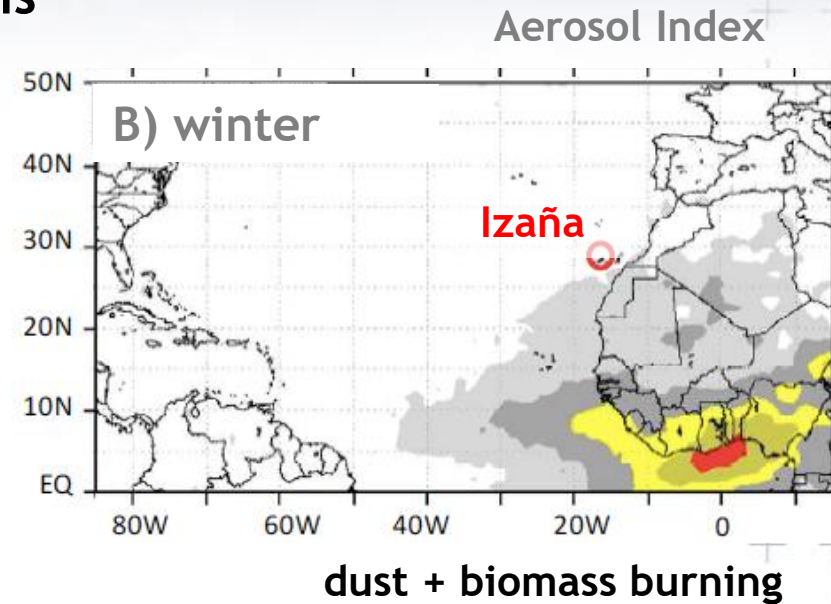


Sergio Rodríguez

srodriguezg@aemet.es

Izaña Atmospheric Research Centre, Tenerife

- North Africa: 50-70% of global dust emissions
- dust exported to the Atlantic in the Saharan Air Layer
- winter:
 - Sahelian and southern Saharan sources
 - SAL is exported to < 2 km.a.s.l. to the tropics
 - North Atlantic Oscillation modulates interannual variability in dust export
 (Ginoux et al., Environ. Modell. Softw., 19, 113-128, 2004)



-North Africa: 50-70% of global dust emissions

-dust exported to the Atlantic
in the Saharan Air Layer

-summer:

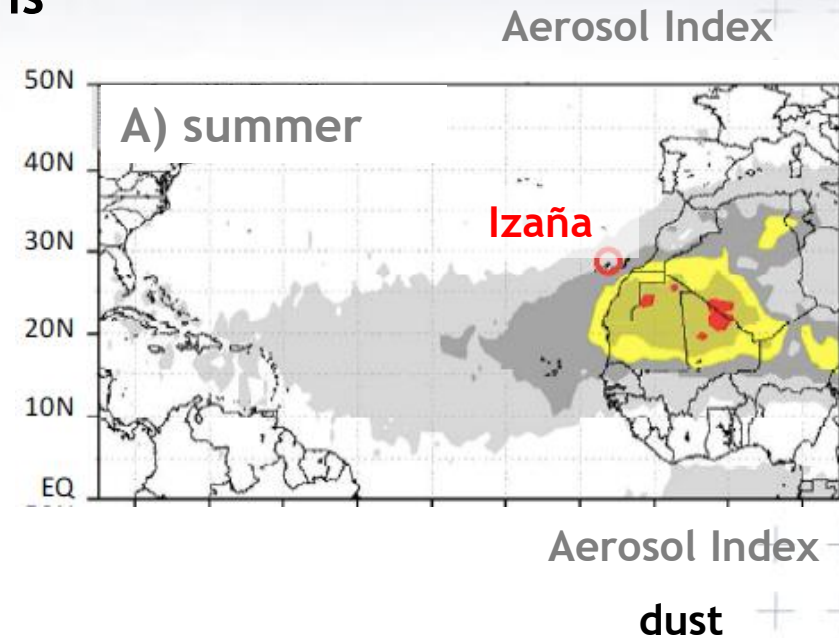
-activation of subtropical Saharan sources

-max dust emissions

-SAL is exported 1- 5 km.a.s.l. to subtropic

-max dust impacts through the North Atlantic

-Izaña is within the Saharan Air Layer



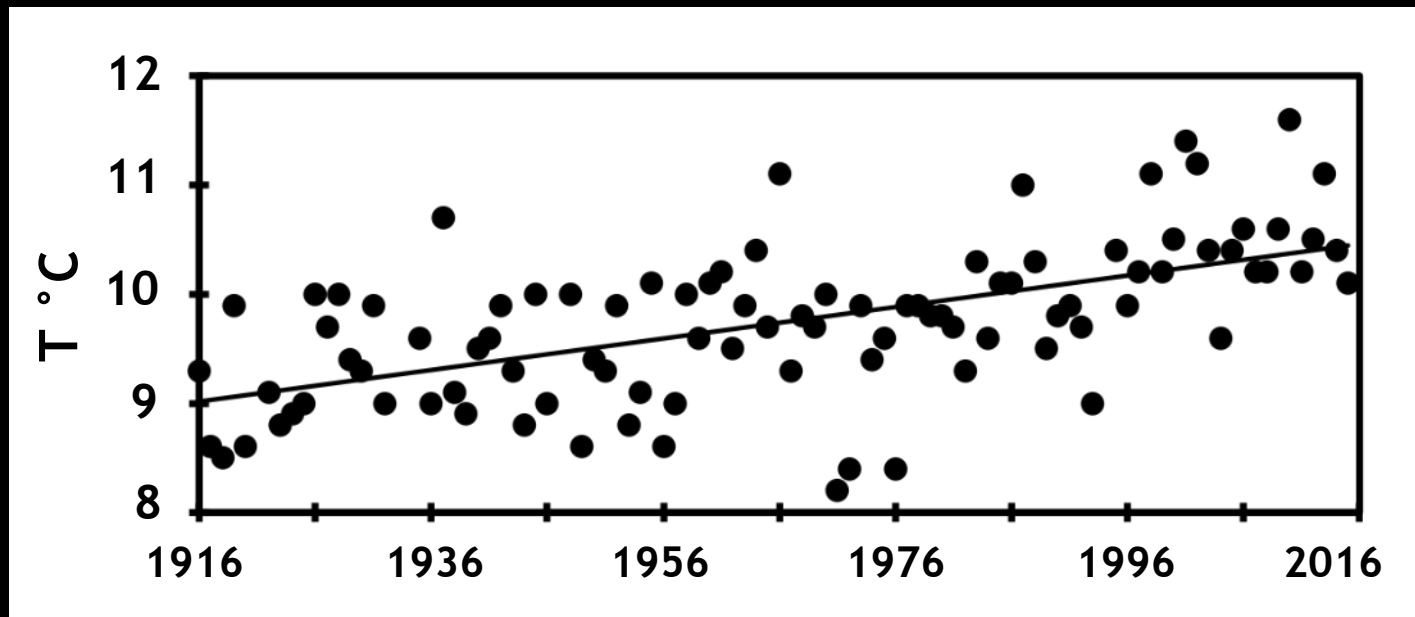
Izaña, 2400 masl

Tenerife Island



Izaña: 100-years of atmospheric observations

1916 - 2016



Izaña: 30 years aerosol observations 1987 - 2016

aerosol chemistry 1987

aerosol physic

number concentration 2006

size distribution 10nm - 20 μ m 2008

scattering total- and back- 3 λ 2008

absorption 1 λ 2007

aethalometer 7 λ 2012

view from Izaña:



-above the marine stratocumulus
-night-time free troposphere

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

sample collection on filter



cellulose

1987-1999 J.M. Prospero, **University of Miami**

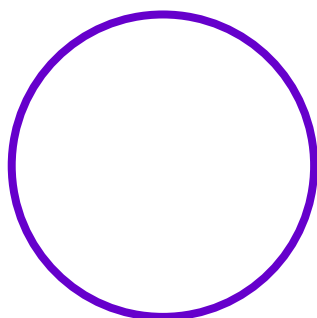
30 m³/h

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 microfibre filter

2002- up to the date **AEMET + CSIC + INFN (Italy)**

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

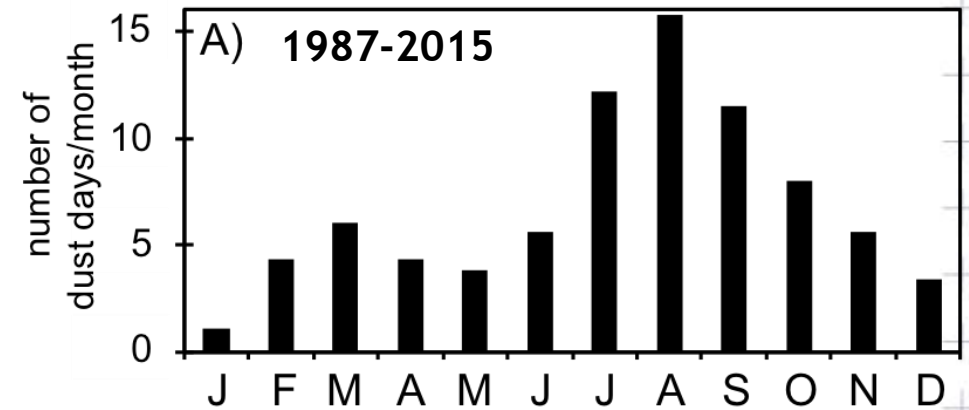
PM_{T} : total particulate matter

PM_{10} : particulate matter diameter $\leq 10 \mu\text{m}$

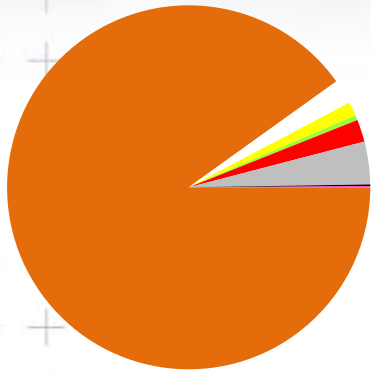
$\text{PM}_{2.5}$: particulate matter diameter $\leq 2.5 \mu\text{m}$

**samples collected at night
free troposphere**

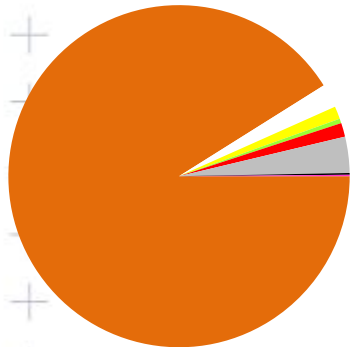
Summer Izaña is within
the SAL



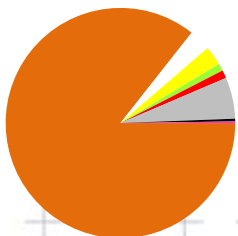
PM_x composition in the SAL



| PM _T 47.3 µg/m ³ | |
|--|------------------------------|
| 91% | 42.6 dust (Al, Fe, Ca, Ti..) |
| 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/m ³ | |
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| PM _{2.5} 18.5 µg/m ³ | |
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Outline

long term variability in the Saharan Air Layer.....

- dust
- dust mixing with pollutants
- dust composition

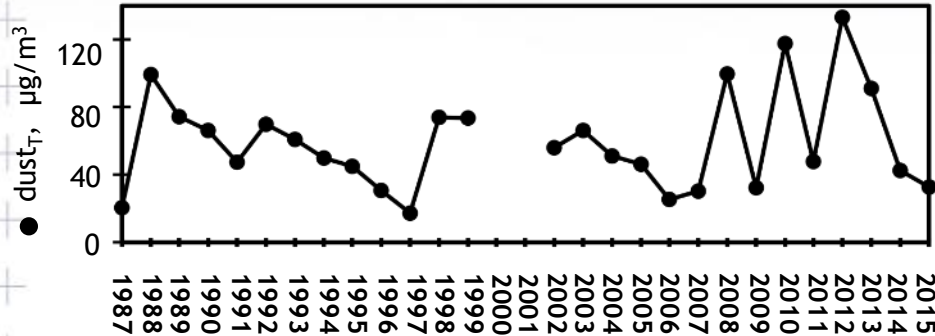


Outline

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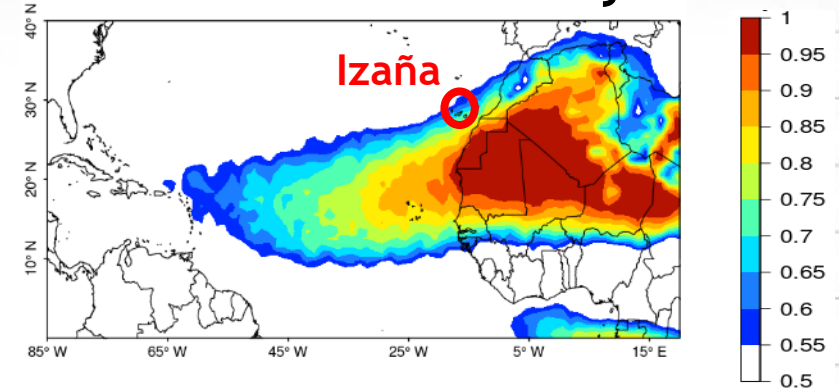
summer dust at Izaña: 1987 - 2015



Max: 133 µg/m³ 2012

Min: 17 µg/m³ 1997

Saharan Air Layer



M DFA: Major Dust Frequency Activity

UV Absorbing Aerosol Index = sensitive to iron oxides in dust

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

= fraction of summertime AI > 1

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

Summer North African meteorological scenario

Complex puzzle from the tropic to the Mediterranean:

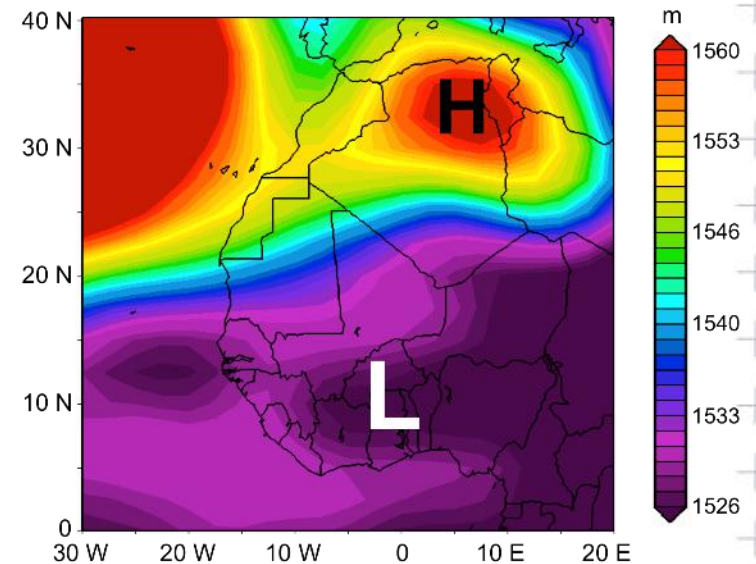
- Subtropical high pressures, $\approx 35^\circ\text{N}$
- Harmattan (\approx trade) winds $25\text{-}30^\circ\text{N}$
- ITCZ, 20°N
- Saharan heat low, 19°N
- Tropical low monsoon, $7\text{-}12^\circ\text{N}$
rain band, $5\text{-}12^\circ\text{N}$
Inflow, $5\text{-}20^\circ\text{N}$

