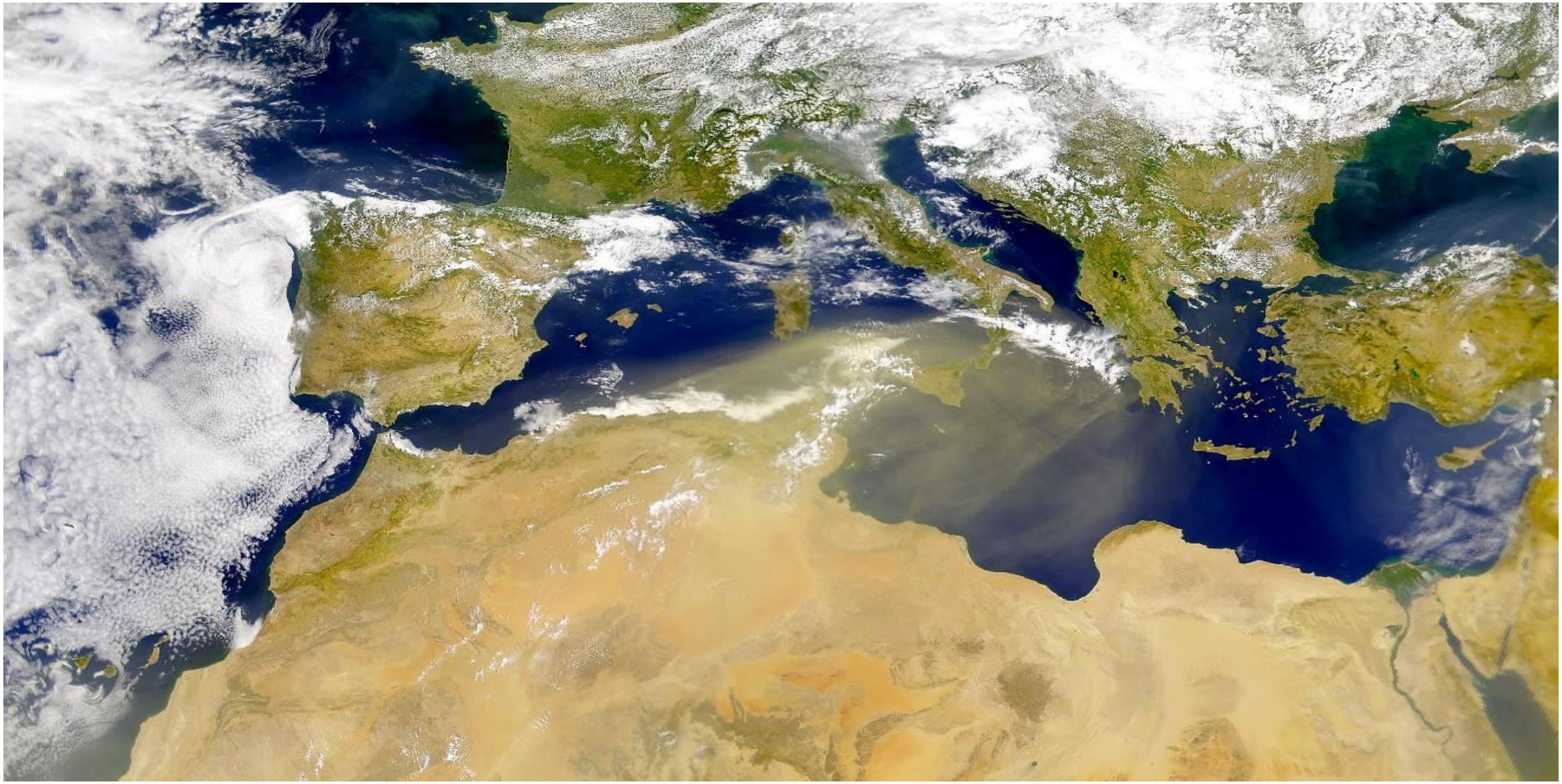
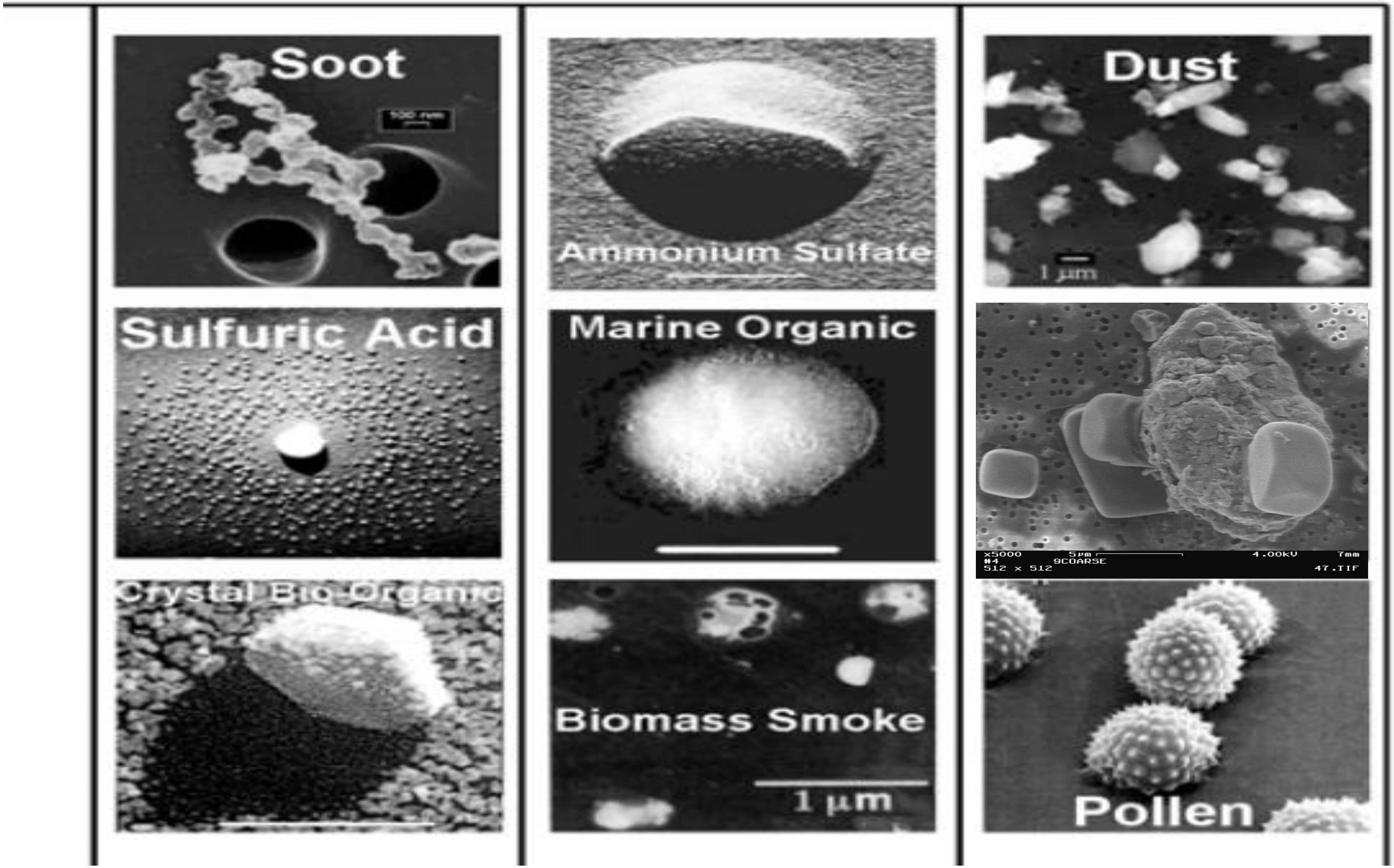
Aerosols and their interaction with climate and biogeochemical cycles in the Mediterranean basin

F. Solmon ICTP, ESP (solmon@ictp.it)

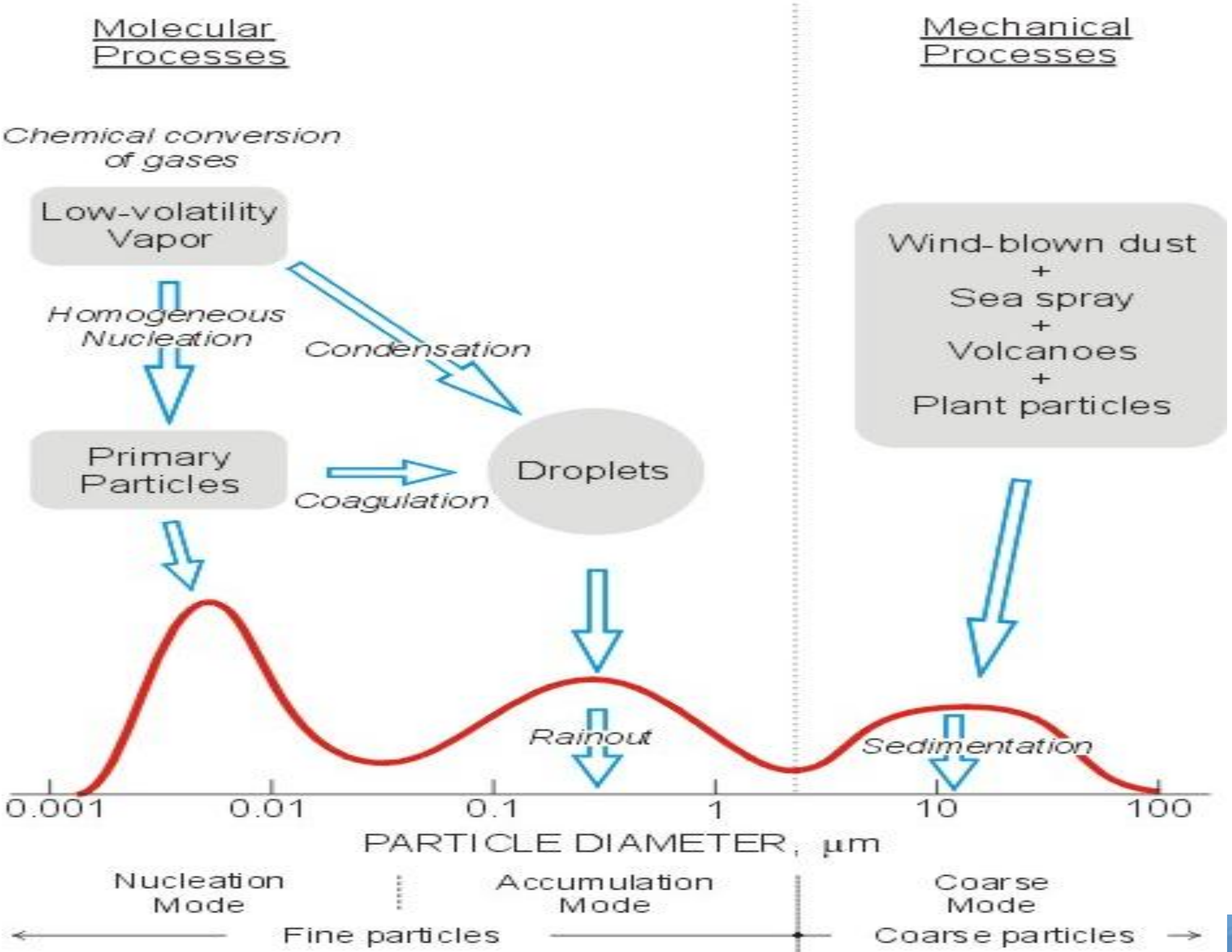


F.Dulac, M. Mallet (CNRS), The ICTP ESP group

Aerosols ?

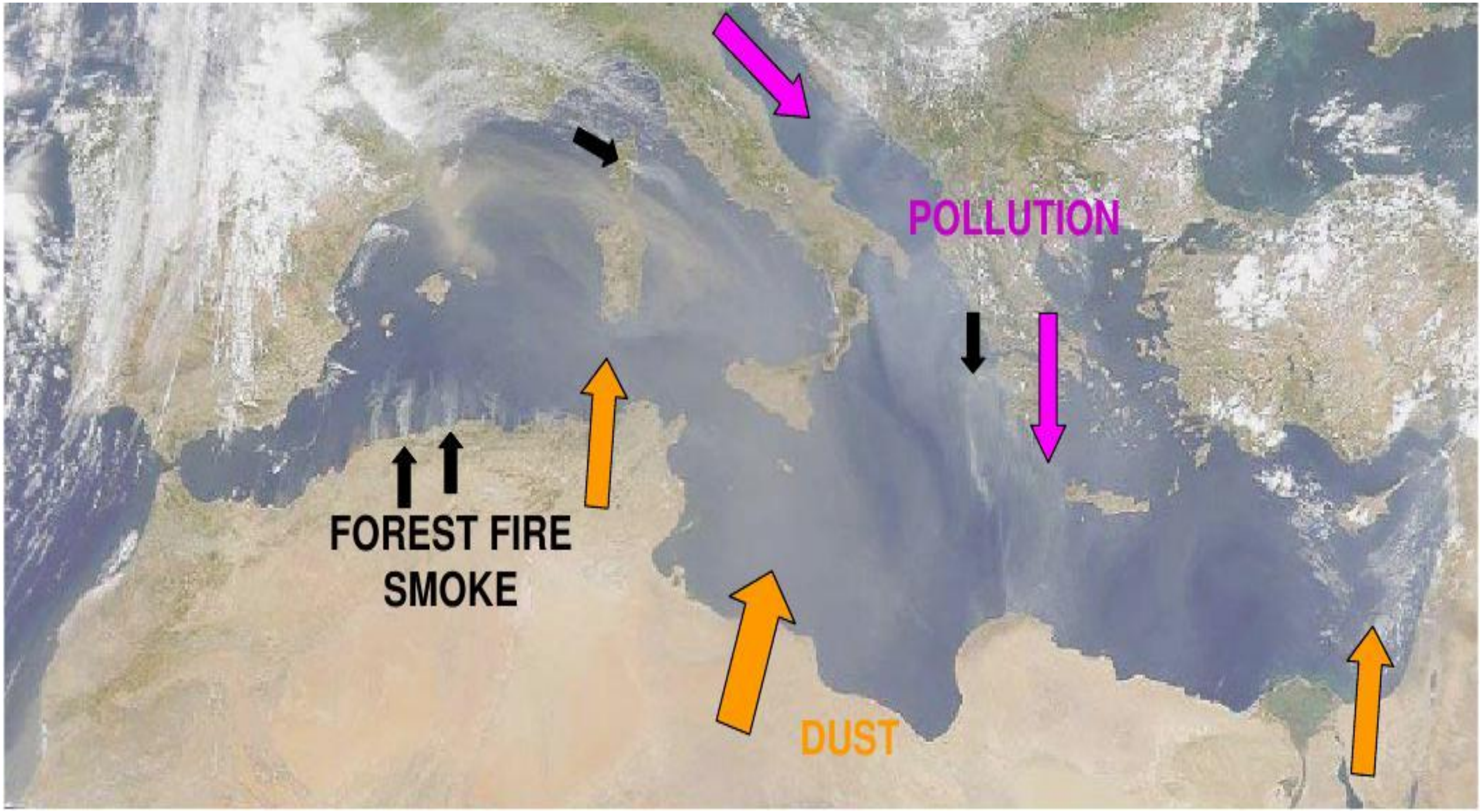

Soot
Ammonium Sulfate
Dust
1 µm
Sulfuric Acid
Marine Organic
x5000 5µm 4.00kV 7mm
#4 9COARSE
512 x 512 47.TIF
Crystal Bio-Organic
Biomass Smoke
1 µm
Pollen

