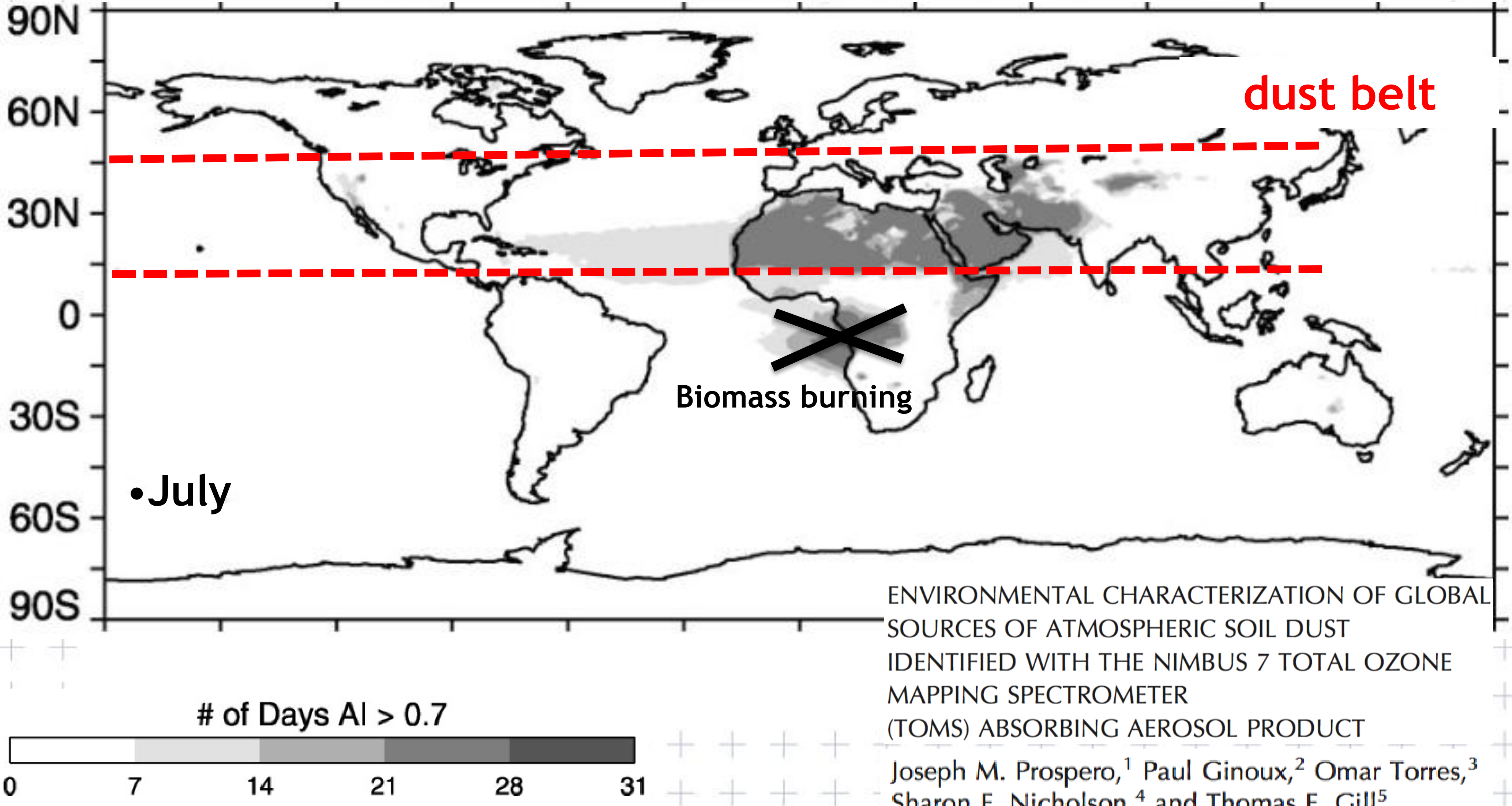
Agencia Estatal de Meteorología

Ground observation of dust

Sergio Rodríguez
srodriguezg@aemet.es
Izaña Atmospheric Research Centre, Tenerife

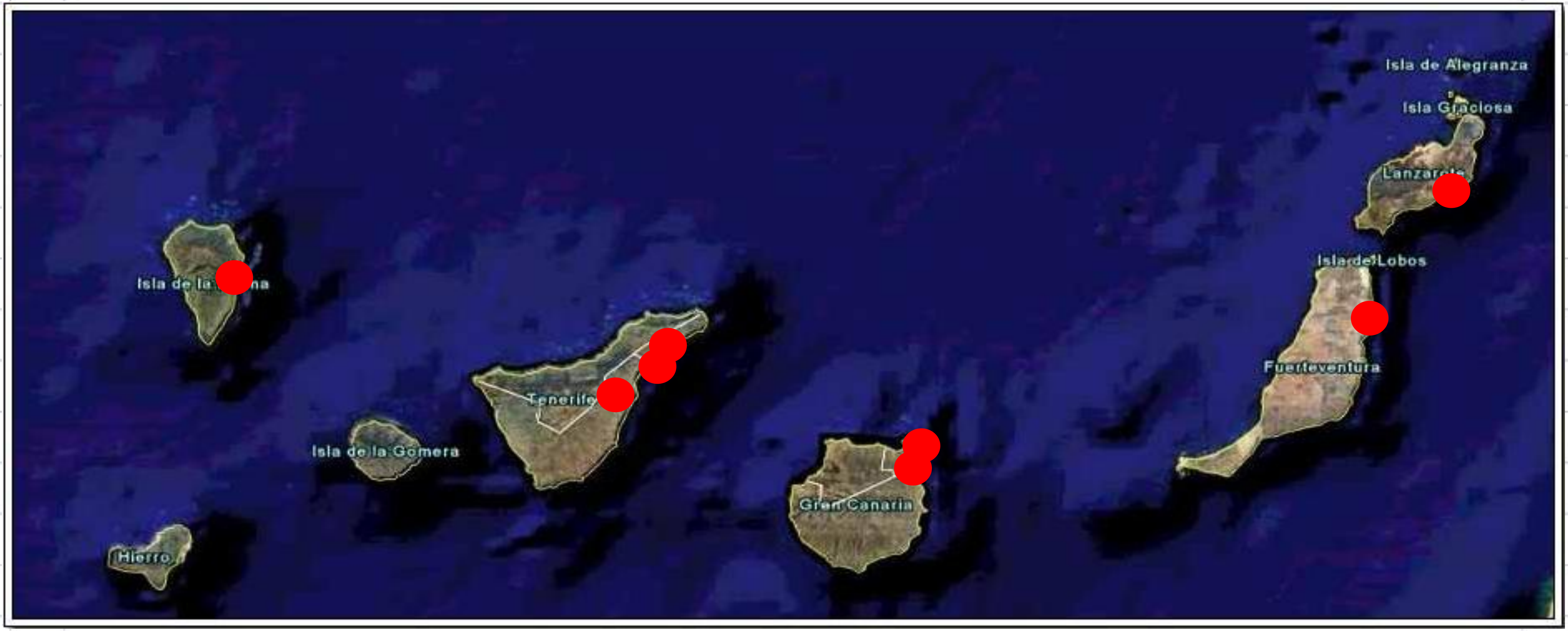


ENVIRONMENTAL CHARACTERIZATION OF GLOBAL SOURCES OF ATMOSPHERIC SOIL DUST IDENTIFIED WITH THE NIMBUS 7 TOTAL OZONE MAPPING SPECTROMETER (TOMS) ABSORBING AEROSOL PRODUCT

Joseph M. Prospero,[1] Paul Ginoux,[2] Omar Torres,[3] Sharon E. Nicholson,[4] and Thomas E. Gill[5]

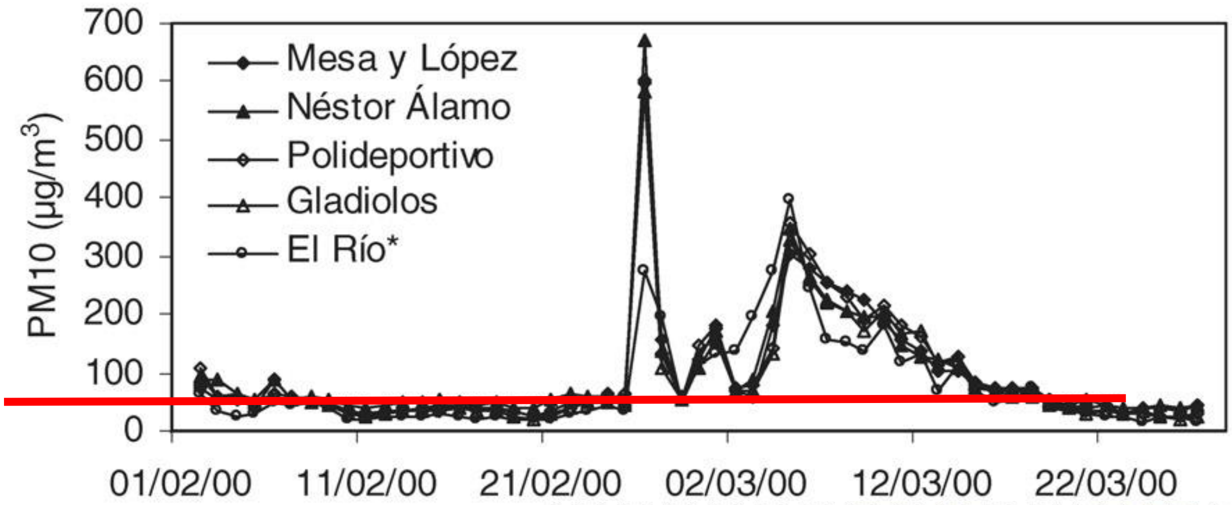
EXAMPLE, Canary Islands

Standarization of PM_{10} y $PM_{2.5}$ in a regional network

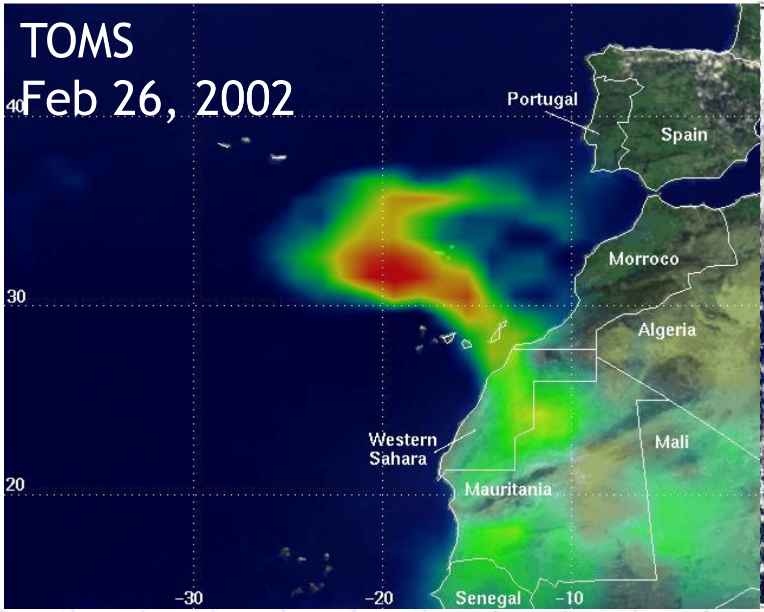


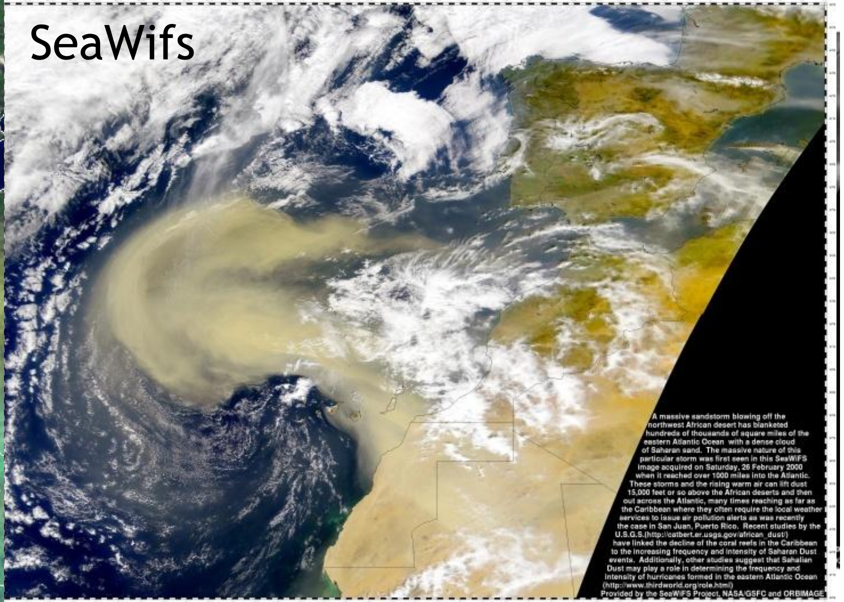
In-situ dust characterization

Air quality stations at Tenerife Island



The WHO recommend PM_{10} (24-h) do not exceed 50 µg/m³


TOMS
Feb 26, 2002


SeaWifs

A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand. The massive nature of this particular storm was first seen in this SeaWIFS image acquired on Saturday, 26 February 2000 when it reached over 1000 miles into the Atlantic. These storms and the rising warm air can lift dust 15,000 feet or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean where they often require the local weather services to issue air pollution alerts as was recently the case in San Juan, Puerto Rico. Recent studies by the U.S.G.S.(http://catbert.er.usgs.gov/african_dust/) have linked the decline of the coral reefs in the Caribbean to the increasing frequency and intensity of Saharan Dust events. Additionally, other studies suggest that Sahalian Dust may play a role in determining the frequency and intensity of hurricanes formed in the eastern Atlantic Ocean (http://www.thirdworld.org/role.html)
Provided by the SeaWIFS Project, NASA/GSFC and ORBIMAGE

Viana et al., Atmospheric Environment , 2002

Standarization of PM_{10} y $PM_{2.5}$ in a regional network

samplers of PM_{10} and $PM_{2.5}$

room of conditioning and weighting filters

1 month in summer (30 days) sampling
1 month in winter (30 days) sampling
at each station

samplers of PM_{10} and $PM_{2.5}$

AEMet
Agencia Estatal de Meteorología

ARAFO

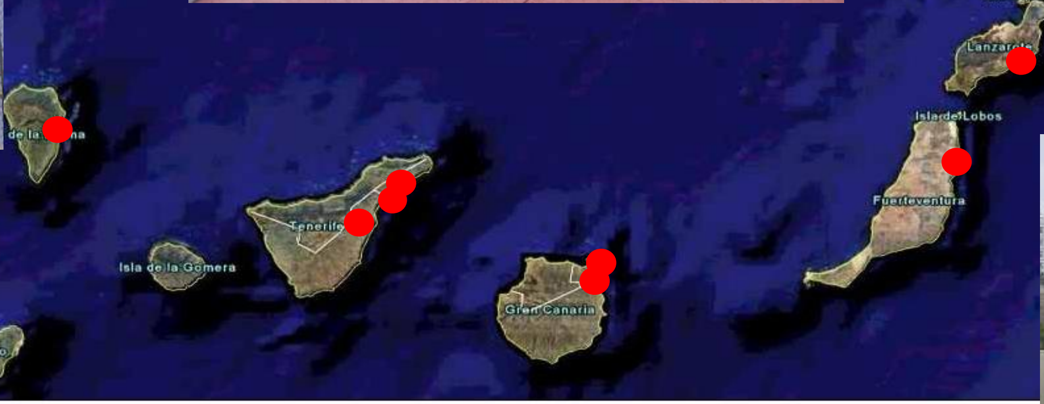
GLADIOLOS

CIUDAD DEPORTIVA

MERCADO CENTRAL

TOME CANO

TELDE

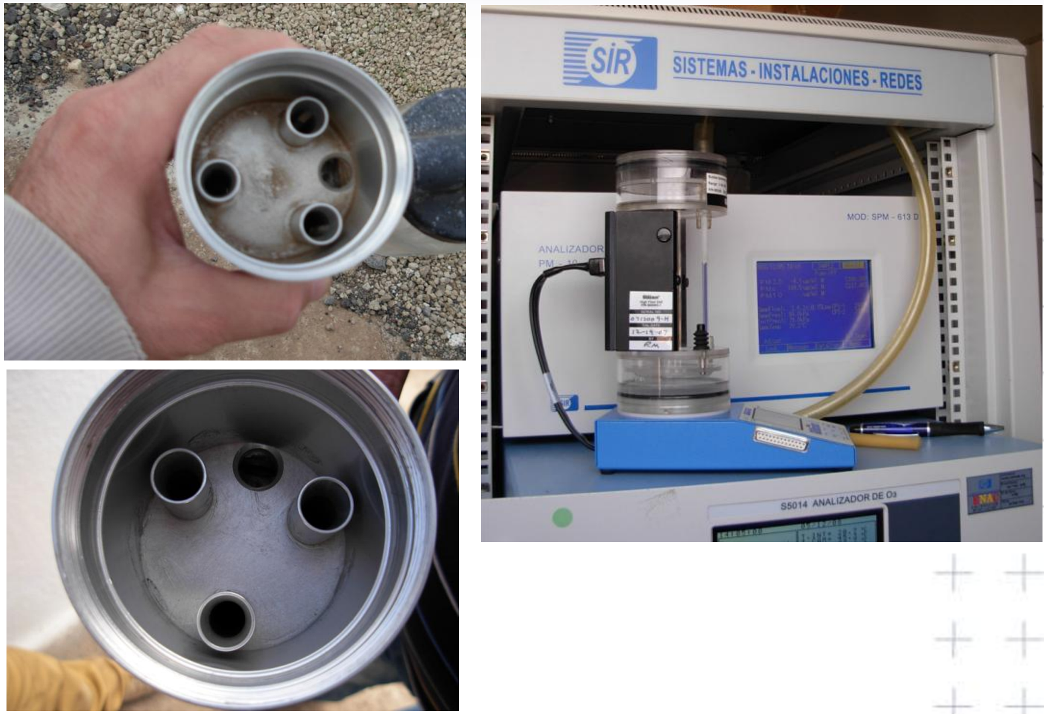


REHOYAS

QUALITY CONTROL

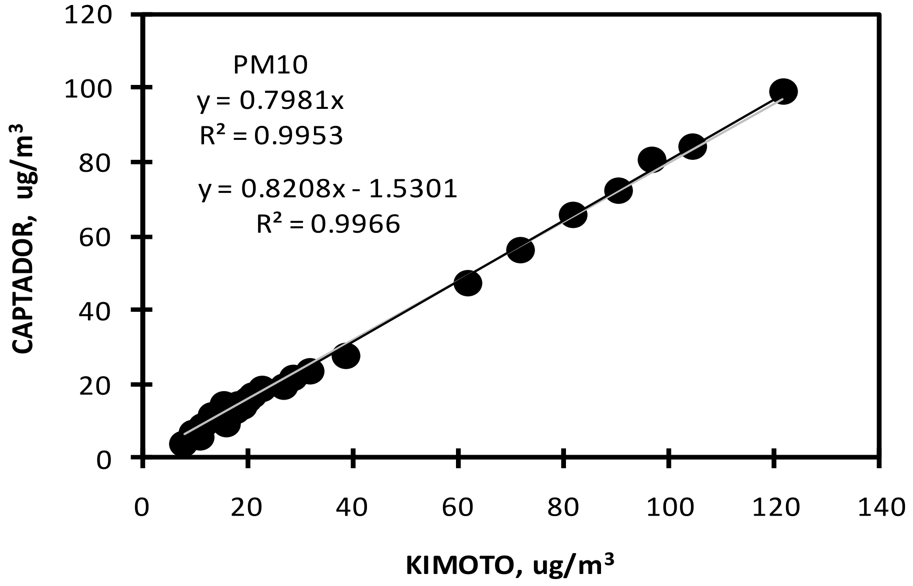
SAMPLER

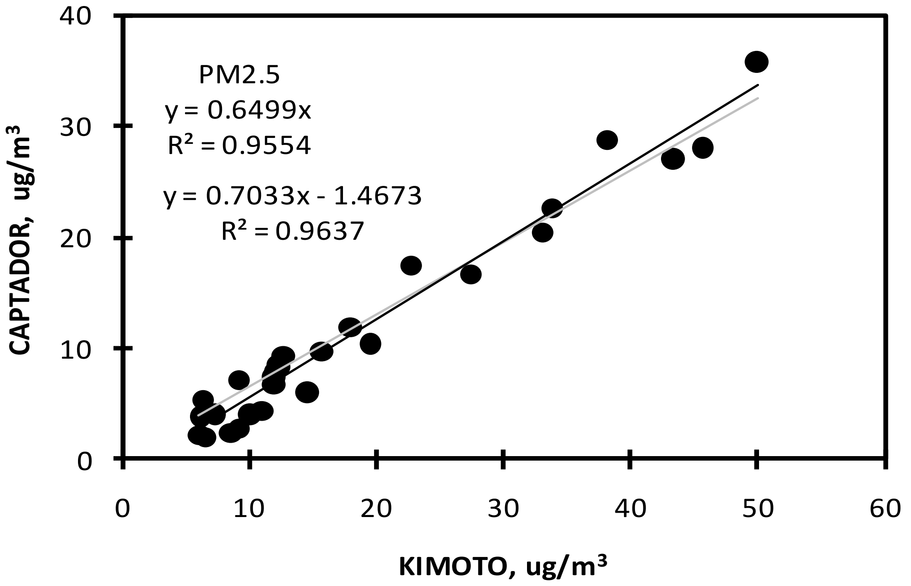
PM monitor



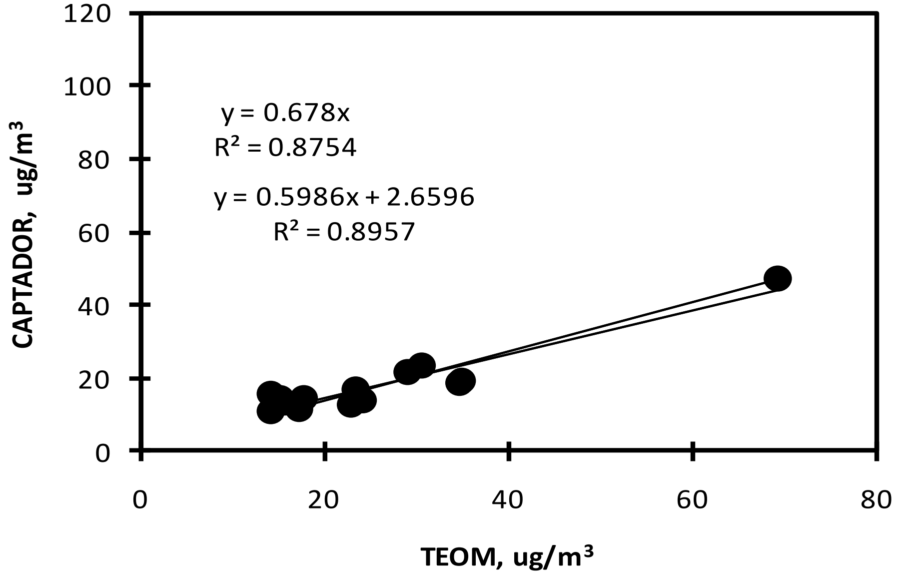
airflow accuracy
calibration of the sensor
leaks
cleaning