H

L

North African Dipole

850hPa geop
1987-2014



Atmos. Chem. Phys., 15, 7471–7486, 2015

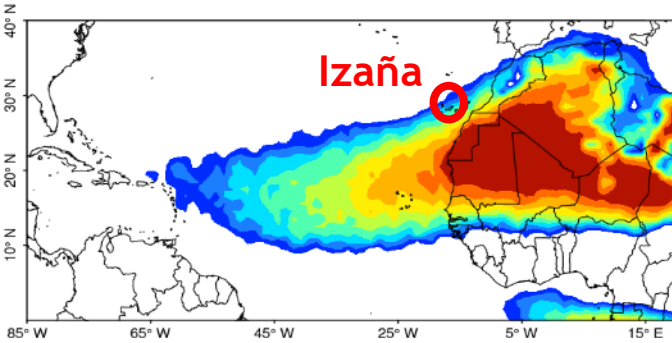
Modulation of Saharan dust export by the North African dipole

S. Rodríguez¹, E. Cuevas¹, J. M. Prospero², A. Alastuey³, X. Querol³, J. López-Solano¹, M. I. García^{1,4}, and S. Alonso-Pérez^{1,3,5}

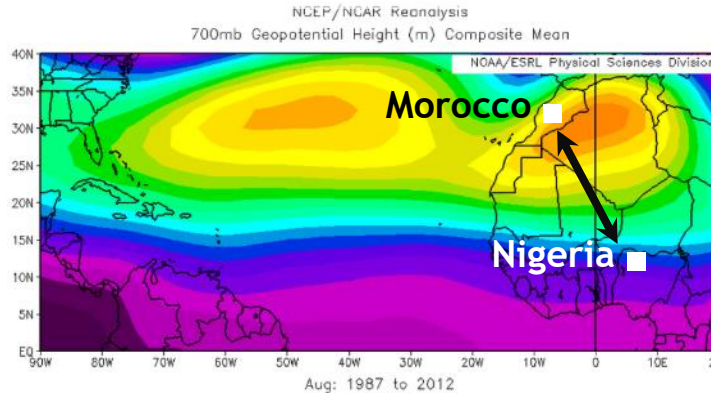
Atmospheric
Chemistry
and Physics

Saharan dust export, connection to... large scale meteorology in North Africa

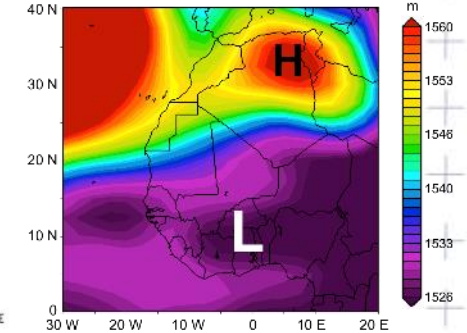
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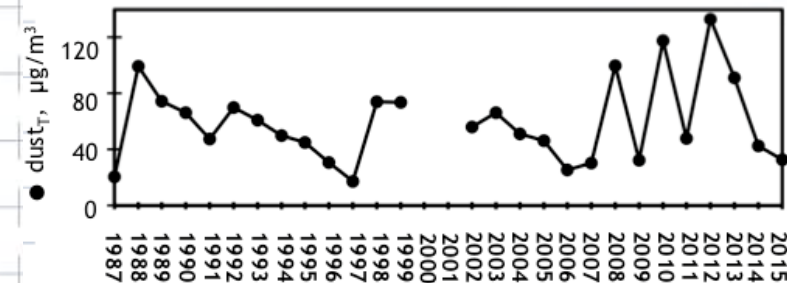
700hPa geop. height



850hPa geop. height



Izaña



North African Dipole Intensity (NAFDI)

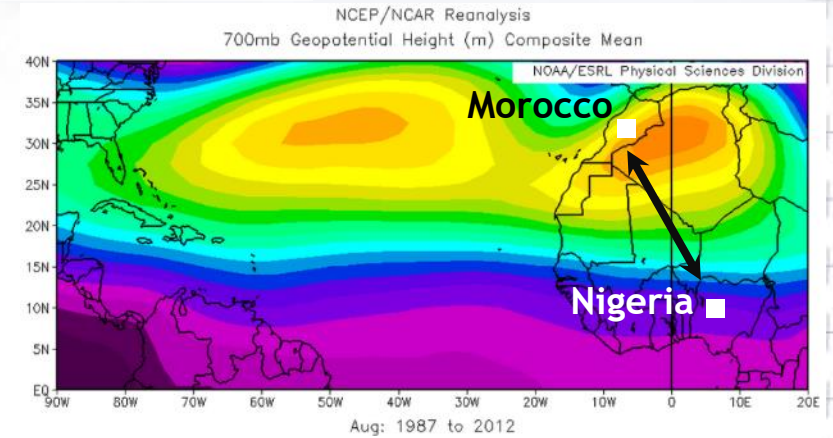
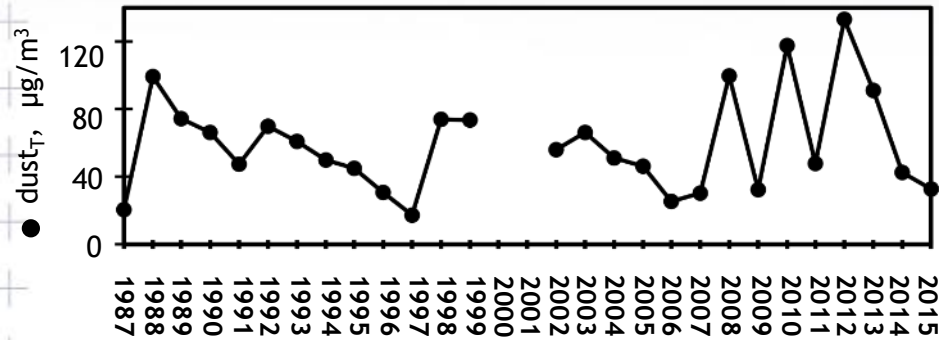
$$NAFDI = \frac{1}{10} ((\Phi_{Mo}^y - \langle \Phi \rangle_{Mo}) - (\Phi_{Ba}^y - \langle \Phi \rangle_{Ba}))$$

700 hPa: relevant level for dust export

In principle, NAFDI is just a measure of the geostrophic component of the North African outflow

but, we will see it provides additional useful information on climate variability

Saharan dust export, connection to... large scale meteorology in North Africa



North African Dipole Intensity

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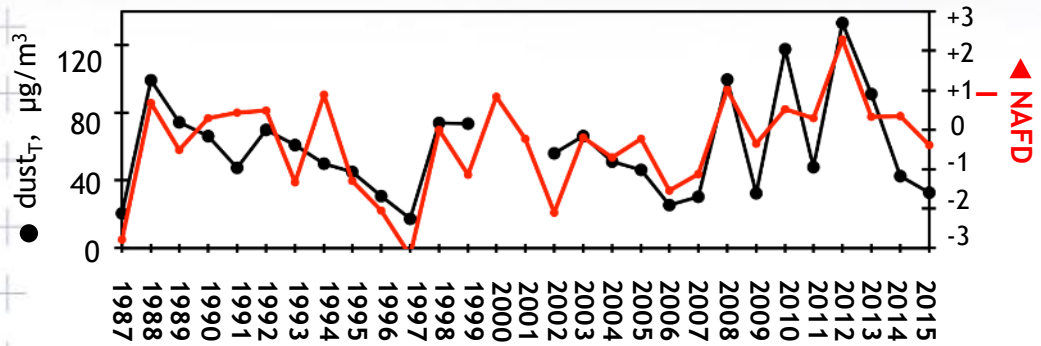
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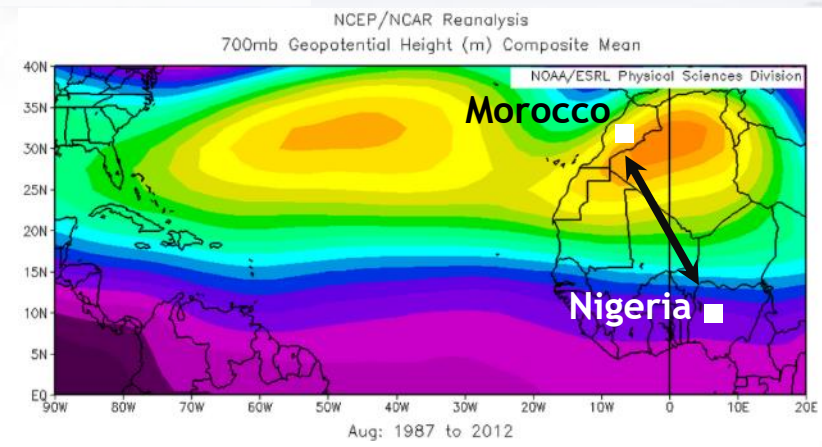
Atmospheric
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and Physics

Saharan dust export, connection to... large scale meteorology in North Africa



Pearson correlation between NAFDI and the dust at Izaña = +0.71

Variability in dust export is associated with variability in NAFDI



North African Dipole Intensity

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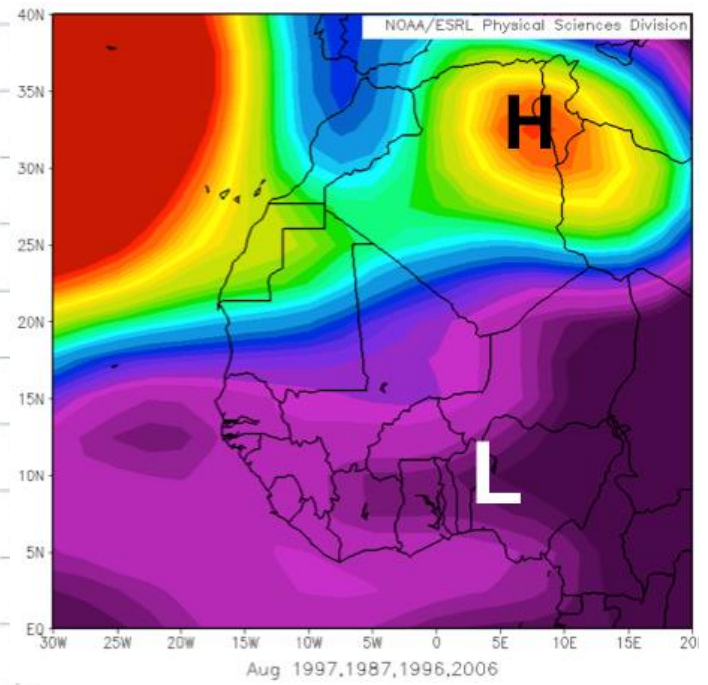
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Atmospheric
Chemistry
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Saharan dust export, connection to... large scale meteorology in North Africa

Low NAFDI summers

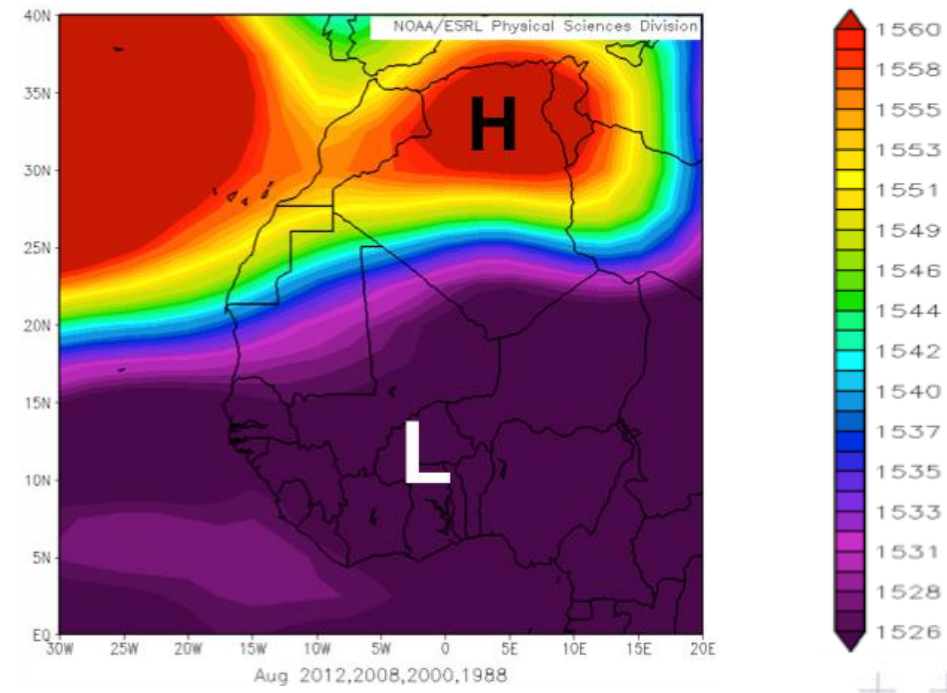
1987, 1996, 1997 and 2006
-2.79, -2.04, -3.19 and -1.54



850 hPa geop. height

High NAFDI summers

1988, 2000, 2008 and 2012
+0.68, +0.83, +1.01 and +2.29

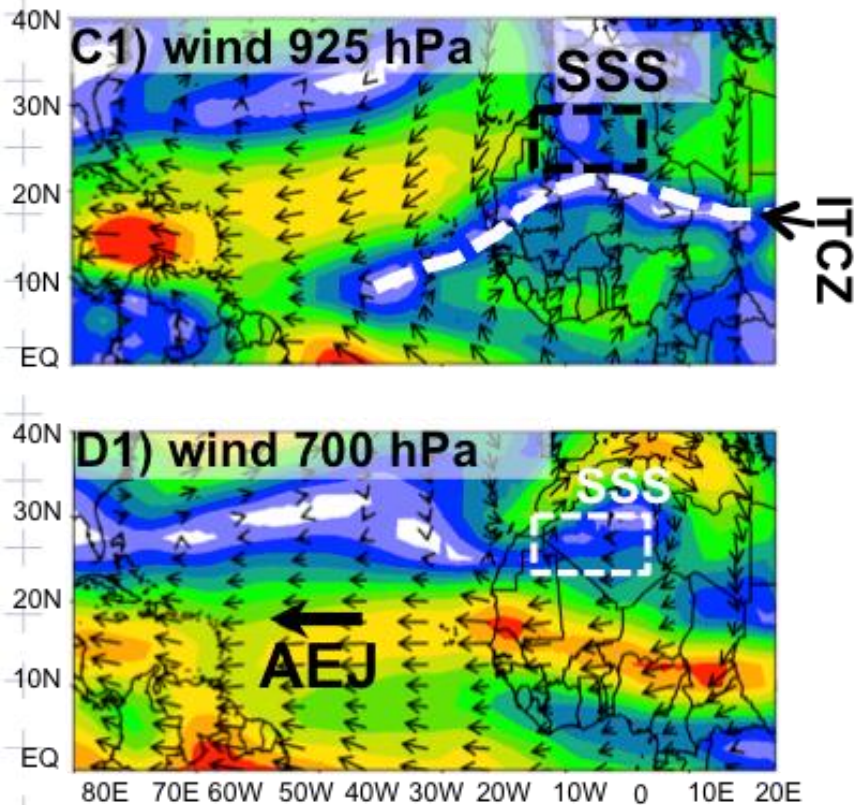


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**Saharan dust export, connection to...
large scale meteorology in North Africa**