Main proccesses of formation

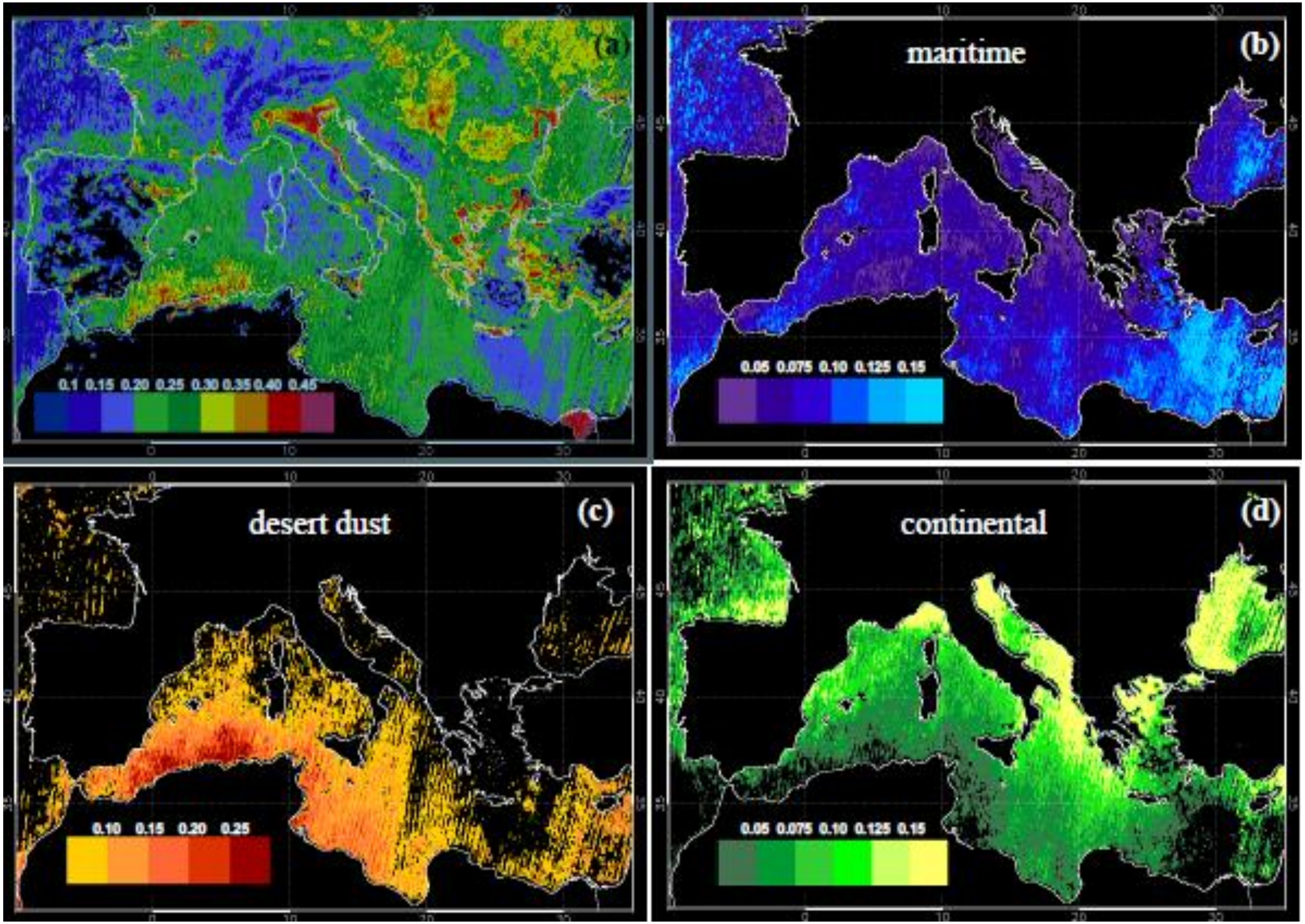


1 : Characterization of the Mediterranean aerosols

Diversity of emissions sources



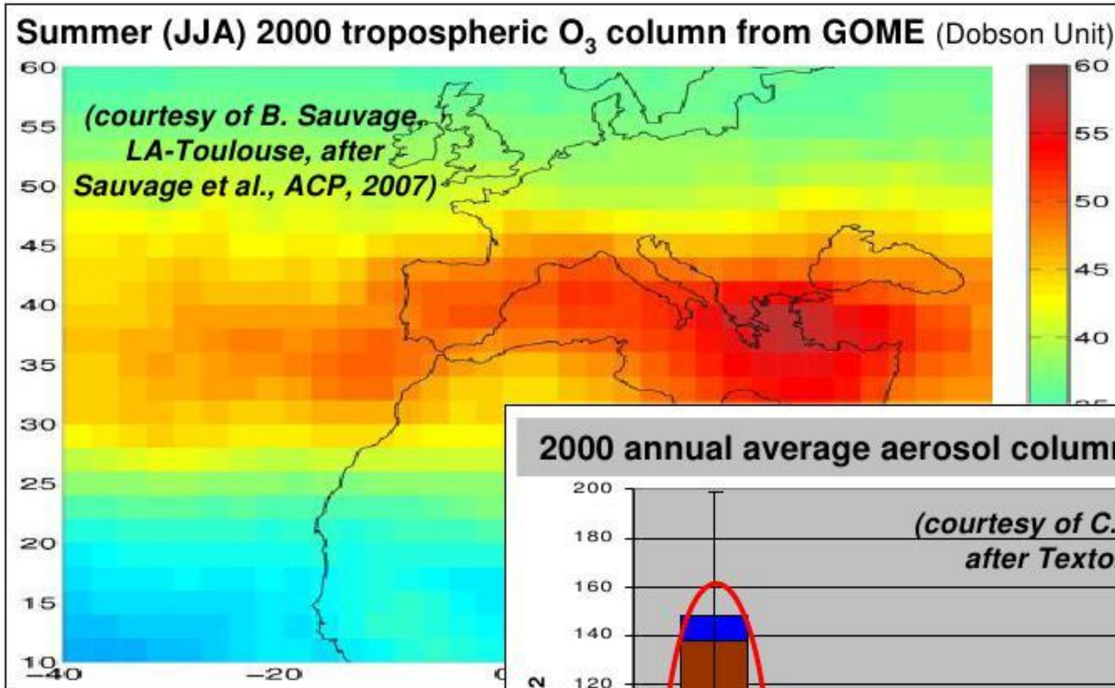
Aerosol optical depths (summer average)



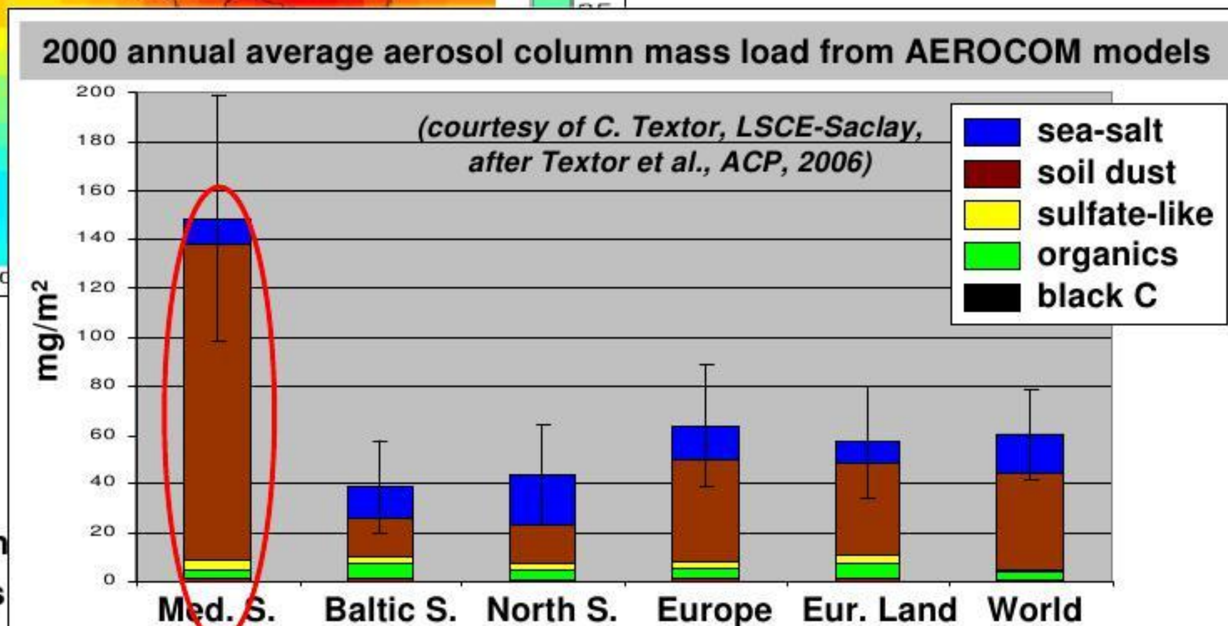
JJA 2005

Barnaba and Gobi 2004

The regional maximum in ozone…

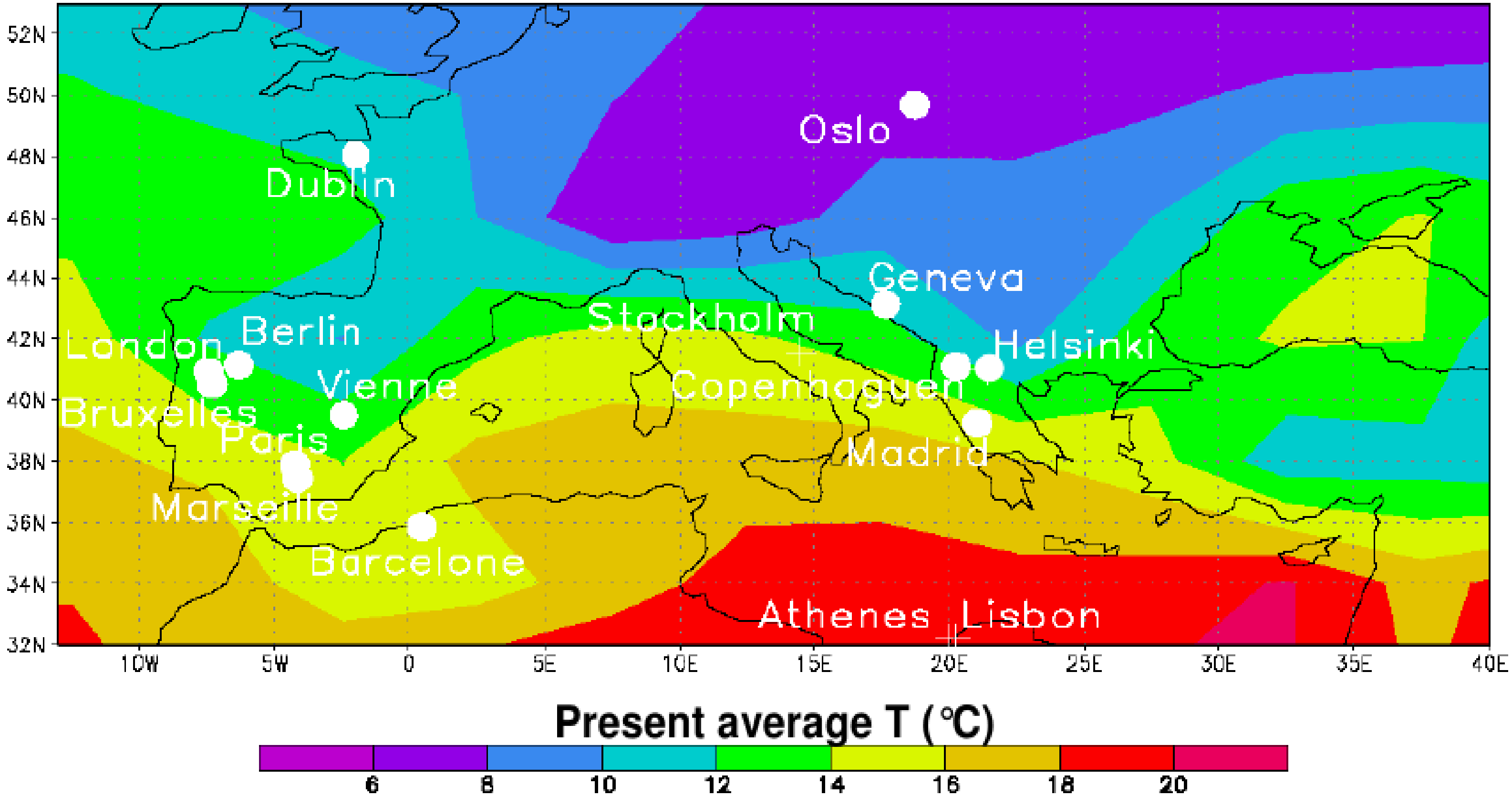


and aerosols



⇨ The long dry, hot and sunny Med. season enhances emissions, photochemistry, continental air mass subsidence and recirculation causing high pollution levels

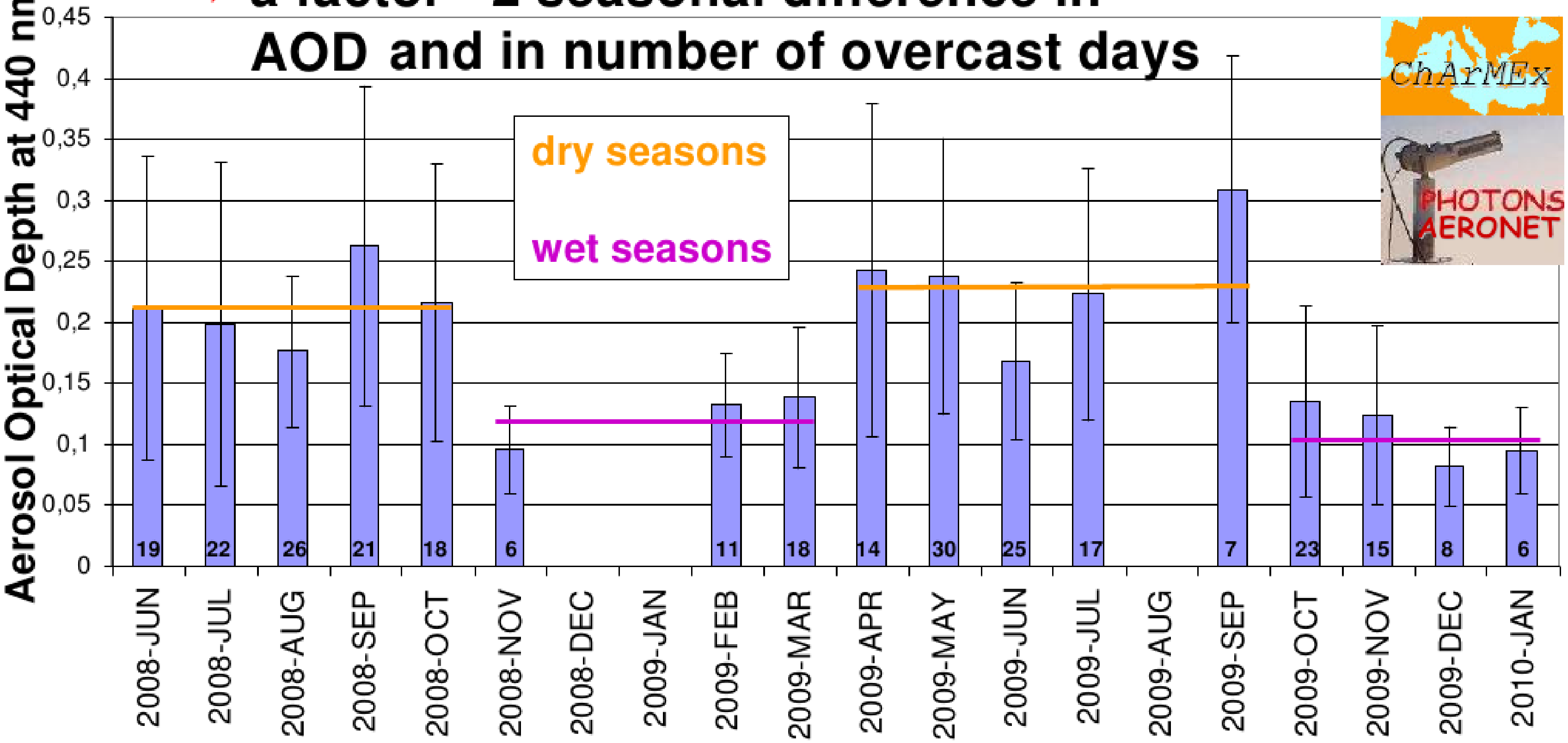
Relocation of European cities according to 2070-2100 mean temperature and precipitation field *(after Hallegatte et al., 2007)*