ARAFO

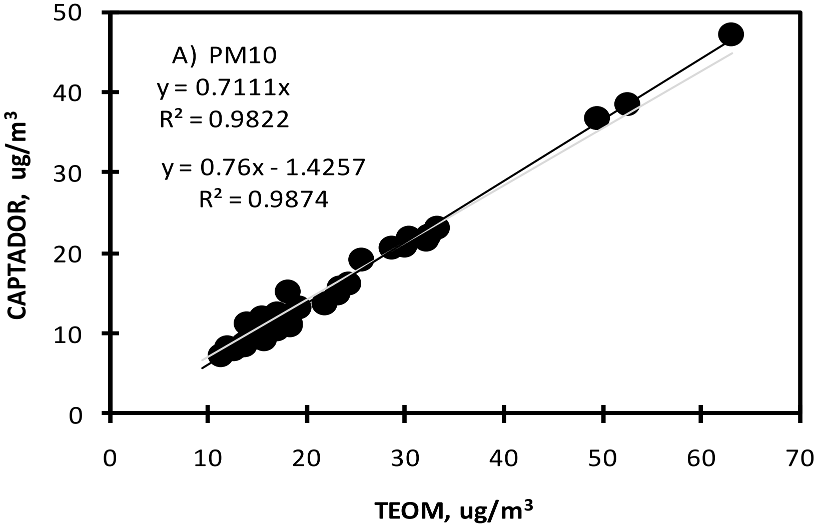


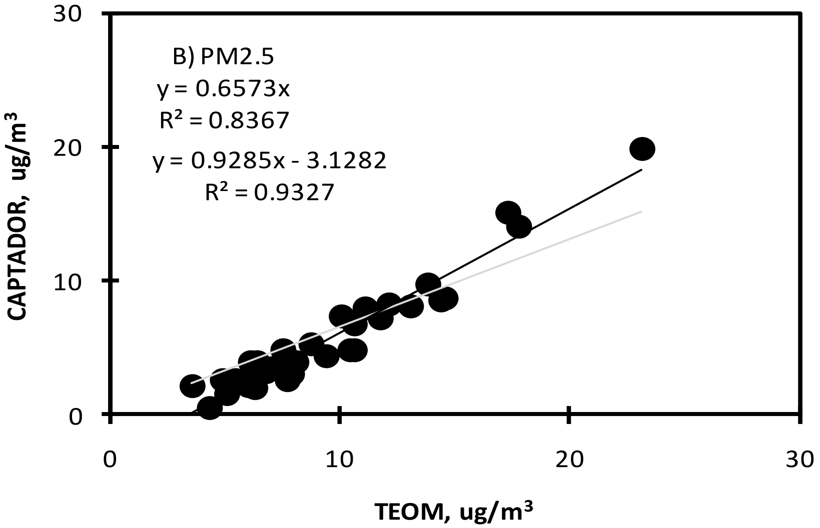


UNIDAD MOVIL



GLADIOLOS





TOME CANO

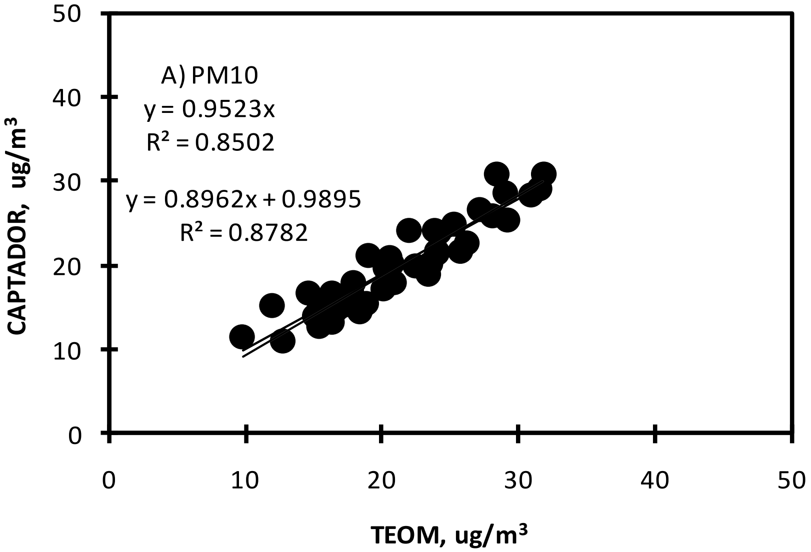


Tabla 1. Recopilación de ecuaciones obtenidas en intercomparaciones de analizadores de PM10.

Estación	Fecha	Periodo	T, ºC	P hPa	Y=a·x	R^2	¿VALIDA?	Y=a·x+b	R^2	¿VALIDA?	N
LA HIDALGA	21/02/2009 – 24/03/2009	INVIERNO	20.2	972	y=0.798x	0.995	SI	y=0.820x + (-1.530)	0.997	SI	28
LOS GLADIOLOS	27/04/2009 – 09/06/2009	PRIMAVERA	24.4	993	y=0.711x	0.982	SI	y=0.760x +(-1.425)	0.987	SI	34
TOME CANO	04/08/2009-17/09/2009	VERANO	28.7	995	y=0.952x	0.850	SI	y=0.896x +(0.989)	0.878	SI	44
MERCADO CENTRAL	17/11/2009-23/01/2010	INVIERNO	25.1	1015	y=1.275x	0.961	SI	y=1.191x +(2.928)	0.969	SI	49
MERCADO CENTRAL	09/01/2001-28/12/2001	ANUAL	24.8		y=1.285x	0.872	SI	y=1.142x +(7.151)	0.893	SI	88
PARQUE REHOYAS	05/03/2010-21/04/2010	INVIERNO	22.5	1003.8	y=1.032x	0.875	SI	y=1.062x +(-0.561)	0.876	SI	37
LOS GLADIOLOS	24/05/2010-07/06/2010	PRIMAVERA	25.8	1004.3	y=0.778x	0.931	SI	y=0.896x +(-3.8461)	0.951	SI	39
TOME CANO	14/04/2010-29/05/2010	PRIMAVERA	22.2	1007.6	y=0.773x	0.871	SI	y=0.747x +(0.615)	0.872	SI	47
LA HIDALGA	11/06/2010-29/07/2010	VERANO	23.8	985.1	y=0.702x	0.757	NO problemas mantenimiento	y=0.612x +(2.893)	0.776	NO problemas mantenimiento	39
MERCADO CENTRAL	23/06/2010-01/08/2010	VERANO	26.7	1014.7	y=1.172x	0.901	SI	y=1.240x +(-1.694)	0.911	SI	35
PARQUE REHOYAS	20/09/2010-17/10/2010	VERANO	27.0	1000.7	y= 1.017x	0.839	SI	y=1.125X +(-3.067)	0.849	SI	61
CIUDAD DEP. ARRECIFE	26/08/2010-08/10/2010	VERANO	25.2	1010.9	y=1.085x	0.922	SI	y=1.042X +(0.832)	0.923	SI	34

Tabla 2. Recopilación de ecuaciones obtenidas en intercomparaciones de analizadores de PM2.5. N: número de muestras válidas usadas.

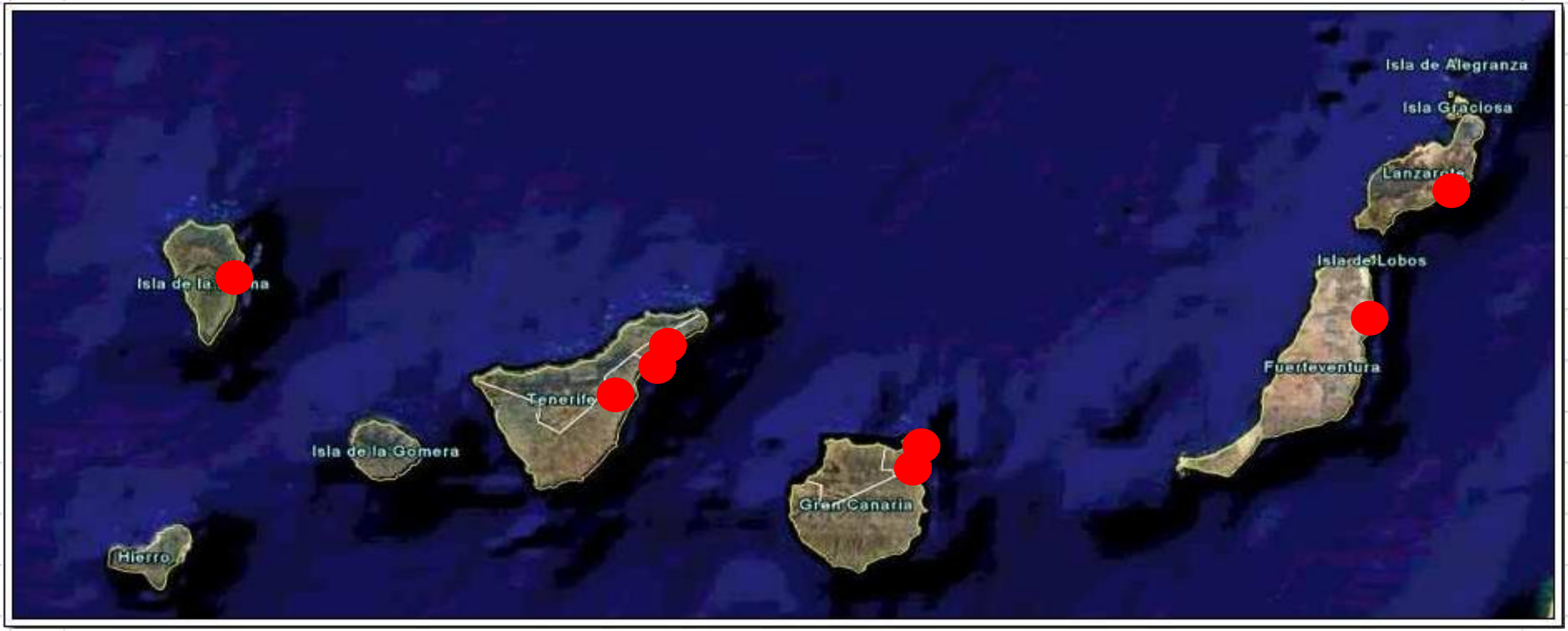
Estación	Fecha	Periodo	T, °C	P hPa	Y=a·x	R^2	¿VALIDO?	Y=a·x+(b)	R^2	¿VALIDO?	N
LA HIDALGA	21/02/2009 – 24/03/2009	INVIERNO	20.2	972	y=0.650x	0.9554	SI	y=0.7033x + (–1.4673)	0.9637	SI	28
LOS GLADIOLOS	27/04/2009 – 09/06/2009	PRIMAVERA	24.4	993	y=0.657x	0.8367	SI	y=0.9285x +(-3.1282)	0.9285	SI	33
MERCADO CENTRAL	17/11/2009-23/01/2010	INVIERNO	25.1	1015	y=0.865x	0.8707	SI	y= 0.7552 +(1.519)	0.8939	SI	45
PARQUE REHOYAS	05/03/2010-21/04/2010	INVIERNO	22.5	1003.8	y=0.768x	0.582	NO, Conc < 10µg/m^3	y=0.908x +(-1.0521)	0.597	NO Conc < 10µg/m^3	37
LOS GLADIOLOS	24/05/2010-07/06/2010	VERANO	25.8	1004.3	y=0.684x	0.686	NO, Conc < 10µg/m^3	y=0.941x +(-2.462)	0.745	NO, Conc < 10µg/m^3	39
LA HIDALGA	11/06/2010-29/07/2010	VERANO	23.8	985.1	y=0.474x	0.680	NO evalua, Conc < 10µg/m^3	y=0.559x +(-1.254)	0.699	NO evalua, Conc < 10µg/m^3	39
MERCADO CENTRAL	23/06/2010-01/08/2010	VERANO	26.7	1014.7	y= 0.825	0.858	SI	y=0.7494 x + 0.912	0.868	SI	35
PARQUE REHOYAS	20/09/2010-17/10/2010	VERANO	27.0	1000.7	y= 0.797x	0.489	NO evalua, Conc < 10µg/m^3	y=1.192X +(-3.243)	0.553	NO evalua, Conc < 10µg/m^3	61
CIUDAD DEP. ARRECIFE	26/08/2010-08/10/2010	VERANO	25.2	1010.9	y=0.650x	0.627	NO evalua, Conc < 10µg/m^3	y=0.558X +(0.564)	0.635	NO evalua, Conc < 10µg/m^3	34

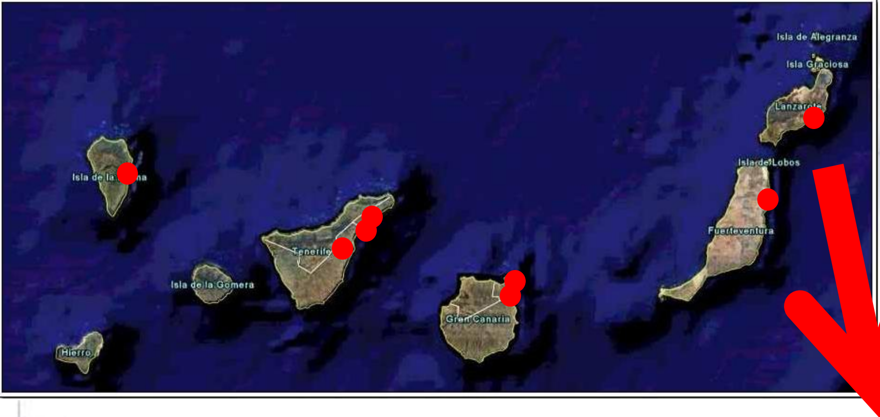
Y=ax+b
$r^2 \geq 0.8$

$$\longrightarrow$$

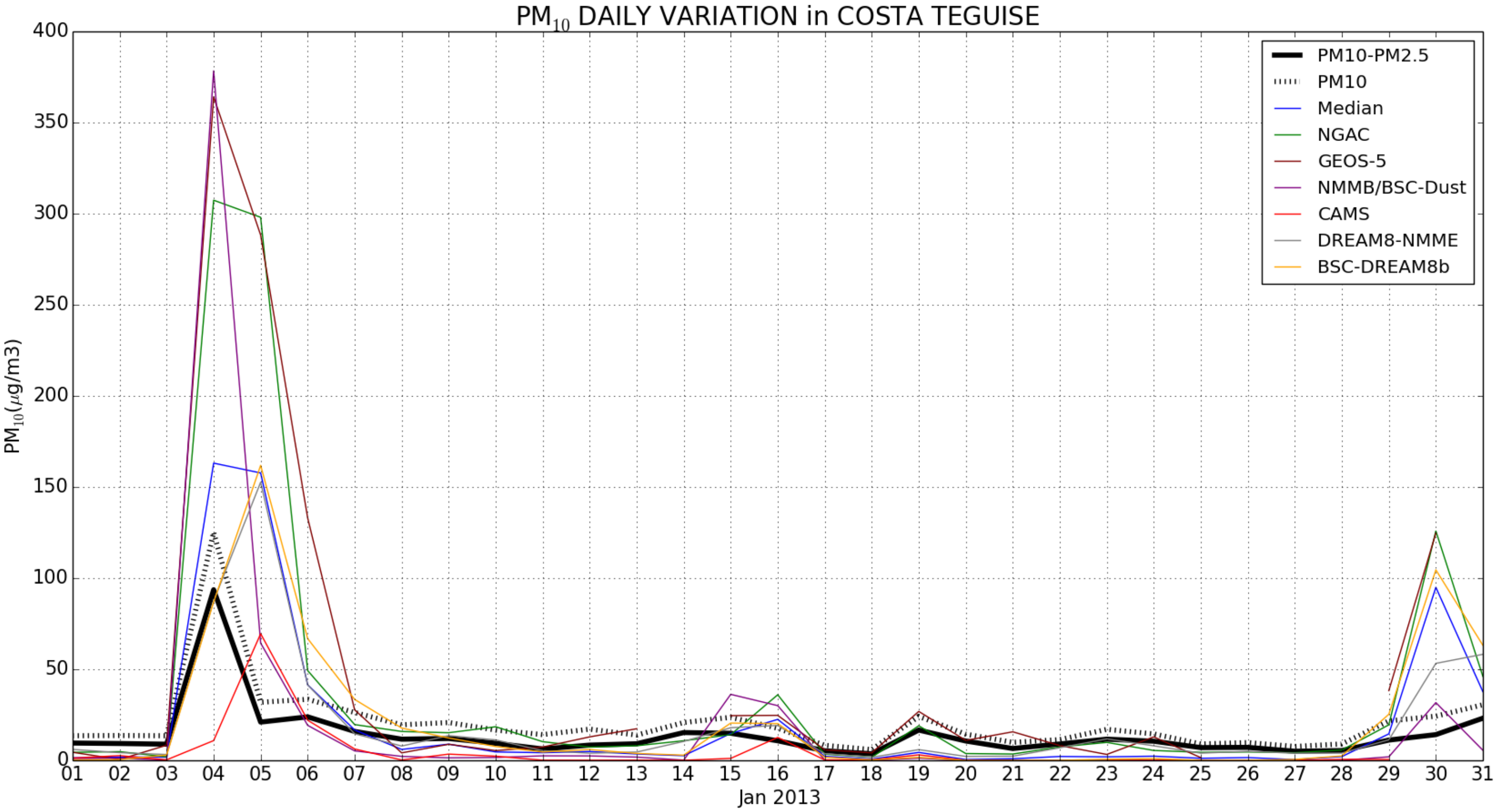
PM_{10} (grav.equiv)=a·PM_{10} (automatic)+b

Standardized PM_{10} y $PM_{2.5}$ levels in the network

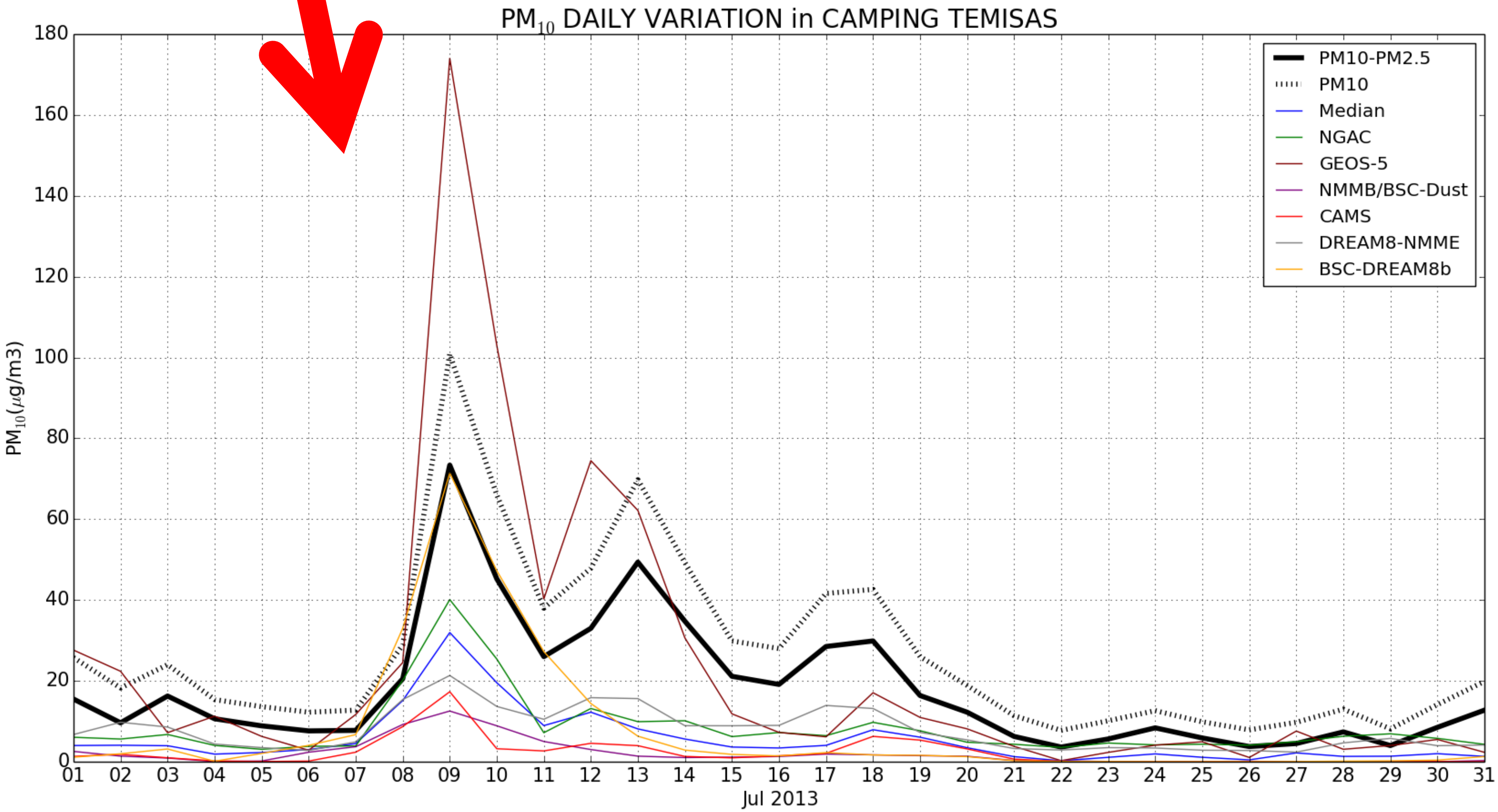




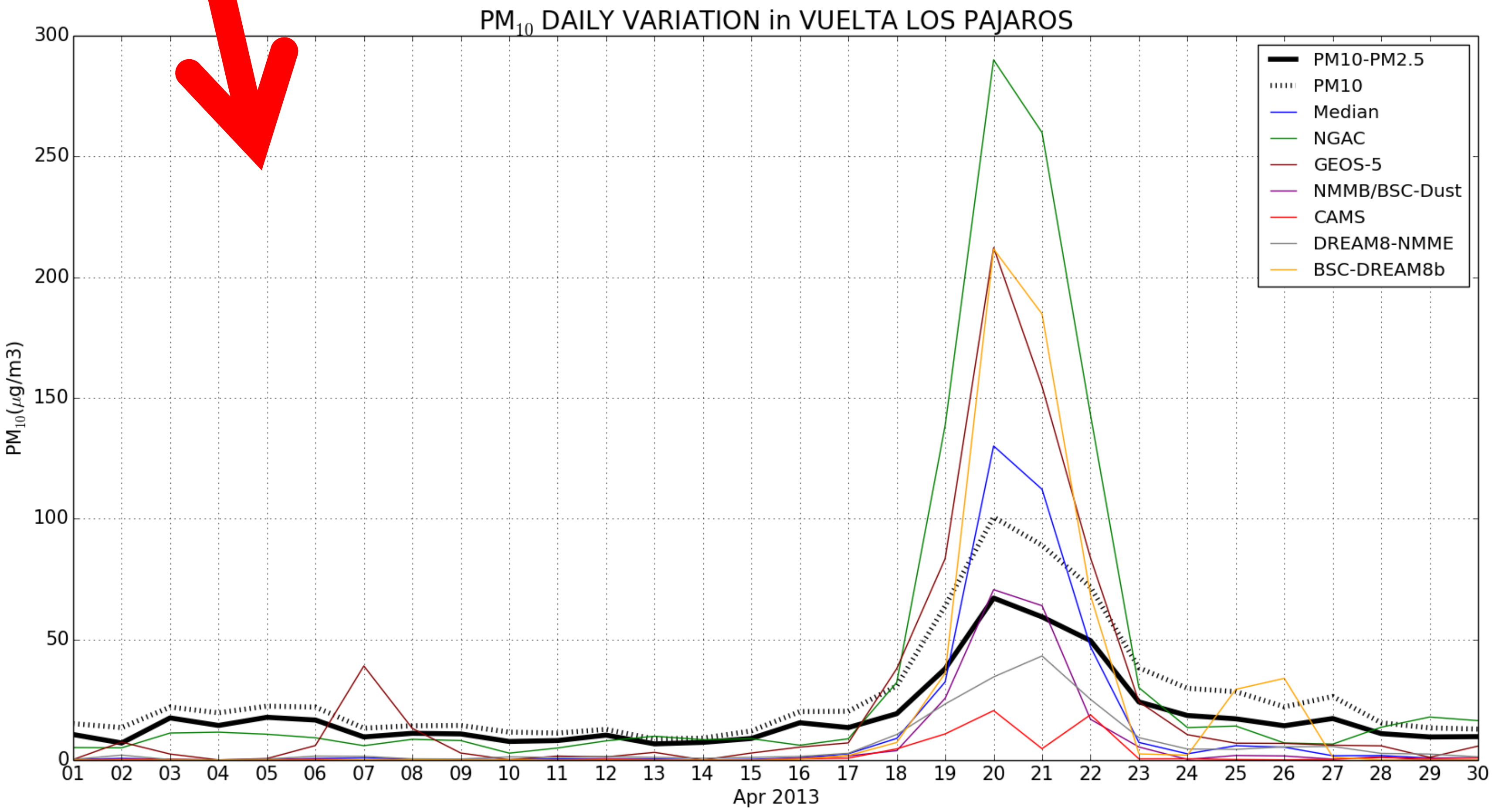
Model validation with standardized PM_{10} y $PM_{2.5}$ data in the network