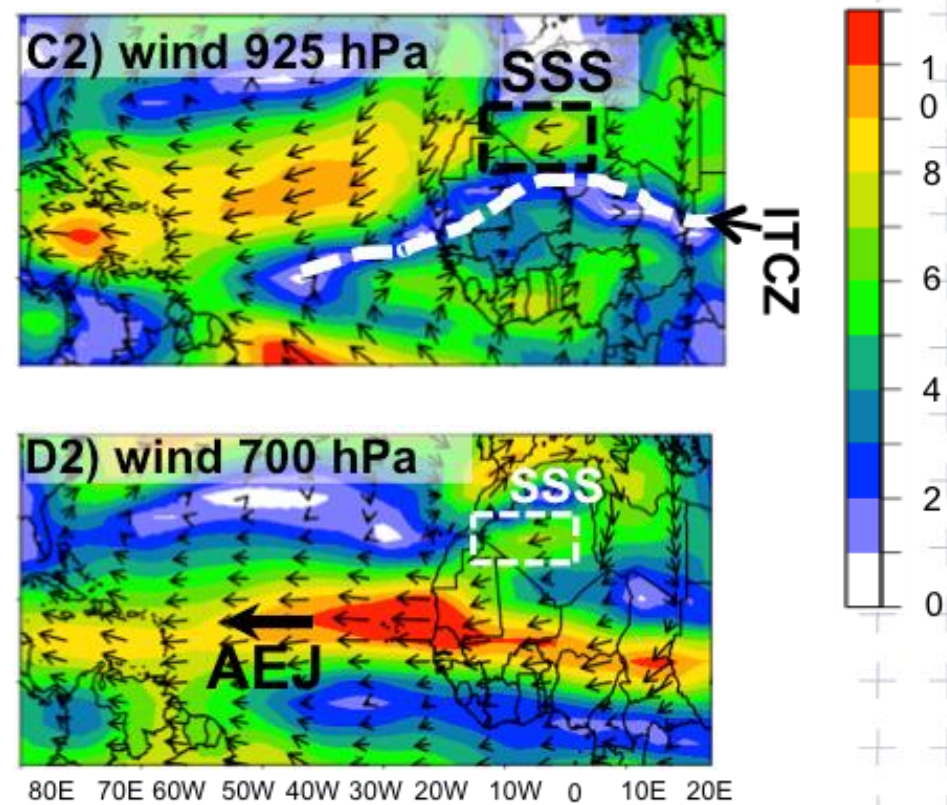
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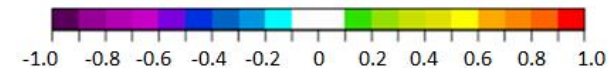
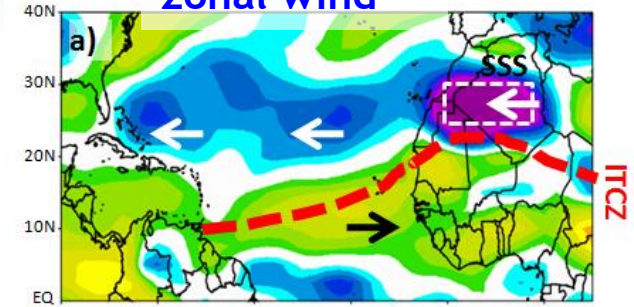
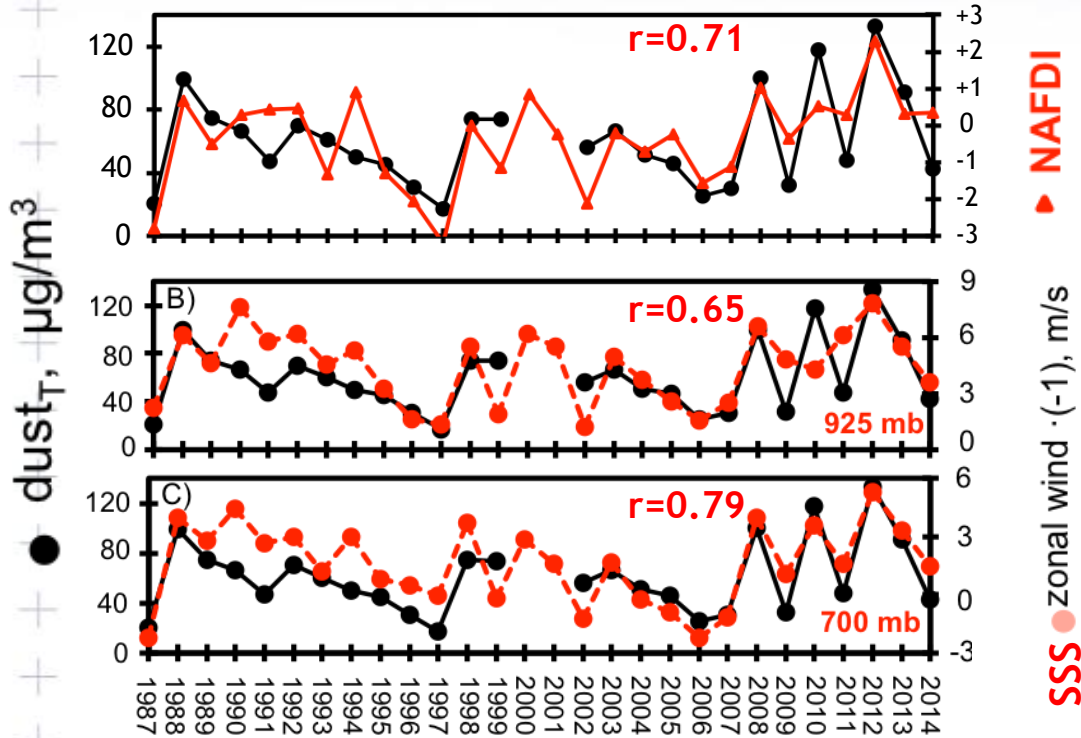
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Subtropical Saharan Stripe-SSS: Central Algeria to Western Saharan, 24 - 30 °N

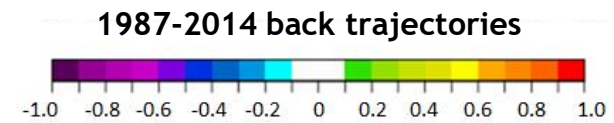
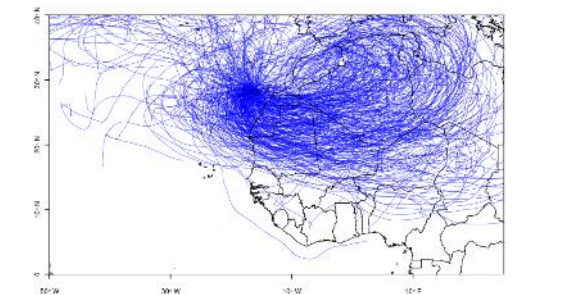
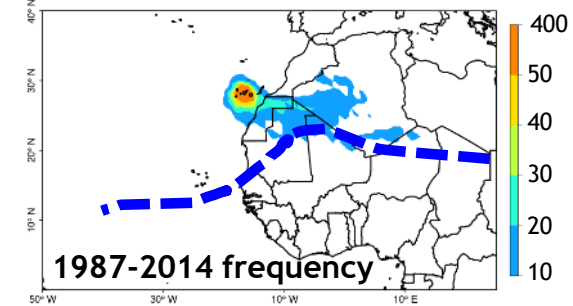
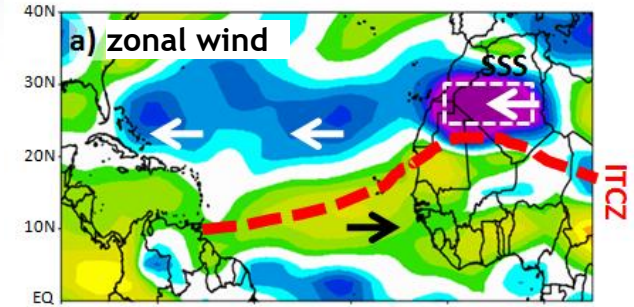
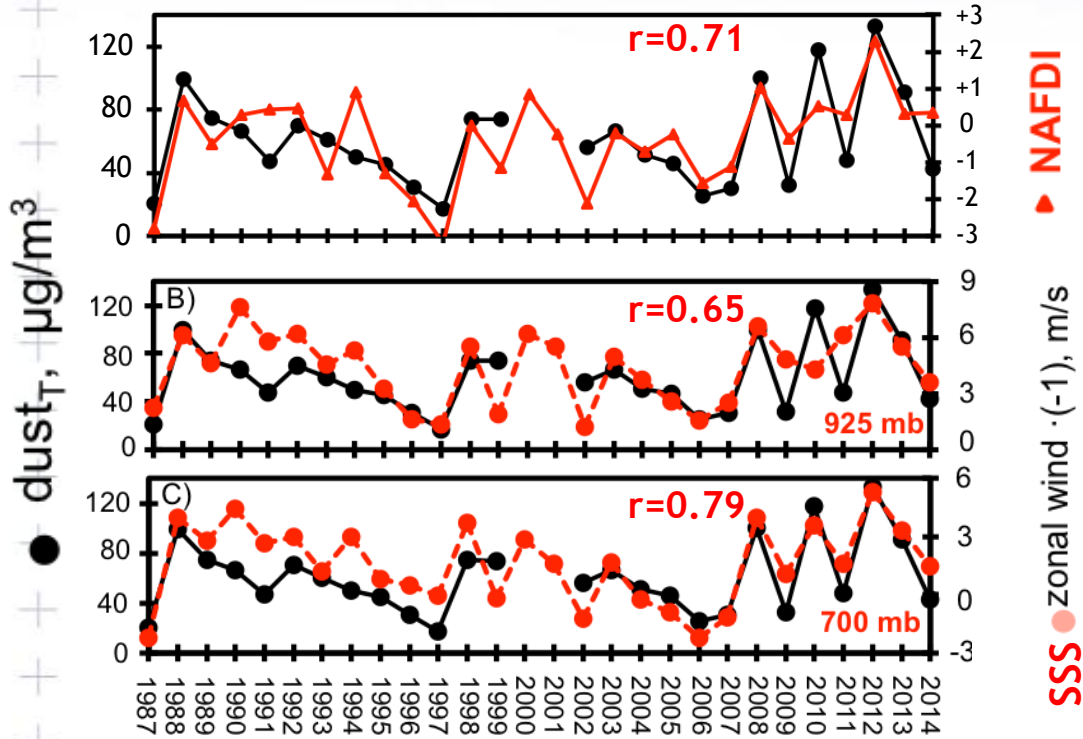
Saharan dust export, connection to... large scale meteorology in North Africa

correlation of NAFDI with... zonal wind



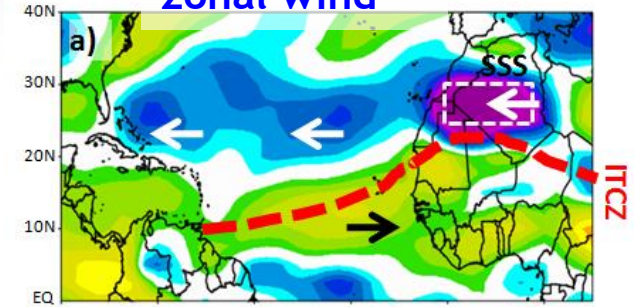
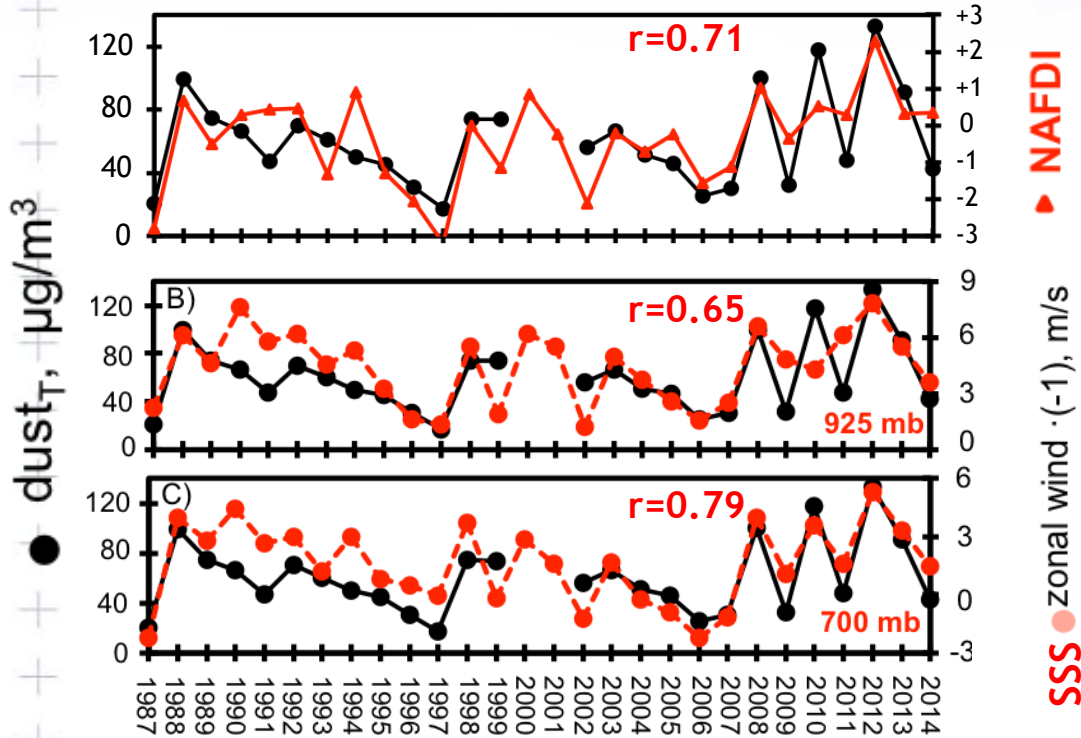
Saharan dust export, connection to... large scale meteorology in North Africa