Importance of understanding atmospheric chemistry in Mediterranean region

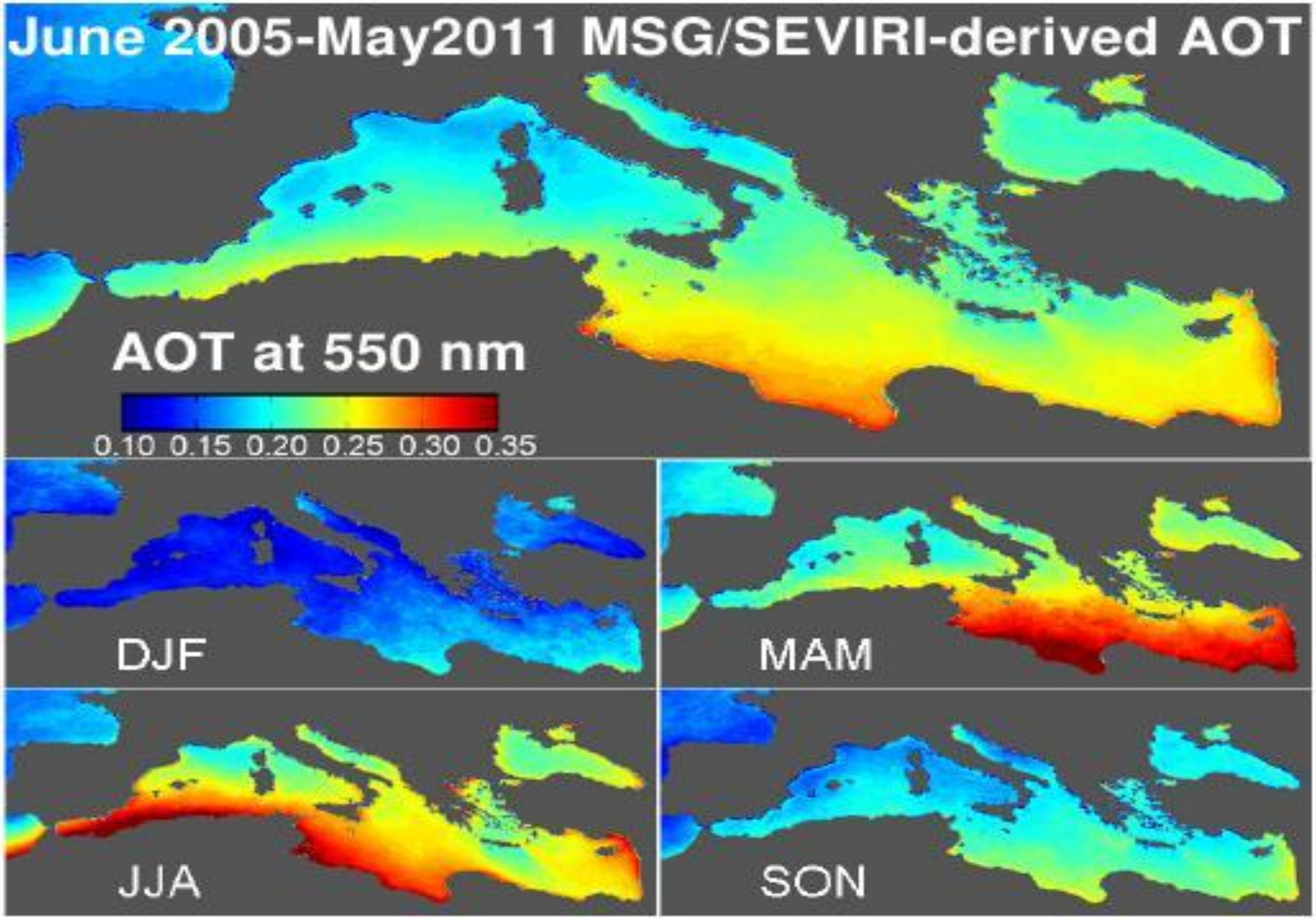
Temporal variability : seasonal scale

⇨ a factor ~2 seasonal difference in AOD and in number of overcast days



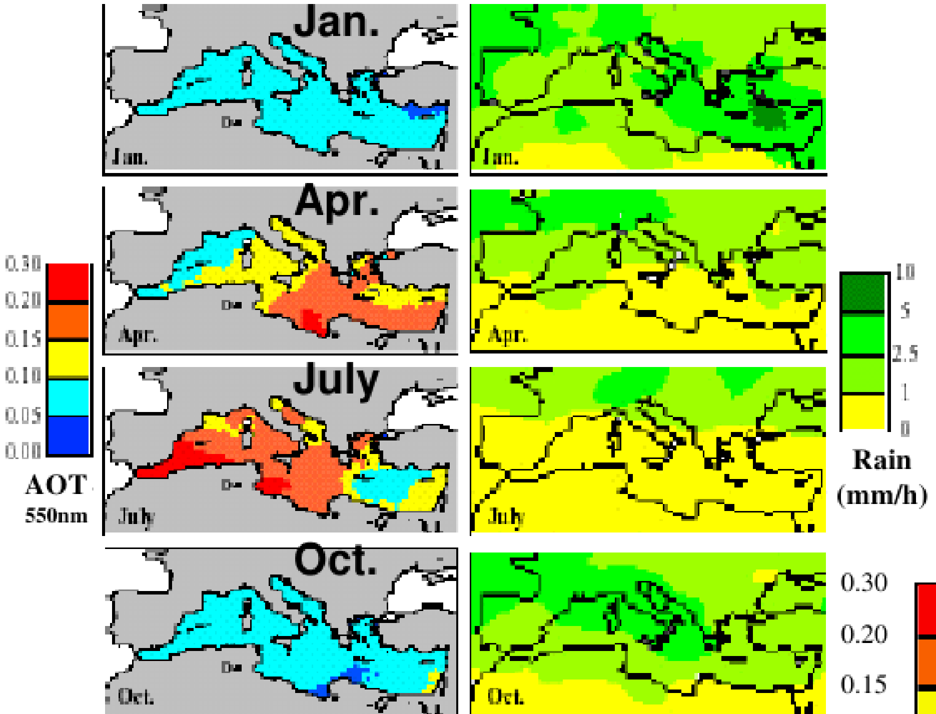
ChArMEx

PHOTONS AERONET



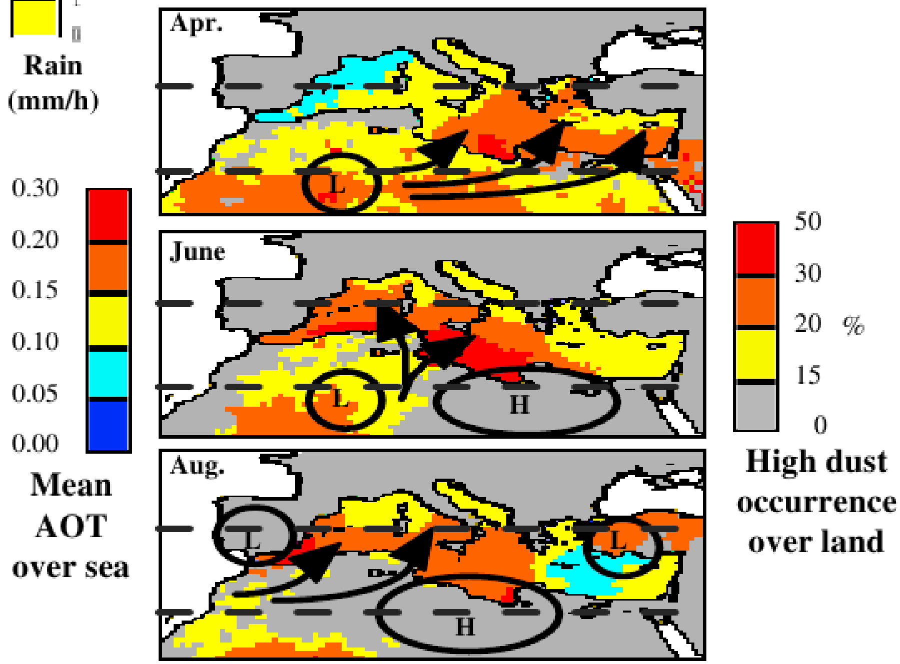
Lionello et al. MedCliVAR book.

A control of the aerosol seasonal variability by rain

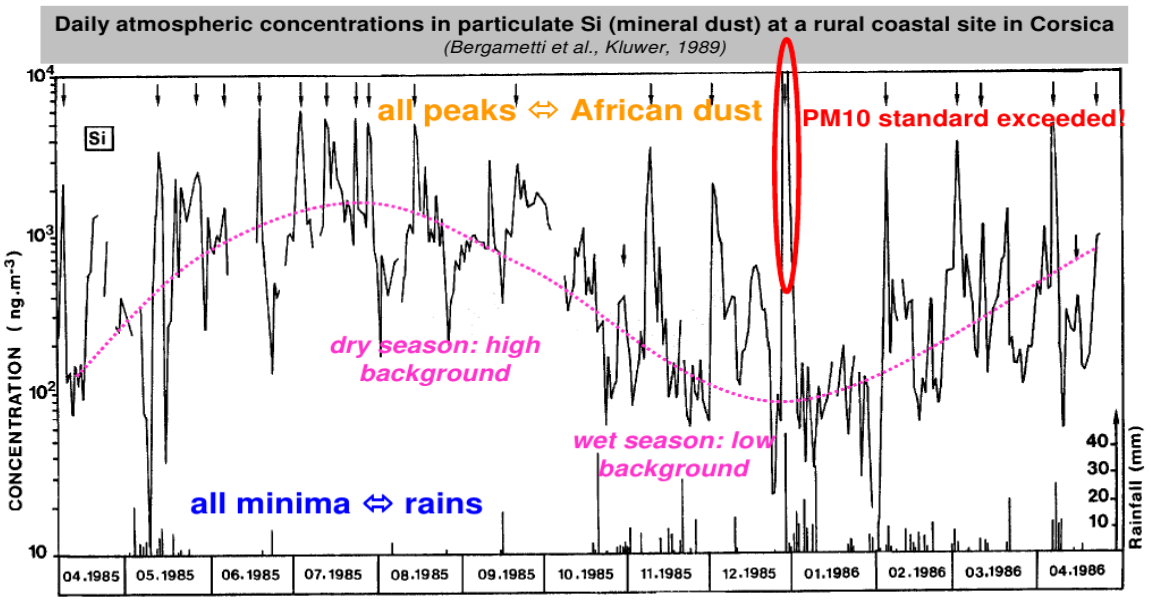


Aerosols: 1984-1994 ave. from Meteosat
Precipitation: 1979-1988 ave. from AMIP
(Moulin et al., JGR, 1998)

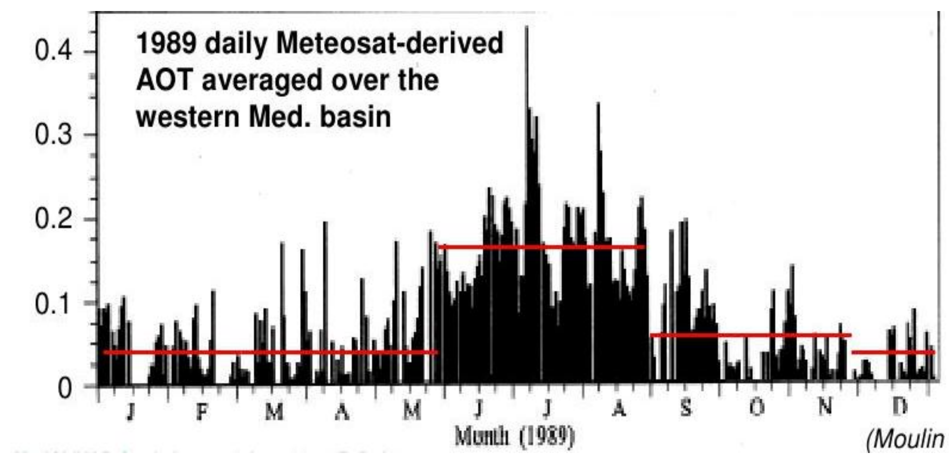
and cyclogenesis



Temporal variability : daily scale



Relevance in term of impacts (air quality)

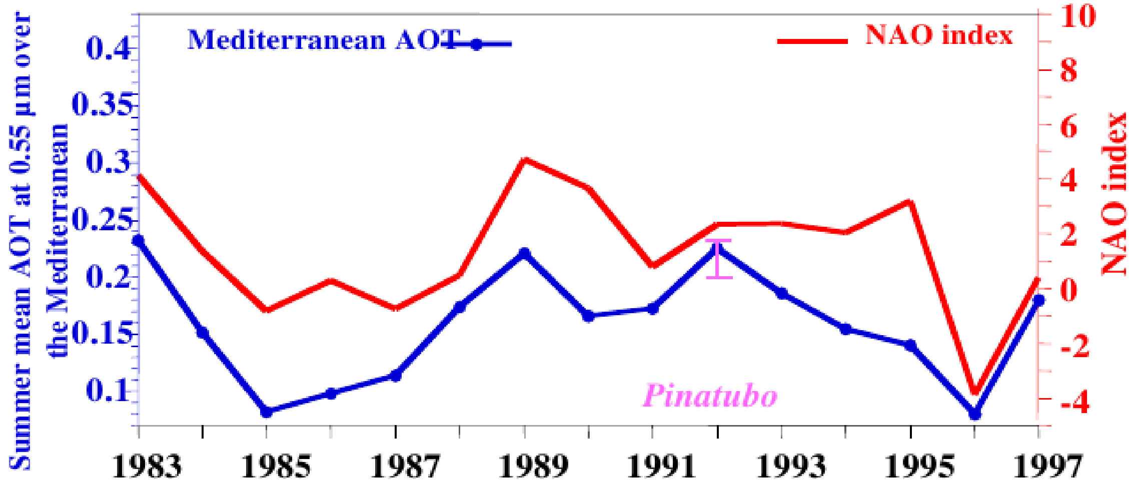


(Moulin et al., JGR, 1998)

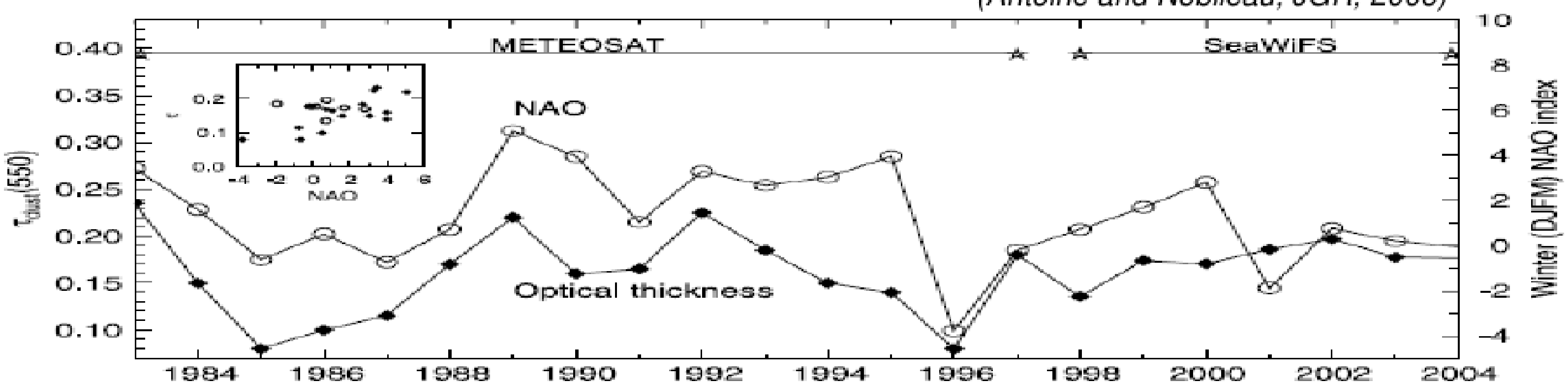
Temporal variability: inter-annual scale