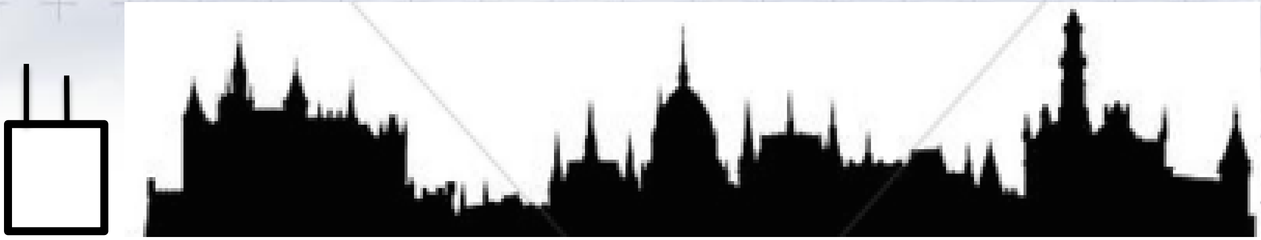


Model validation with standardized PM_{10} y $PM_{2.5}$ data in the network



Model validation with standardized PM_{10} y $PM_{2.5}$ data in the network





dust air quality

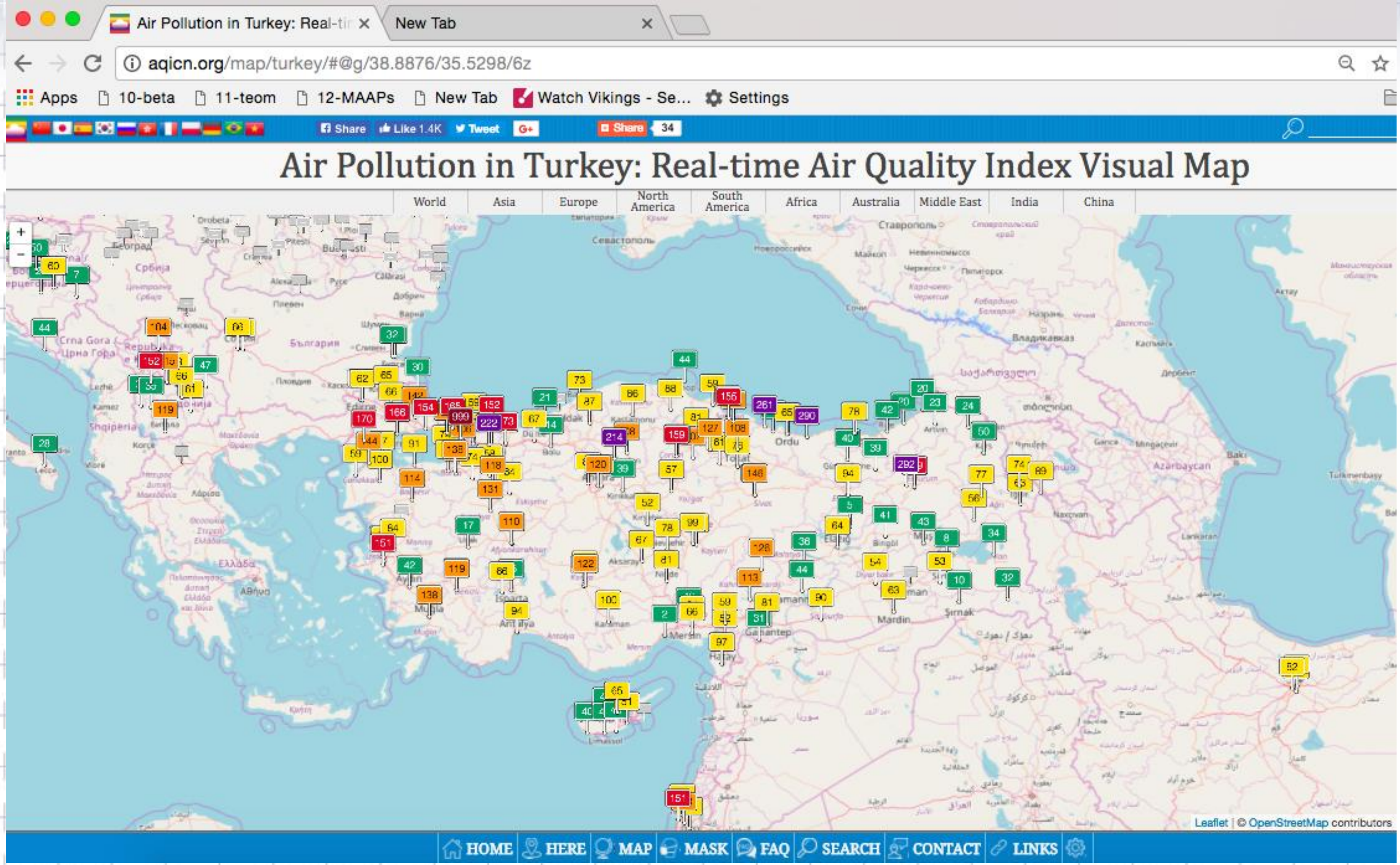
1. PM$_{10}$ and PM$_{2.5}$ levels

-method-01: reference - manual gravimetry

-method-02: automatic

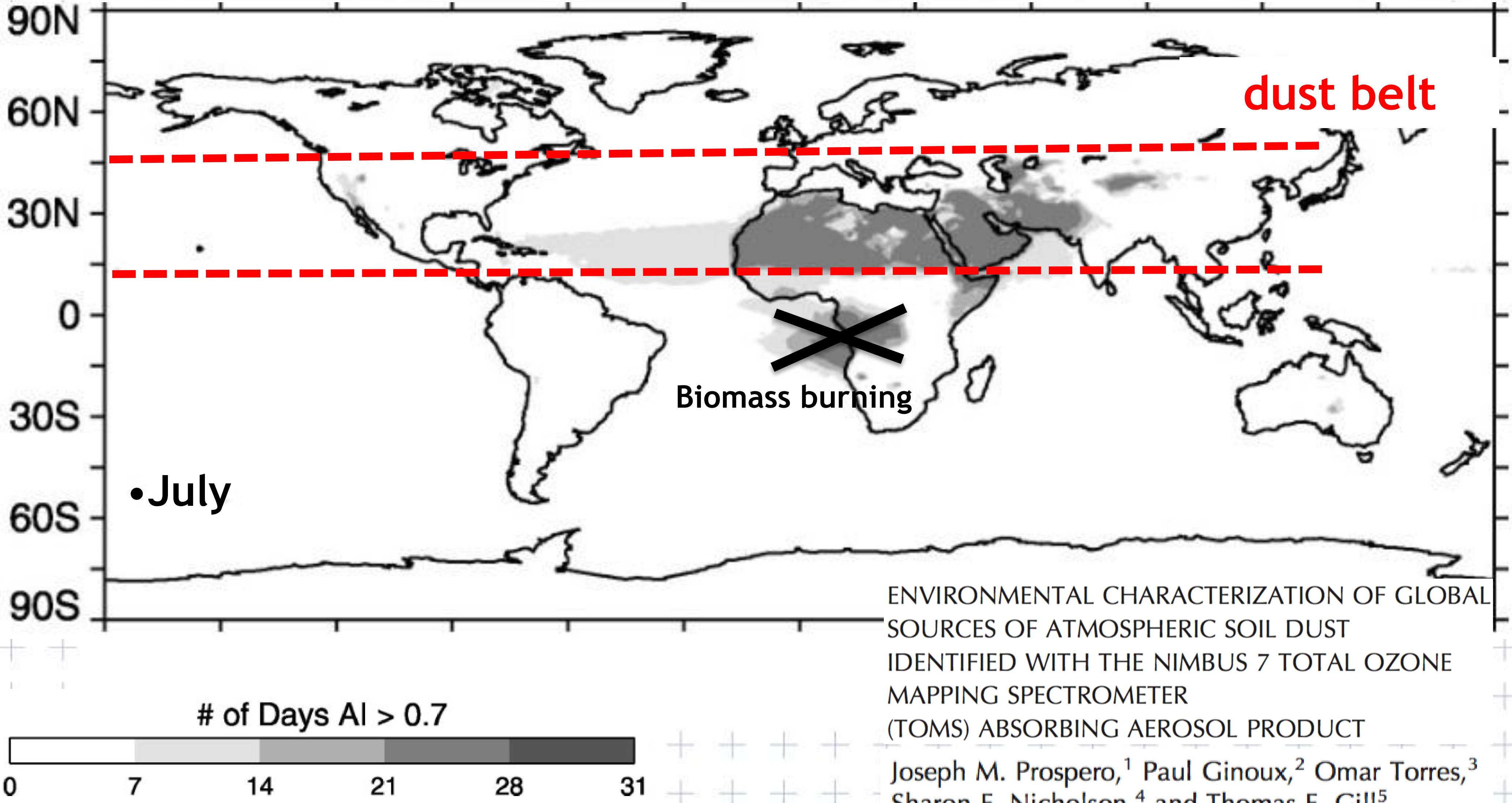
	Manual gravimetry	automatic
advantage:	reference method	high time resolution, 1h
disadvantage:	poor time resolution, 24-h average manual work takes 3 days to know PM$_{10}$	Needs validation

we recommend to use the two methods:
-automatic, continuously
-gravimetric: intercomparisons - 1 month summer, 1 month winter



aqicn.org/map/turkey/#@g/38.8876/35.5298/6z

Air Pollution in Turkey: Real-time Air Quality Index Visual Map



dust belt

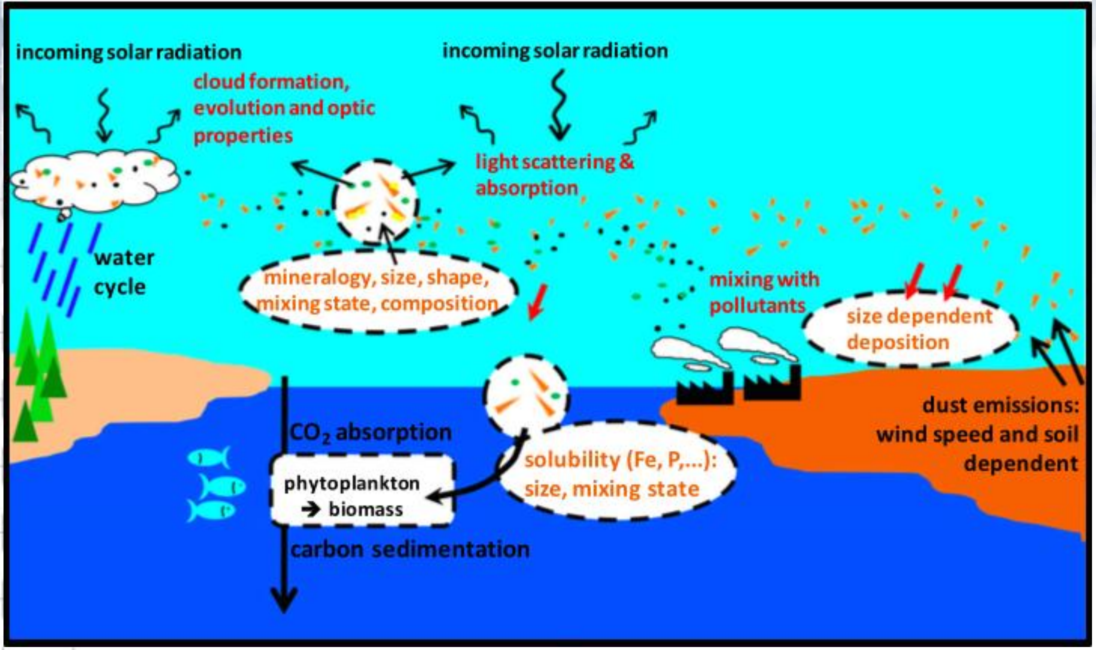
Biomass burning

- July

ENVIRONMENTAL CHARACTERIZATION OF GLOBAL SOURCES OF ATMOSPHERIC SOIL DUST IDENTIFIED WITH THE NIMBUS 7 TOTAL OZONE MAPPING SPECTROMETER (TOMS) ABSORBING AEROSOL PRODUCT

Joseph M. Prospero,[1] Paul Ginoux,[2] Omar Torres,[3] Sharon E. Nicholson,[4] and Thomas E. Gill[5]

Dust and climate



Rodríguez et al., 2012

Ground based observations of:

Mineralogy
Composition
Mixing with pollutants
Size distribution
Key properties

in-situ techniques

Radiative Forcing:

- aerosol dust- radiation interaction

  light scattering and absorption

  negative forcing

- aerosol dust- cloud interaction

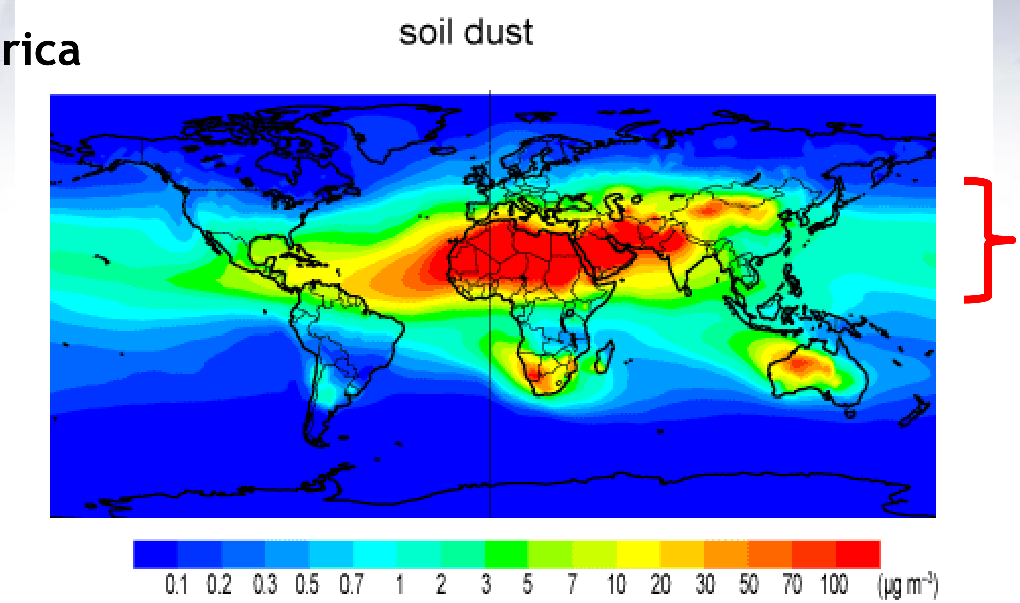
  droplets and ice clouds formation
  clouds optical properties

  negative forcing
  magnitude (?)

Dust deposition:

-fertilization (P and Fe) of the ocean
implications on CO_2 budget

Air Quality
Europe & North America



} dust belt

Air Quality
‘cities in the dust belt’

dust and health

Outline

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

-dust
-dust mixing with pollutants
-dust composition

Ground based observation of:

Mineralogy
Composition
Mixing with pollutants
Size distribution
Key properties

in-situ techniques

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

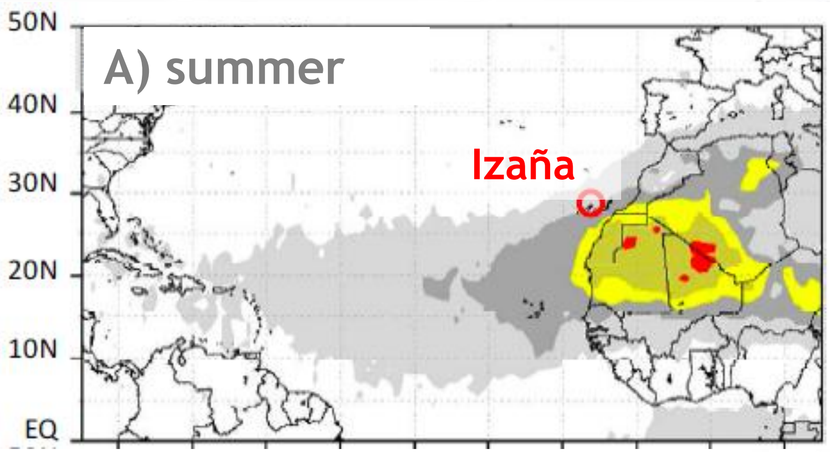
-dusty Saharan Air Layer

-<u>summer</u>:

- -activation of subtropical Saharan sources
- -max dust emissions

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

Aerosol Index



Aerosol Index

dust

Izaña: 30 years aerosol observations
1987 - 2016

aerosol chemistry	1987
aerosol physic	
number concentration	2006
size distribution 10nm - 20 µm	2008
scattering total- and back- 3 λ	2008
absorption 1 λ	2007
aethalometer 7 λ	2012

view from Izaña:


regular dust-free conditions


summer Saharan Air Layer

-above the marine stratocumulus
-night-time free troposphere

sample collection on filter

PM_{10} and $PM_{2.5}$

Gravimetry, 20°C 30-35% HR

Elements: Al, Fe, Ca, Mg, Na, Mn, Ti, ...→ dust

Salts: $SO_4^{=}$, NO_3^{-}, NH_4^{+}, and Cl^{-}

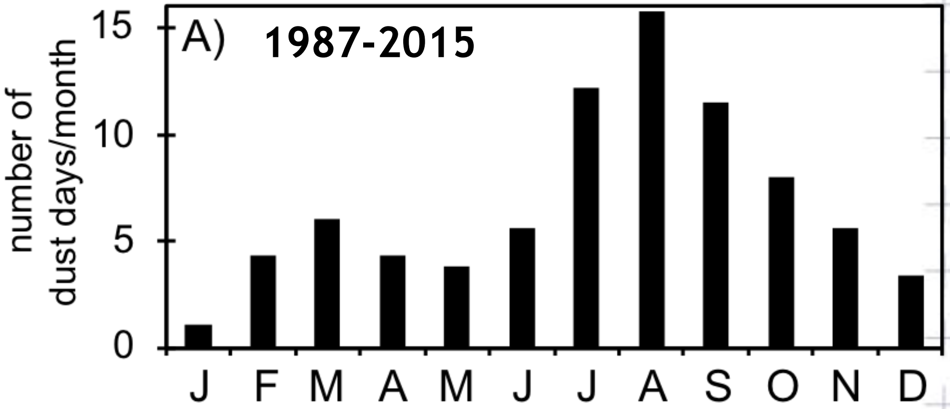
OC, EC

Lab chemical analysis

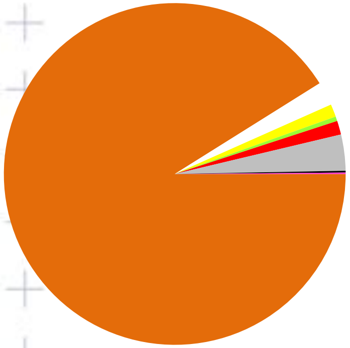
IPC-AES, -MS
HPLC
TOT

Quartz filters

Summer Izaña is within the SAL

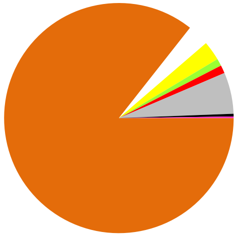


PM$_x$ composition in the Saharan Air Layer



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

Quartz filters

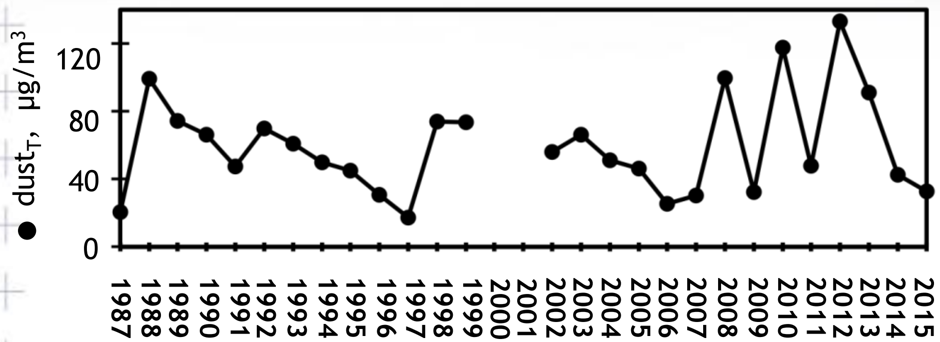
dust = $Al_2O_3 + SiO_2 + CaCO_3 + \ldots.$

Outline

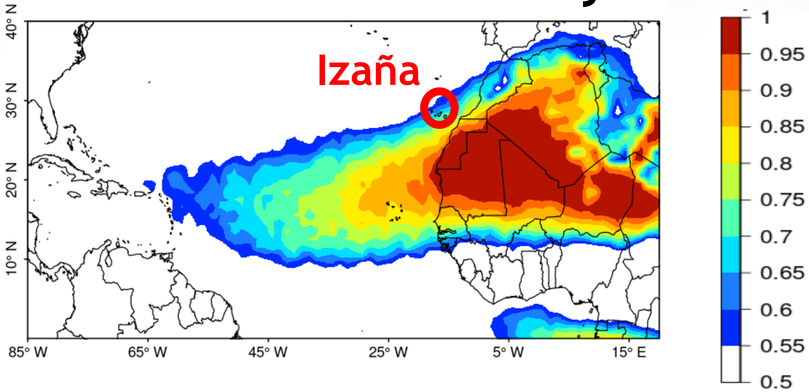
long term variability in the Saharan Air Layer.....