Correlation coefficient between NAFDI and



Saharan dust export, connection to...
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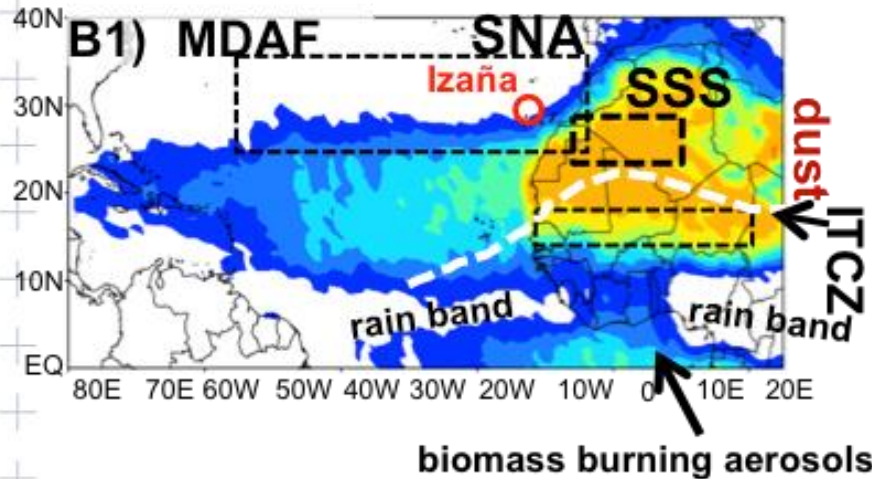
Variability in the summer dust export has been mainly controlled by winds



**Saharan dust export, connection to...
large scale meteorology in North Africa**

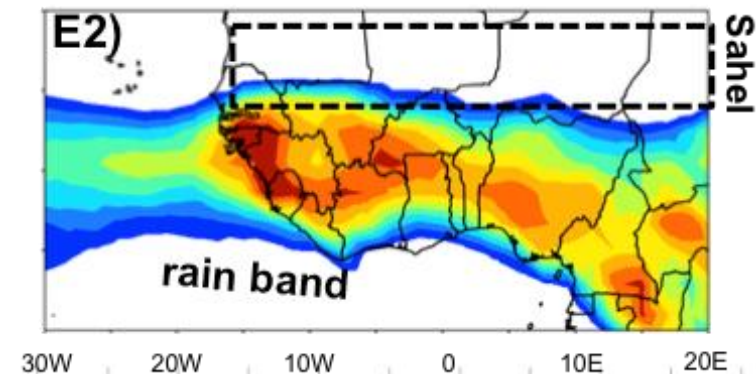
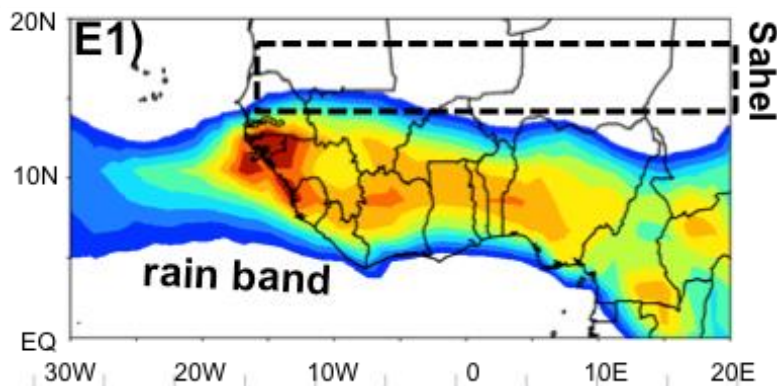
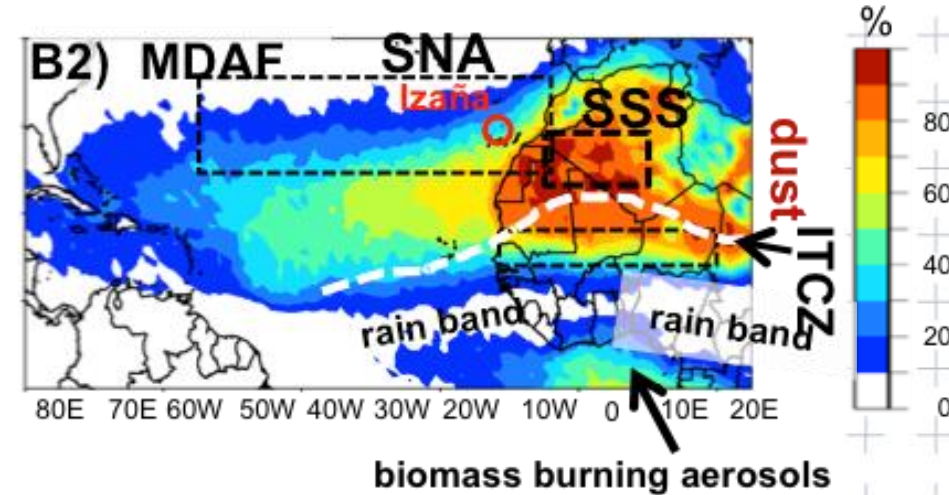
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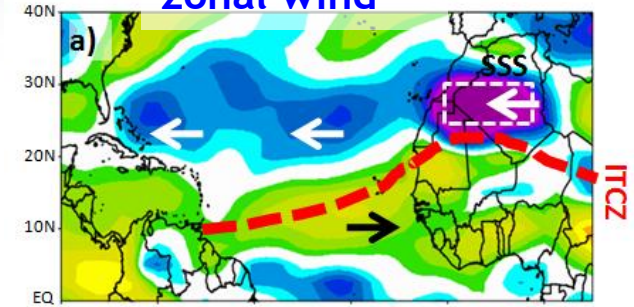
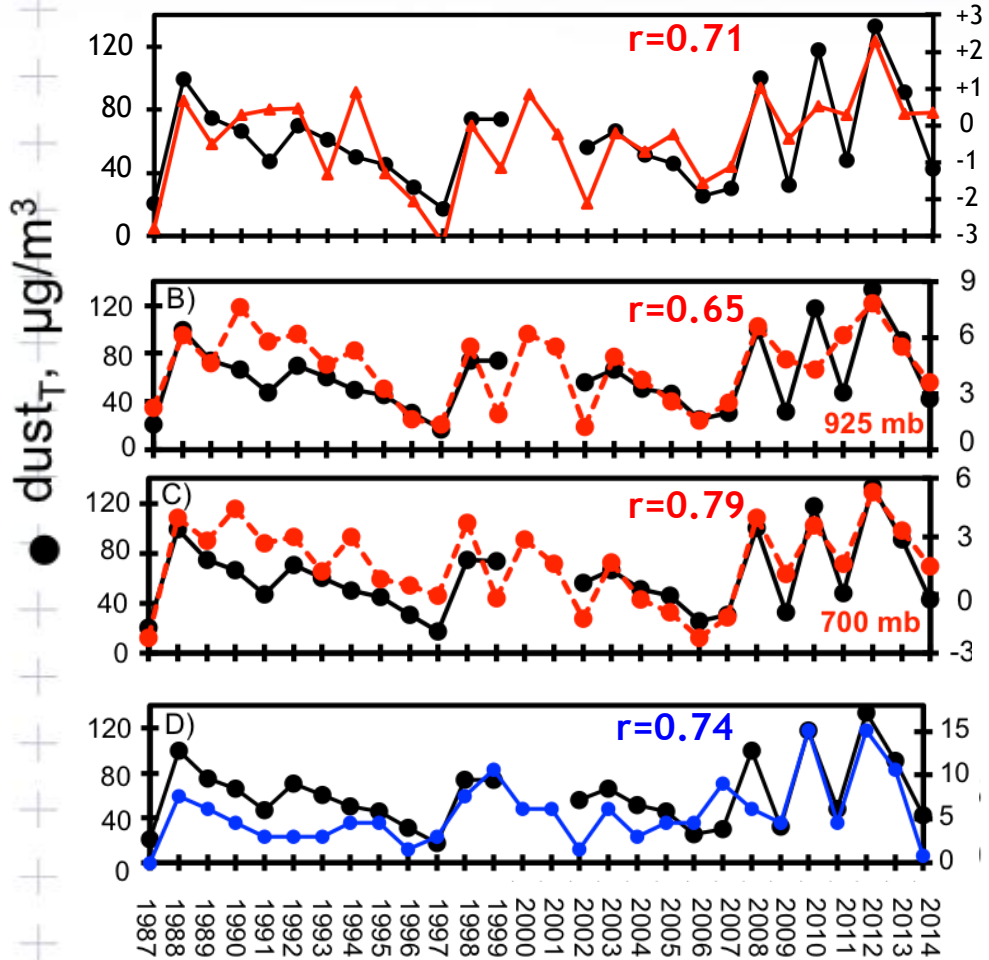
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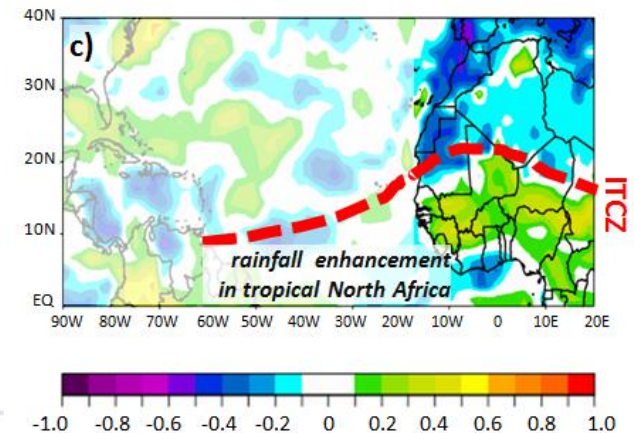
the monsoon rain band shift northward in high NAFDI summers

Saharan dust export, connection to... large scale meteorology in North Africa

correlation of NAFDI with... zonal wind



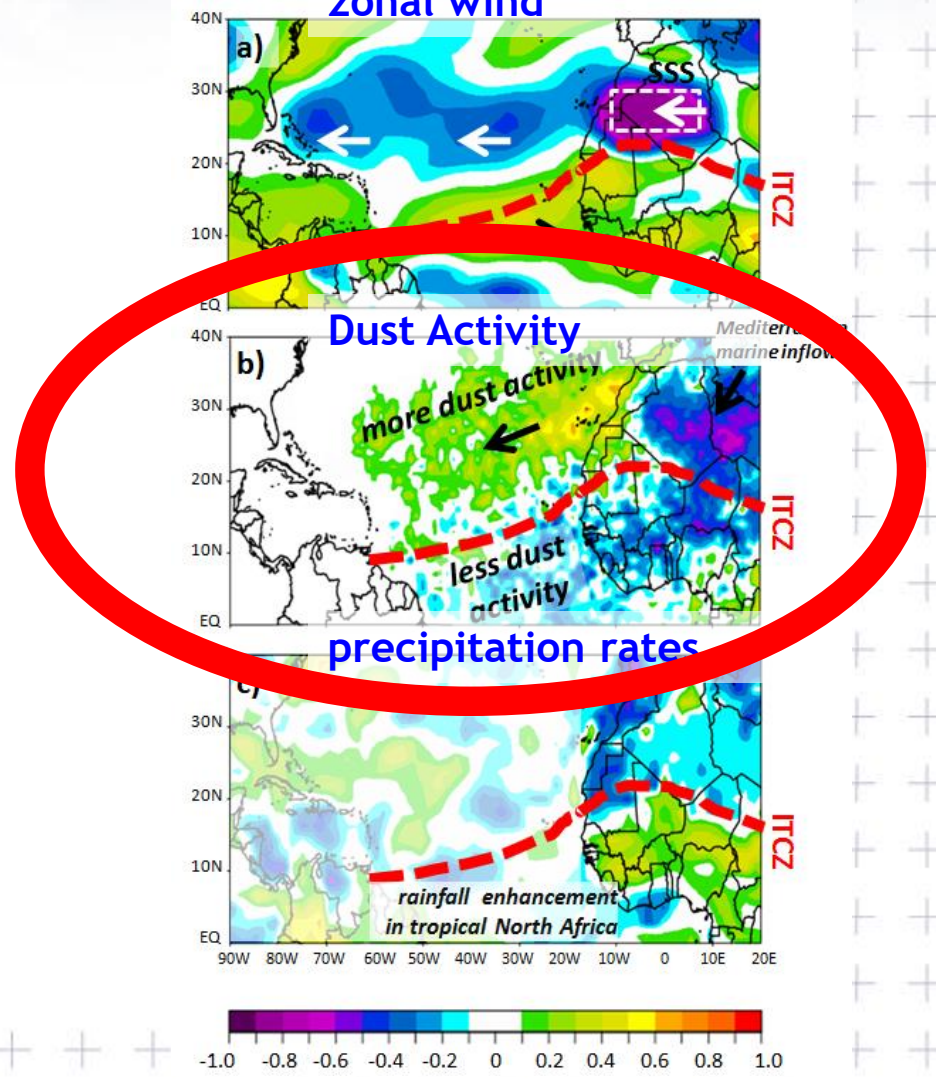
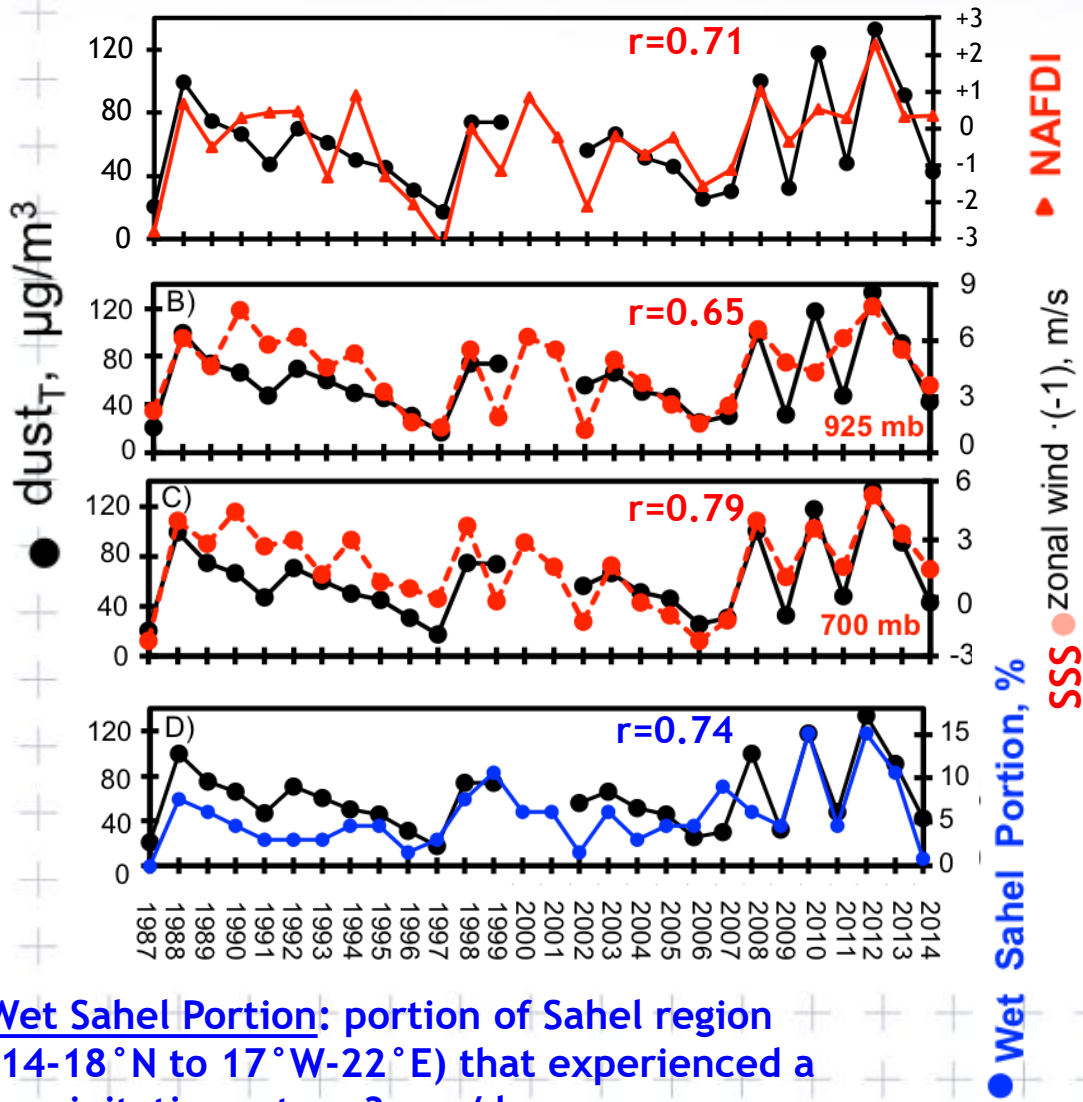
correlation of NAFDI with... precipitation rates