A : Climate control

(Extended from Moulin et al., Nature, 1997; courtesy of C. Moulin, LSCE)



(Antoine and Nobileau, JGR, 2006)

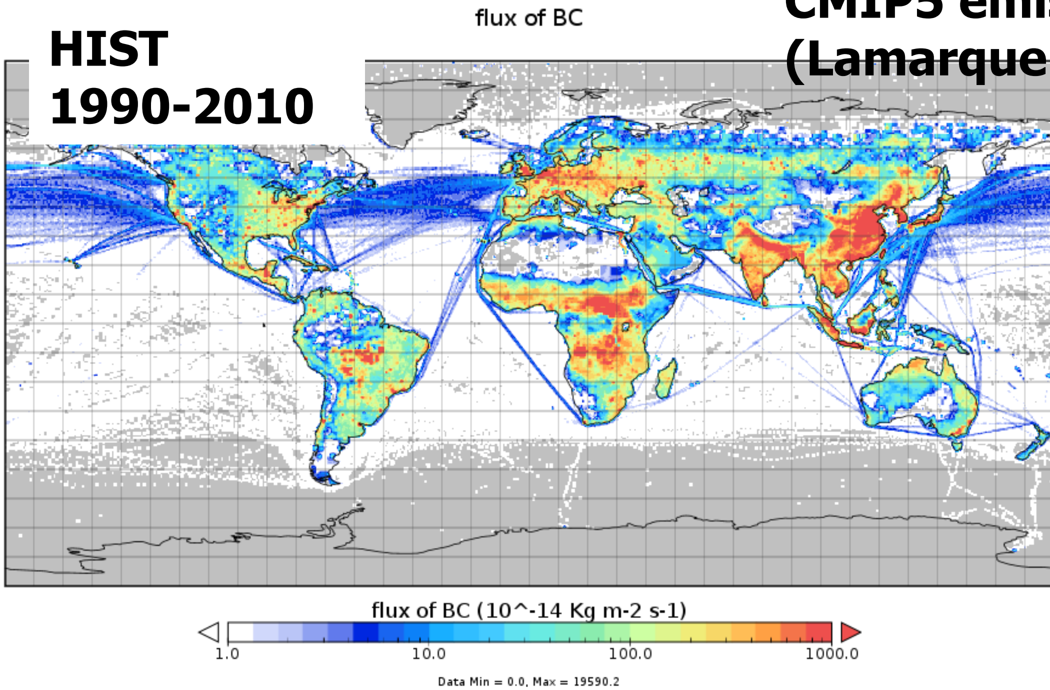


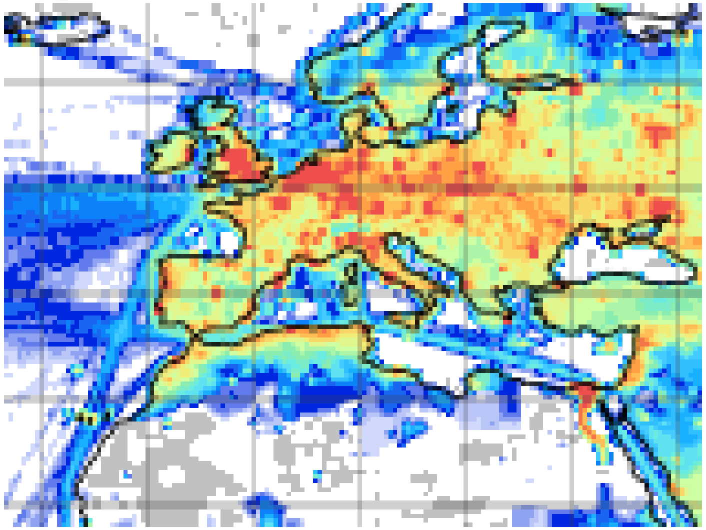
Temporal variability: inter-annual scale

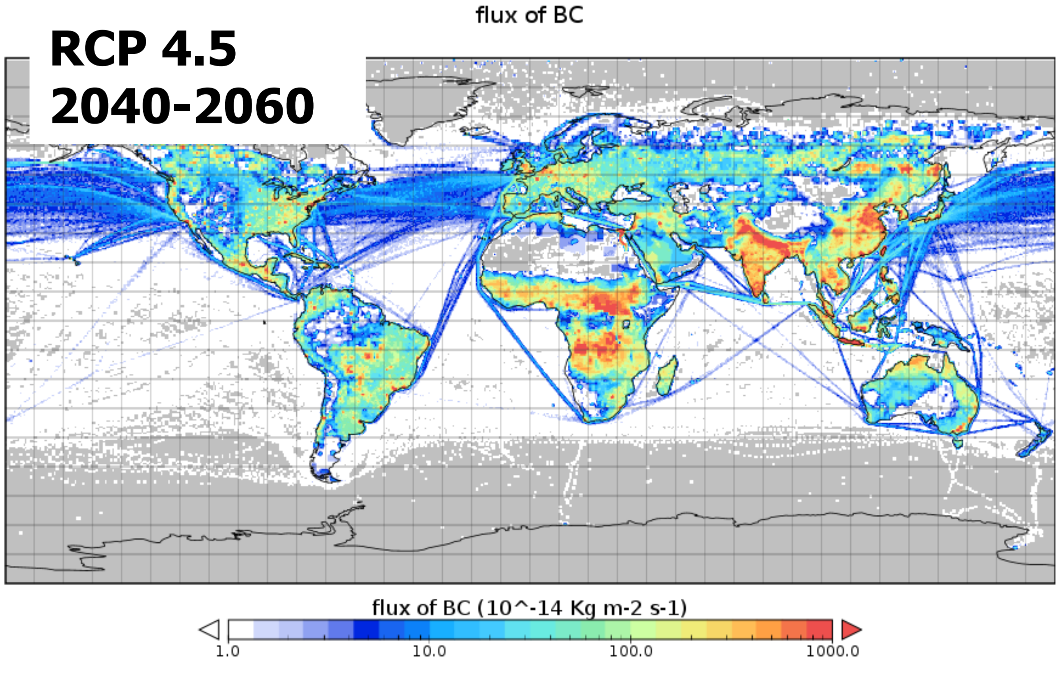
B : Emission control

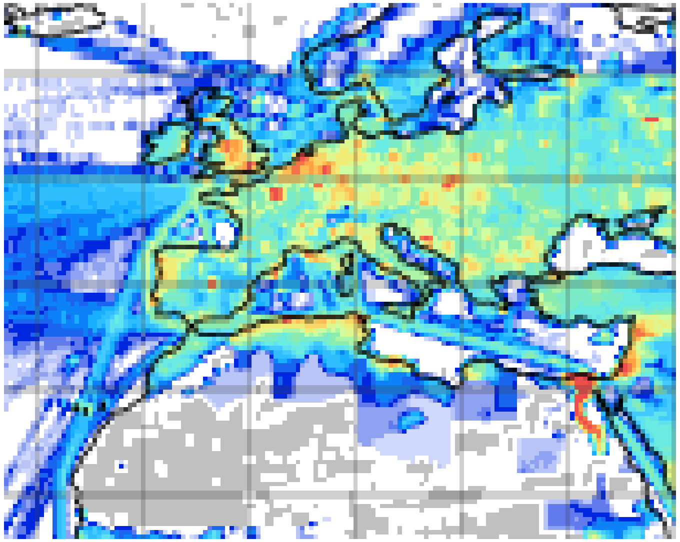
Anthropogenic emission evolution

CMIP5 emissions (Lamarque et al.)









Temporal variability: inter-annual scale

B : Emission control

Anthropogenic emission evolution

Land use change - ecosystem evolution (partly controlled by climate) (dust / biomass burning / biogenic emissions)

MODIS-derived episodes of large forest fire plumes affecting the western Med.
(Pace et al., JGR, 2005)

Year	Period	AOT_{550}
2000	20-23 July	0.21±0.04
2001	25-29 July	0.24±0.09
2002	27-30 July	0.16±0.15
2003	8-12 July	0.22±0.06
	4-14 August*	0.21±0.04
2004	15-17 August	0.11±0.05

*heat wave

MODIS observations between 2000 and 2004 show that the summer 2003 forest fire aerosol episode was the longest lasting and covered the largest area (Pace et al., 2005, JGR).

Modelling of atmospheric climate /chemistry/ aerosols in Mediterranean regions : a number of challenges !

Example 1 : Dust modelling

e.g. RegCM : Dust module

$$\frac{\partial \chi}{\partial t} = -\bar{V} \cdot \nabla \chi + F_H + F_V + T_{CUM} + S_\chi - R_{w,ls} - R_{w,cum} - D_{dep} + \sum Q_p - Q_l$$

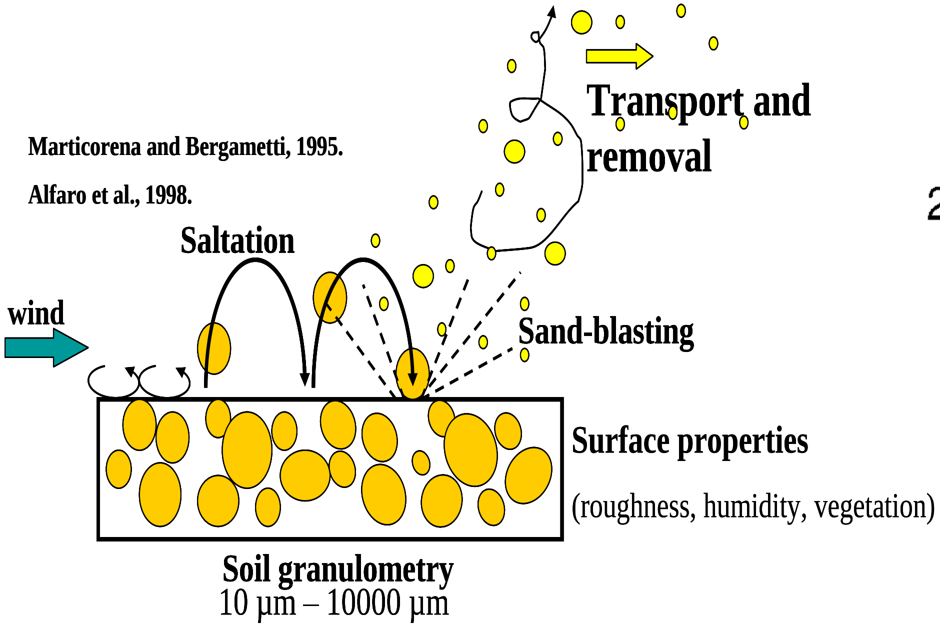
Transport ($-\bar{V} \cdot \nabla \chi + F_H + F_V + T_{CUM}$)

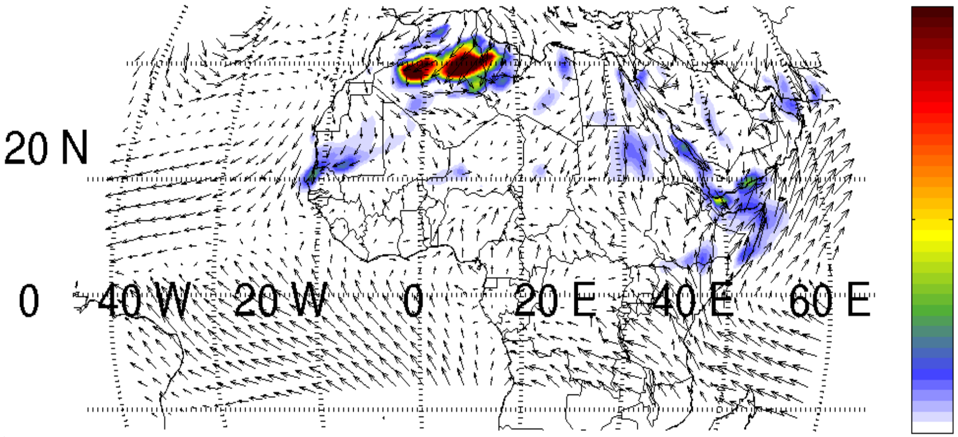
Primary Emissions (S_χ)

Removal terms ($R_{w,ls}$, $R_{w,cum}$, D_{dep})

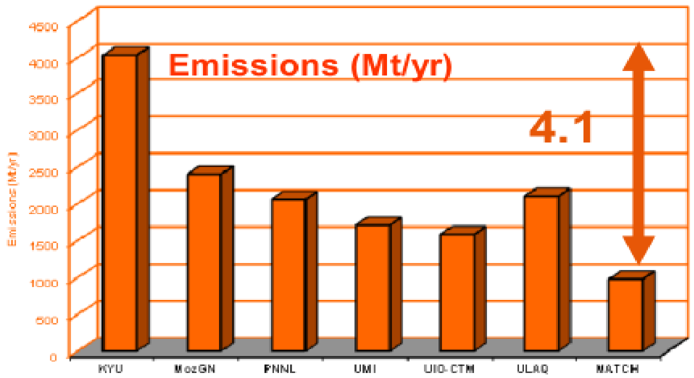
Physico – chemical transformations ($\sum Q_p - Q_l$)

Particles and chemical species considered

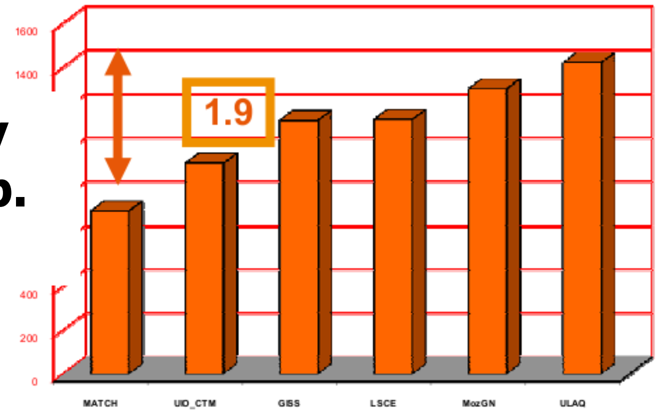


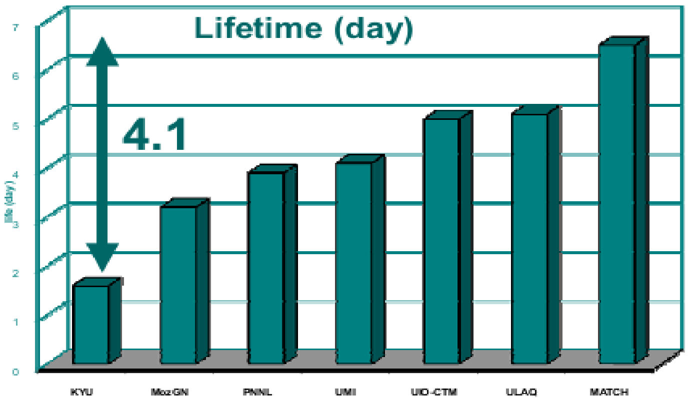


Global dust model intercomparison :

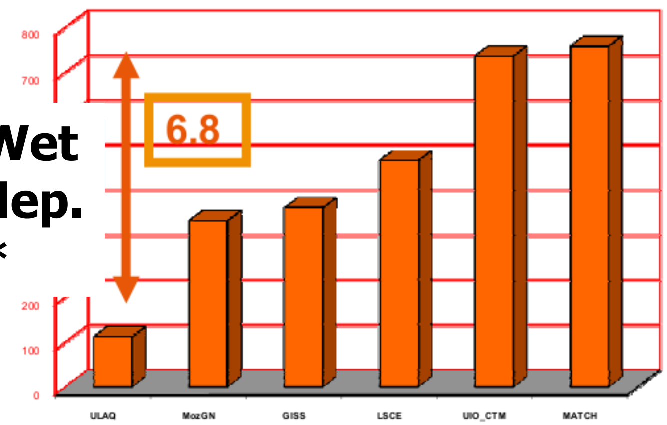


Dry dep. *





Wet dep. *



*** Prescribed emissions**

data from AEROCOM (Aerosol Model Comparison; http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/; Textor et al., Atmos. Chem. Phys., 2006; 2007)

Importance of dust EMISSION size distribution:

Different approaches ...