-dust
-dust mixing with pollutants
-dust composition

summer dust at Izaña: 1987 - 2015



Saharan Air Layer



Max: 133 µg/m³ 2012

Min: 17 µg/m³ 1997

MDFA: Major Dust Frequency Activity

UV Absorbing Aerosol Index = sensitive to iron oxides in dust

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

= 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:

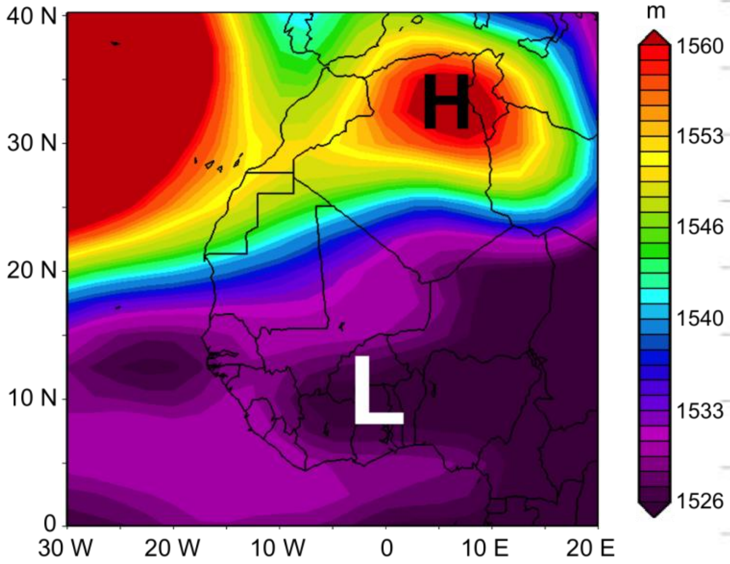
- -Subtropical high pressures, ≈35°N
- -Harmattan (≈trade) winds 25-30 °N
- -ITCZ, 20°N
- -Saharan heat low, 19°N
- -Tropical low monsoon, 7-12°N
  - rain band, 5-12°N
  - Inflow, 5-20°N

H

L

North African Dipole

850hPa geop
1987-2014



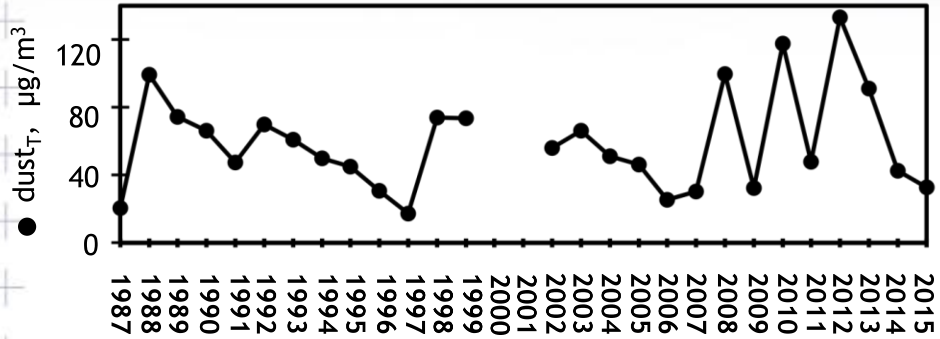
Atmos. Chem. Phys., 15, 7471–7486, 2015

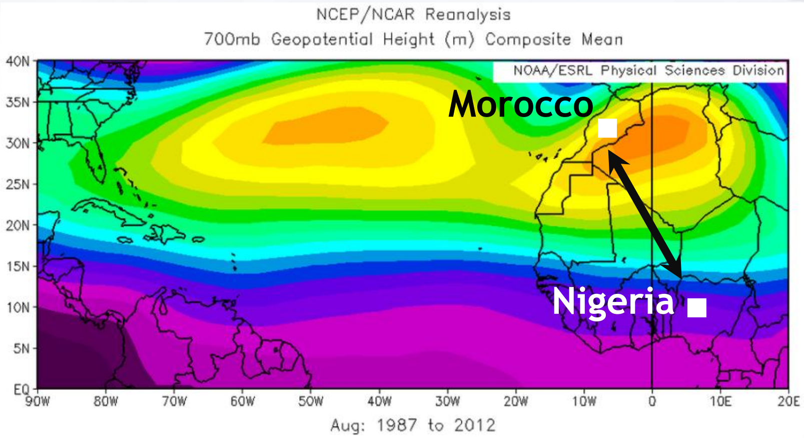
Modulation of Saharan dust export by the North African dipole

S. 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]

Atmospheric Chemistry and Physics

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



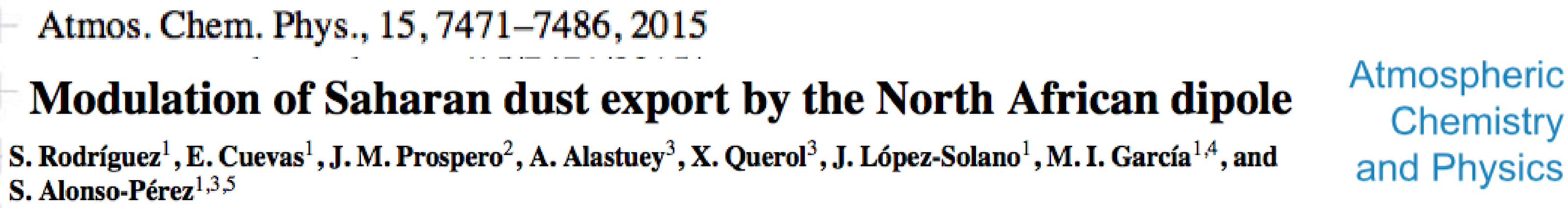

NCEP/NCAR Reanalysis
700mb Geopotential Height (m) Composite Mean

Aug: 1987 to 2012

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

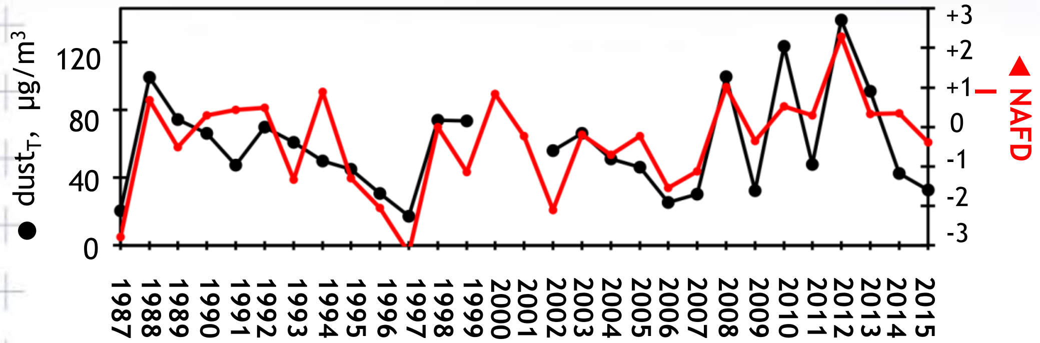

Atmos. Chem. Phys., 15, 7471–7486, 2015

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]

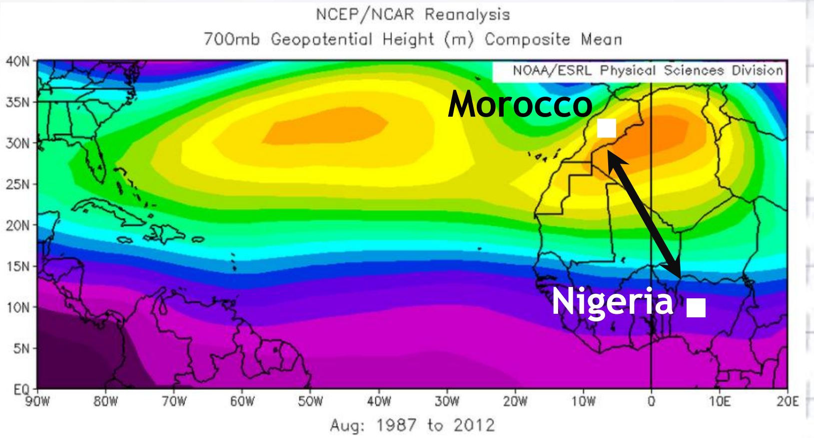
Atmospheric Chemistry and Physics

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



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

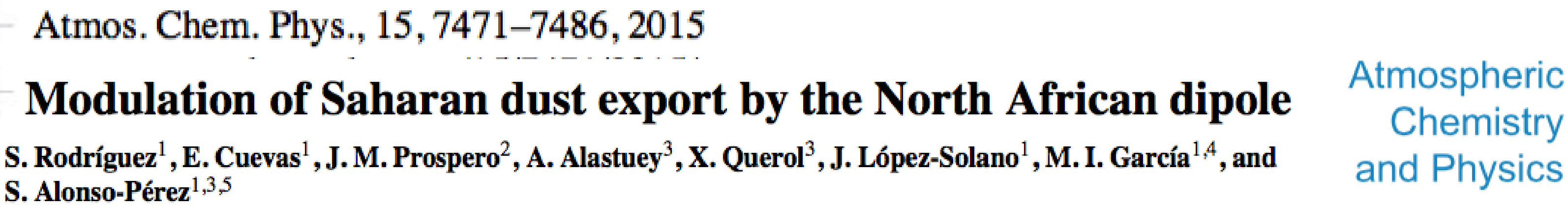
Variability in dust export is associated with variability in NAFDI



North AFrican Dipole Intensity

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

700 hPa: relevant level for dust export



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

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]

Atmospheric Chemistry and Physics

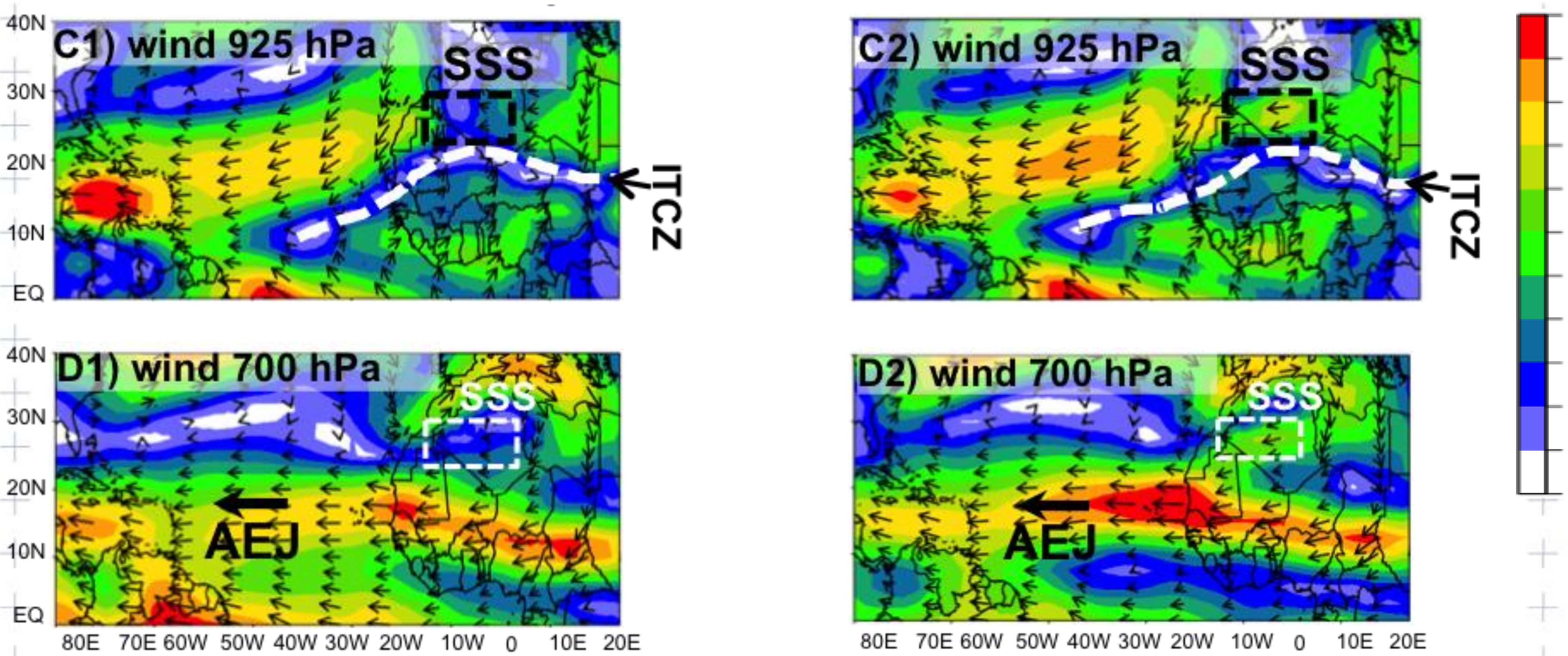
Saharan dust export, connection to…
large scale meteorology in North Africa

Low NAFDI summers

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

High NAFDI summers

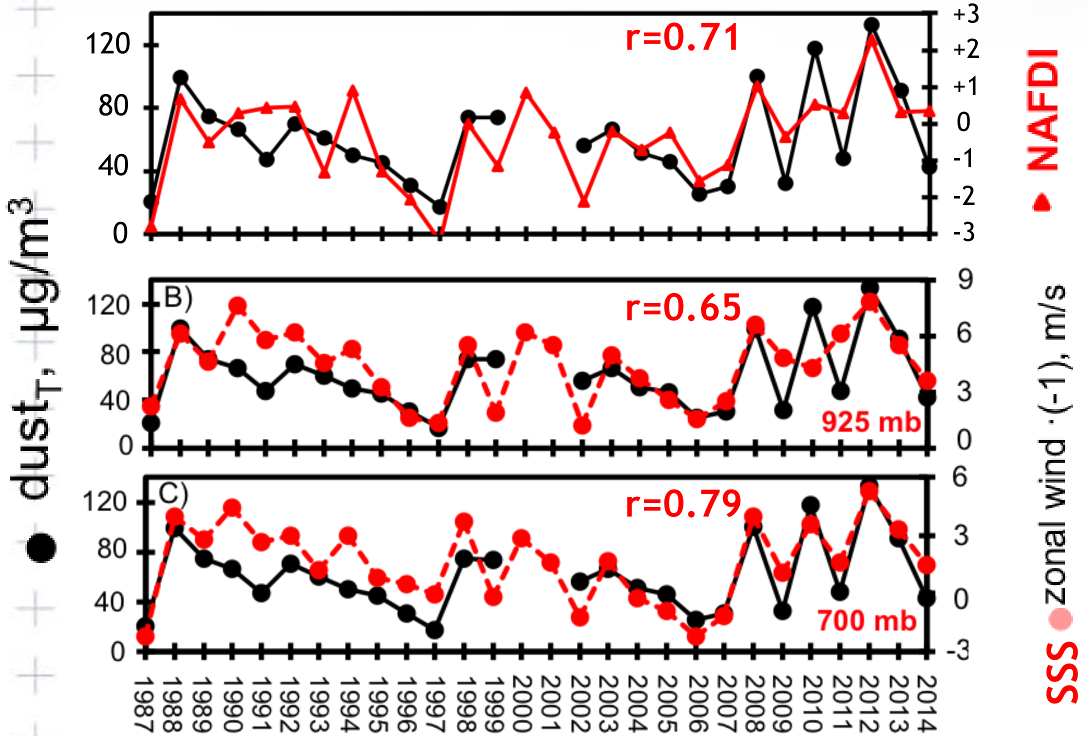
1988, 2000, 2008 and 2012
+0.68, +0.83, +1.01 and +2.29

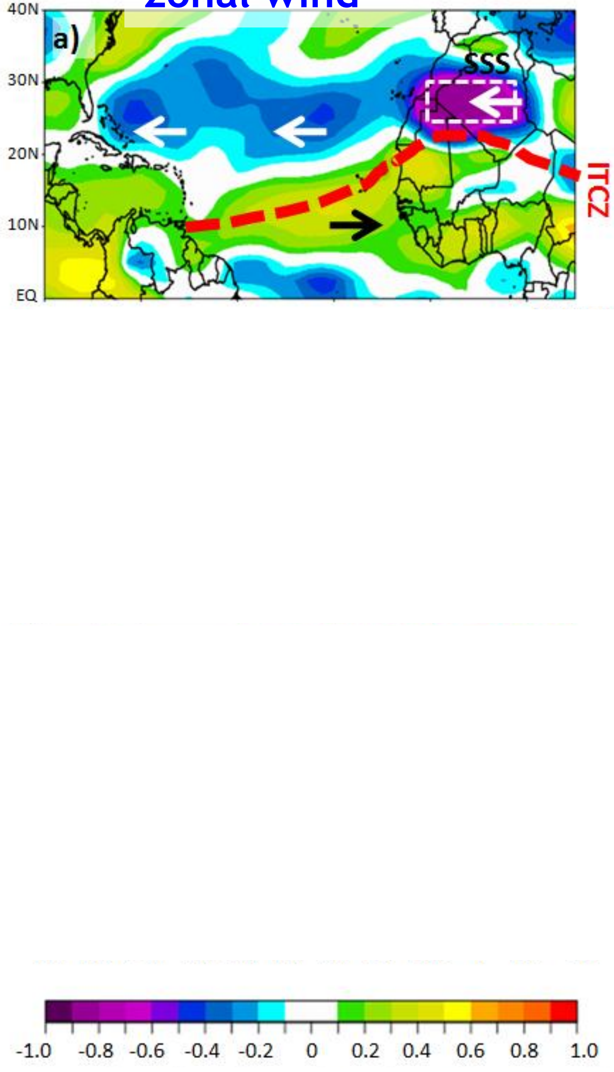


Subtropical Saharan Stripe-SSS: Central Algeria to Western Saharan, 24 - 30 °N

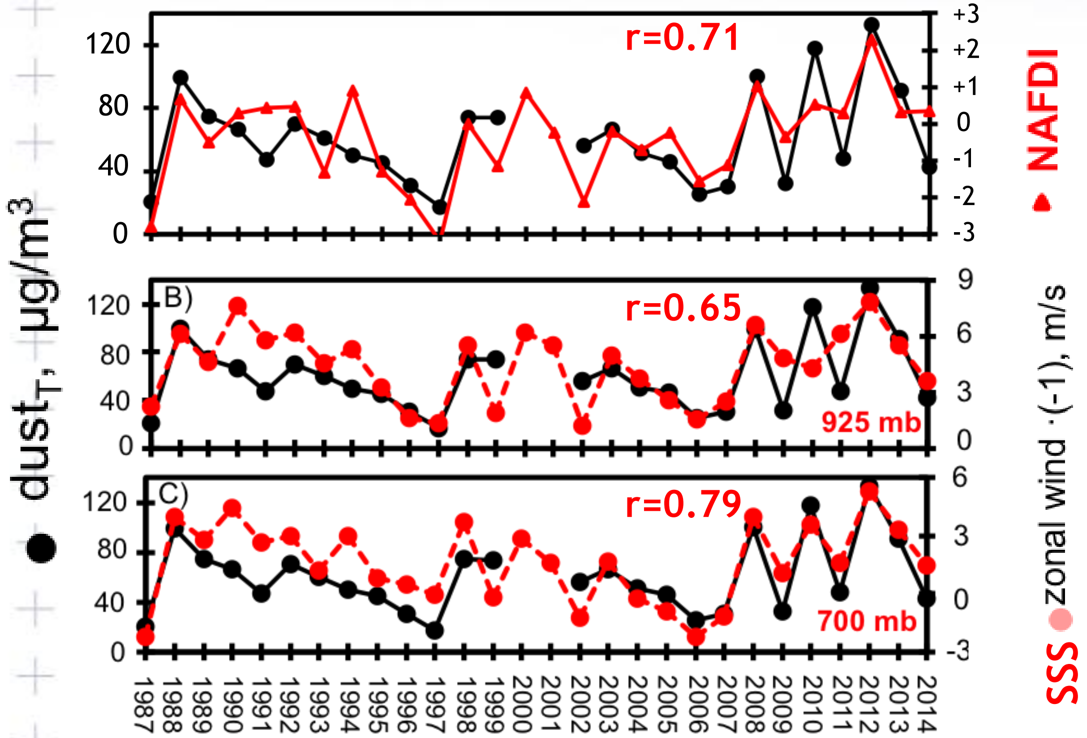
Saharan dust export, connection to…
large scale meteorology in North Africa

correlation of NAFDI with…
zonal wind

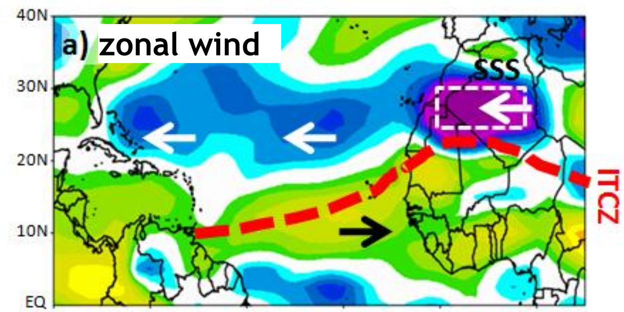


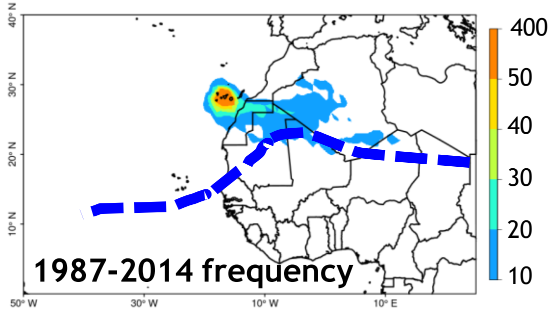


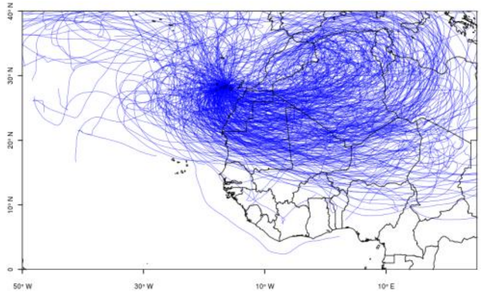
Saharan dust export, connection to…
large scale meteorology in North Africa



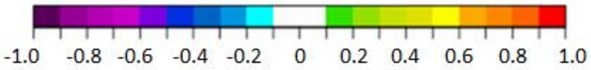
Correlation coefficient between NAFDI and





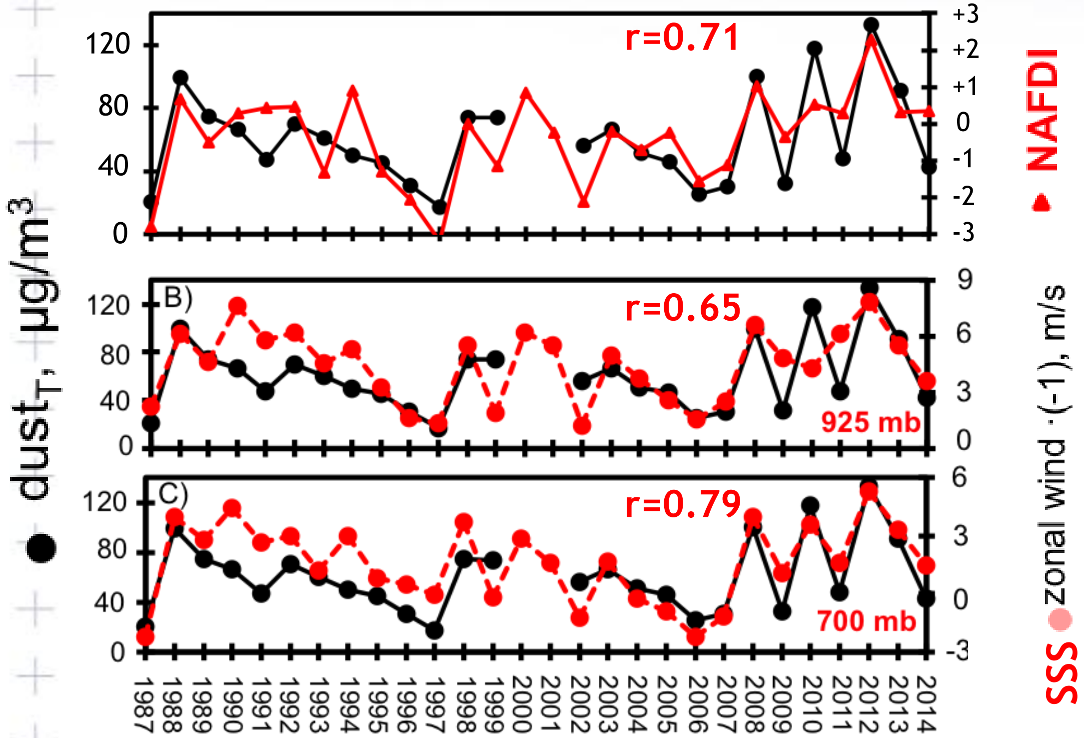


1987-2014 back trajectories

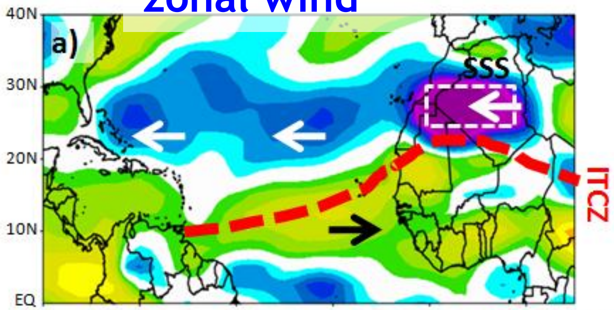


Saharan dust export, connection to…

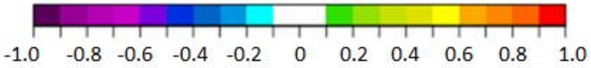
large scale meteorology in North Africa



correlation of NAFDI with… zonal wind



Variability in the summer dust export has been mainly controlled by winds



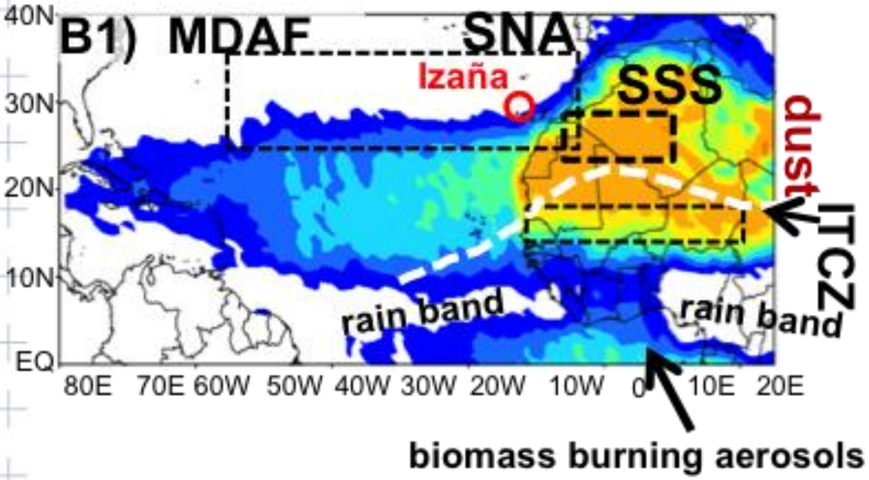
Saharan dust export, connection to… large scale meteorology in North Africa