Wet Sahel Portion: portion of Sahel region (14-18°N to 17°W-22°E) that experienced a precipitation rate ≥ 3 mm/day

**Saharan dust export, connection to...
large scale meteorology in North Africa**

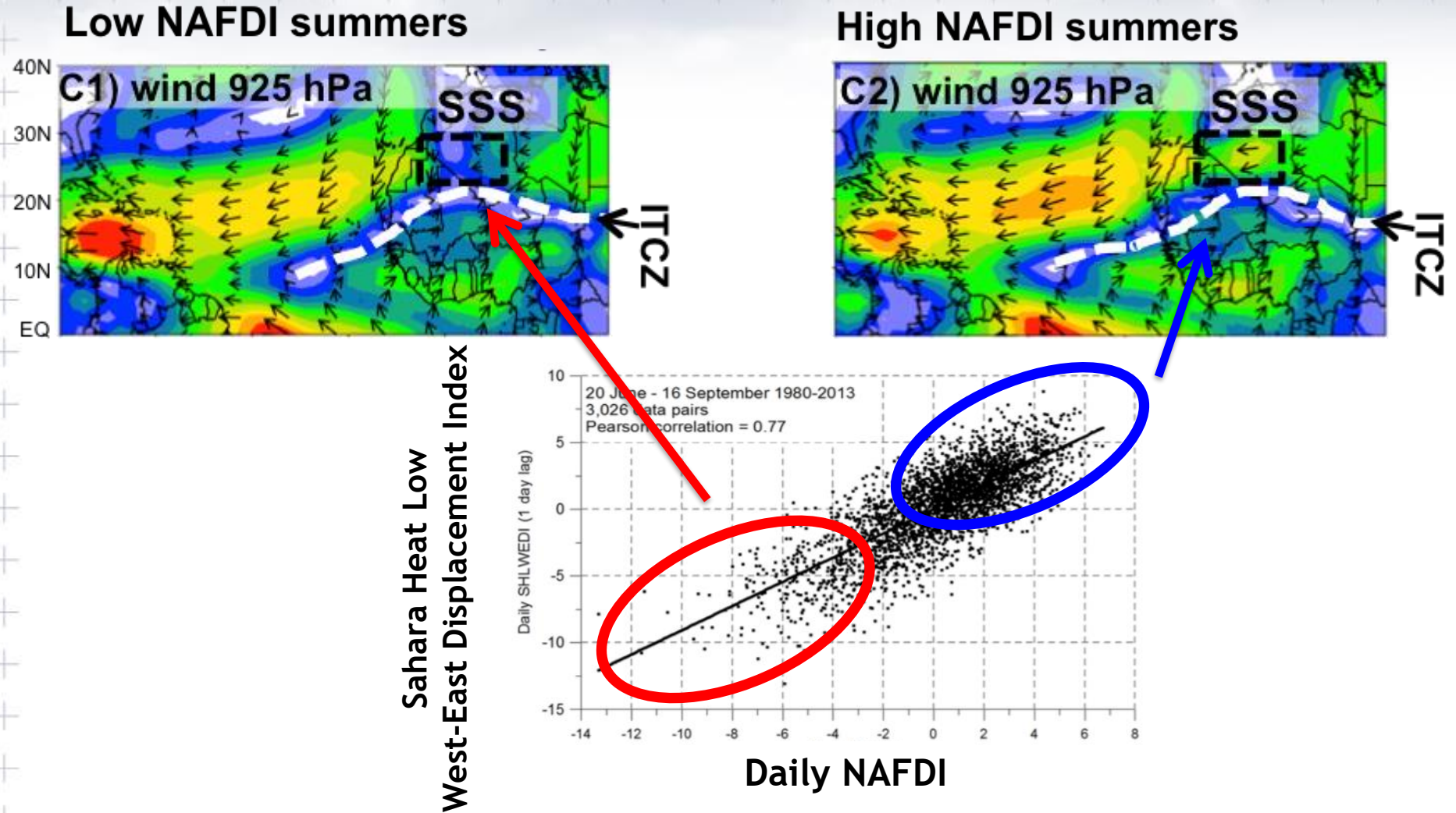
**correlation of NAFDI with...
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Wet Sahel Portion: portion of Sahel region (14-18°N to 17°W-22°E) that experienced a precipitation rate ≥ 3 mm/day

Sahara Heat Low

West-East Displacements are modulated by NAFDI



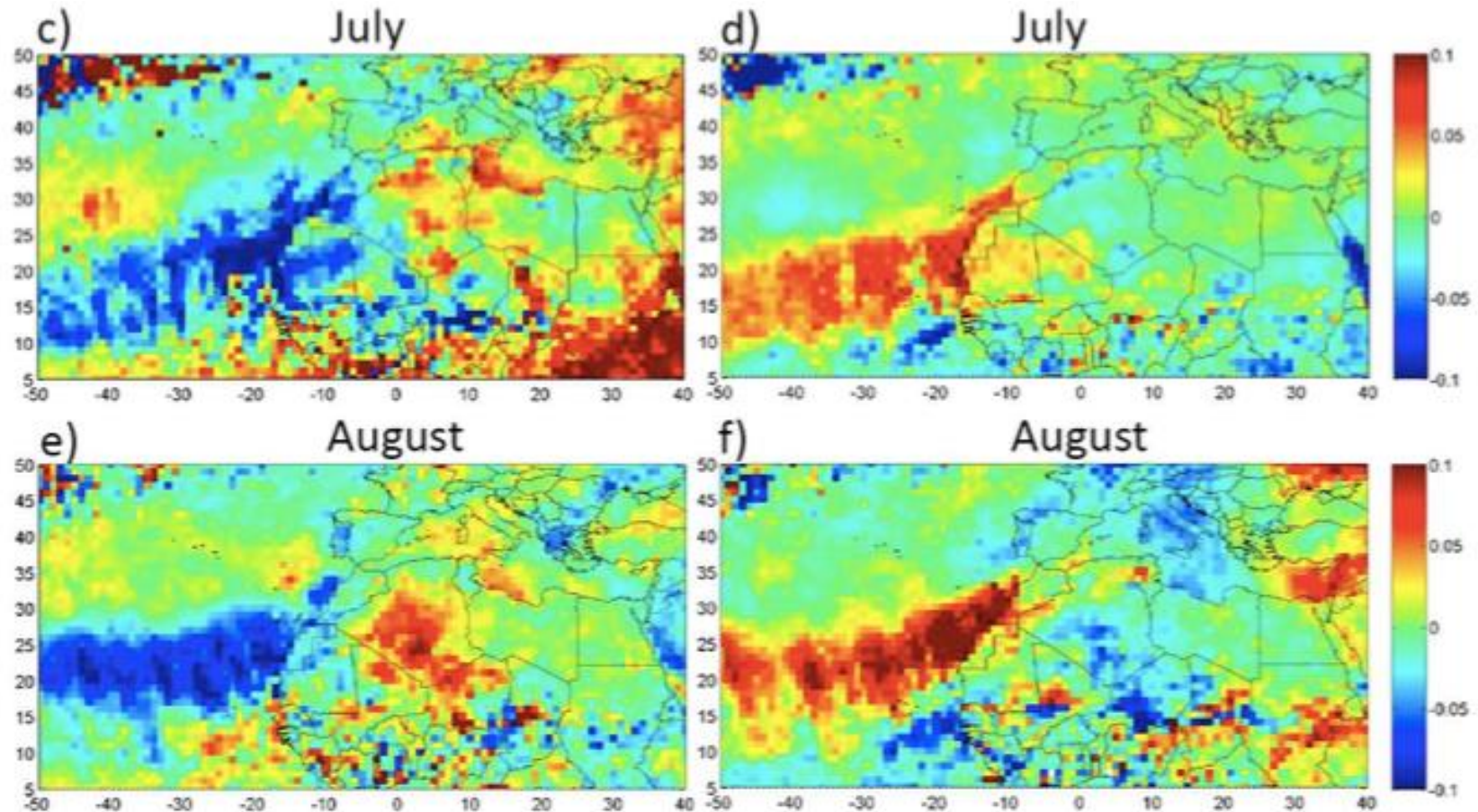
spatial variability in source activation and dust export modulated by NAFDI

MODIS- satellite AOD

Low (-) NAFDI , < -0.4

High (+) NAFDI , $> +0.4$

Enhanced impacts on Mediterranean Enhanced impacts on Atlantic - SAL



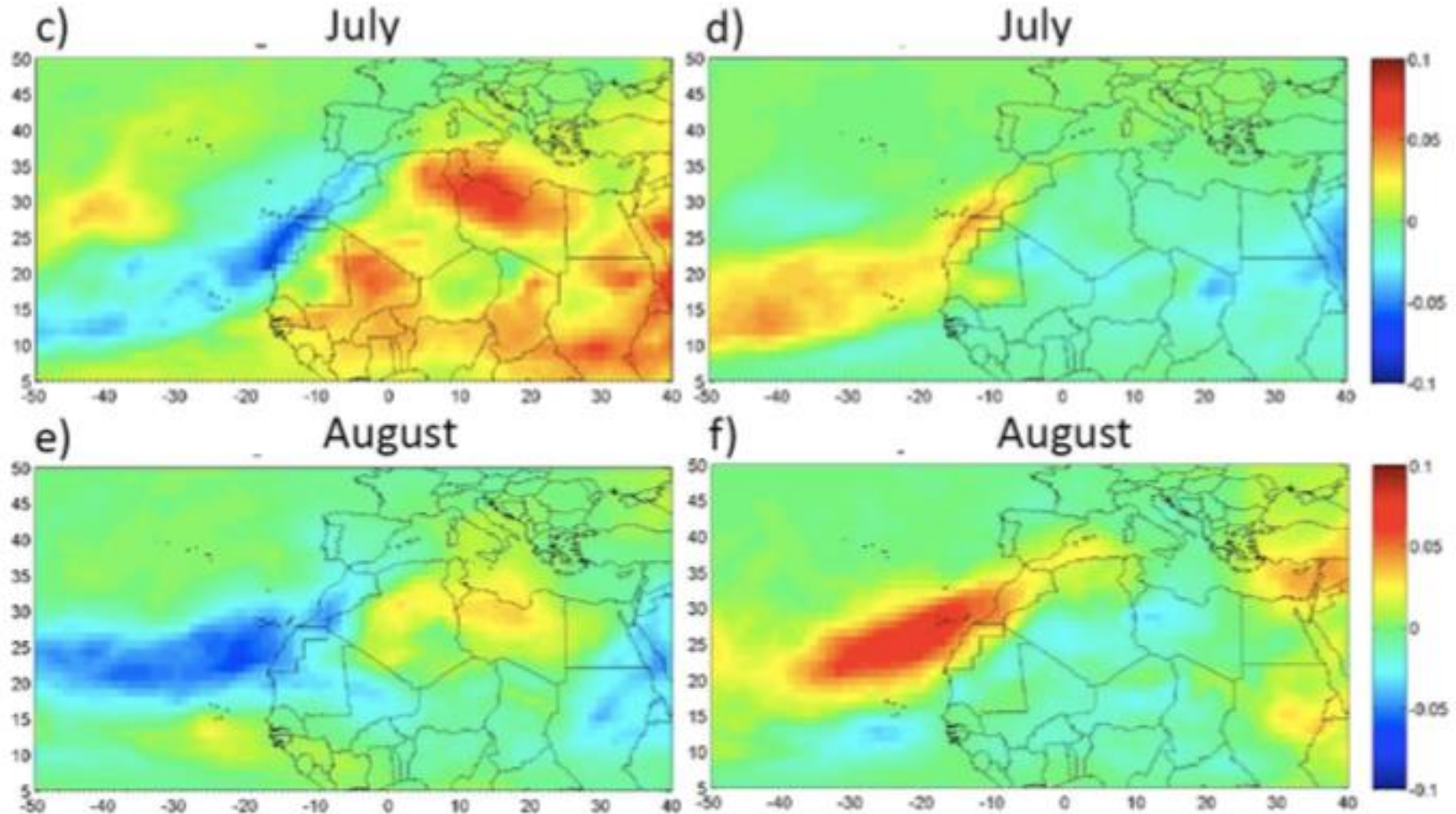
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MACC- modelling AOD

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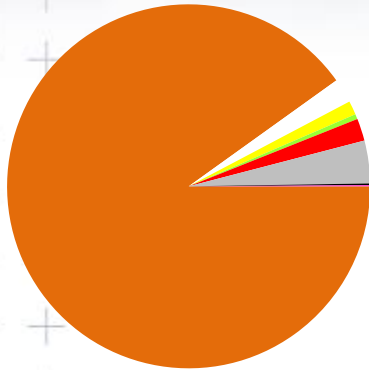


Outline

long term variability in the Saharan Air Layer.....