Physically based calculation :

Established from wind tunnel studies

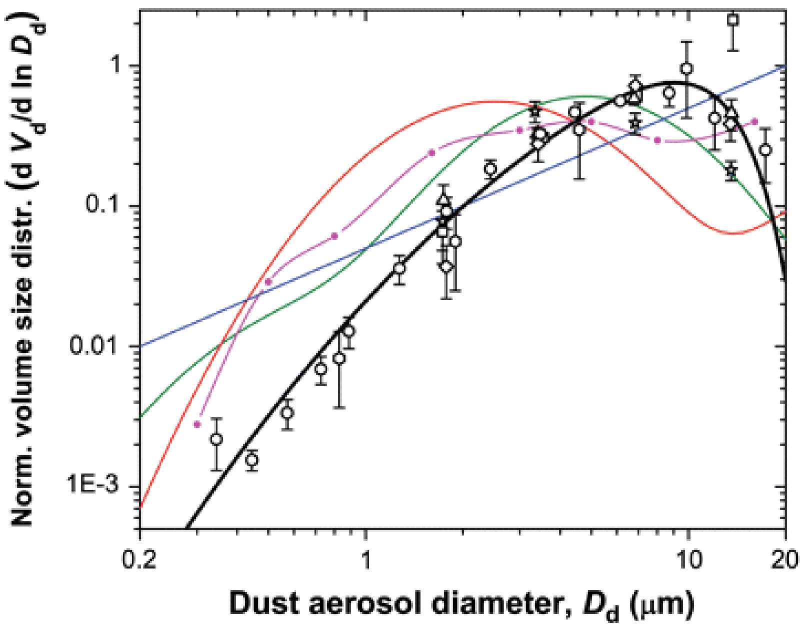
Calculate size distribution from saltation kinetic energy flux and cohesive binding forces in soil aggregates.

Requires parameters that are not easily determined

Prescribed distribution :

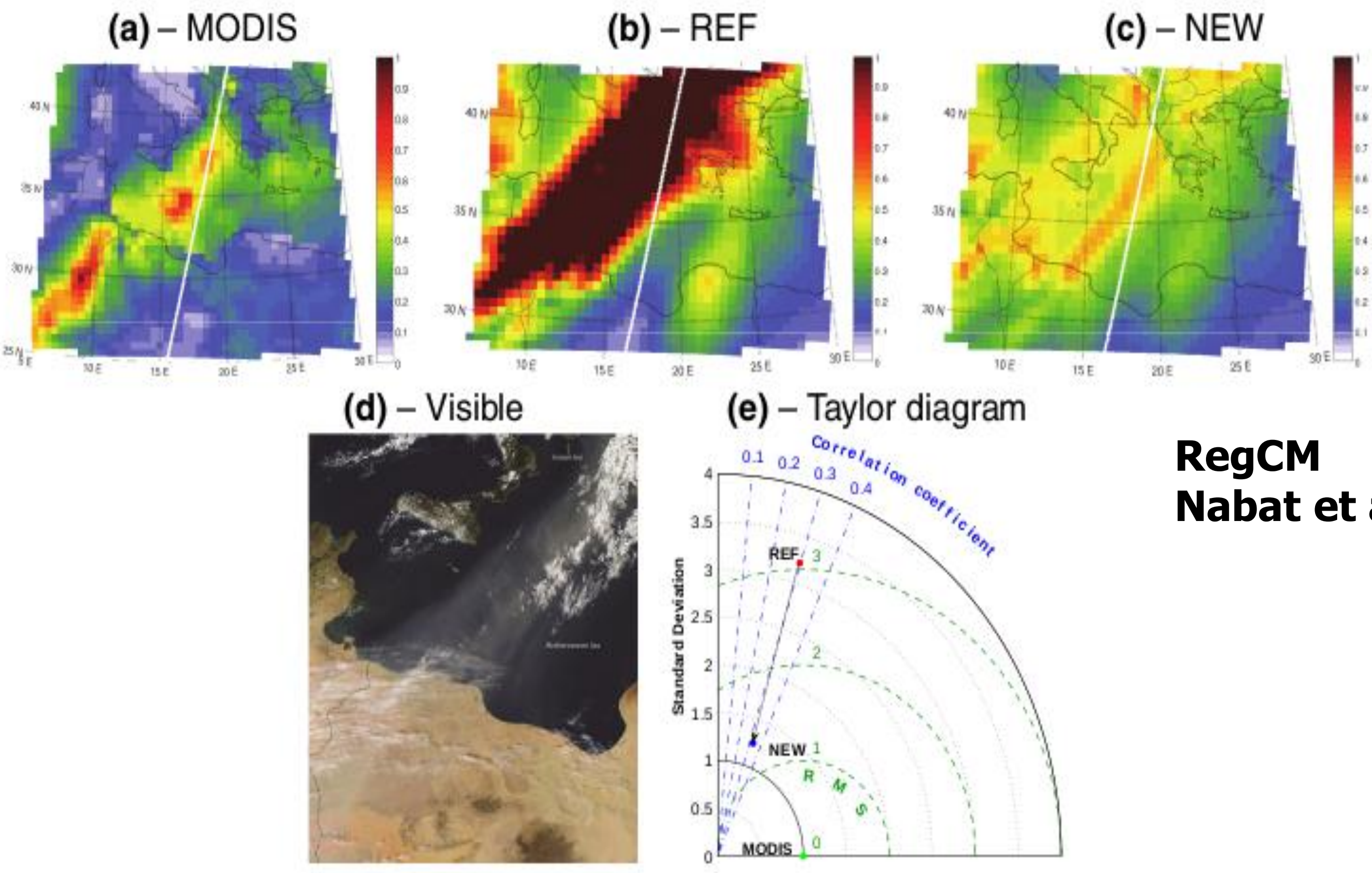
From in situ measurements

From a scaling theory (Kok et al.,)



•**Impact on deposition (and so dust budget)**

•**Impact on optical properties (extinction and AOD)**

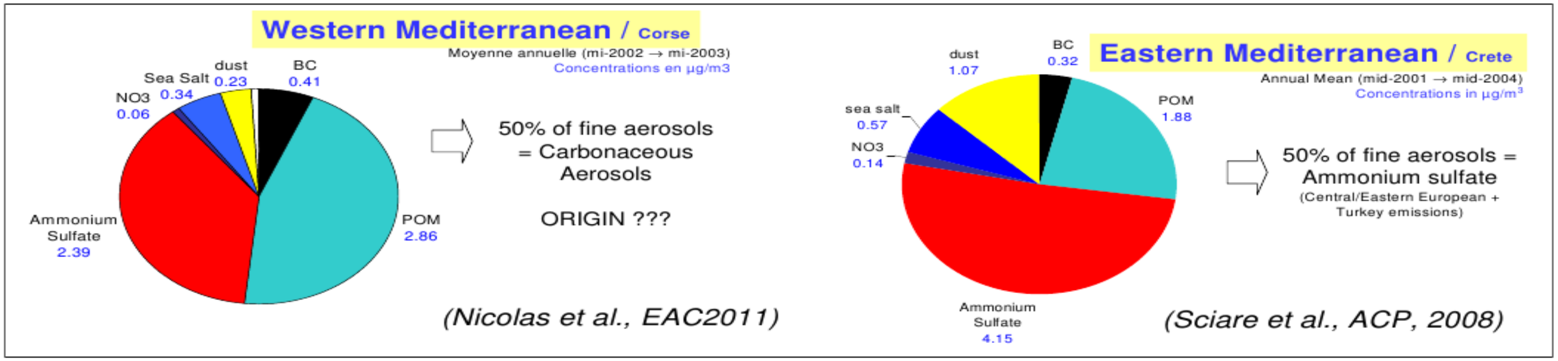


RegCM
Nabat et al., ACPD

Modelling of atmospheric chemistry/ aerosols in Mediterranean regions : a number of challenges !

Example 2 : Secondary aerosol formation

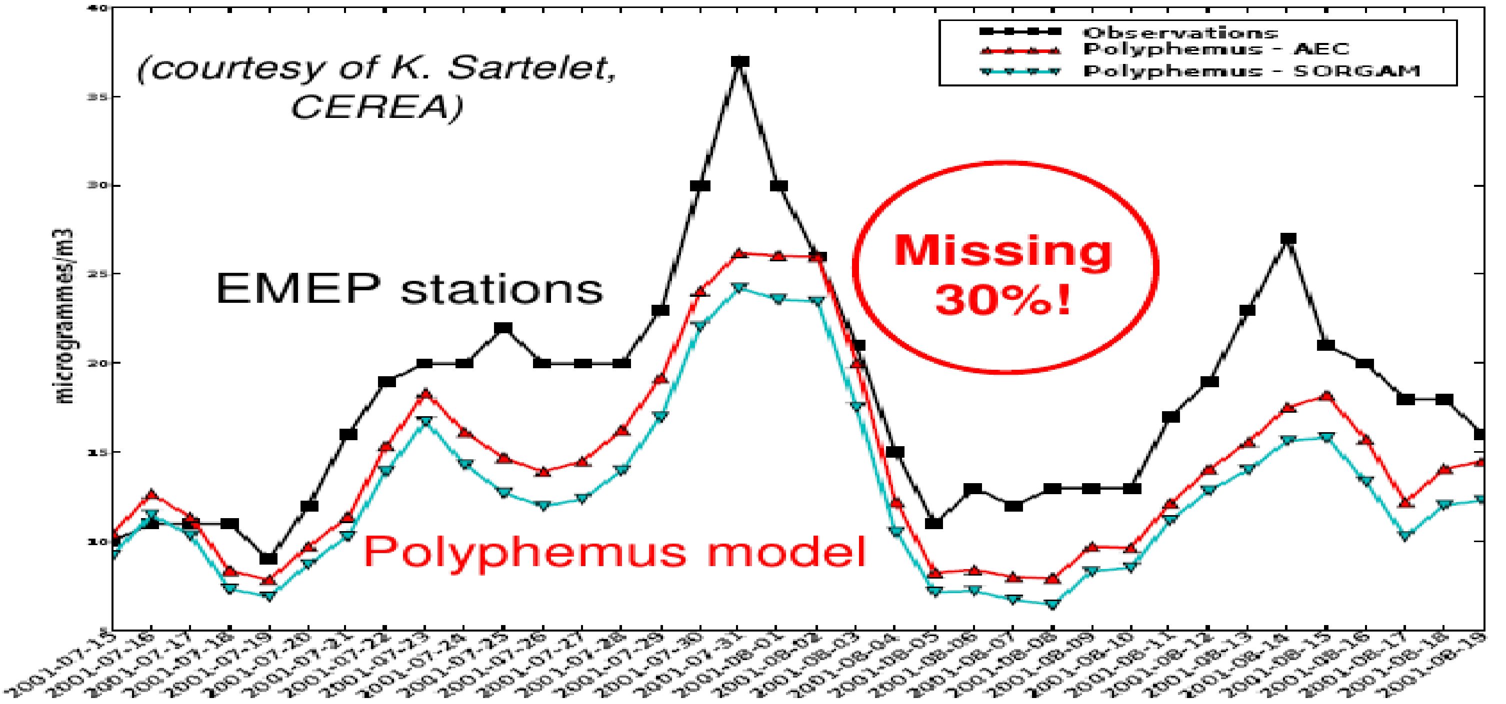
Secondary aerosol particles dominate the fine (PM2.5) particulate fraction



⇨ **Sulfate dominate in the eastern basin**
Organics dominate in the northwestern basin

Relevance of PM2.5 for air quality, ecosystem impact, and climate (direct and indirect effects)

daily PM10 over Europe in summer 2001

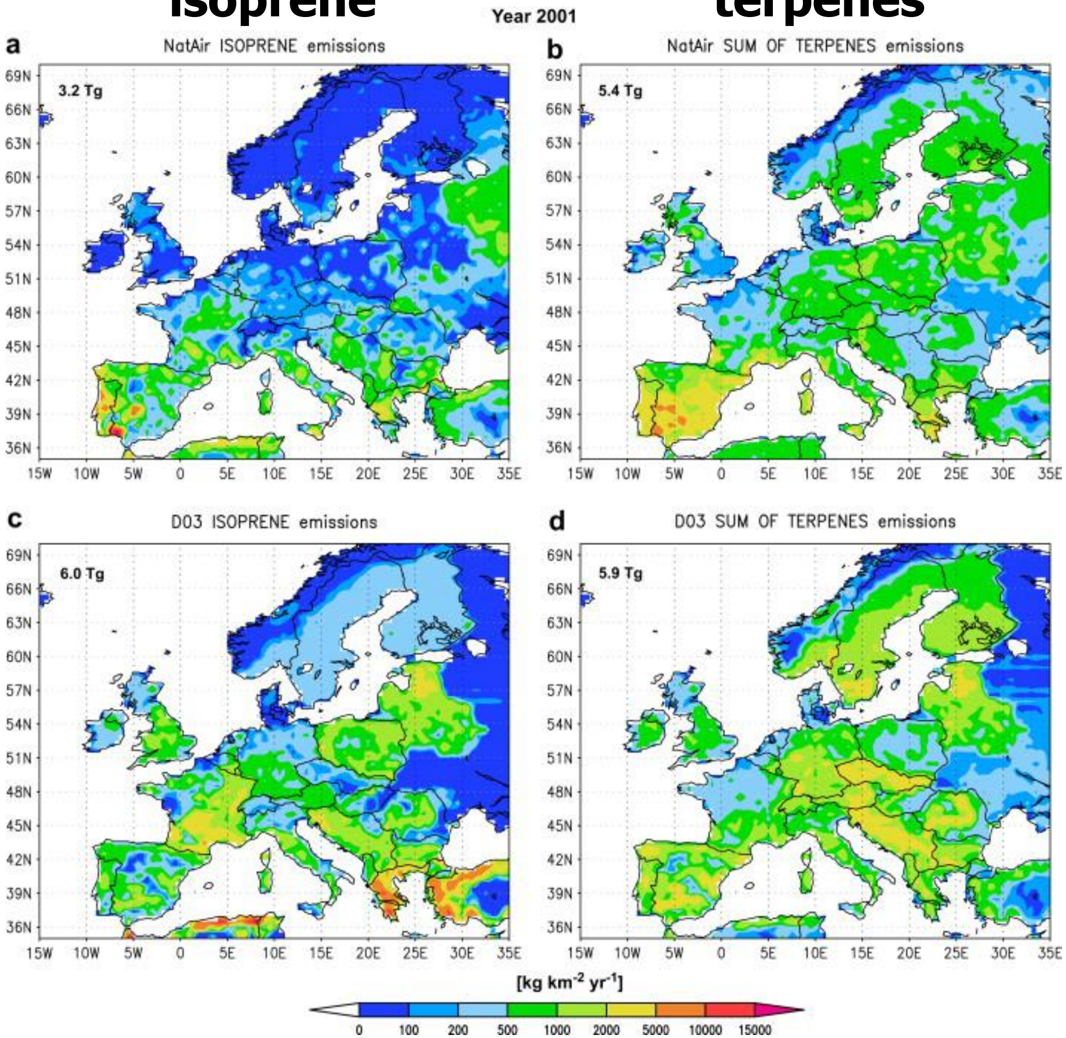


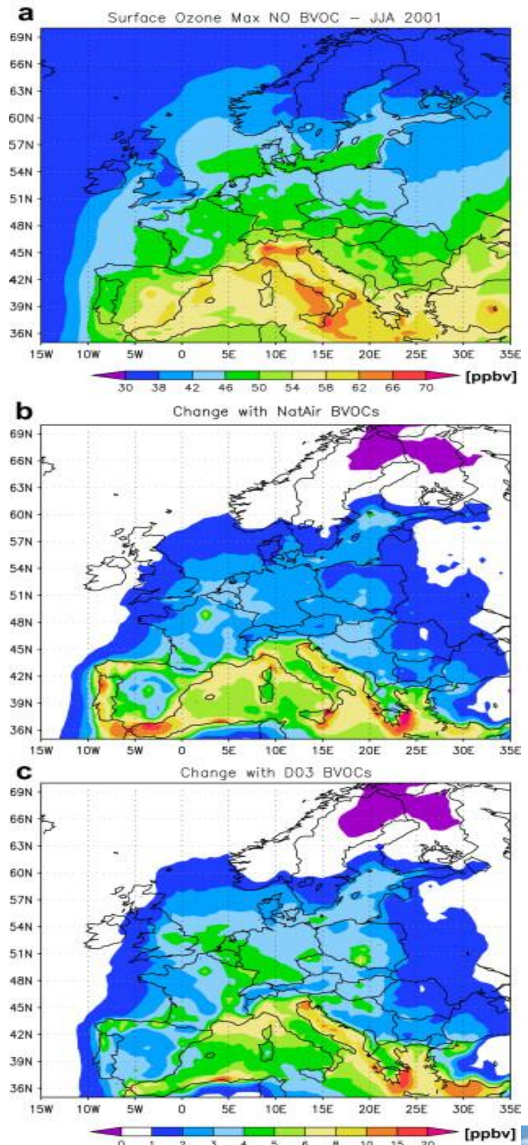
- **•Importance of including photo-oxidation processes (ozone chemistry / simulation of organic aerosol precursors)**