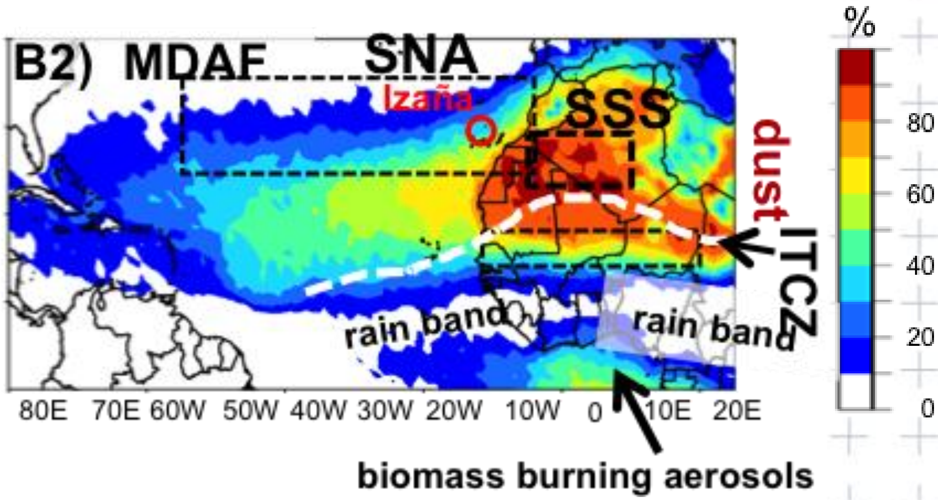
Low NAFDI summers

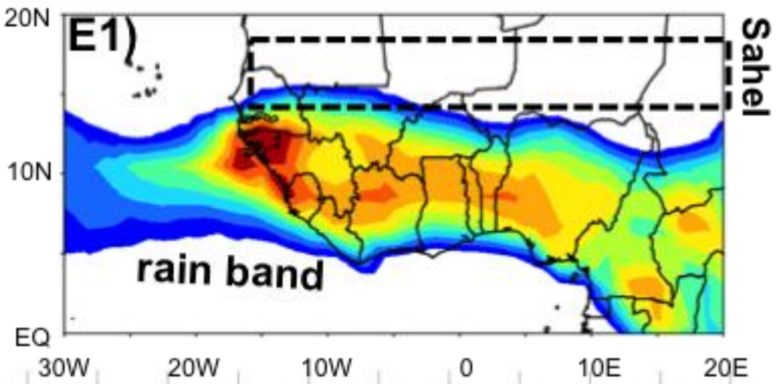
1987, 1996, 1997 and 2006
-2.79, -2.04, -3.19 and -1.54

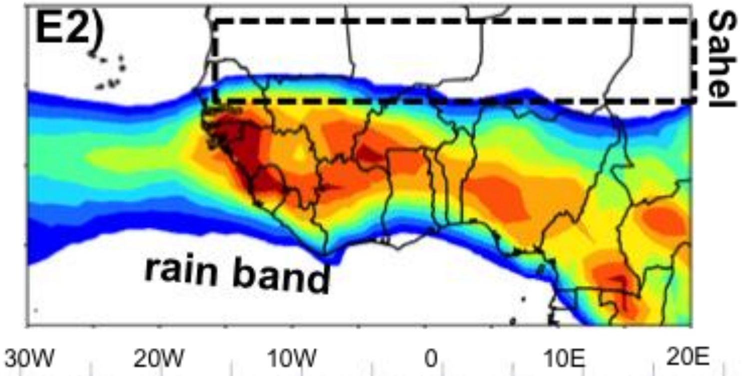
High NAFDI summers

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



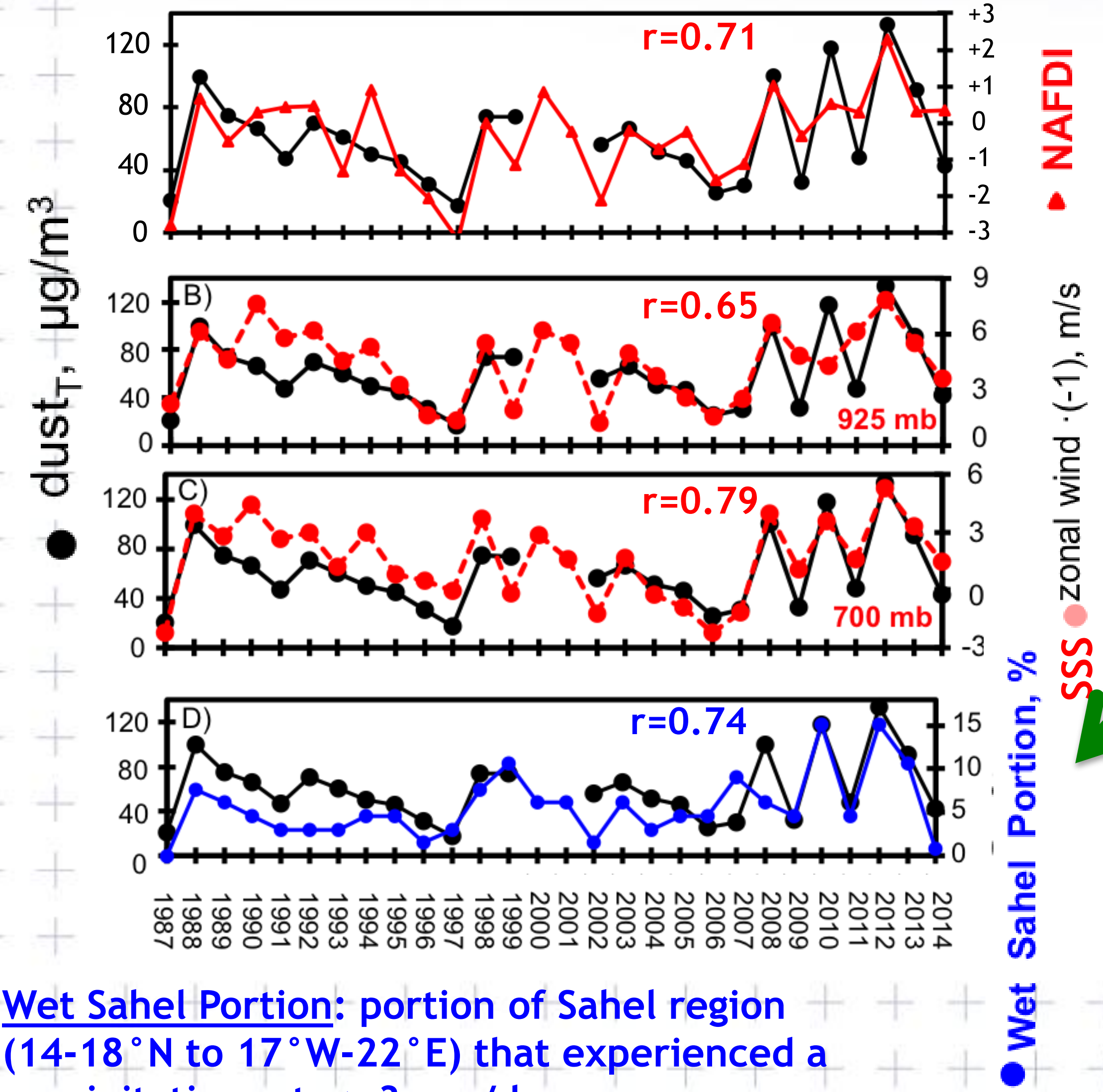




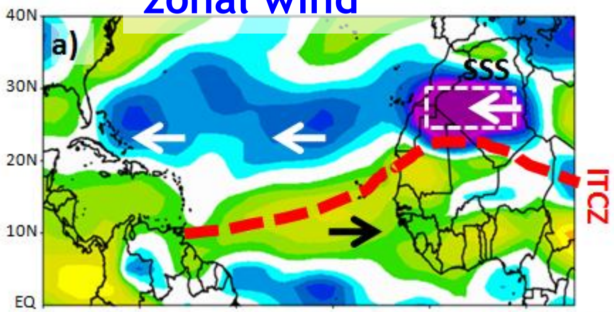


the monsoon rain band shift northward in high NAFDI summers

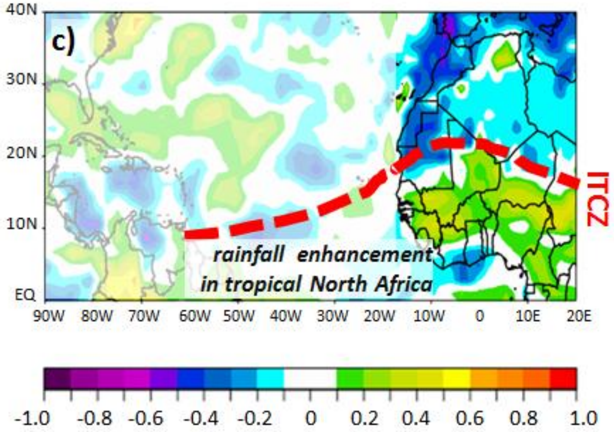
Saharan dust export, connection to… large scale meteorology in North Africa



correlation of NAFDI with… zonal wind

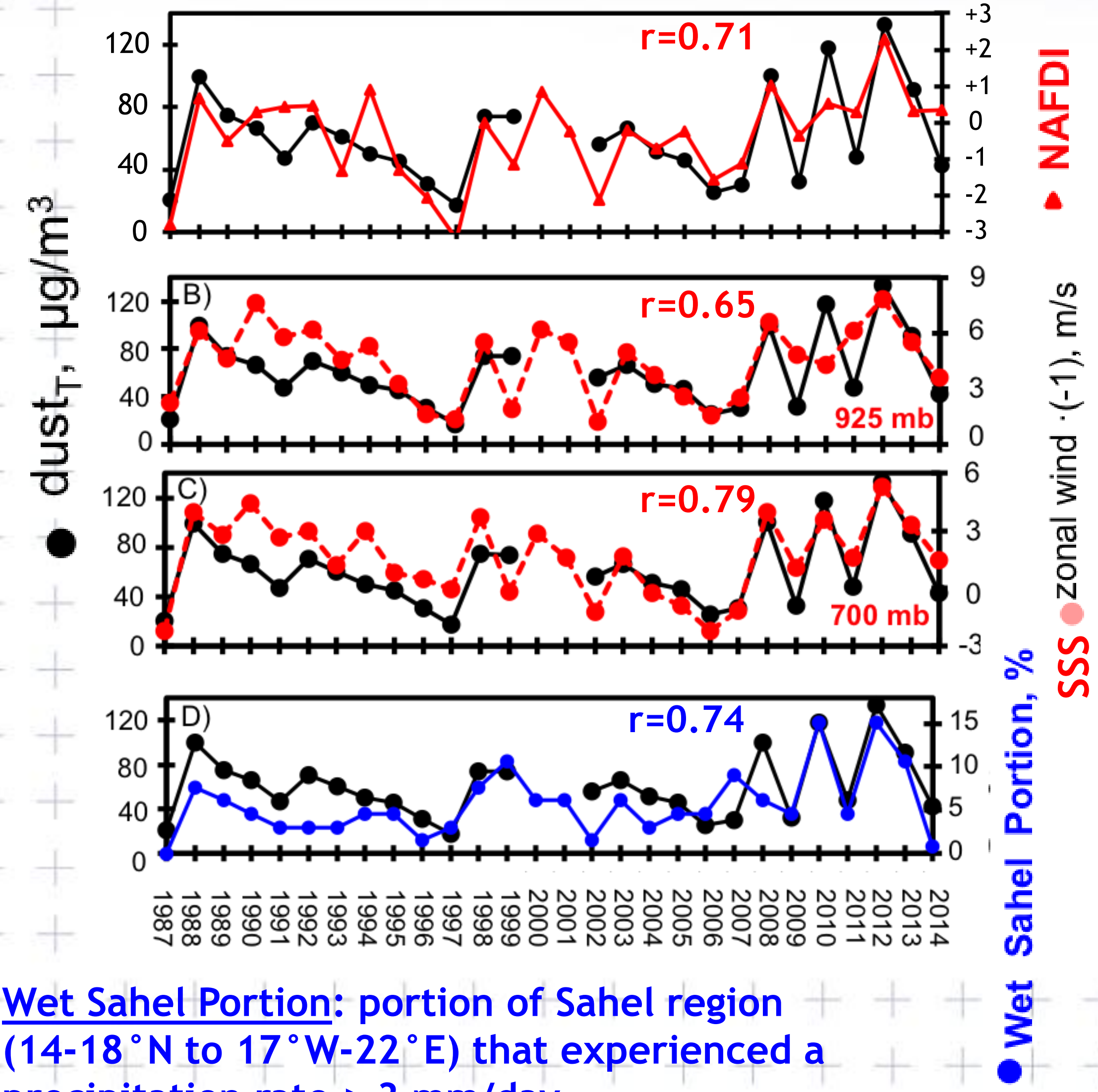


correlation of NAFDI with… precipitation rates



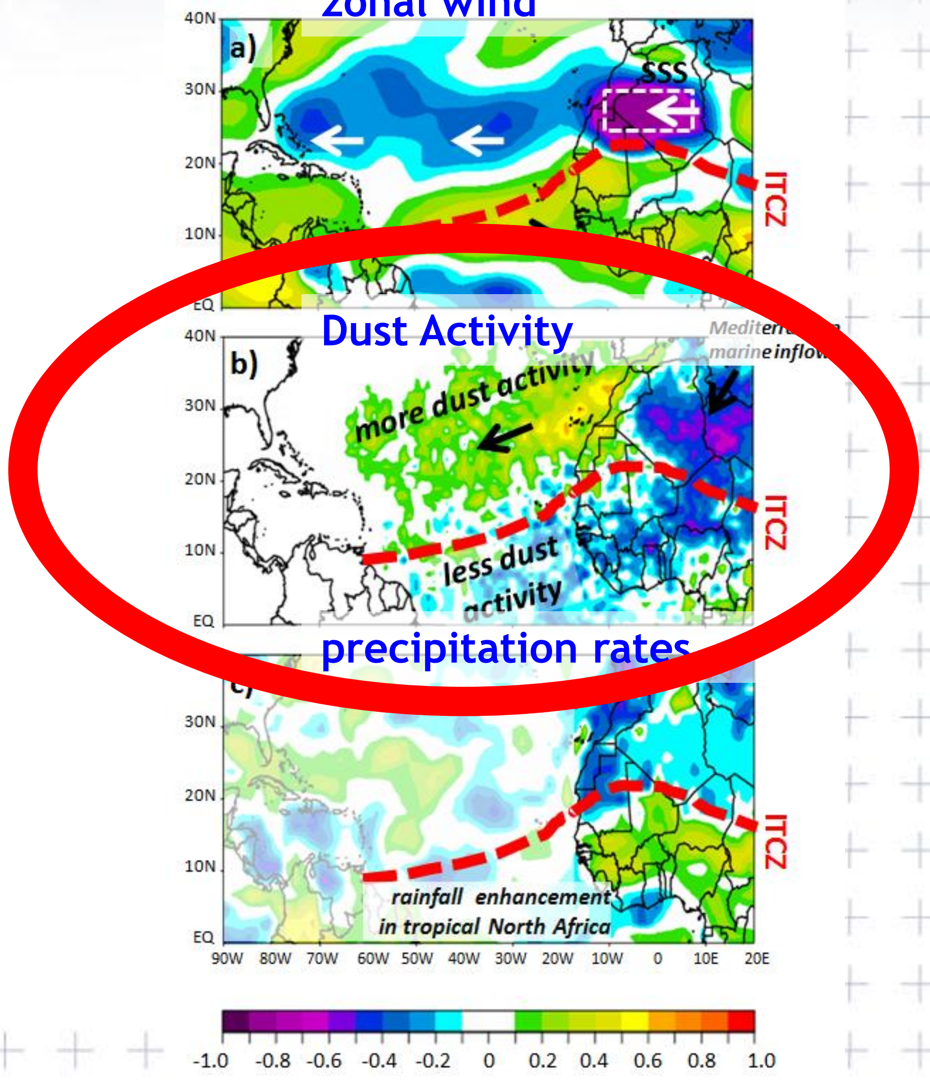
Wet Sahel Portion: portion of Sahel region (14-18˚N to 17˚W-22˚E) that experienced a precipitation rate ≥ 3 mm/day

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



correlation of NAFDI with…

zonal wind



Dust Activity

precipitation rates

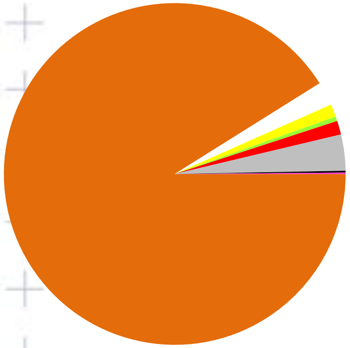
Wet Sahel Portion: portion of Sahel region (14-18°N to 17°W-22°E) that experienced a precipitation rate ≥ 3 mm/day

Outline

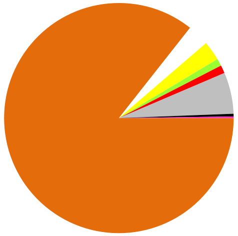
long term variability in the Saharan Air Layer.....

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

PM_x composition in the SAL

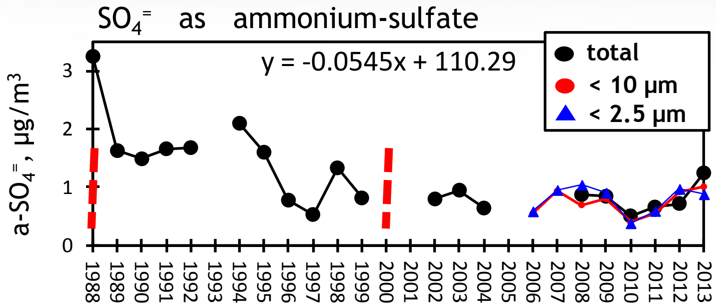


PM_{10}		42.0 µg/m^3	
91%	🟧	38.3	dust
2.2%	⬜	0.9	none ammonium-sulfate
1.2%	🟨	0.5	ammonium-sulfate
0.4%	🟩	0.2	ammonium
1.3%	🟥	0.6	nitrate
3.4%	▨	1.4	organic matter
0.2%	⬛	0.07	elemental carbon

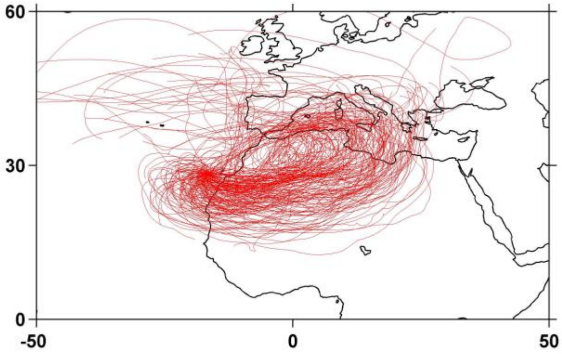


$PM_{2.5}$		18.5 µg/m^3	
85%	🟧	15.8	dust
3.0%	⬜	0.6	none ammonium-sulfate
2.7%	🟨	0.5	ammonium-sulfate
1.0%	🟩	0.2	ammonium
1.1%	🟥	0.2	nitrate
5.8%	▨	1.1	organic matter
0.4%	⬛	0.07	elemental carbon

ammonium-sulfate in the Saharan Air Layer

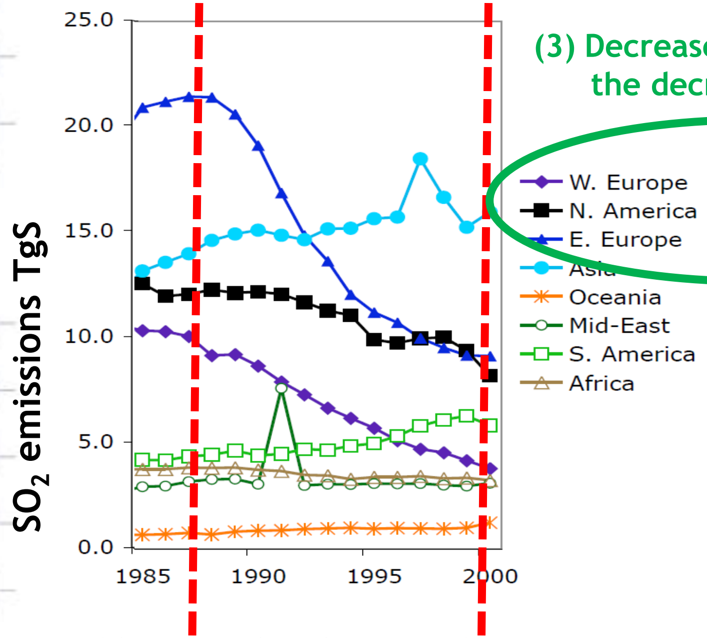


(1) air laden in Saharan dust has previously passed over the Mediterranean and Europe



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

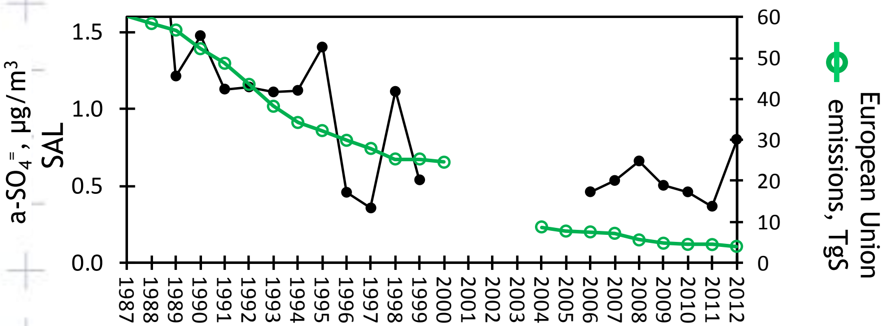
(2) North African emissions of SO$_2$ did not changed significantly during the 1990s

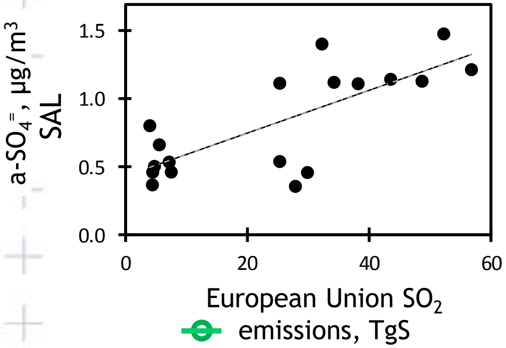
Reversal of the trend in global anthropogenic sulfur emissions