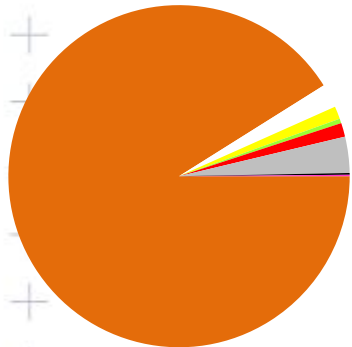
- dust
- dust mixing with pollutants**
- dust composition

PM_x composition in the SAL



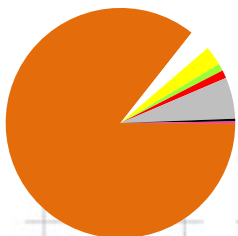
PM_T 47.3 μg/m³

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PM₁₀ 42.0 μg/m³

| | | |
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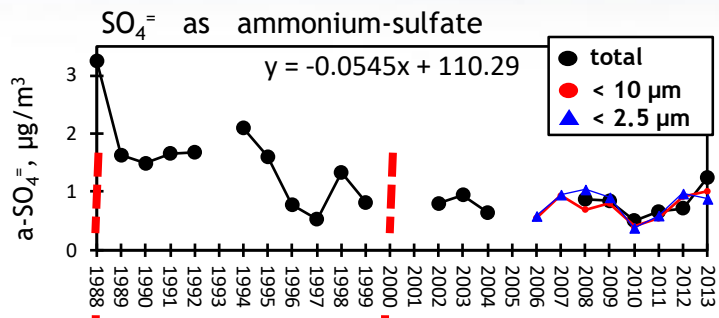


PM_{2.5} 18.5 μg/m³

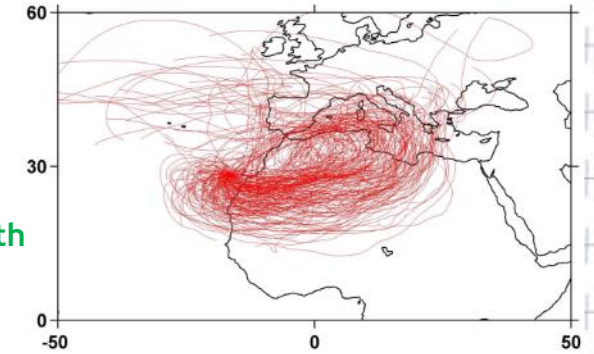
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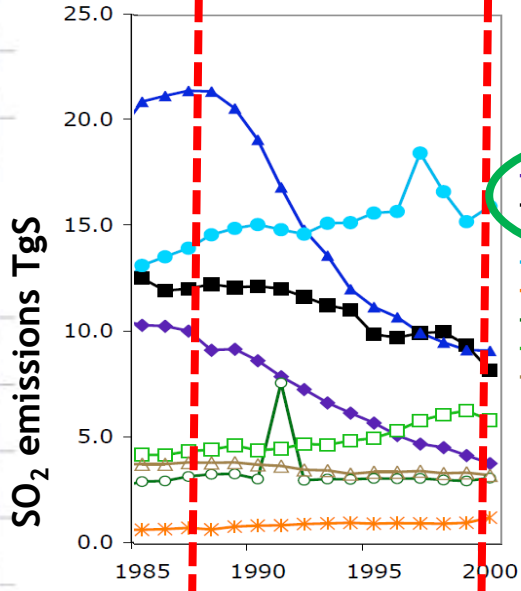
ammonium-sulfate in the Saharan Air Layer



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



August 1987-2012, dust days



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

55% decrease
55% decrease

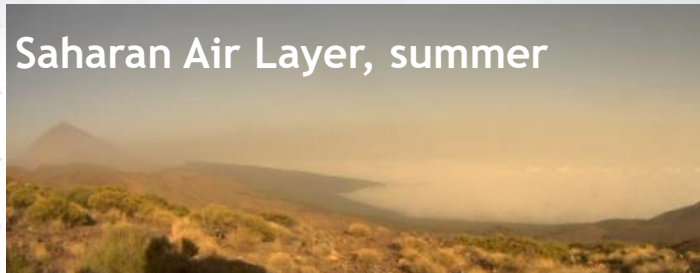
no significant change

(2) North African emissions of SO₂ did not changed significantly during the 1990s

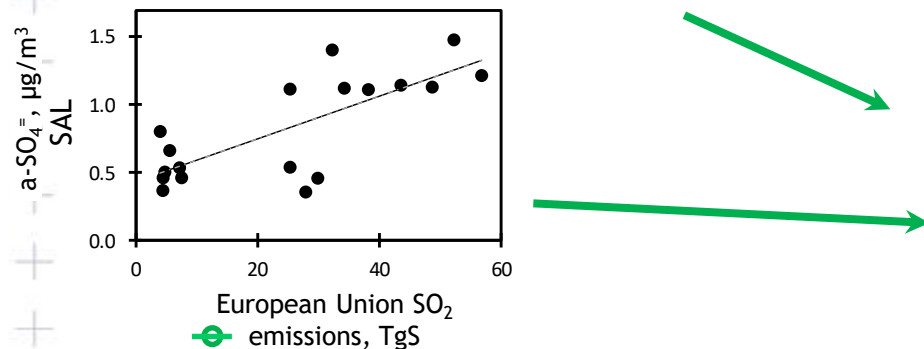
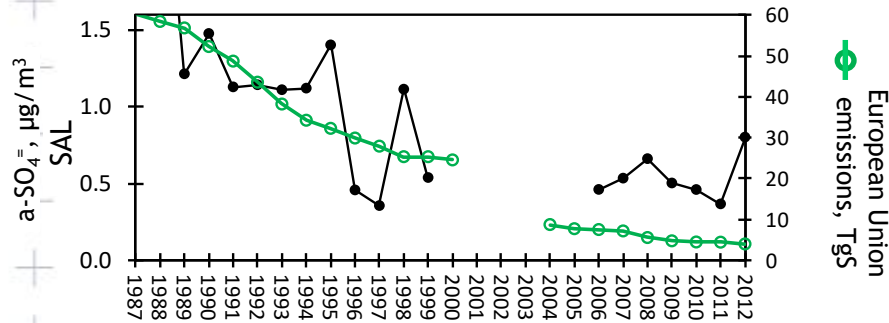
Reversal of the trend in global anthropogenic sulfur emissions

David I. Stern*
Global Environmental Change 16 (2006) 207-220

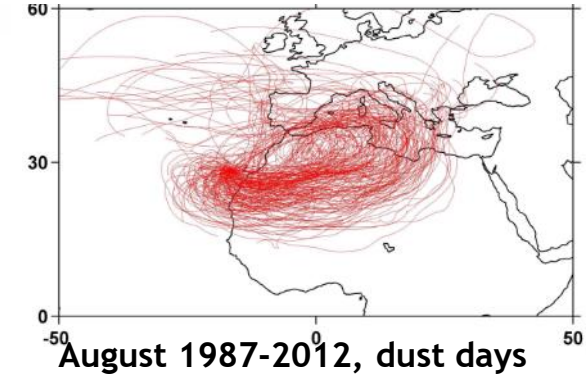
ammonium-sulfate in the Saharan Air Layer



Saharan Air Layer, summer



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



decrease in a-sulfate in the Saharan Air Layer is correlated with the decrease in European SO₂ 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)

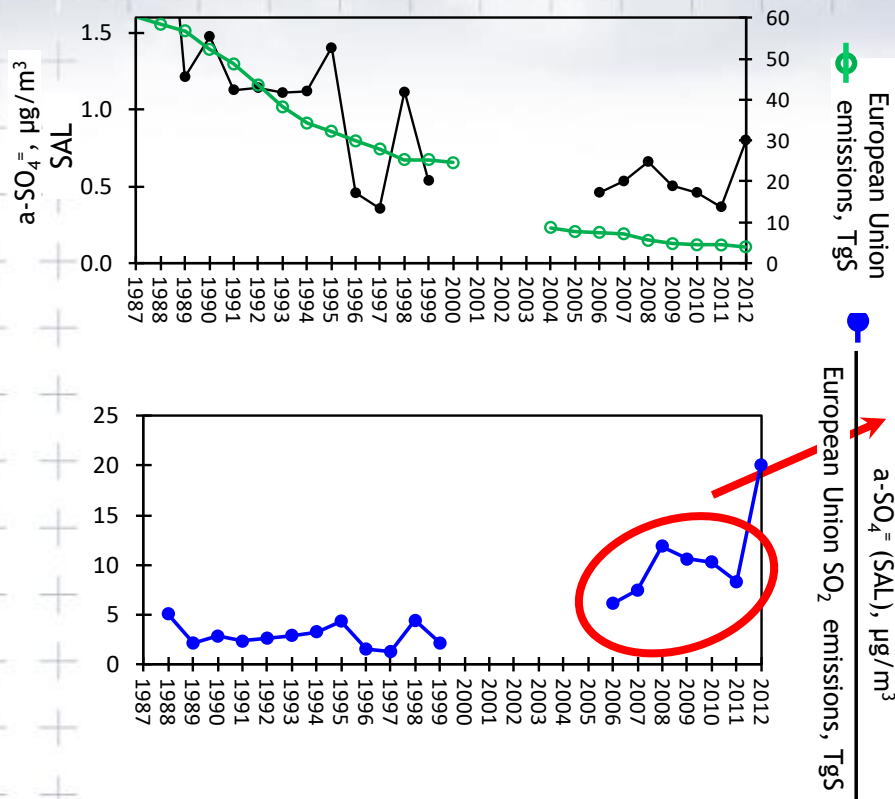
European Environment Agency

Reversal of the trend in global anthropogenic sulfur emissions

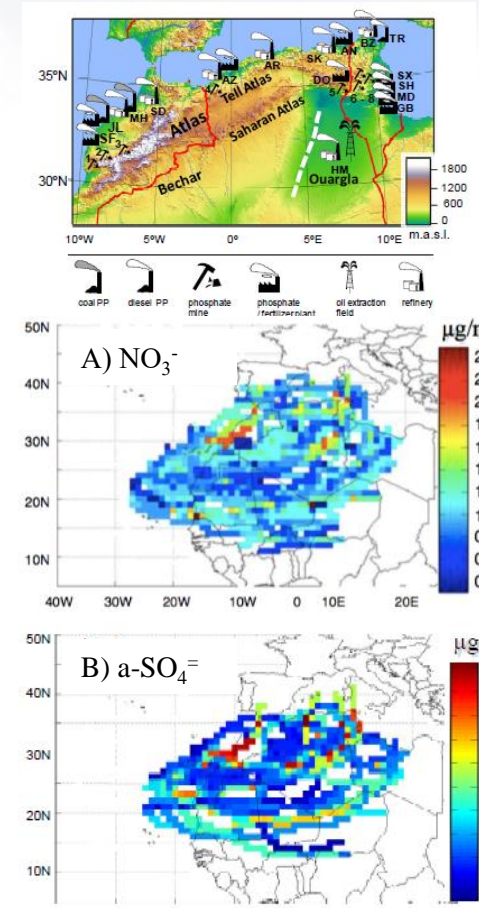
David I. Stern*

Global Environmental Change 16 (2006) 207-220

ammonium-sulfate in the Saharan Air Layer

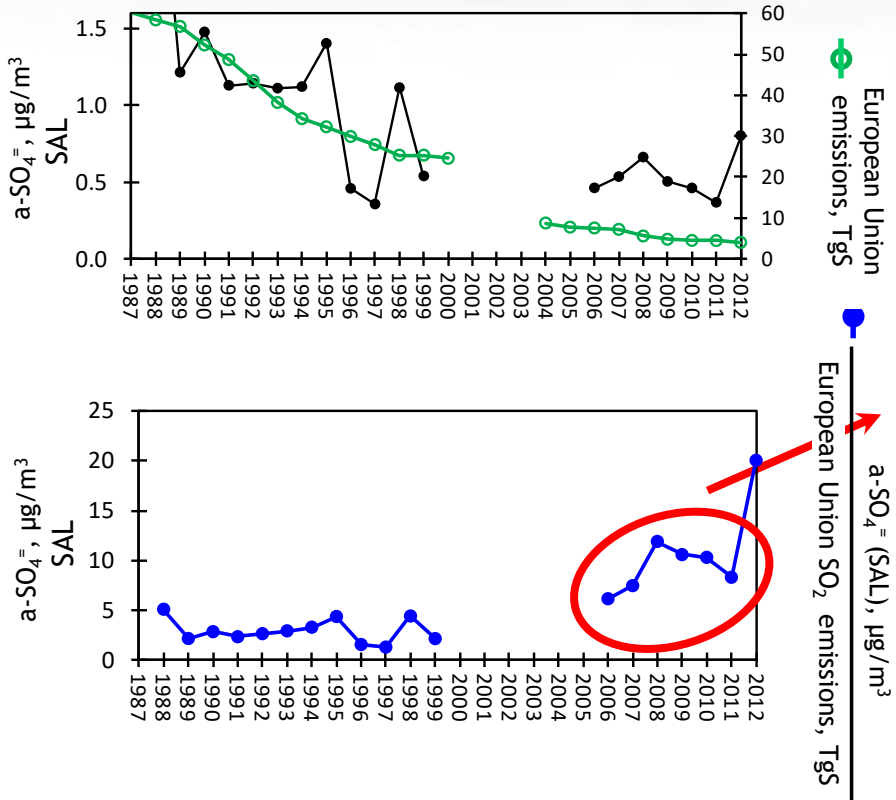


industrial emissions North Africa

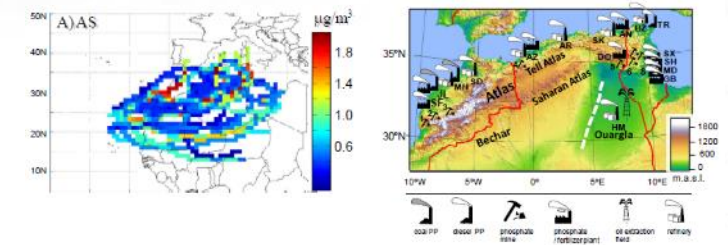


Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer
 Rodríguez et al., 2011
 Atmos. Chem. Phys., 11, 6663–6685, 2011

ammonium-sulfate in the Saharan Air Layer

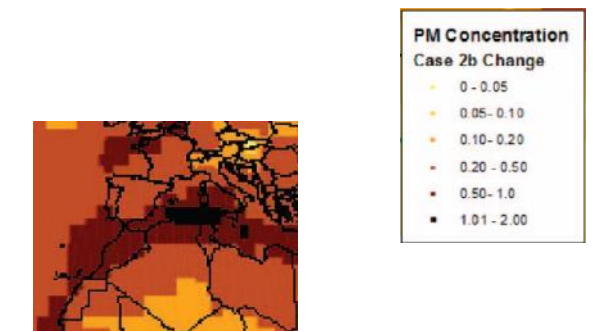


north African emissions (?)



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

ship emissions in the Mediterranean (?)