- **•Biogenic emissions of gas-phase precursors**
  -BVOC from forest/
  -DMS and organic from Marine

Example : Biogenic emissions from 2 different models and impact on ozone

isoprene **terpenes**



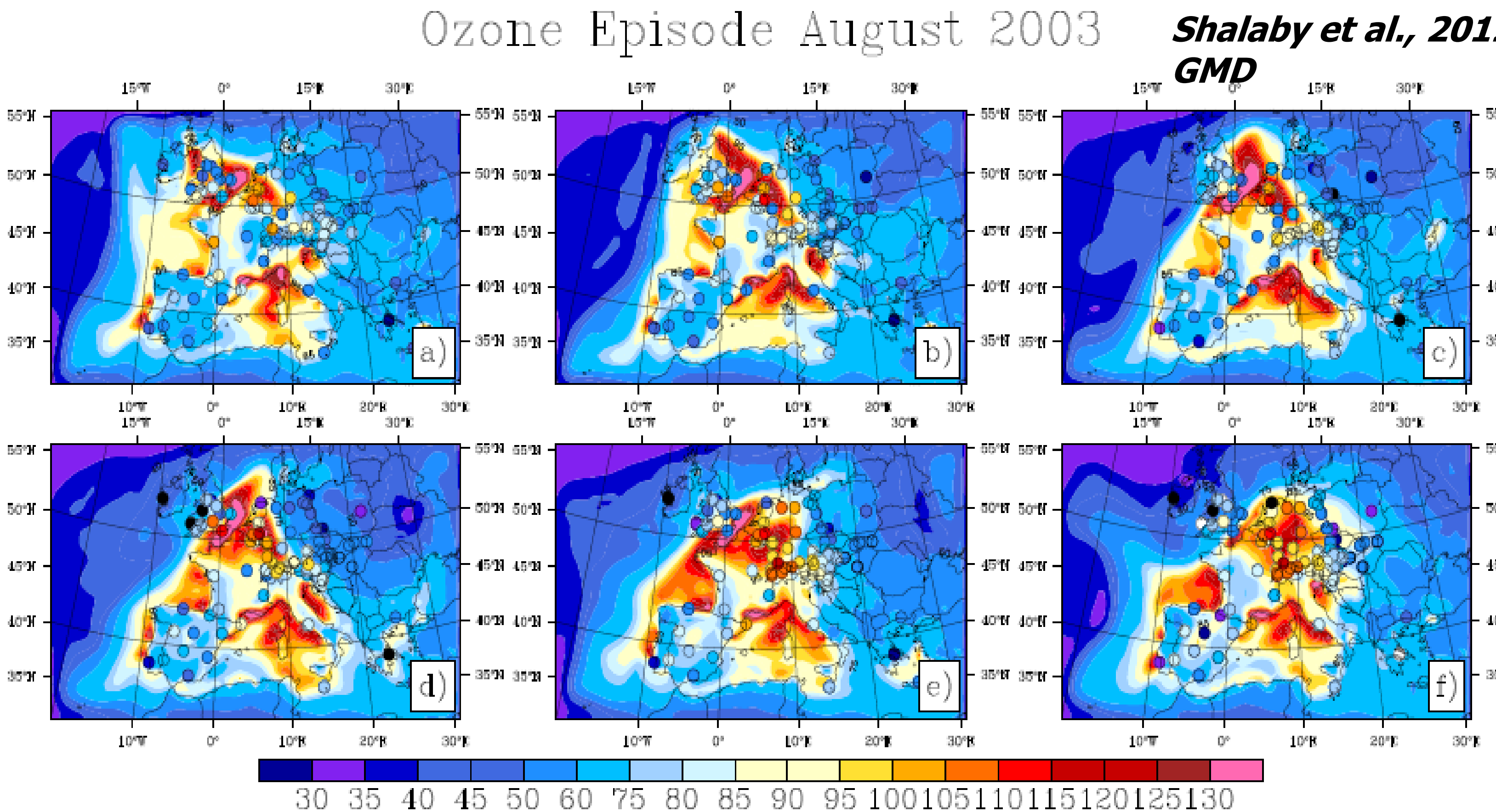


Curci et al., 2009

Towards the development of climate chemistry models …

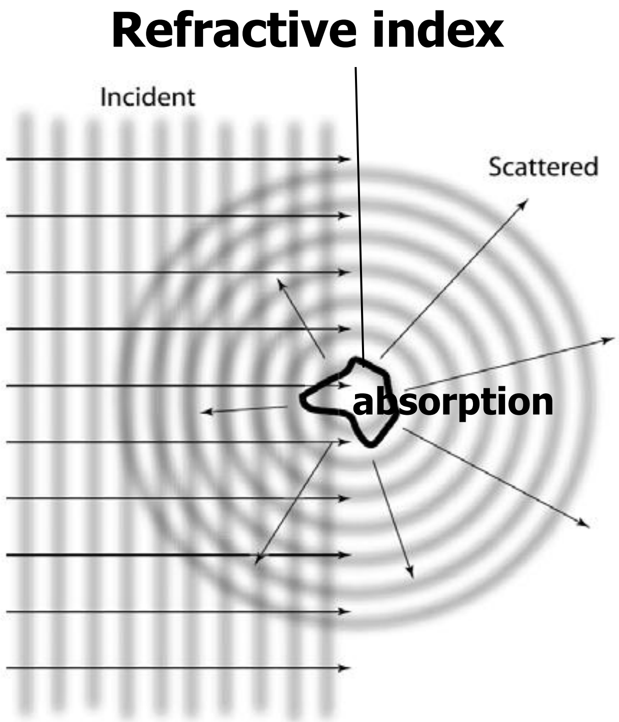
e.g : RegCM4-CHEM ozone simulation of 2003 heat wave

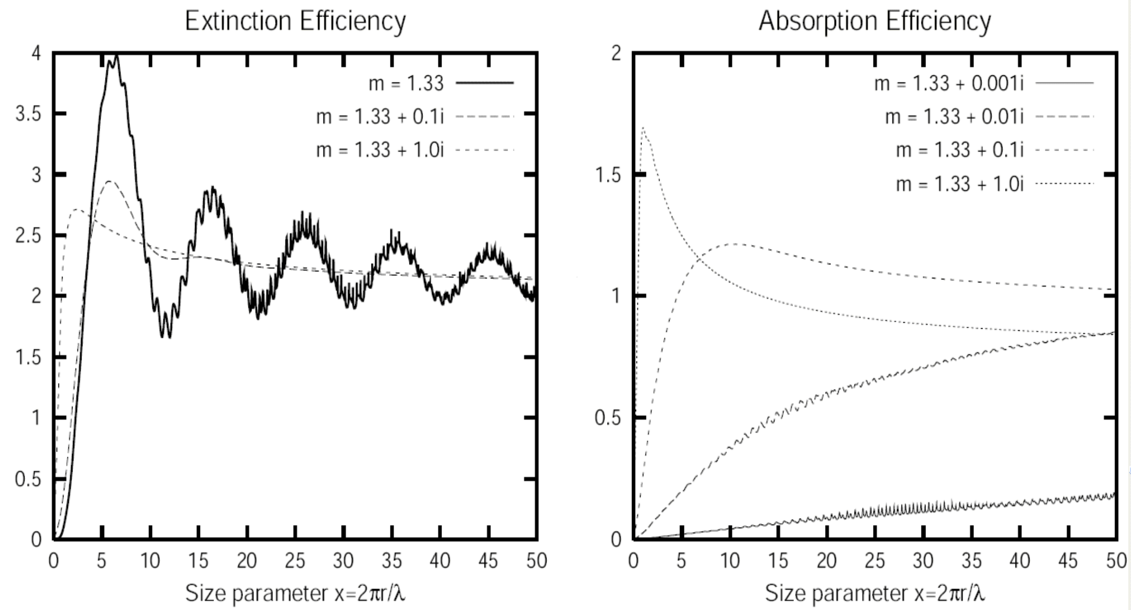
Shalaby et al., 2012 , GMD

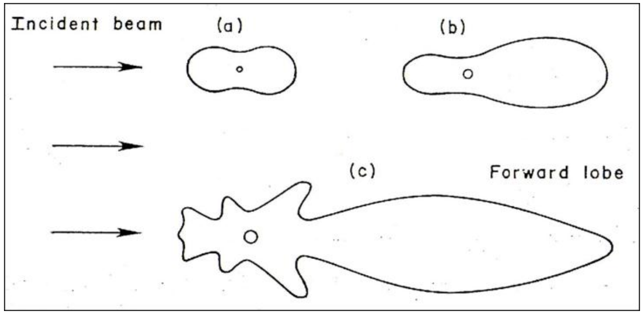


2 : Climatic feedbacks of aerosols in the Mediterranean region

A: Aerosol/radiation interaction : DIRECT EFFECT

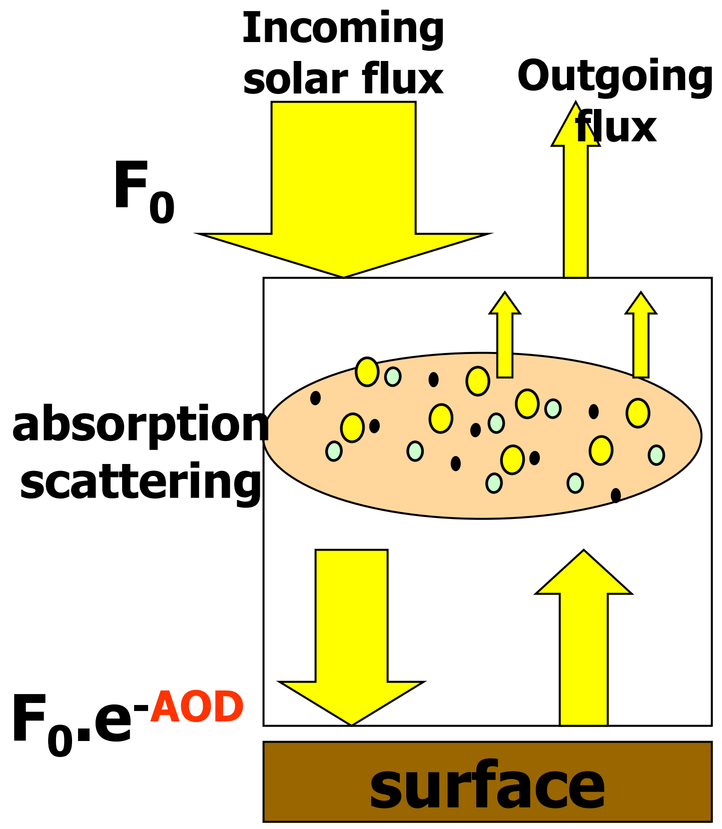






Direct effect

Aerosol Short Wave radiative forcing



Aerosol optical depth AOD describes the aerosol extinction due to the **sum** of **absorption and scattering** effects.

➡ **TOA SW Radiative forcing** : difference of outgoing fluxes without and with aerosol

All other atmospheric and surface variables being fixed.

> 0. = warming of the system

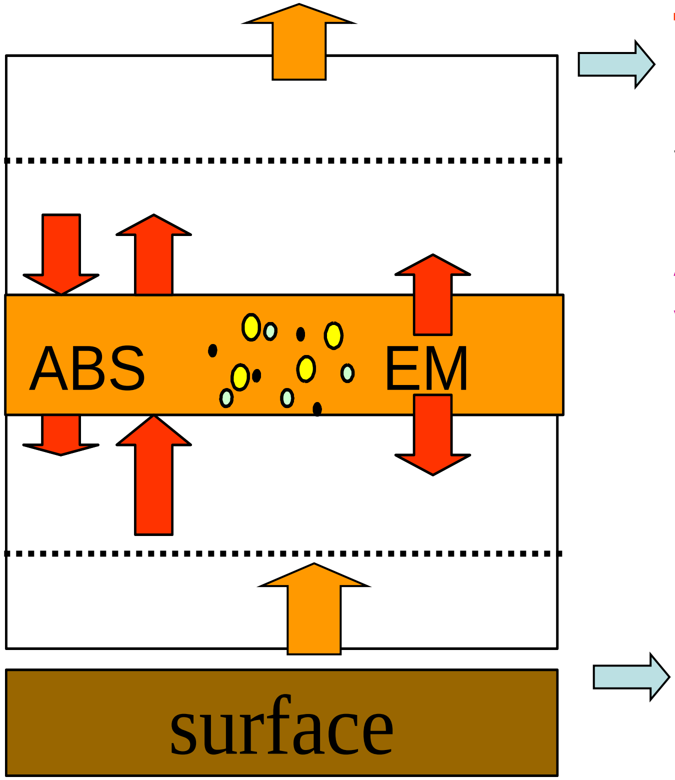
< 0. = cooling of the system

➡ **SRF SW Radiative forcing :** difference of net flux at the surface

Always < 0. = cooling of the surface

Dust Long Wave radiative forcing

Atmospheric layers absorb and emit (grey body) in thermal radiation range.