David I. Stern*

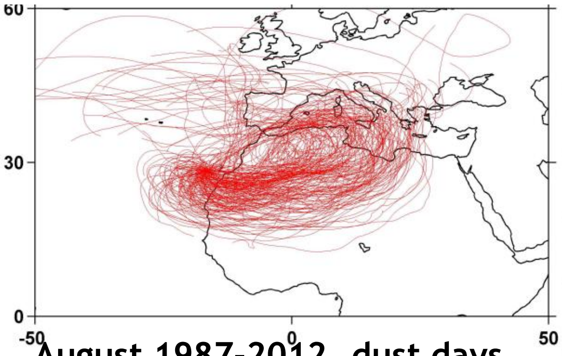
Global Environmental Change 16 (2006) 207–220

ammonium-sulfate in the Saharan Air Layer



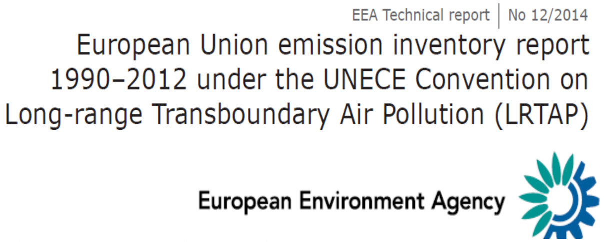


air laden in Saharan dust has previously passed over the Mediterranean and Europe



August 1987-2012, dust days

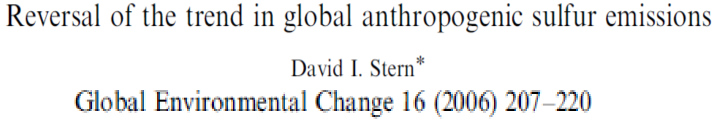
decrease in a-sulfate in the Saharan Air Layer is correlated with the decrease in European SO$_2$ emissions



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

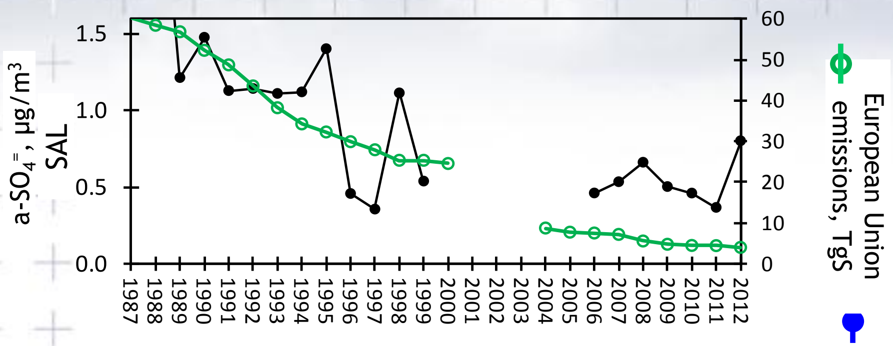


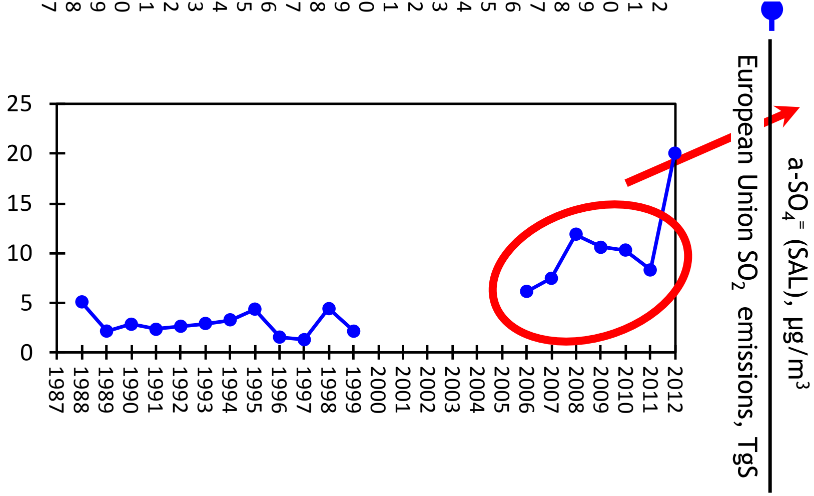
Reversal of the trend in global anthropogenic sulfur emissions

David I. Stern*

Global Environmental Change 16 (2006) 207–220

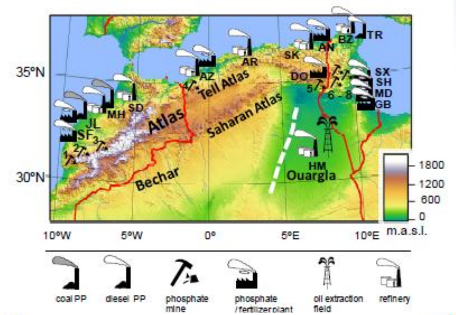
ammonium-sulfate in the Saharan Air Layer

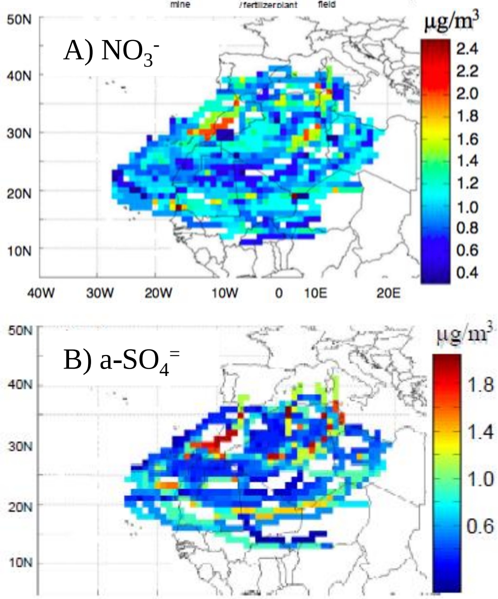




other sources contributing

industrial emissions North Africa



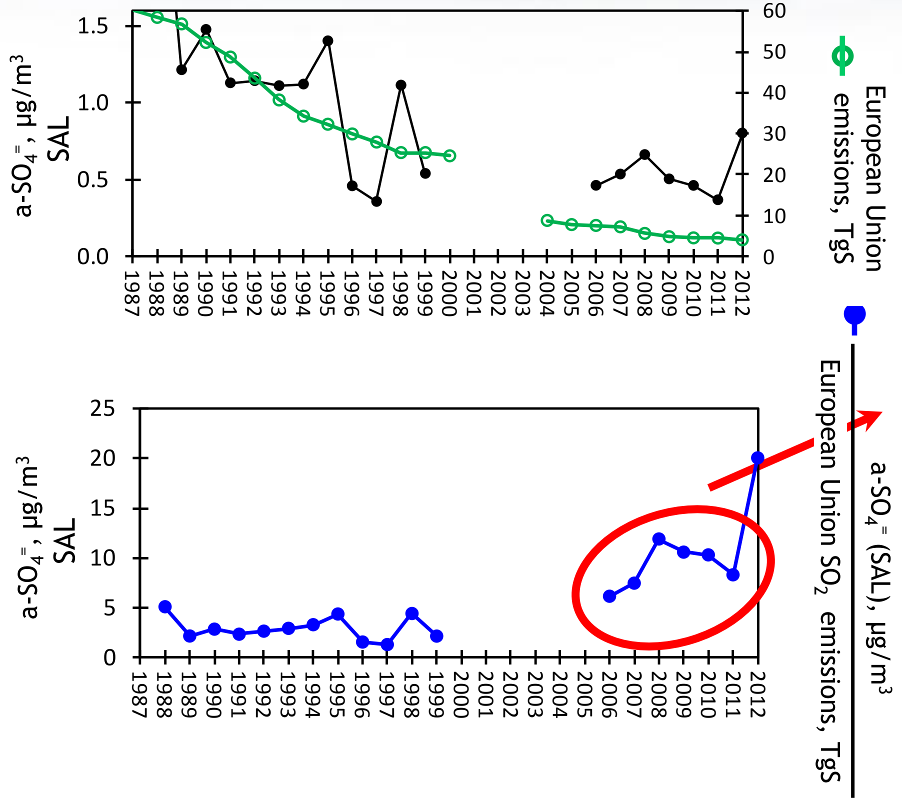


Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

Rodríguez et al., 2011

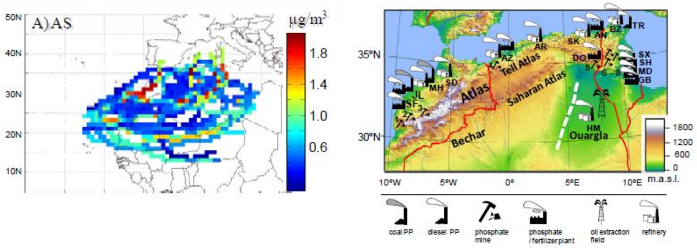
Atmos. Chem. Phys., 11, 6663–6685, 2011

ammonium-sulfate in the Saharan Air Layer



other sources contributing

north African emissions (?)

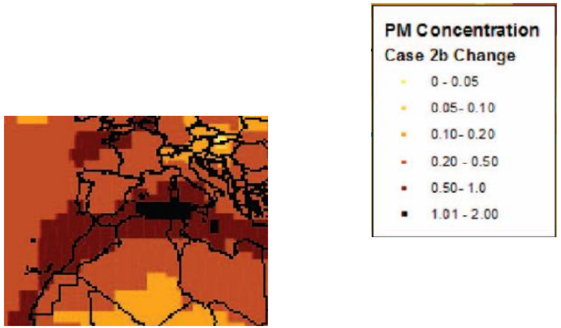


Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

Rodríguez et al., 2011

Atmos. Chem. Phys., 11, 6663–6685, 2011

ship emissions in the Mediterranean (?)



Mortality from Ship Emissions: A Global Assessment

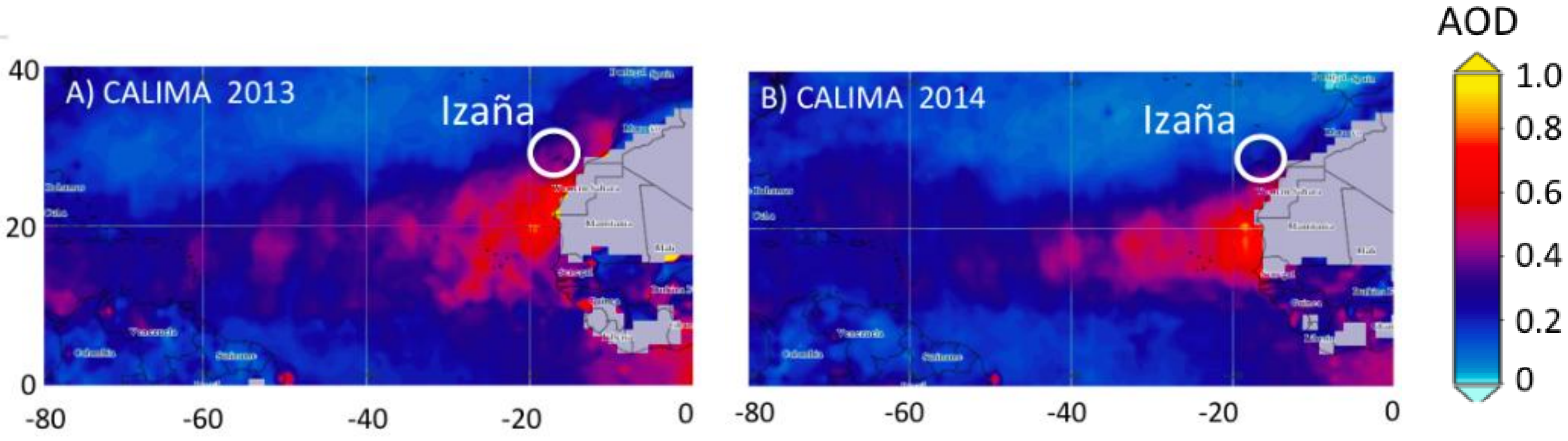
Environ. Sci. Technol. **2007**, *41*, 8512–8518

Cobett et al., 2007

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 Boose[1], Berko Sierau[1], M. Isabel García[2,3], Sergio Rodríguez[2], Andrés Alastuey[4], Claudia Linke[5], Martin Schnaiter[5], Piotr Kupiszewski[6], Zamin A. Kanji[1], and Ulrike Lohmann[1]

Atmos. Chem. Phys., 16, 9067–9087, 2016

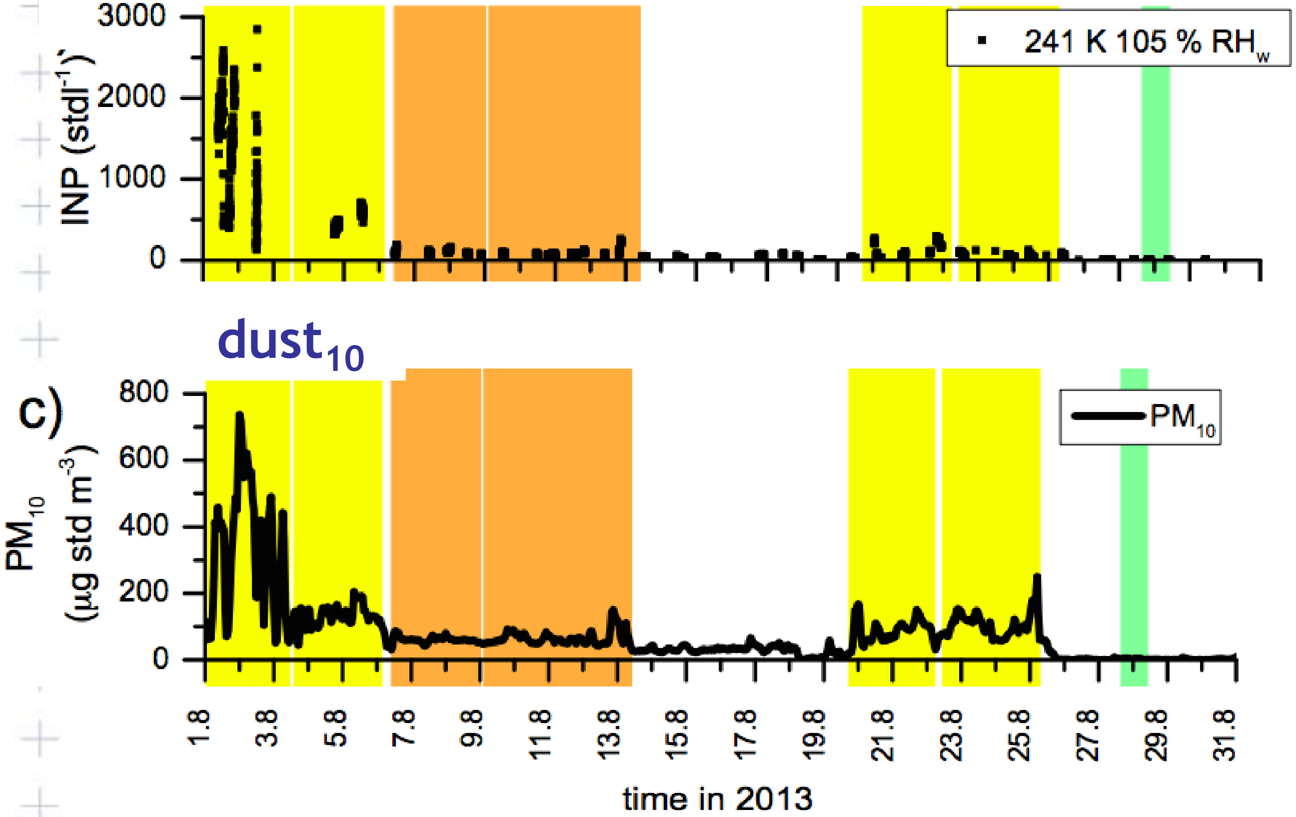
Atmospheric
Chemistry
and Physics

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

dust mixing with pollutants & implications

dust and ice nucleation

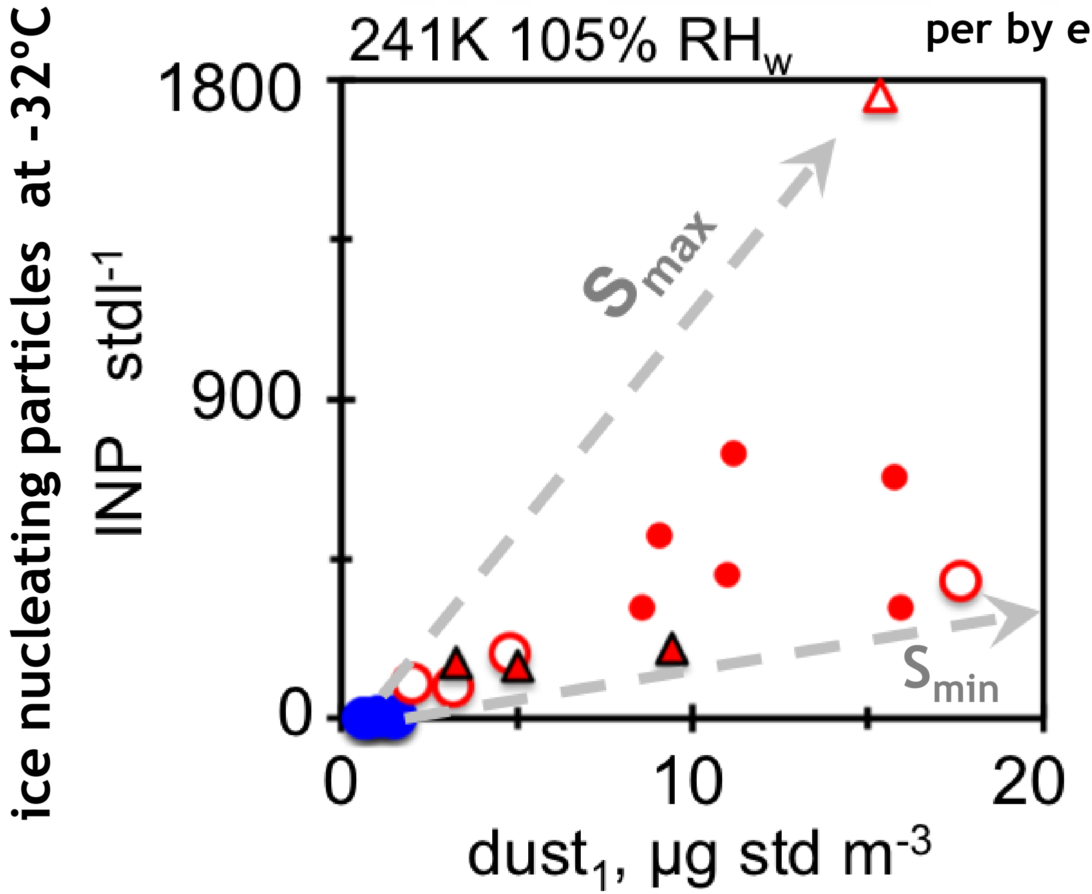
ice nuclei activated at -32°C



PINC measurements
Portable Ice Nucleation Chamber

dust mixing with pollutants & implications

dust and ice nucleation



maximum number of ice crystals per by each µg of dust

mineralogy feldpars (?)

aged dust (?)

minimum number of ice crystals per by each µg of dust

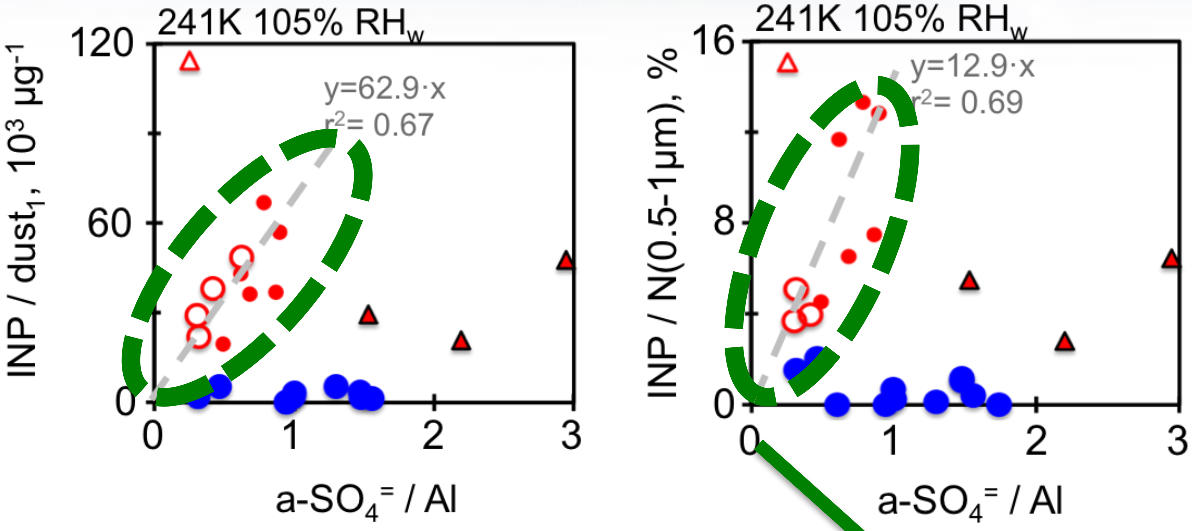
dust mixing with pollutants & implications

dust and ice nucleation

○ SAL 2014

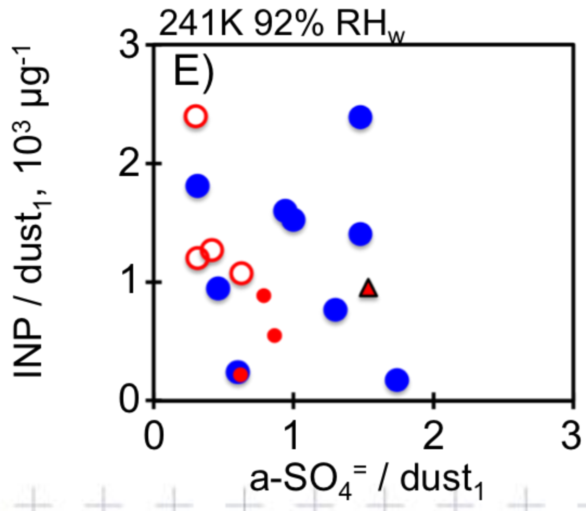
● SAL 2013

● Atlantic airflows



condensation freezing
Regime ice formation

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

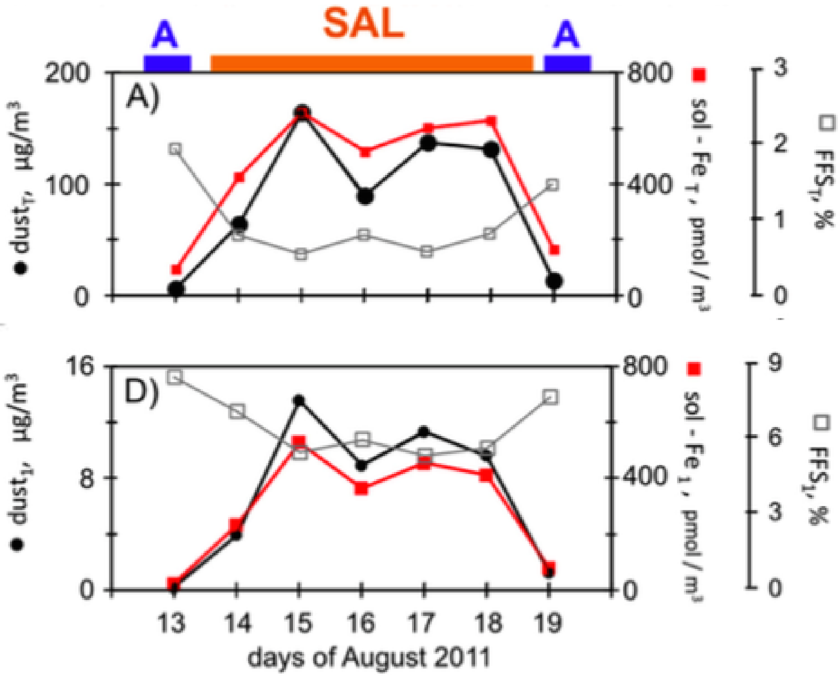


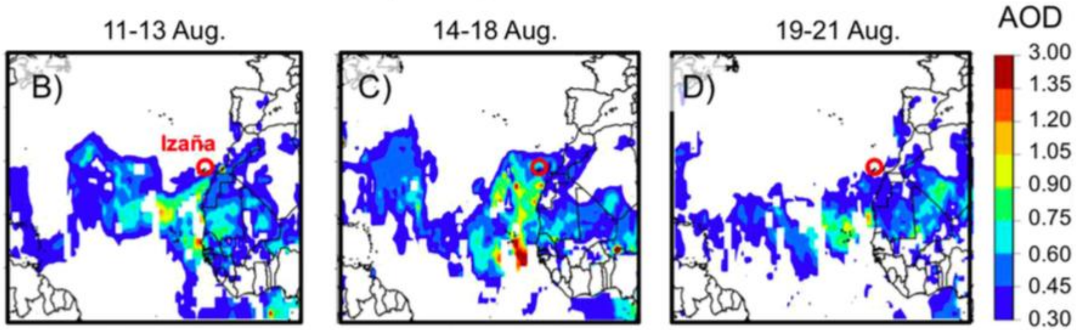
deposition
regime ice
formation

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

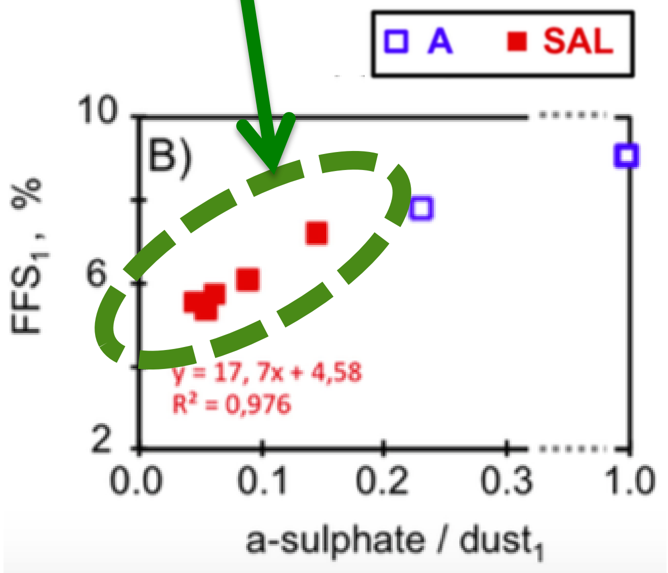
dust, iron and ocean fertilization

We studied iron solubility in the Saharan Air Layer.