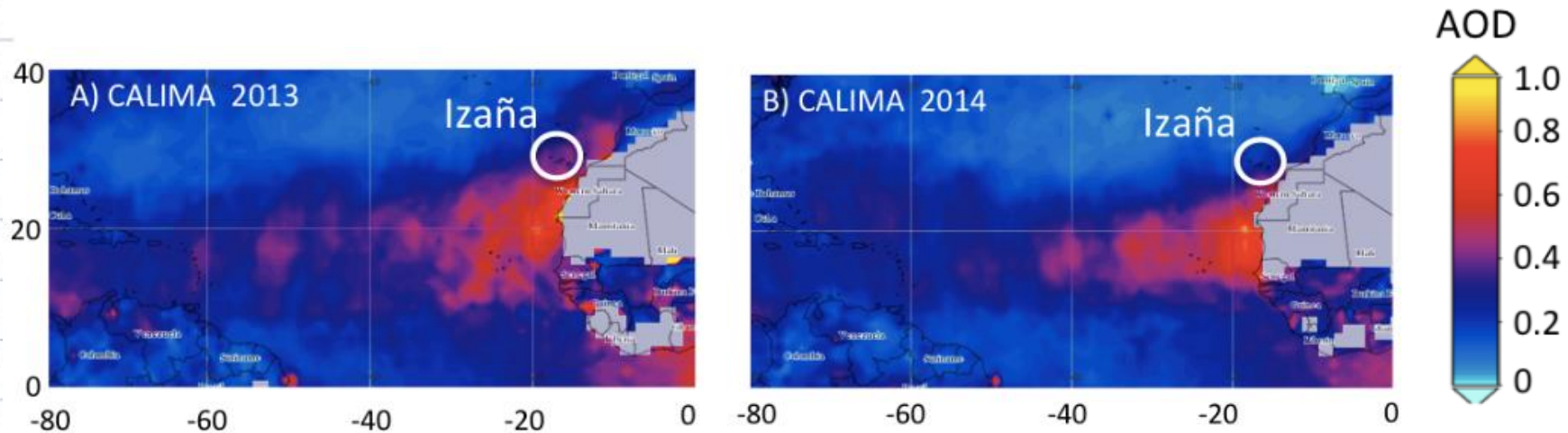


Mortality from Ship Emissions: A Global Assessment
 Environ. Sci. Technol. 2007, 41, 8512–8518
 Cobett et al., 2007

dust mixing with pollutants & implications

dust and ice nucleation

CALIMA campaigns in August 2013 and 2014



Ice nucleating particles in the Saharan Air Layer

Yvonne Boose¹, Berko Sierau¹, M. Isabel García^{2,3}, Sergio Rodríguez², Andrés Alastuey⁴,
Claudia Linke⁵, Martin Schnaiter⁵, Piotr Kupiszewski⁶, Zamin A. Kanji¹, and Ulrike Lohmann¹

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-192, 2016

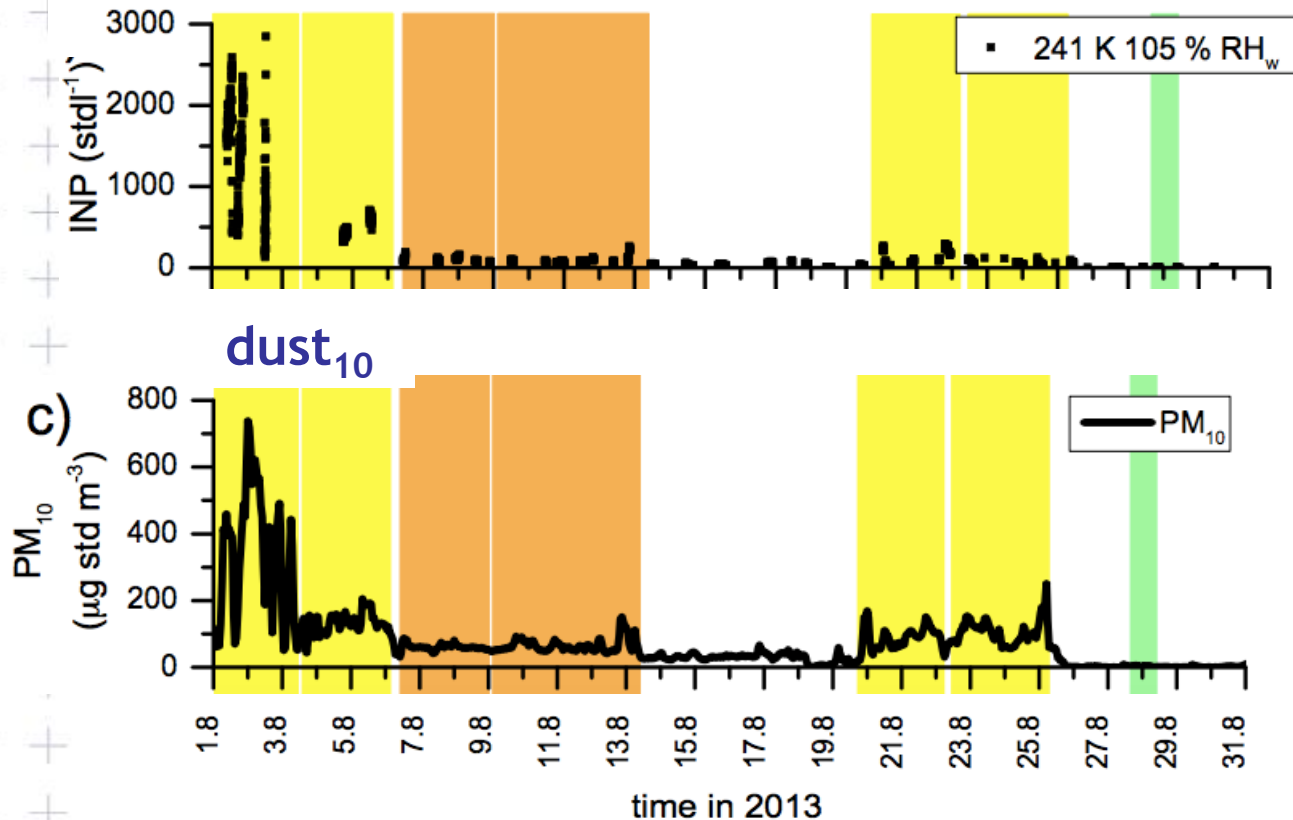
Institute for Atmospheric and Climate Science, ETH Zürich
Izaña Atmospheric Research Centre, Tenerife

Atmospheric
Chemistry
and Physics
Discussions

dust mixing with pollutants & implications

dust and ice nucleation

ice nuclei activated at -32°C



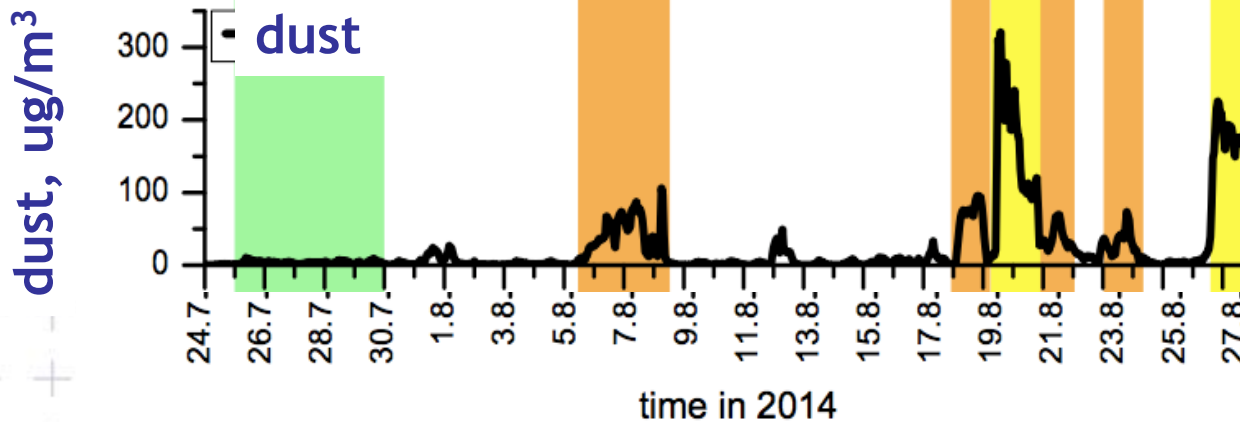
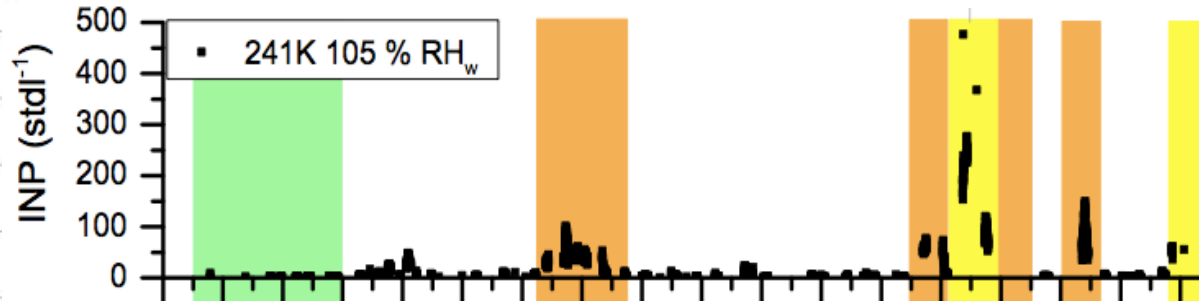
PINC measurements
Portable Ice Nucleation Chamber



dust mixing with pollutants & implications

dust and ice nucleation

ice nucleating particles at -32°C

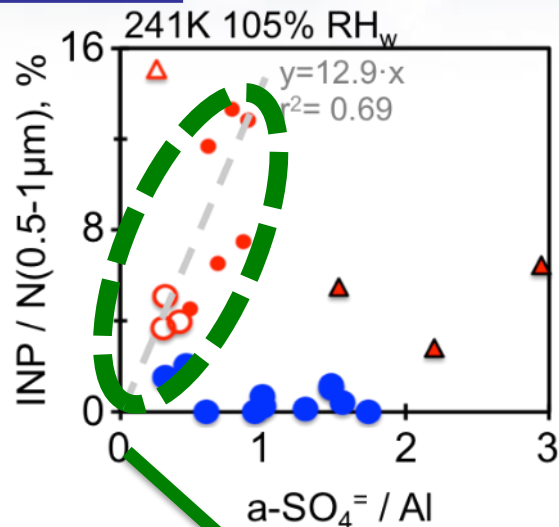
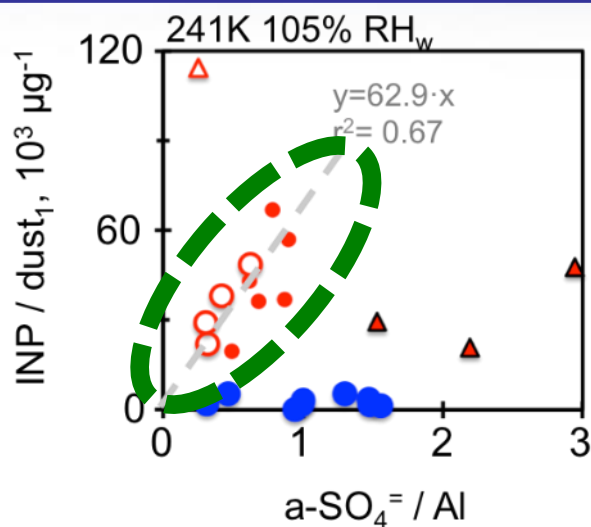


PINC measurements
Portable Ice Nucleation Chamber

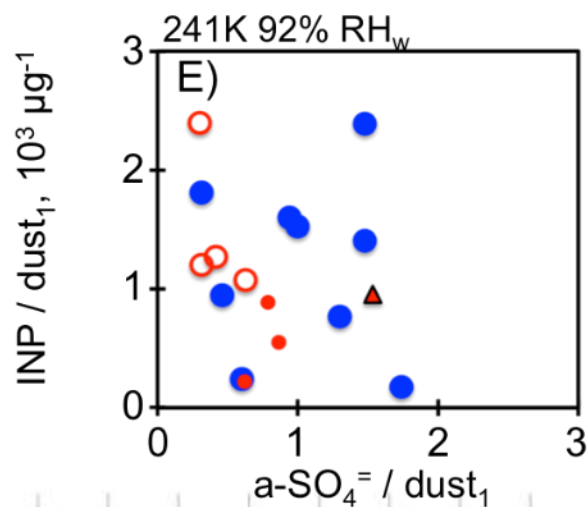


dust mixing with pollutants & implications

dust and ice nucleation



condensation freezing
Regime ice formation



deposition
regime ice
formation

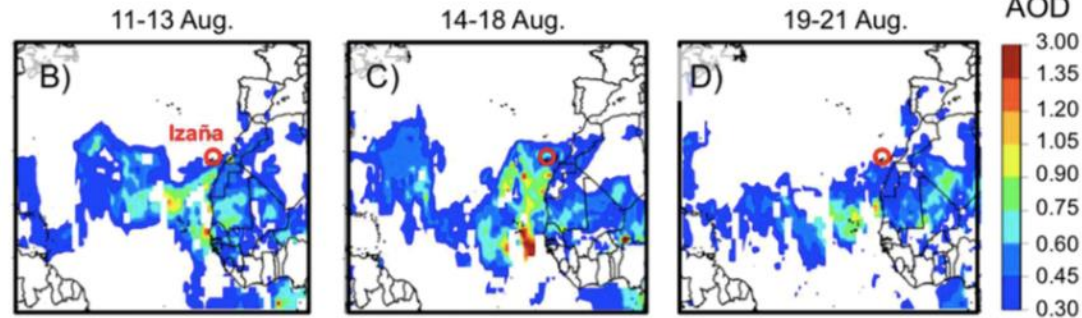
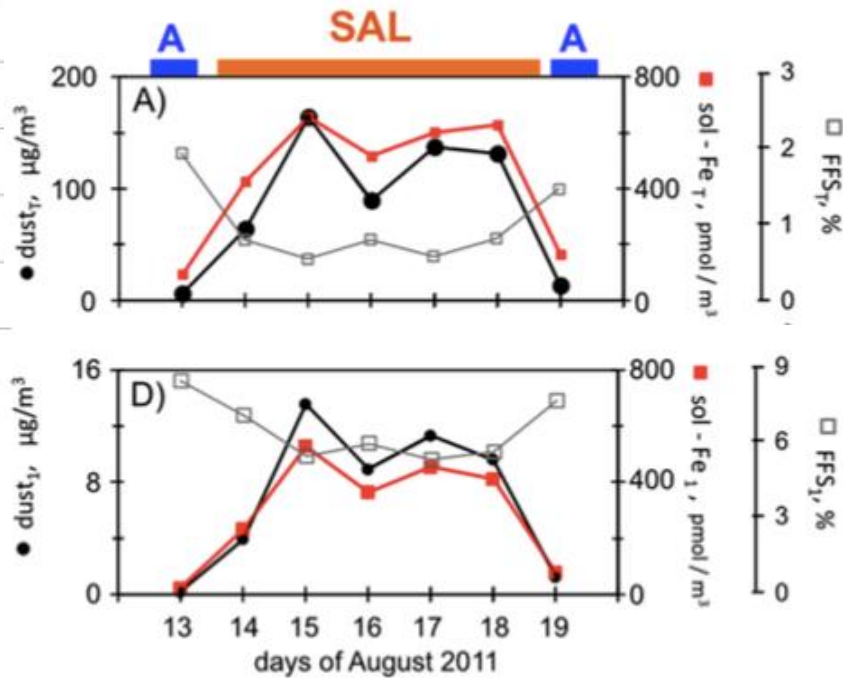
the presence of ammonium - sulphate
mixed with dust
is favouring the formation of ice crystals in
the condensation freezing regime