TOA LW Radiative forcing :
difference of outgoing fluxes without and with aerosol

All other atmospheric and surface variables being fixed

SRF LW Radiative forcing :
difference of net flux at the surface

Always > 0. = relative warming of the surface …

Aerosol Radiative forcing in the Mediterranean region : RegCM simulations

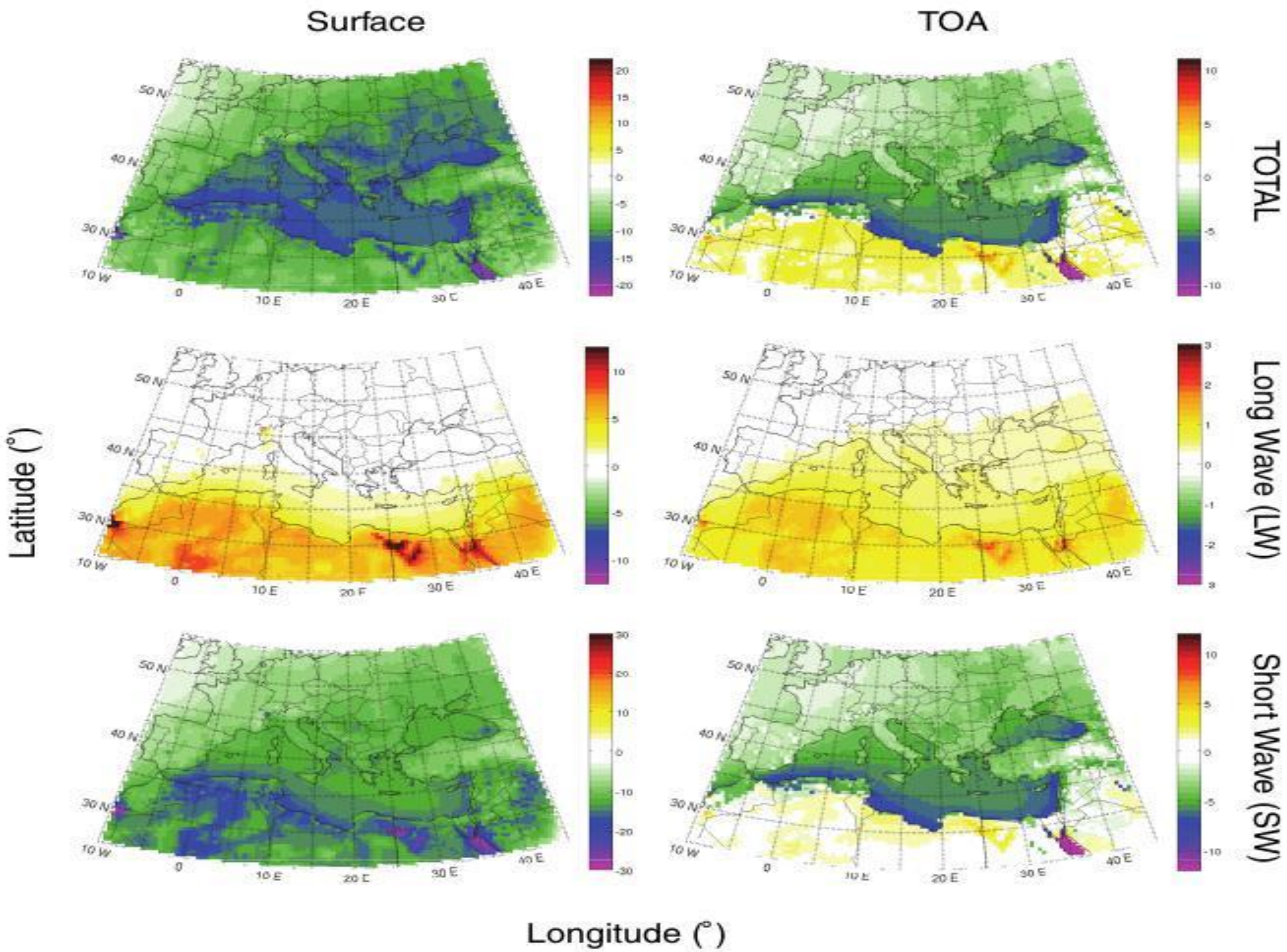
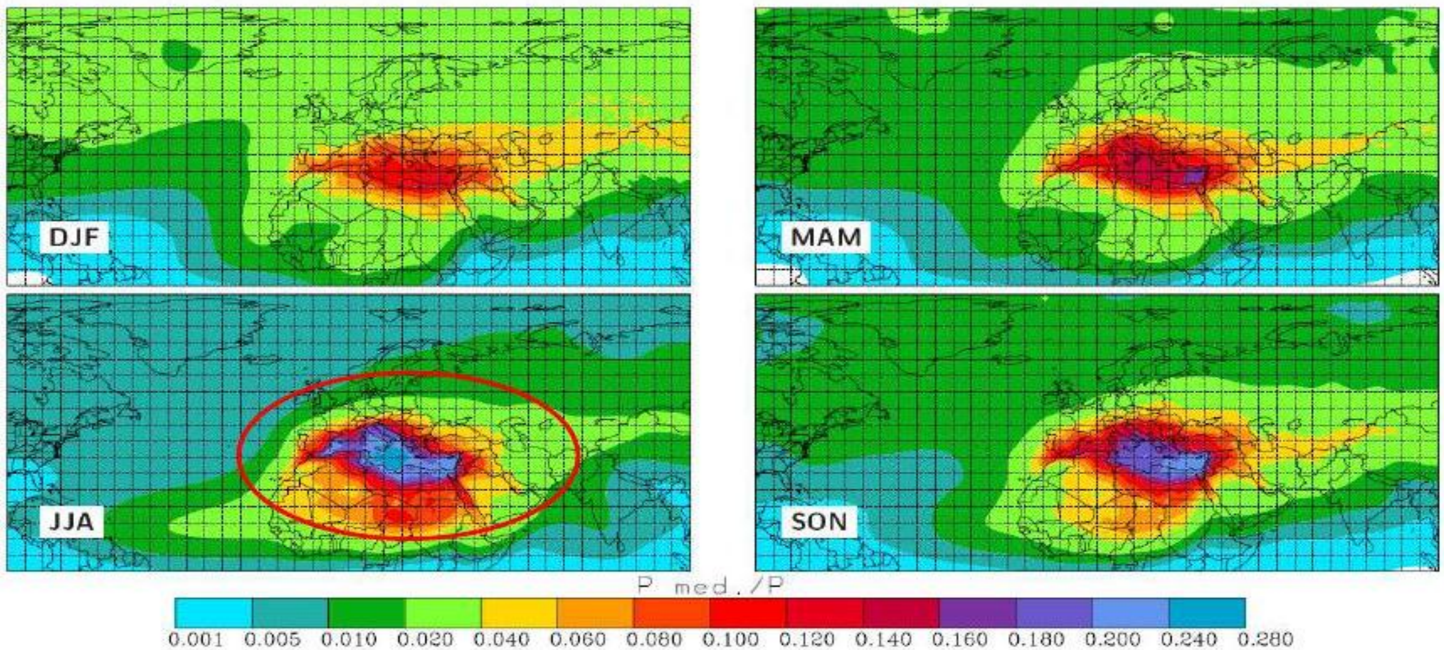


Fig. 14. Direct radiative forcing (in $\mathrm{W\,m^{-2}}$) simulated in NEW 2000–2009, at the surface (left) and at the top of the atmosphere (TOA, right), for total (top), longwave (middle) and shortwave (bottom) radiations.

Assessing the Regional climate responses to aerosol forcing …

1 : impact of surface dimming on evaporation, water budget and hydrological cycle in the mediterranean basin ?



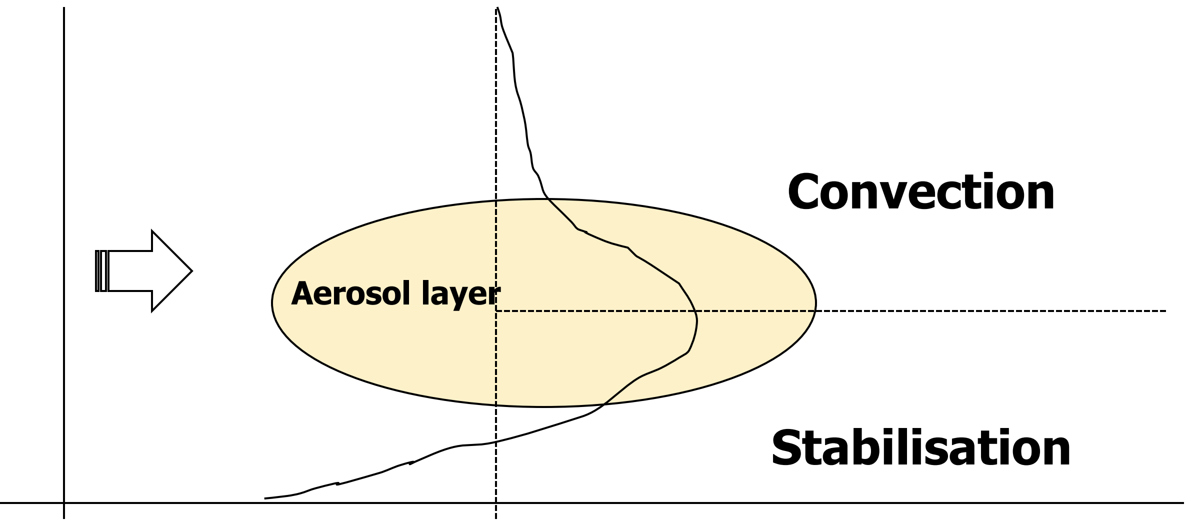
Fraction of precipitated water that evaporated inside the Mediterranean basin by different seasons (DJF, MAM, JJA and SON). Schicker et al. ACP (2010)

⇨ **Use of coupled ocean-atmosphere regional climate model**

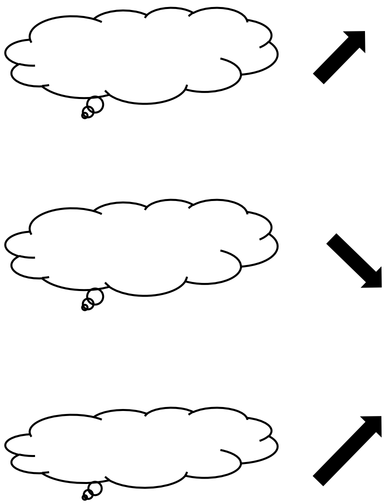
2 : perturbation of temperature profiles

➡ **Feedback on convection clouds, and regional dynamics**

Temperature profile



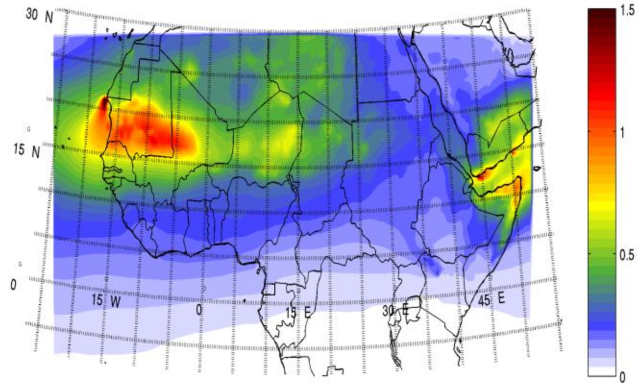
Semi-direct effects

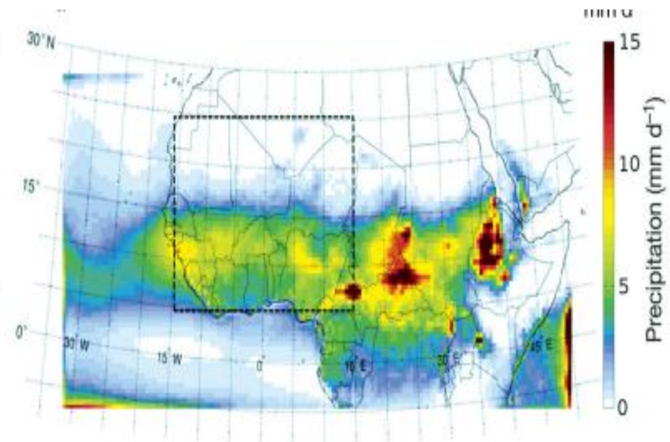


- **Amplitude of the response depends on environment (convective / unstable vs. Stable , surface albedo, …)**

- **Sensitivity to single scattering albedo (aerosol composition).**

Example , impact in monsoon region (RegCM JJA 1996-2006))