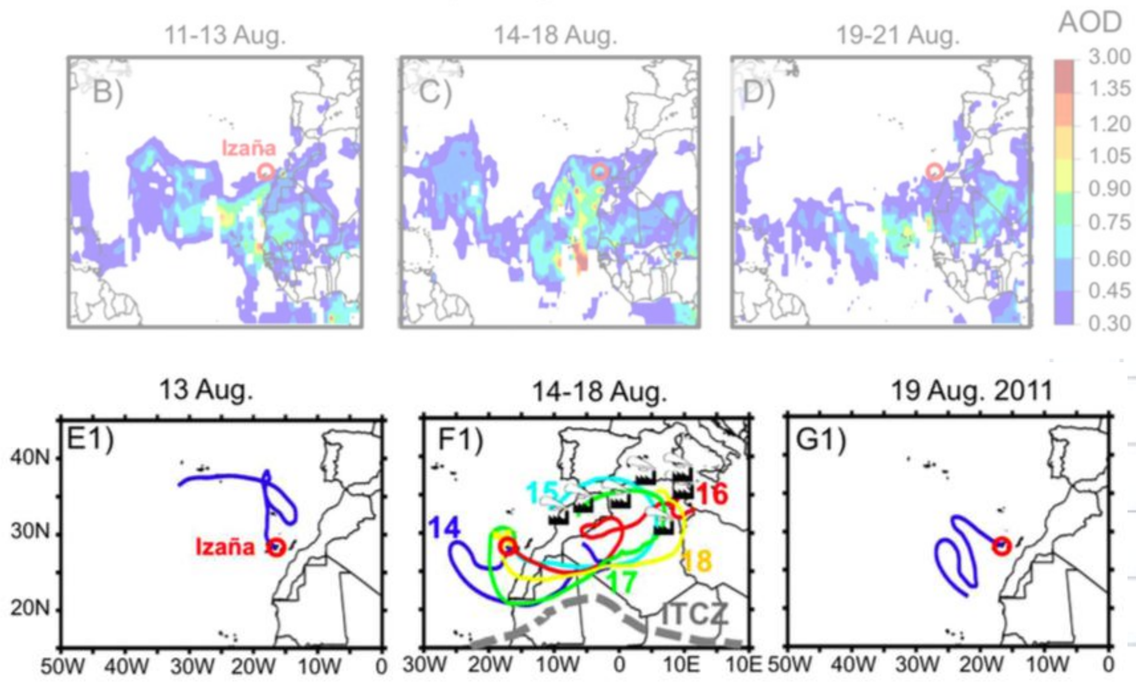
We found that the presence of ammonium sulphate in the SAL is associated with a higher fractional iron solubility

Fractional Fe Solubility

Soluble-Fe to total Fe



ammonium-sulphate to dust



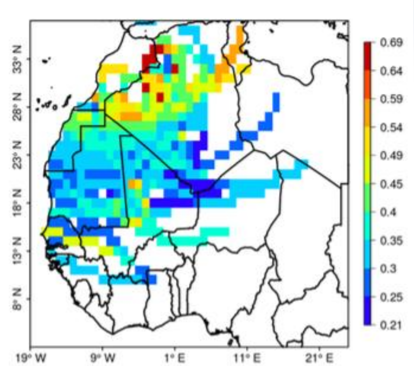
Outline

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

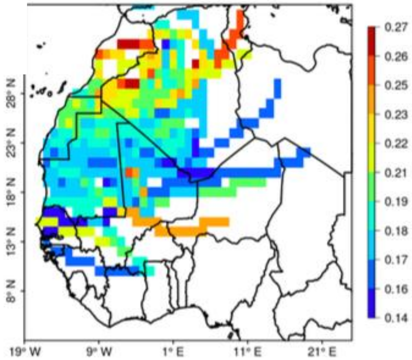
- -dust
- -dust mixing with pollutants
- -dust composition

Izaña samples and back-trajectories

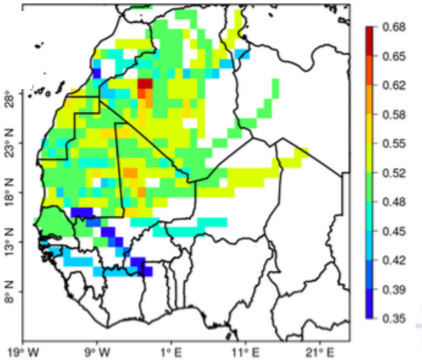
Ca / Al

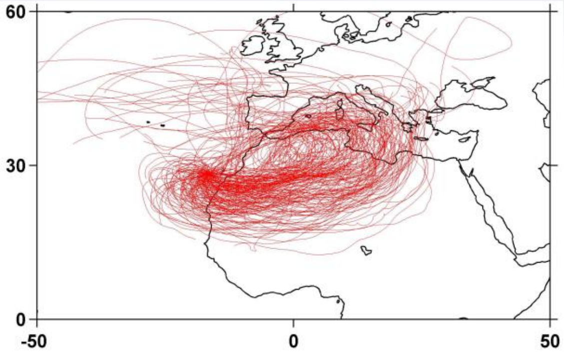


Mg / Al

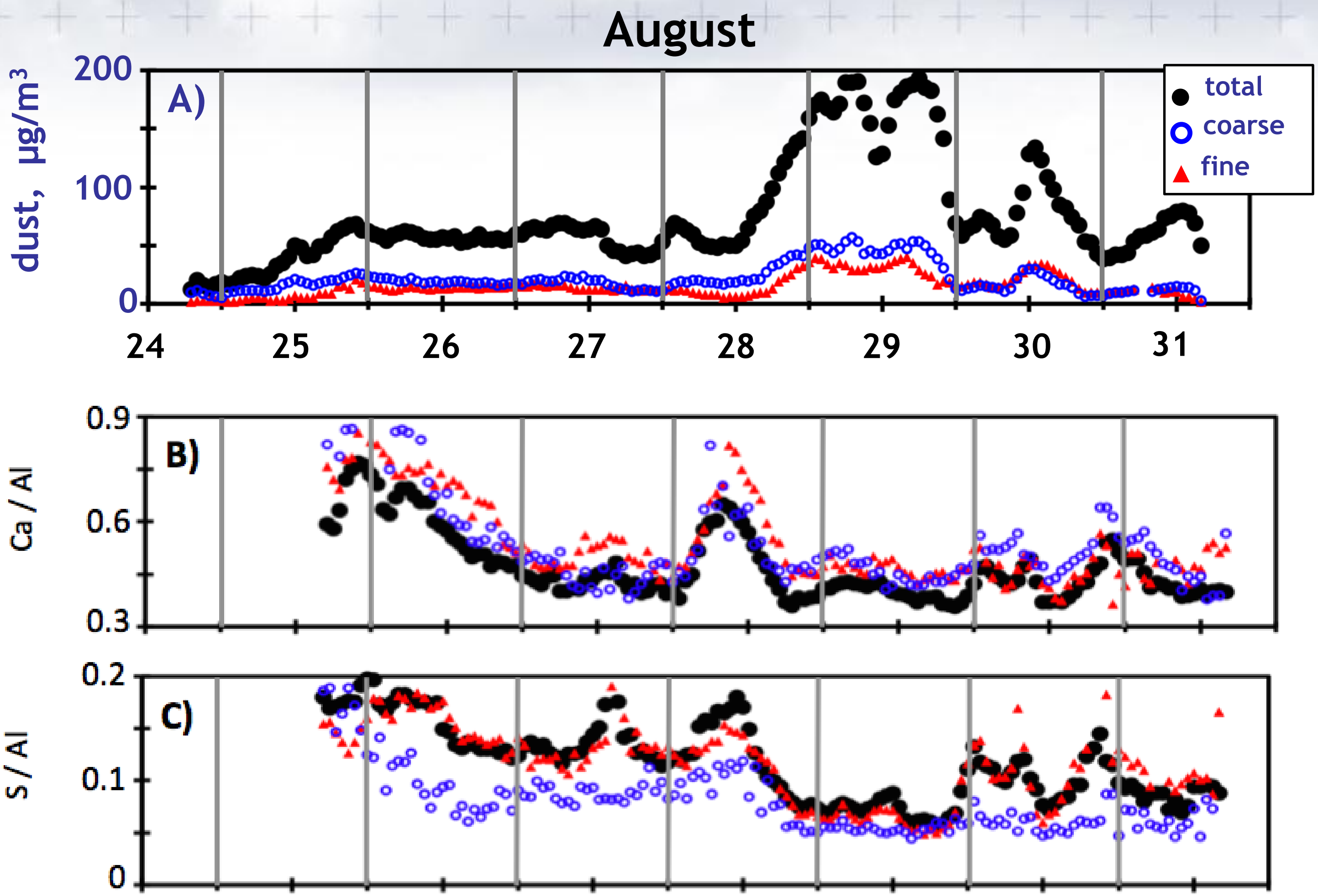


Fe / Al

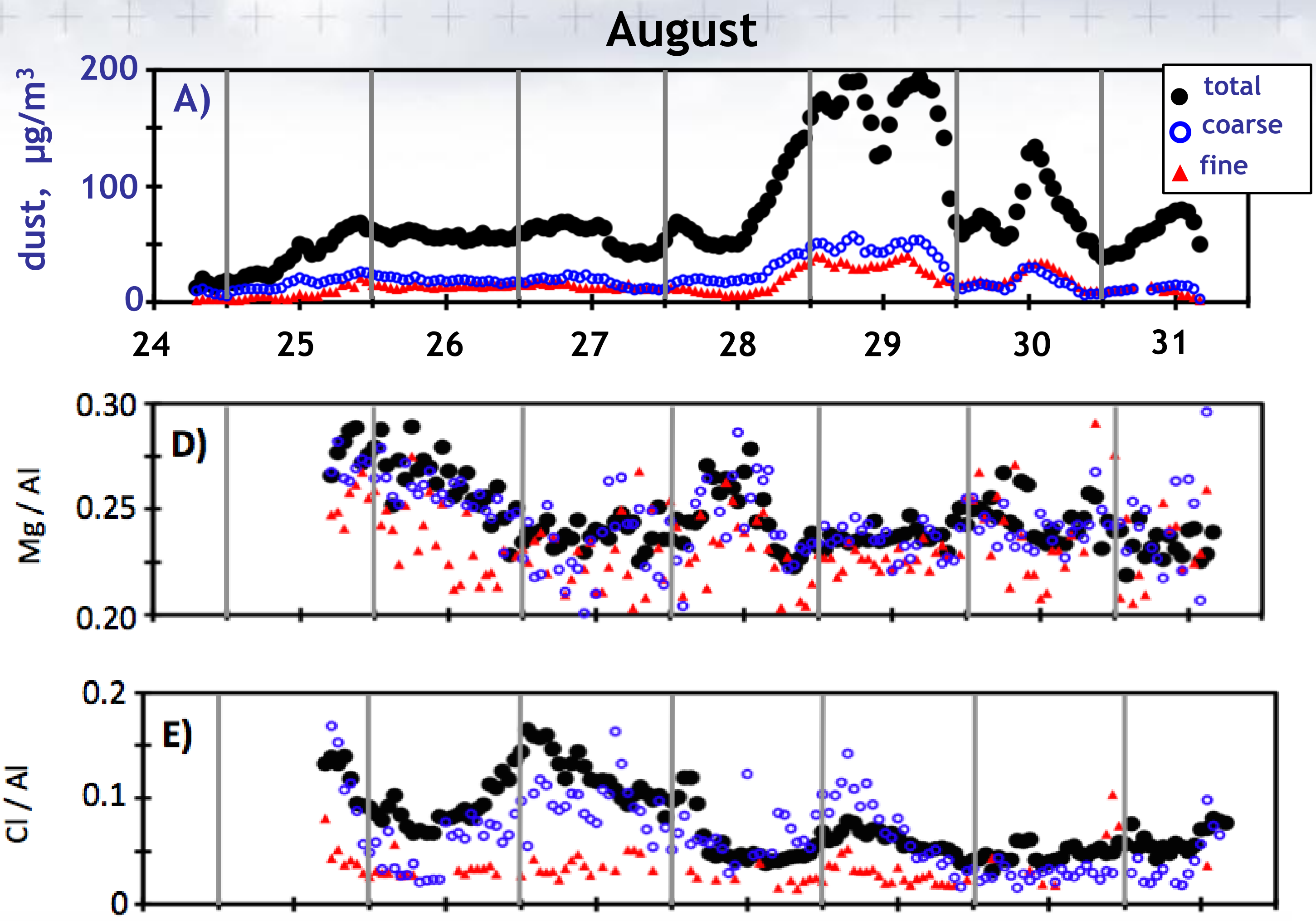




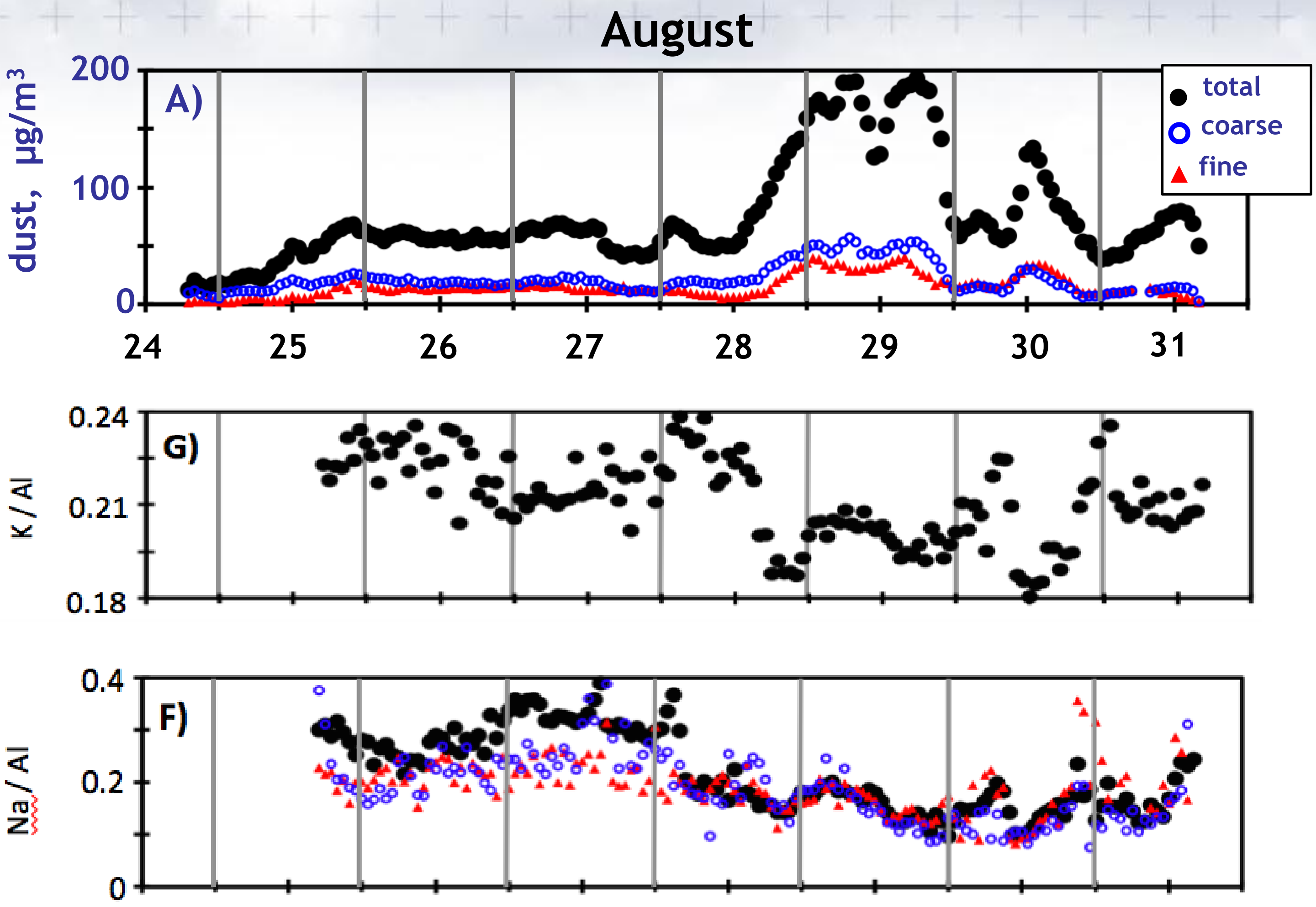
August



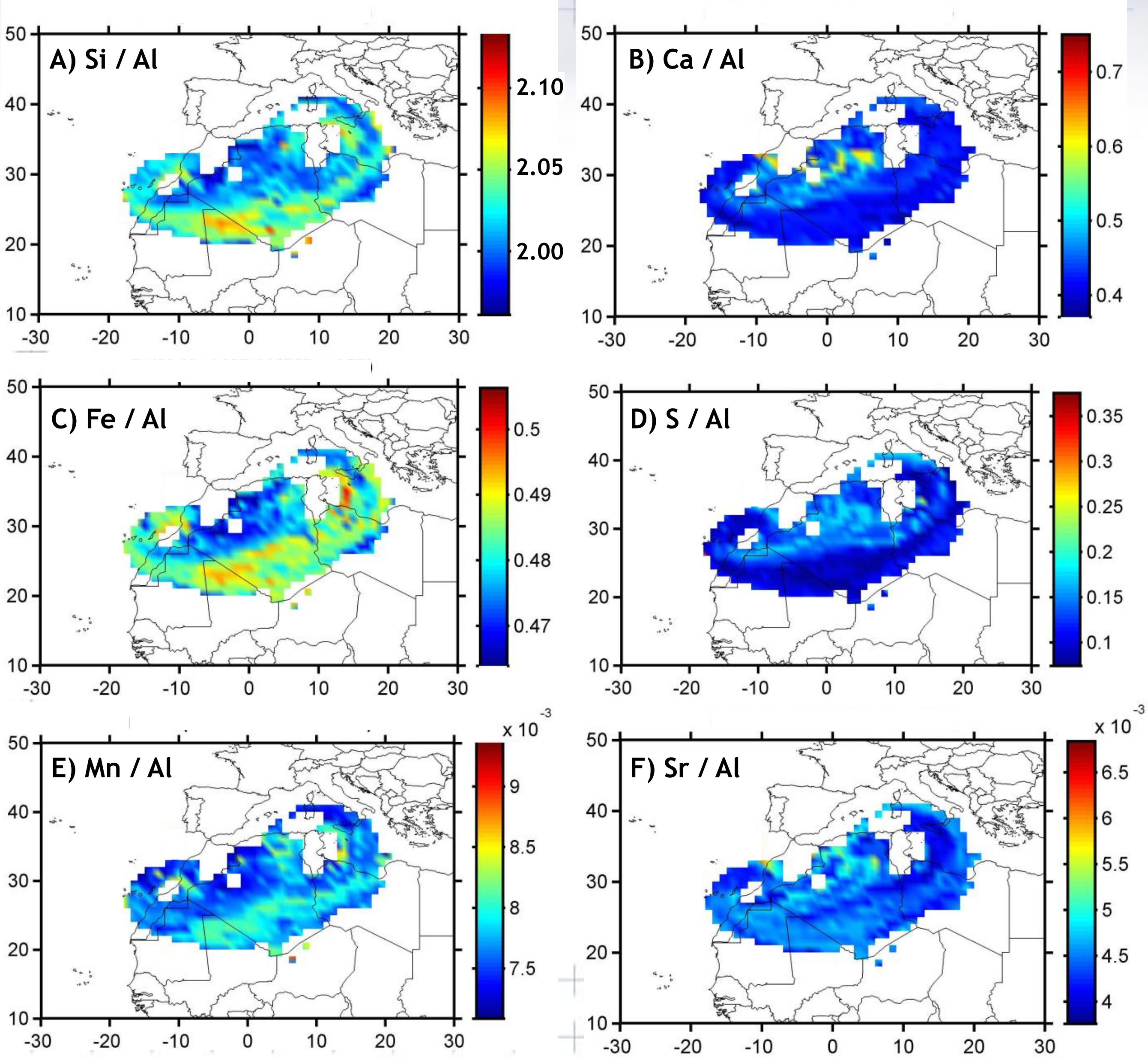
1 week: 1hour resolution dust chemistry

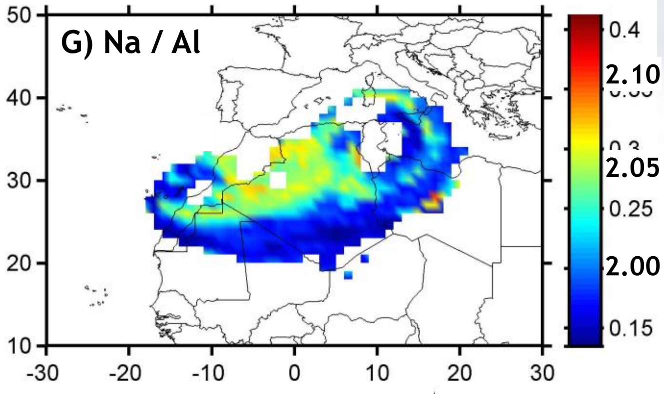


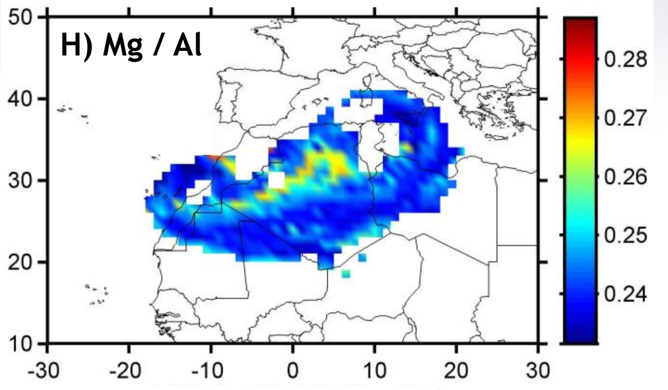
1 week: 1hour resolution dust chemistry

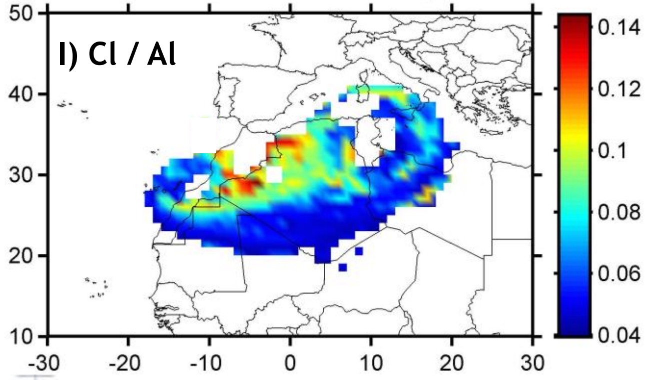


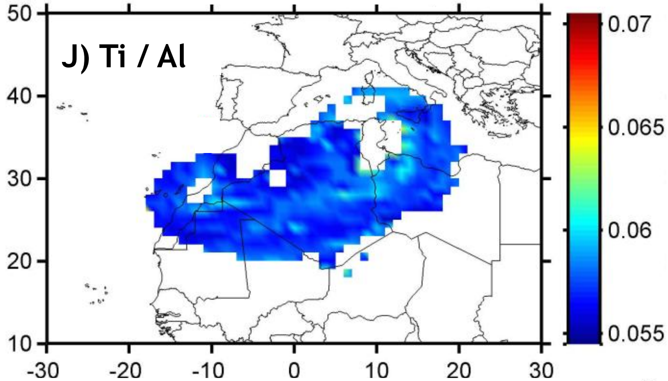
1 week: 1hour resolution dust chemistry

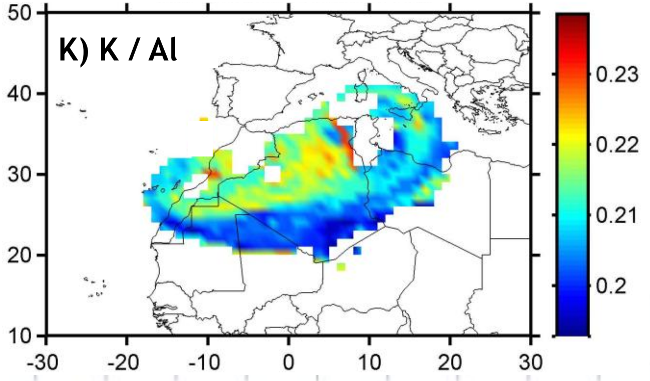

A) Si / Al
2.10
2.05
2.00
B) Ca / Al
0.7
0.6
0.5
0.4
C) Fe / Al
0.5
0.49
0.48
0.47
D) S / Al
0.35
0.3
0.25
0.2
0.15
0.1
E) Mn / Al
x 10^-3
9
8.5
8
7.5
F) Sr / Al
x 10^-3
6.5
6
5.5
5
4.5
4
50
40
30
20
10
-30
-20
-10
0
10
20
30