- SAL 2014
- SAL 2013
- Atlantic airflows

dust mixing with pollutants & implications

dust, iron and ocean fertilization

We studied iron solubility in the Saharan Air Layer



Atmospheric Environment 133 (2016) 49–59

Soluble iron dust export in the high altitude Saharan Air Layer

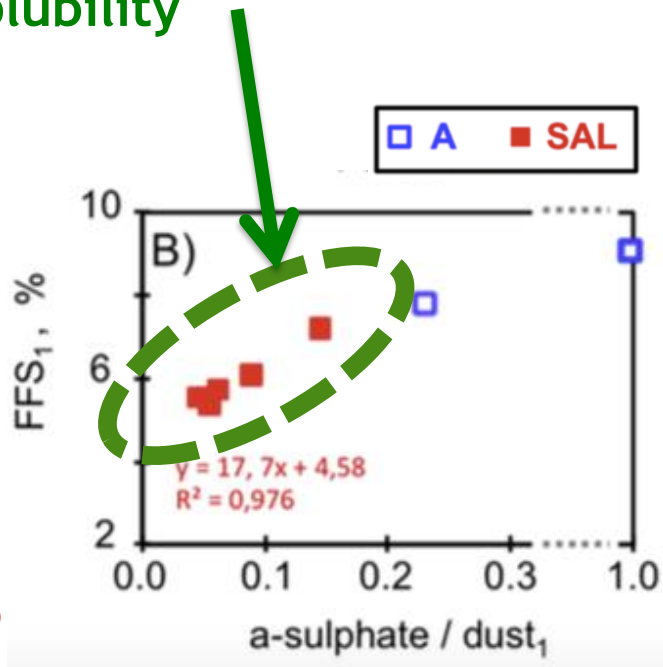
L.M. Ravelo-Pérez^a, S. Rodríguez^{b,*}, L. Galindo^c, M.I. García^{b,c}, A. Alastuey^d,
J. López-Solano^b

dust mixing with pollutants & implications

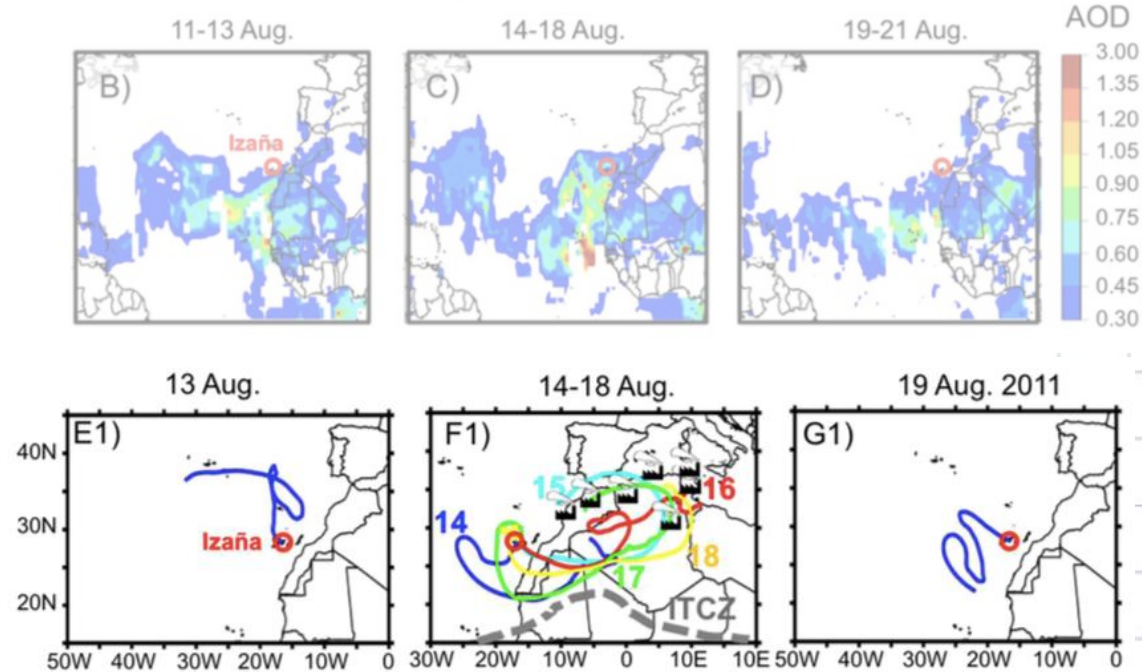
dust, iron and ocean fertilization

We studied iron solubility in the Saharan Air Layer.
We found that the presence of ammonium sulphate in the SAL is associated with a higher fractional iron solubility

Fractional Fe Solubility
Soluble-Fe to total Fe



ammonium-sulphate to dust





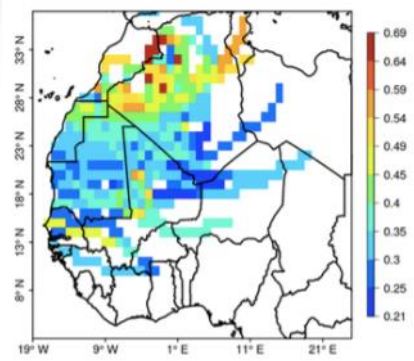
Outline

long term variability in the Saharan Air Layer.....

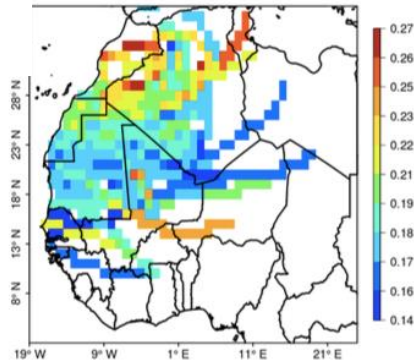
- dust
- dust mixing with pollutants
- dust composition**

Izaña samples and back-trajectories

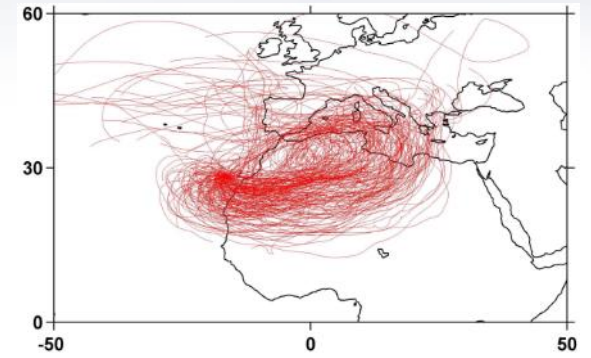
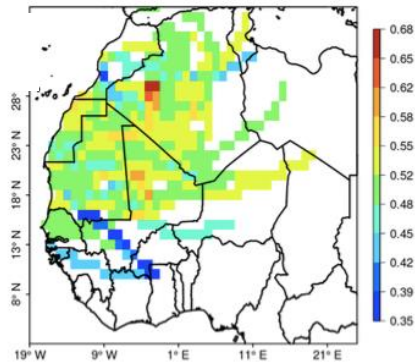
Ca / Al



Mg / Al



Fe / Al

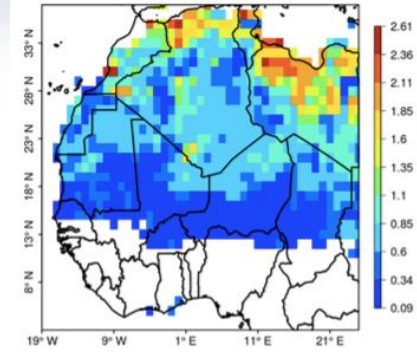
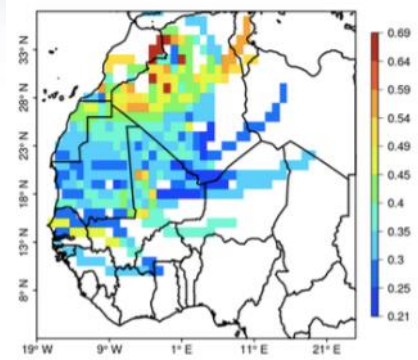


Izaña samples and back-trajectories

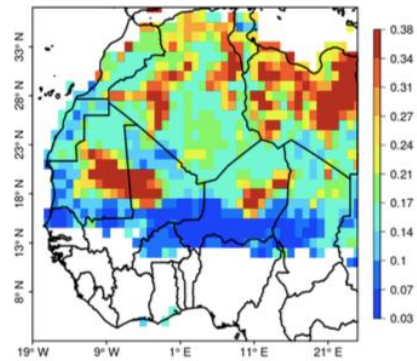
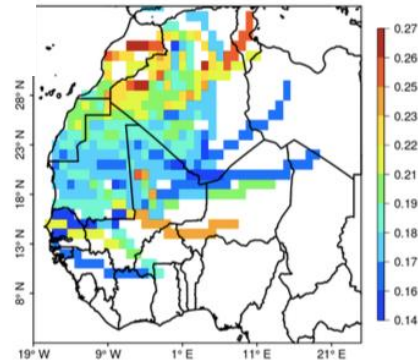
GISS emission map NASA

Perez et al., 2016. GLR, submitted

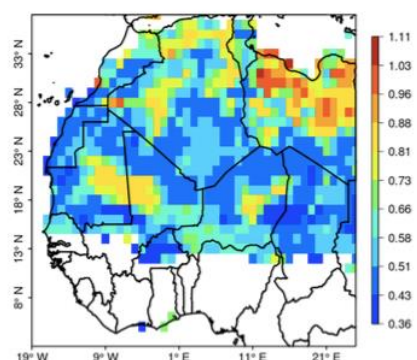
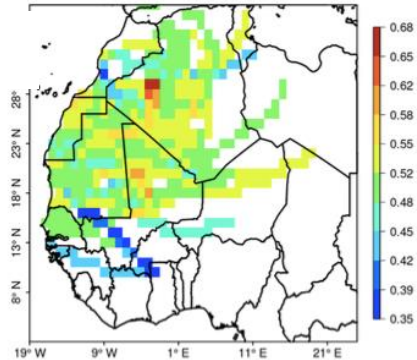
Ca / Al



Mg / Al

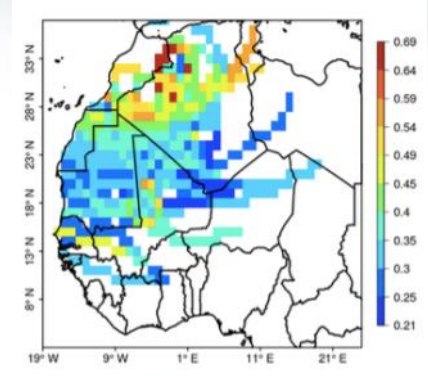


Fe / Al

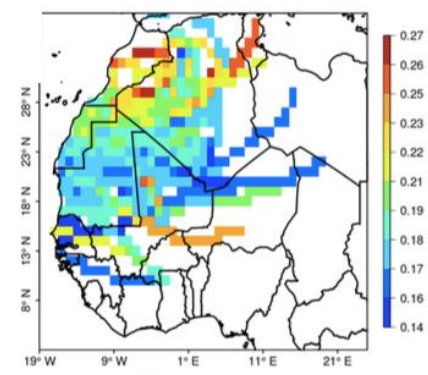


Izaña samples and back-trajectories

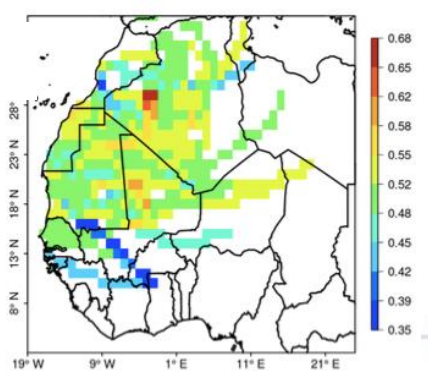
Ca / Al



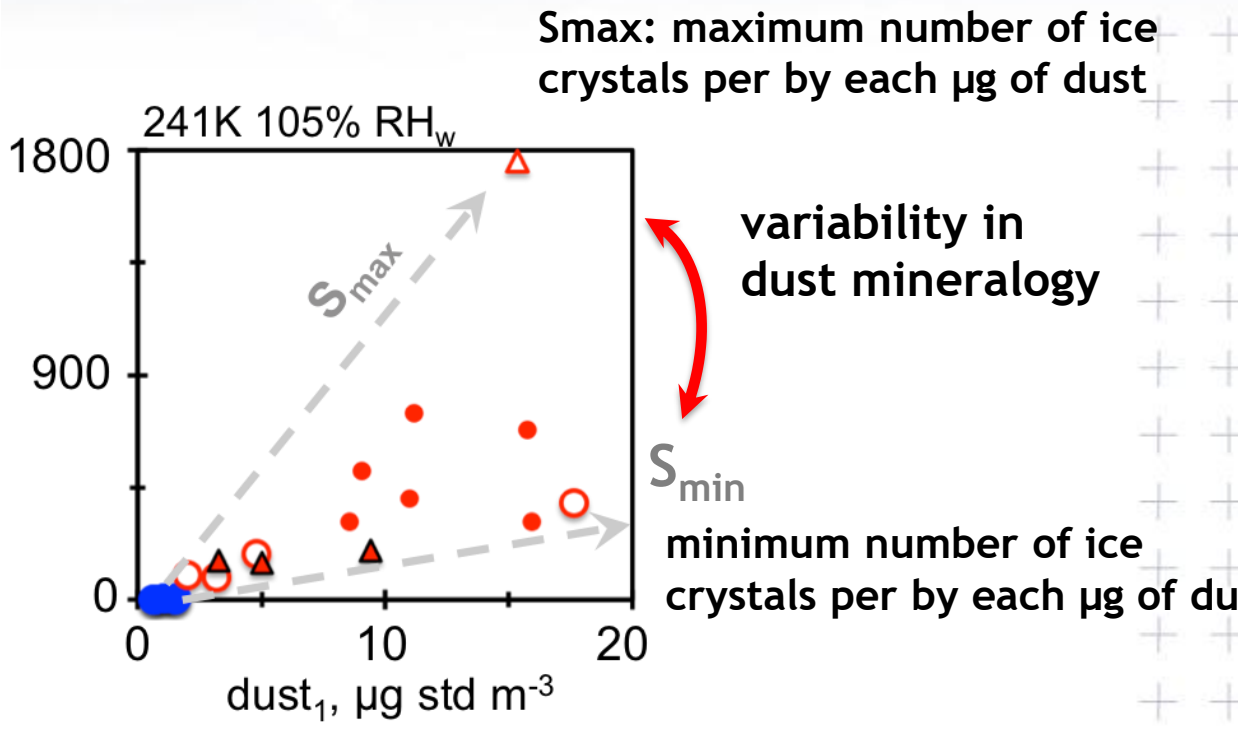
Mg / Al



Fe / Al



ice nucleating particles at -32°C





Highlights

long term variability in the Saharan Air Layer.....

-dust

- modulation of the North African Dipole Intensity - NAFDI
- amount of dust in the SAL
- north-south-ward shifts of the SAL

-dust mixing with pollutants

- some pollutants modifying climate relevant dust properties
- impact of long term pollutants emissions near Sahara

-dust composition

- improve long term observations of dust composition & mineralogy



Trans-Atlantic African Dust Transport Under El Niño 2015 Scenario

M.I. GARCIA^{1,2}, J.M. PROSPERO³, S. RODRIGUEZ², P. ZUIDEMA³,
E. SOSA², A. ALASTUEY⁴, F. LUCARELLI⁵, G. CALZOLAI⁵, J. LOPEZ-SOLANO²



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