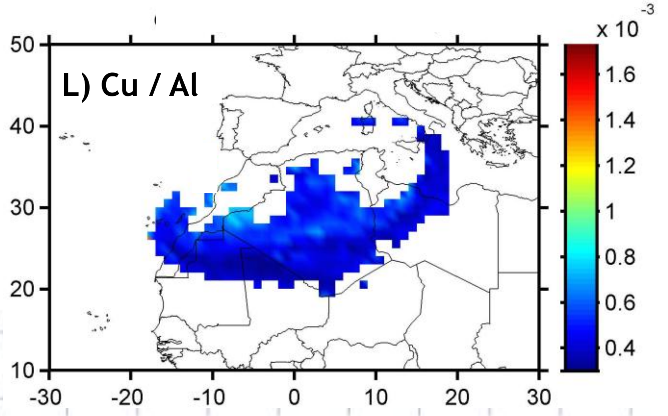

G) Na / Al
50
40
30
20
10
-30
-20
-10
0
10
20
30
0.4
2.10
0.3
2.05
0.25
2.00
0.15

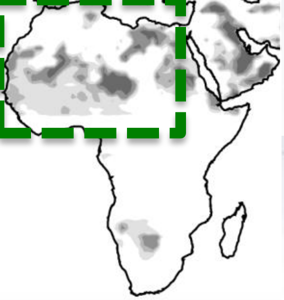

H) Mg / Al
50
40
30
20
10
-30
-20
-10
0
10
20
30
0.28
0.27
0.26
0.25
0.24


I) Cl / Al
50
40
30
20
10
-30
-20
-10
0
10
20
30
0.14
0.12
0.1
0.08
0.06
0.04


J) Ti / Al
50
40
30
20
10
-30
-20
-10
0
10
20
30
0.07
0.065
0.06
0.055

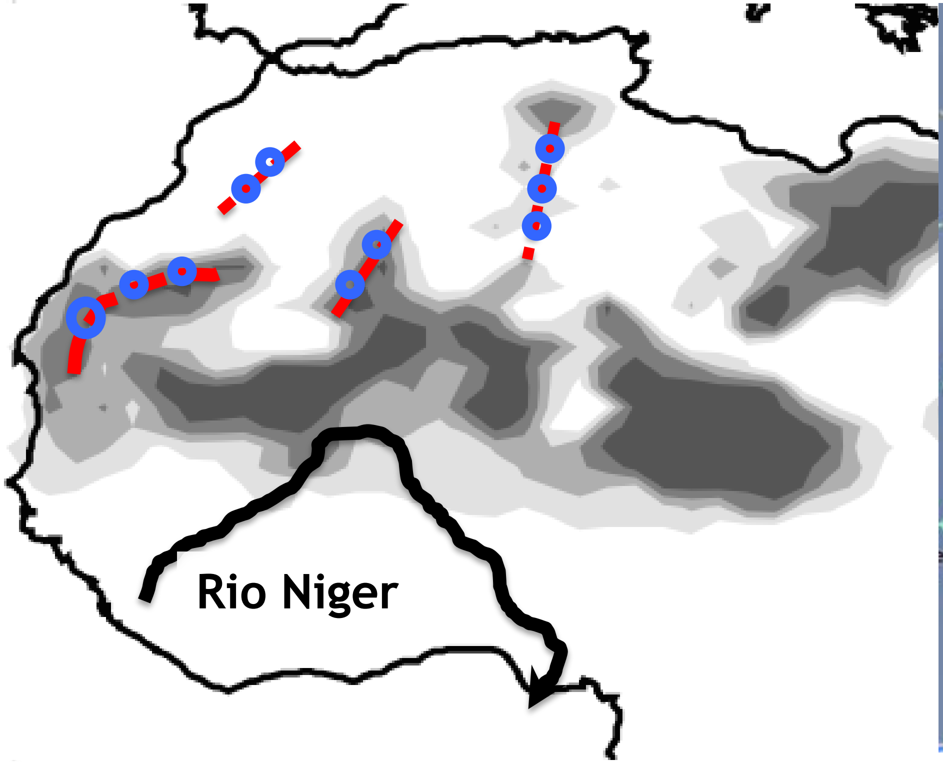

K) K / Al
50
40
30
20
10
-30
-20
-10
0
10
20
30
0.23
0.22
0.21
0.2

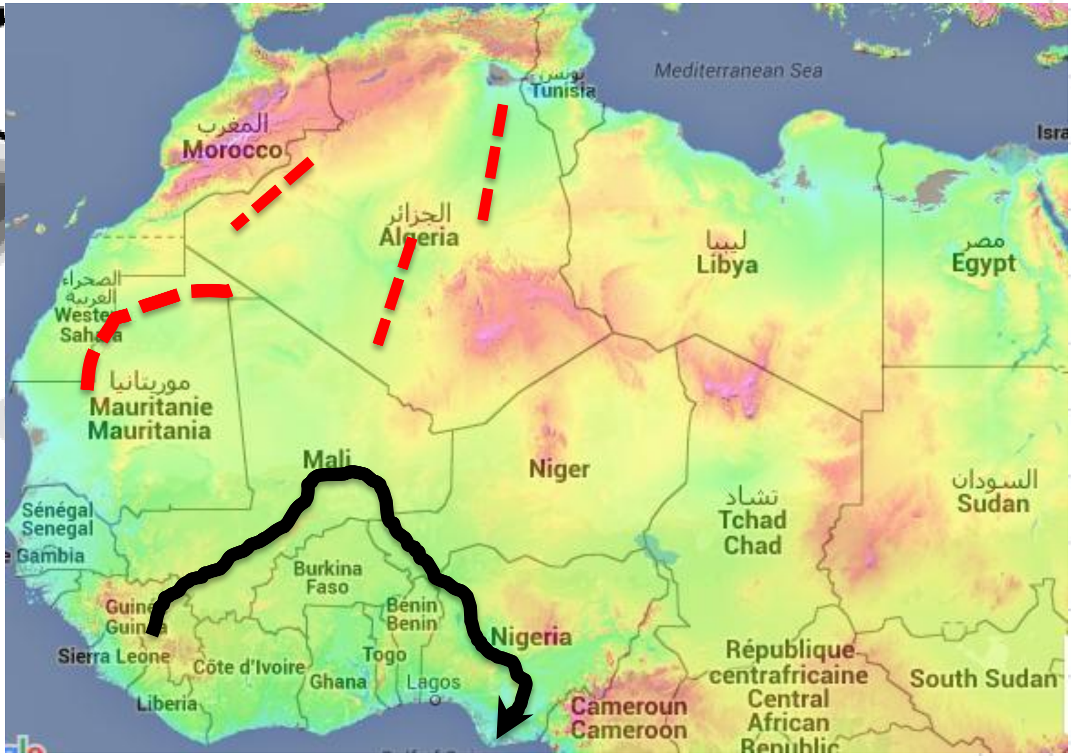

L) Cu / Al
x 10^-3
50
40
30
20
10
-30
-20
-10
0
10
20
30
1.6
1.4
1.2
1
0.8
0.6
0.4



Sahara
Sahel

Sahara

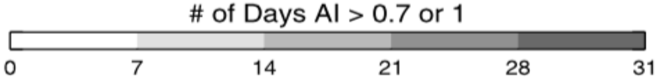


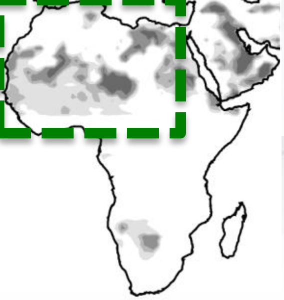


🟥 bajas tropográficas
Wakis: barrancos con inundaciones estacionales

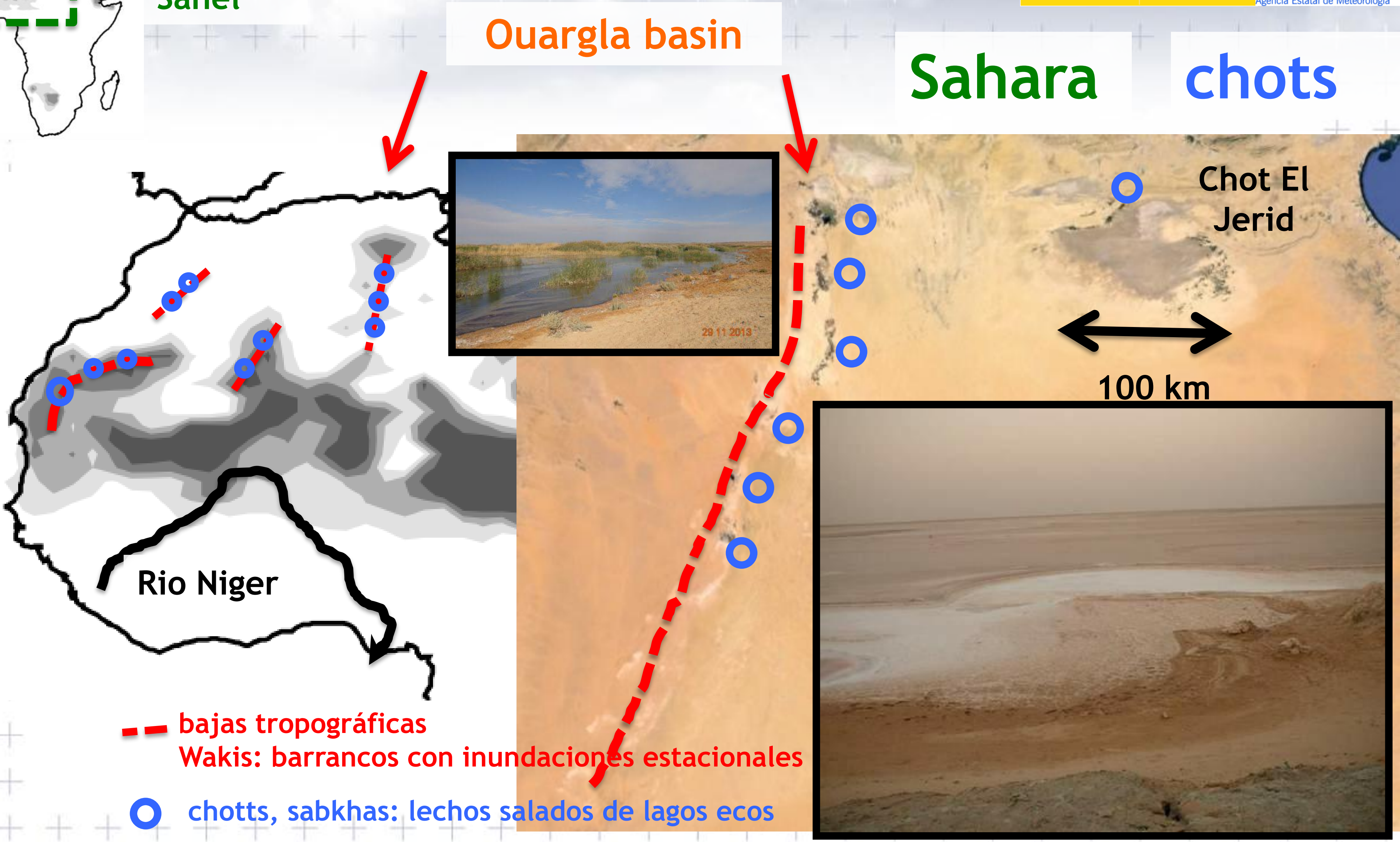
○ chots, sabkas: lechos salados de lagos ecos

Detección satélite



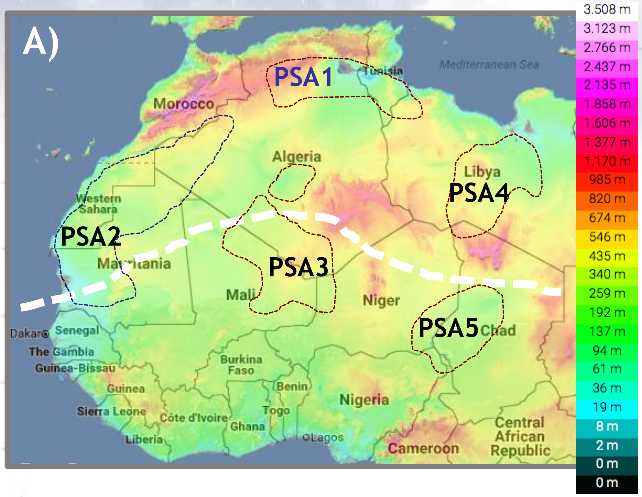


Sahara chots

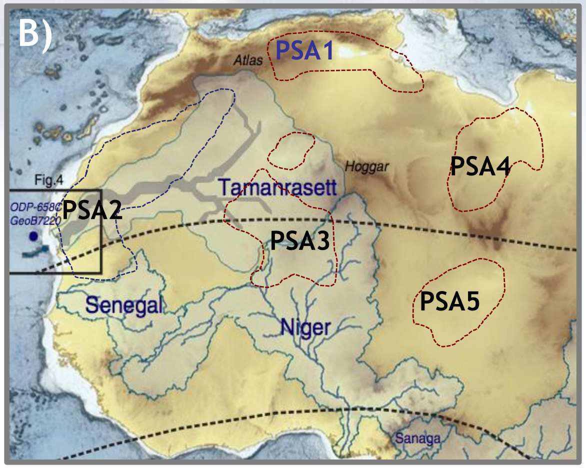


- - bajas tropográficas
Wakis: barrancos con inundaciones estacionales

○ chotts, sabkhas: lechos salados de lagos ecos topography



watershed



Scheuvens et al. (2013)

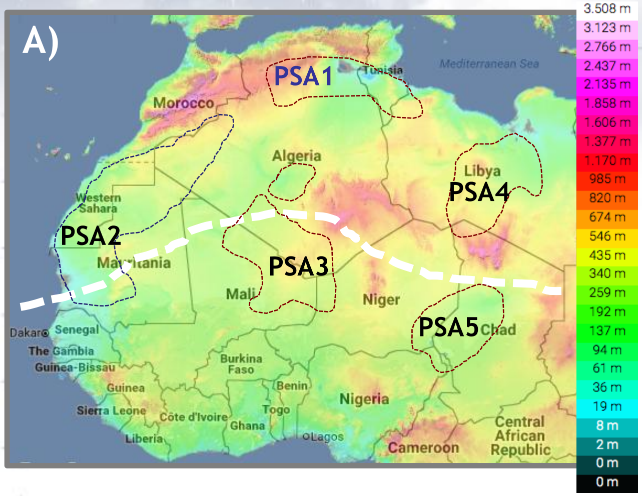
Potential Source Areas:

PSA1 rich in Ca, S, Sr, K and Mg

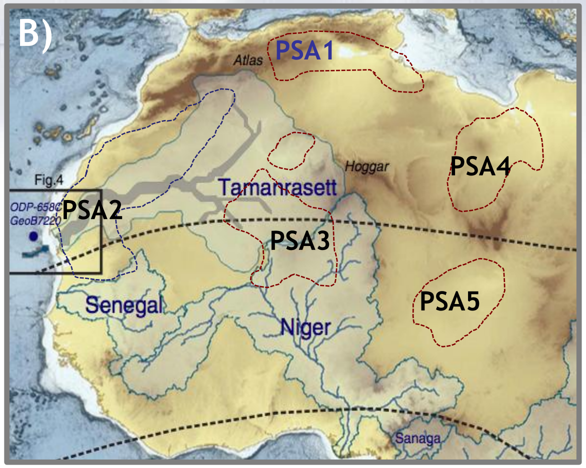
PSA2 rich in Na and Cl

PSA3 rich in Si, Fe and Mn

topography



watershed



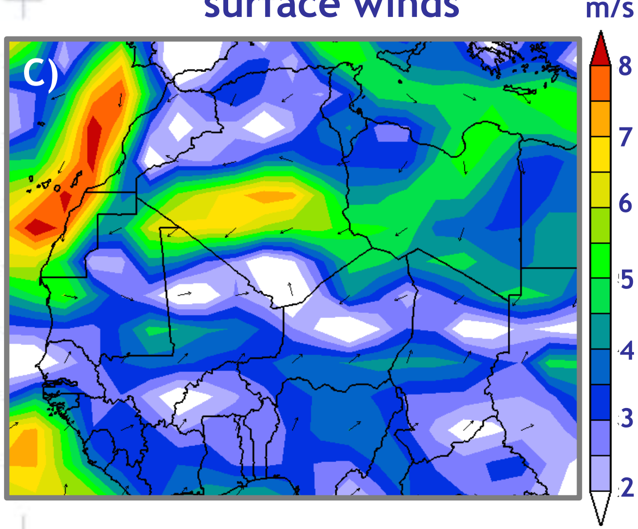
Potential Source Areas:

PSA1 rich in Ca, S, Sr, K and Mg

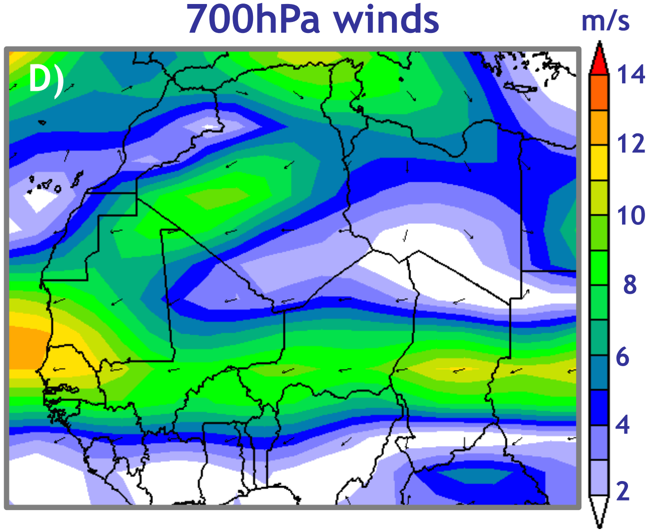
PSA2 rich in Na and Cl

PSA3 rich in Si, Fe and Mn

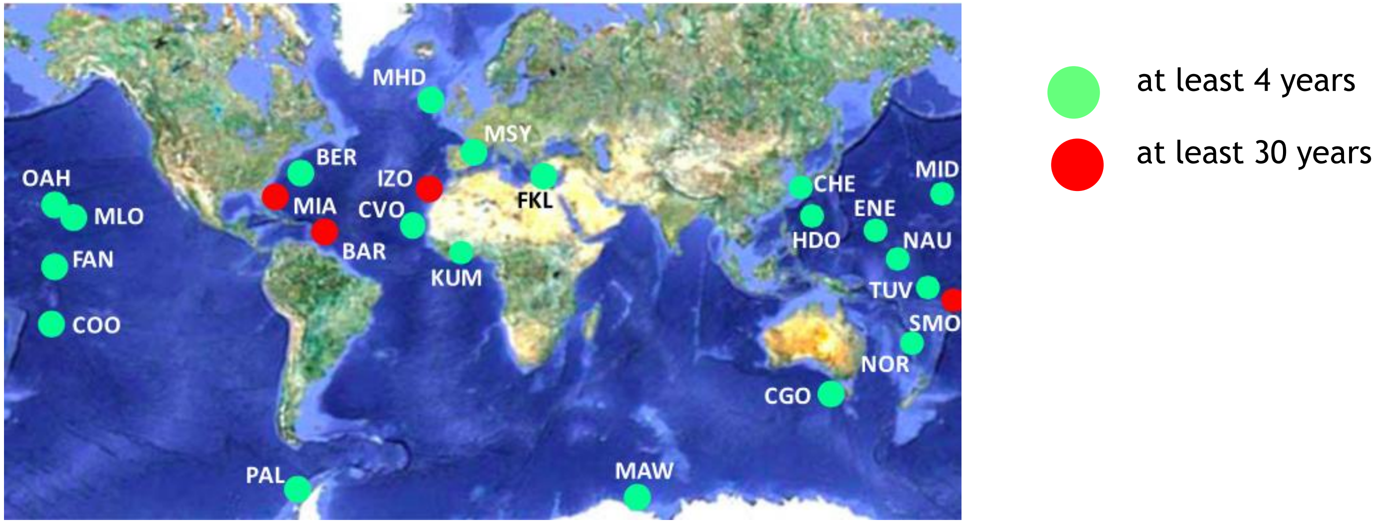
surface winds



700hPa winds



long term in-situ aerosol dust programmes



Rodríguez et al., 2012. A review of methods for long term in situ characterization of aerosol dust. Aeolian Research, 6, 55–74

Highlights:

deficit of multidecadal in-situ observations

- Mineralogy
- Composition
- Mixing with pollutants
- Size distribution
- Key properties

complementary to satellite, models

dust microphysical properties affecting climate, health, environment