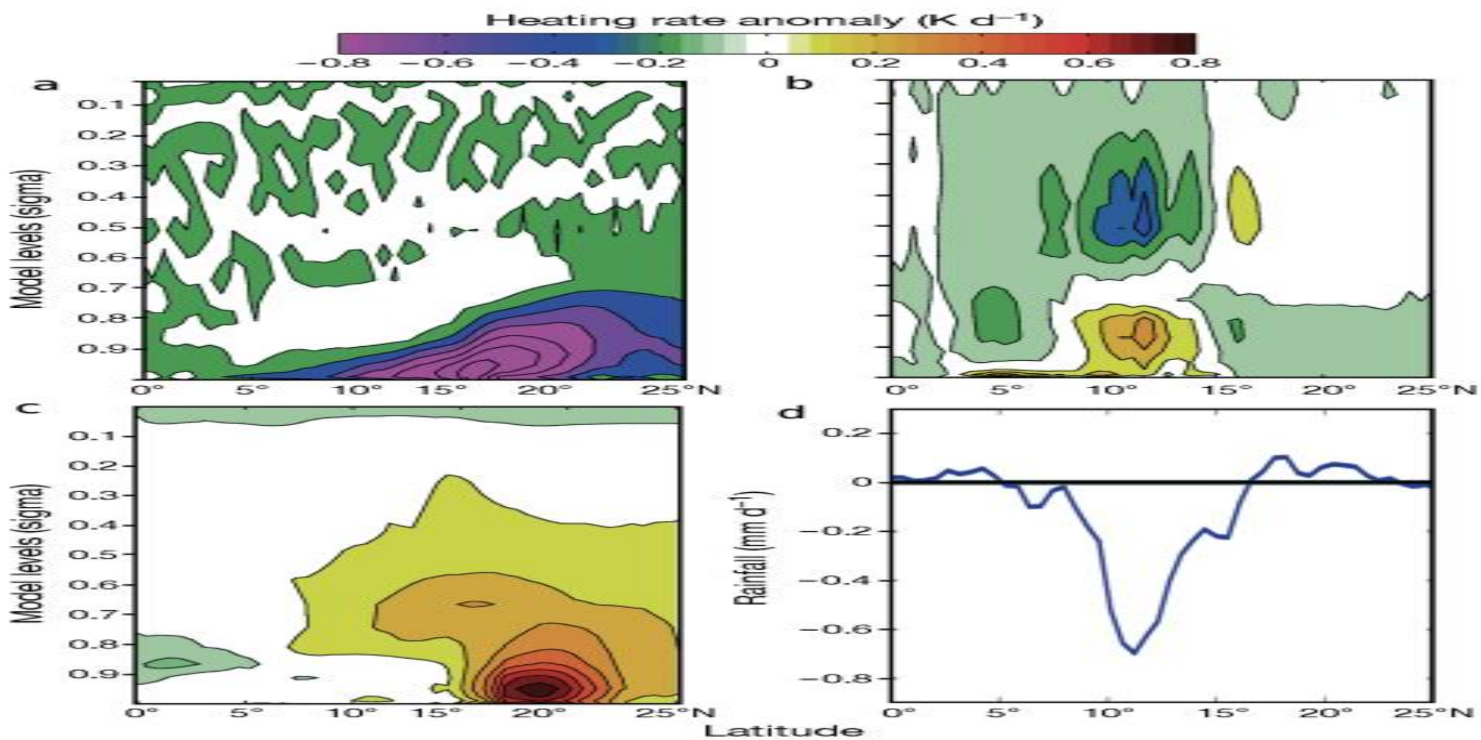


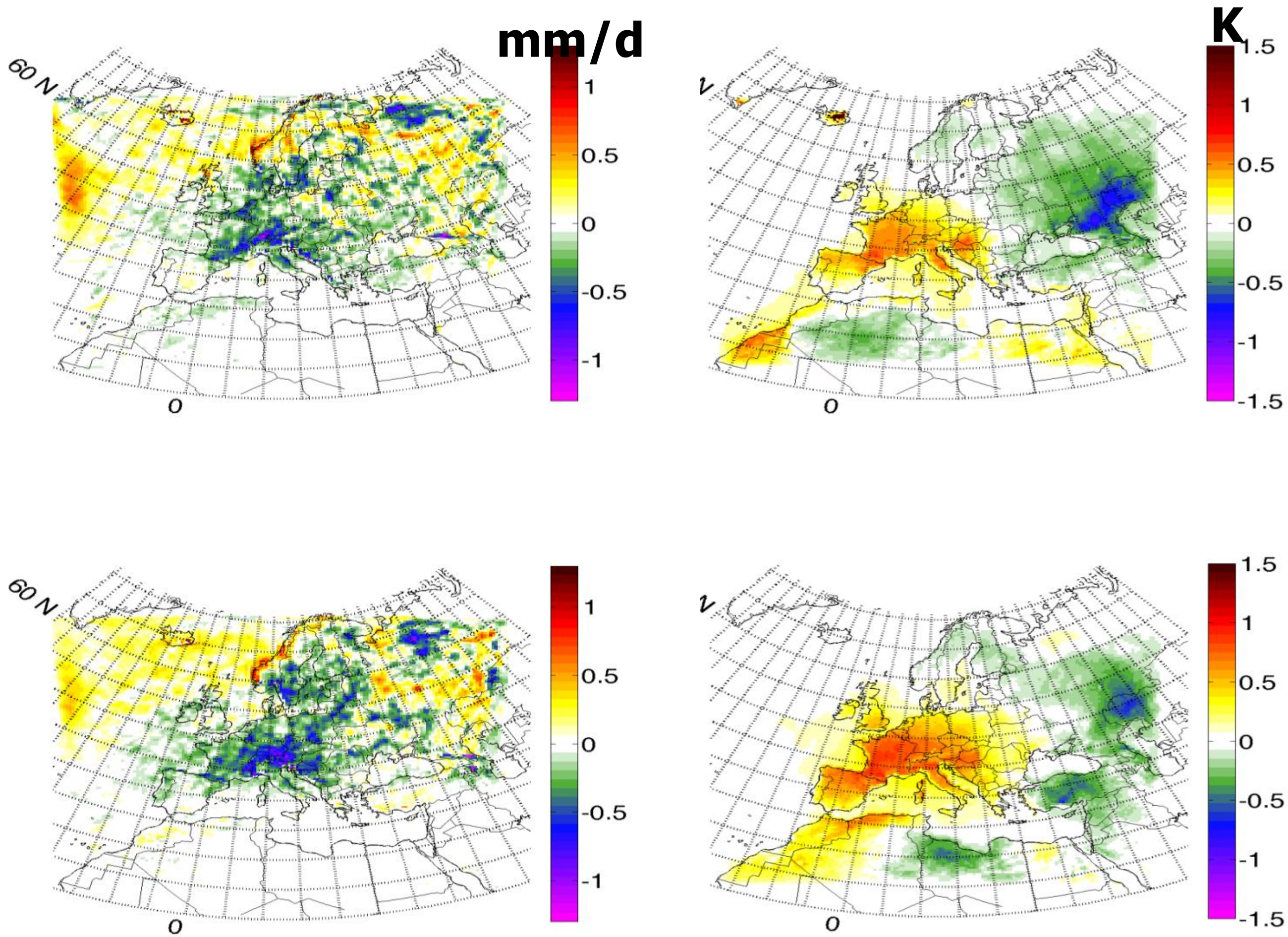
Fig. 4. Meridional cross section of heating rates and precipitation anomalies calculated from the standard (STD, DUST-CTL) experiment for Jun–Aug (JJA) 1996–2006 and spatially averaged for 15° W–15° E (see box in Fig. 2d). (a) Turbulent mixing, (b) convective, and (c) radiative heating rate anomalies. (d) Corresponding precipitation anomaly (DUST–NODUST)

Additional Issues when assessing impact of aerosol with climate models ..

MEG-CTL
(JJA 2001-2010)

CTLp - CTL
(JJA2001-2010)

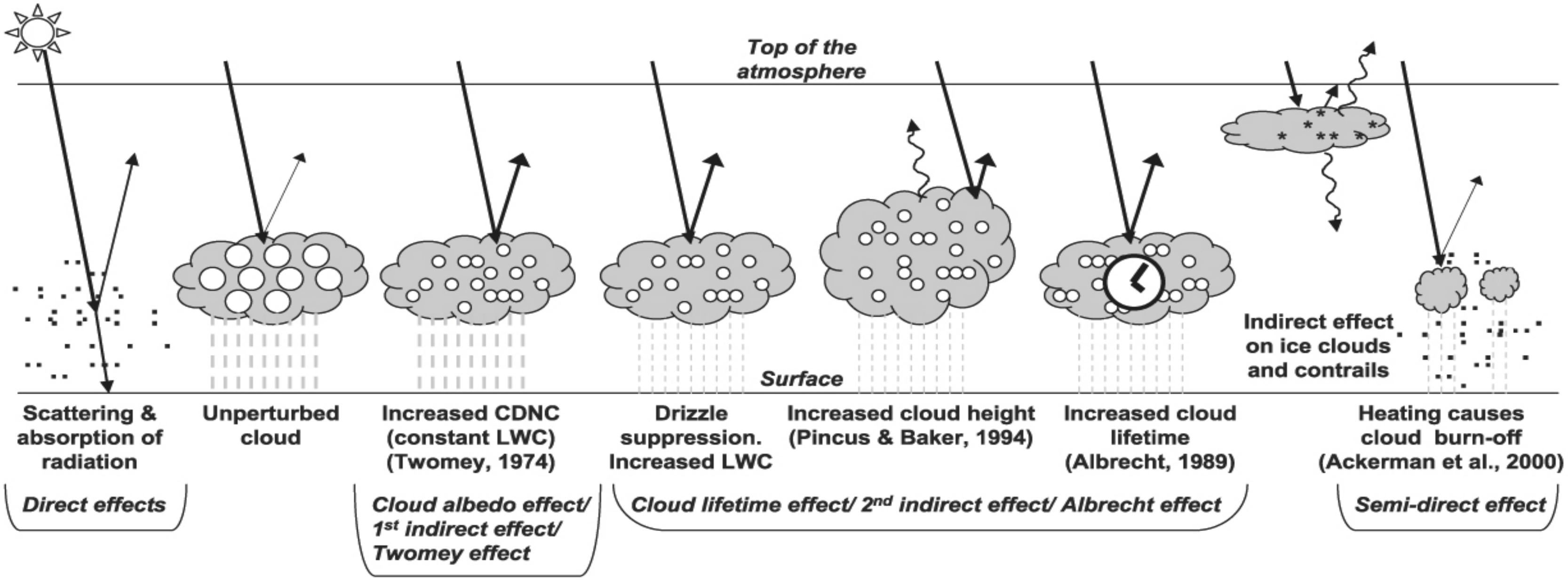
CTLp:
a random perturbation (limited to 1.E-3.qv, SST) is applied at the boundary during the run.



→ **Not possible to isolate an aerosol physical feedback from internal variability response of the model**
Ensemble runs needed / intense calculation

B : Indirect effects ...

- **Aerosol /cloud microphysic interactions**



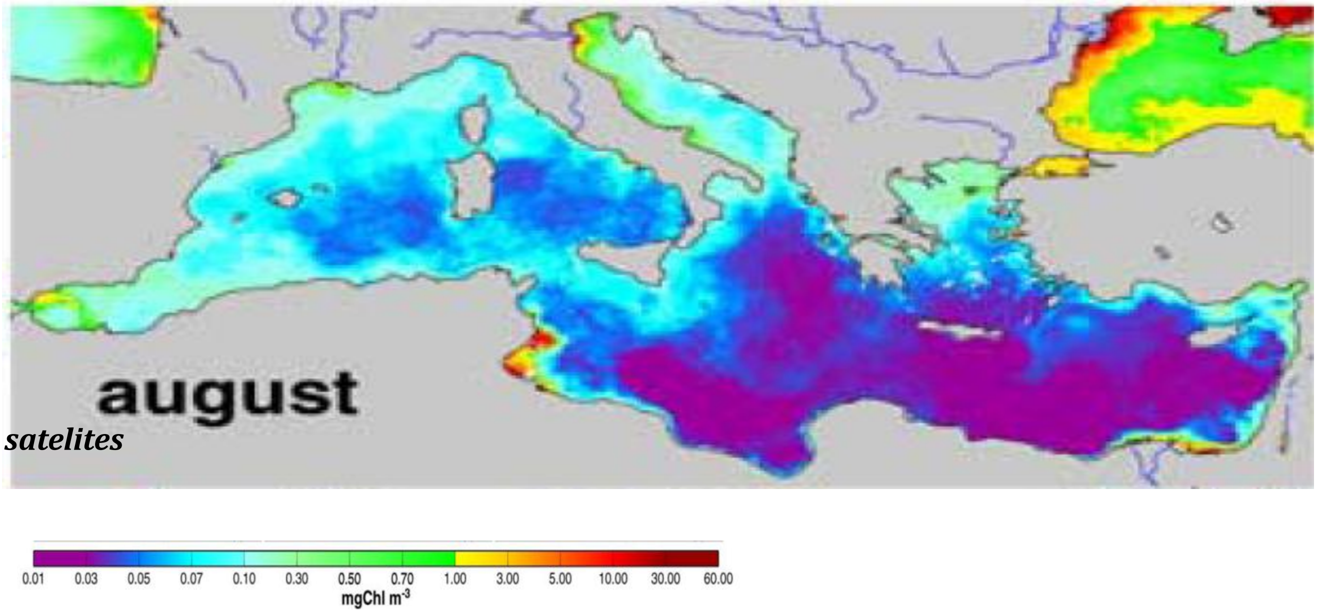
- **Aerosol deposition on snow**

- **Impact on climate via biogeochemical effects**

3: Biogeochemical impacts

MEDITERRANEAN SEA : THE LOW NUTRIENT LOW CHLOROPHYLL

VERY POOR BIOMASS IN SEAWATER: HIGHLY TRANSPARENT WATERS



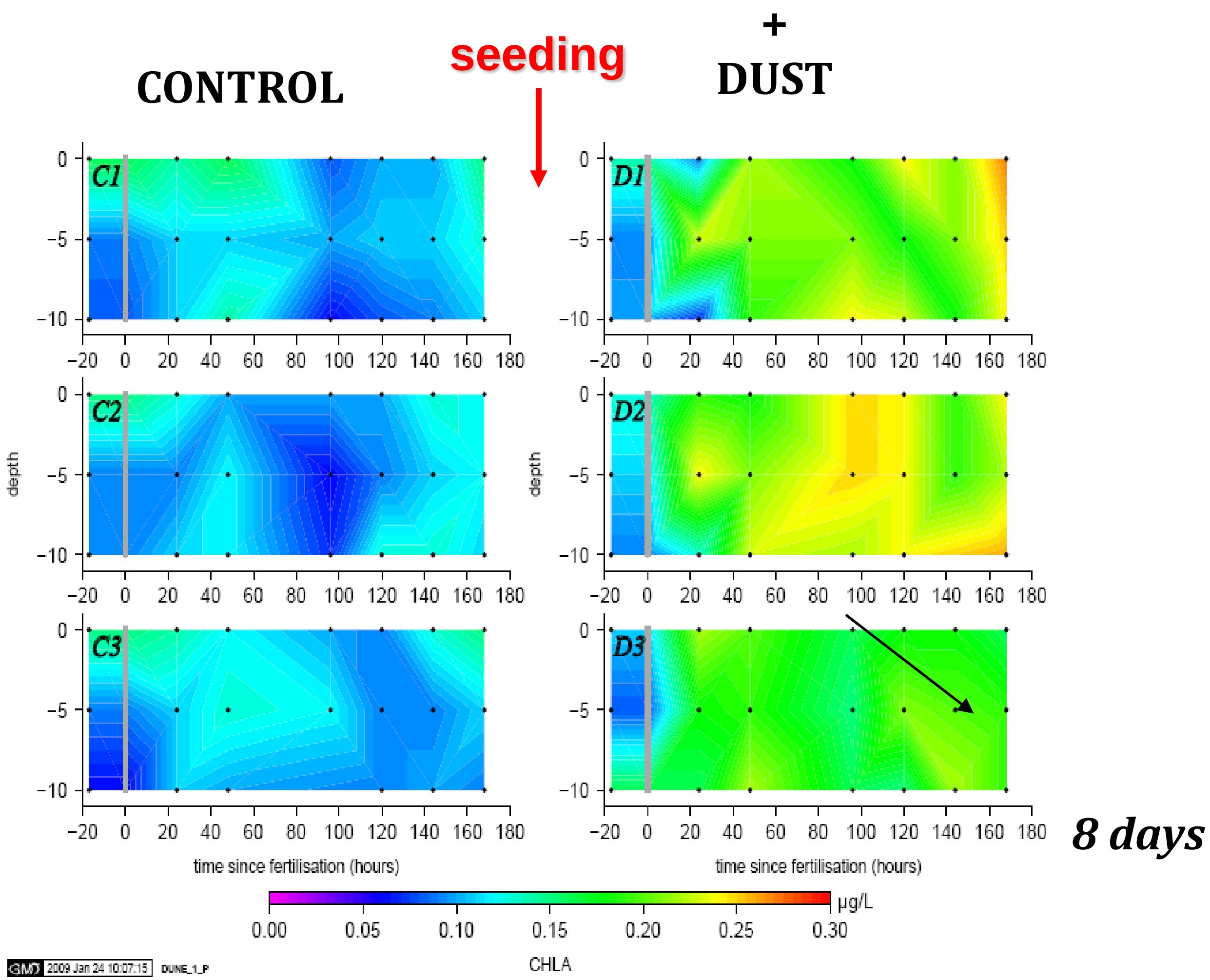
Chla as seen by satelites (ocean color)

Bosc et al., 2004

- **on average, an ocean with low Chla concentrations because low nutrient concentrations during 6 months of the year**

➡ **Atmosphere aerosol (Dust + anthropogenic) is an important source of nutrients in nutrients depleted regions (P,N,Fe,..)**

In situ aerosol fertilisation experiments:



From C. Guieu CNRS/LOV

DUNE PROJ.

The biogeochemical impact is determined by:

Atmospheric control

- **Deposition flux**
- **Chemical state of the nutrient when deposited to ecosystem (solubility, Bioavailability).**
- **Aerosol size distribution**

Anthropogenic sources vs. Natural sources

Atmospheric processing

Gas phase scheme

Example : Iron dissolution modelling

O_3

Anthro. aerosols

Meskhidze et al., 2005

Solmon et al., 2009

1: Assume an initial mineral composition for the dust

Table 3. Concentration of Major Minerals in the Soil and Clay Fractions of Surface Soils in the Gobi Desert and in Mineral Dust Originating From These Soils

Mineral	In Soil,[a] % wt		In Mineral Dust and Used as Initial Condition for Model Simulation,[b] % wt
	In Silt	In Clay	
Anhydrite $CaSO_4$	6	0	6
Calcite $CaCO_3$	12	0	11
Albite $NaAlSi_3O_8$	18	8	17
Microcline $KAlSi_3O_8$	8	5	8
Illite[c] $K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2$	18	42	20
Smectite/Montmorillonite[c] $Na_{0.6}Al_{1.4}Mg_{0.6}Si_4O_{10}(OH)_2 \cdot 4H_2O$	7	15	8
Hematite[d] Fe_2O_3	5	8	5
Quartz SiO_2	21	10	20
Kaolinite $Al_2Si_2O_5(OH)_4$	5	12	5
Total	100	100	100

ISORROPIA

The biogeochemical impact is determined by:

Atmospheric control

- **Deposition flux**

- **Chemical state of the nutrient when deposited to ecosystem (solubility, Bioavailability).**

- **Aerosol size distribution**

Anthropogenic sources
vs.
Natural sources

Atmospheric processing

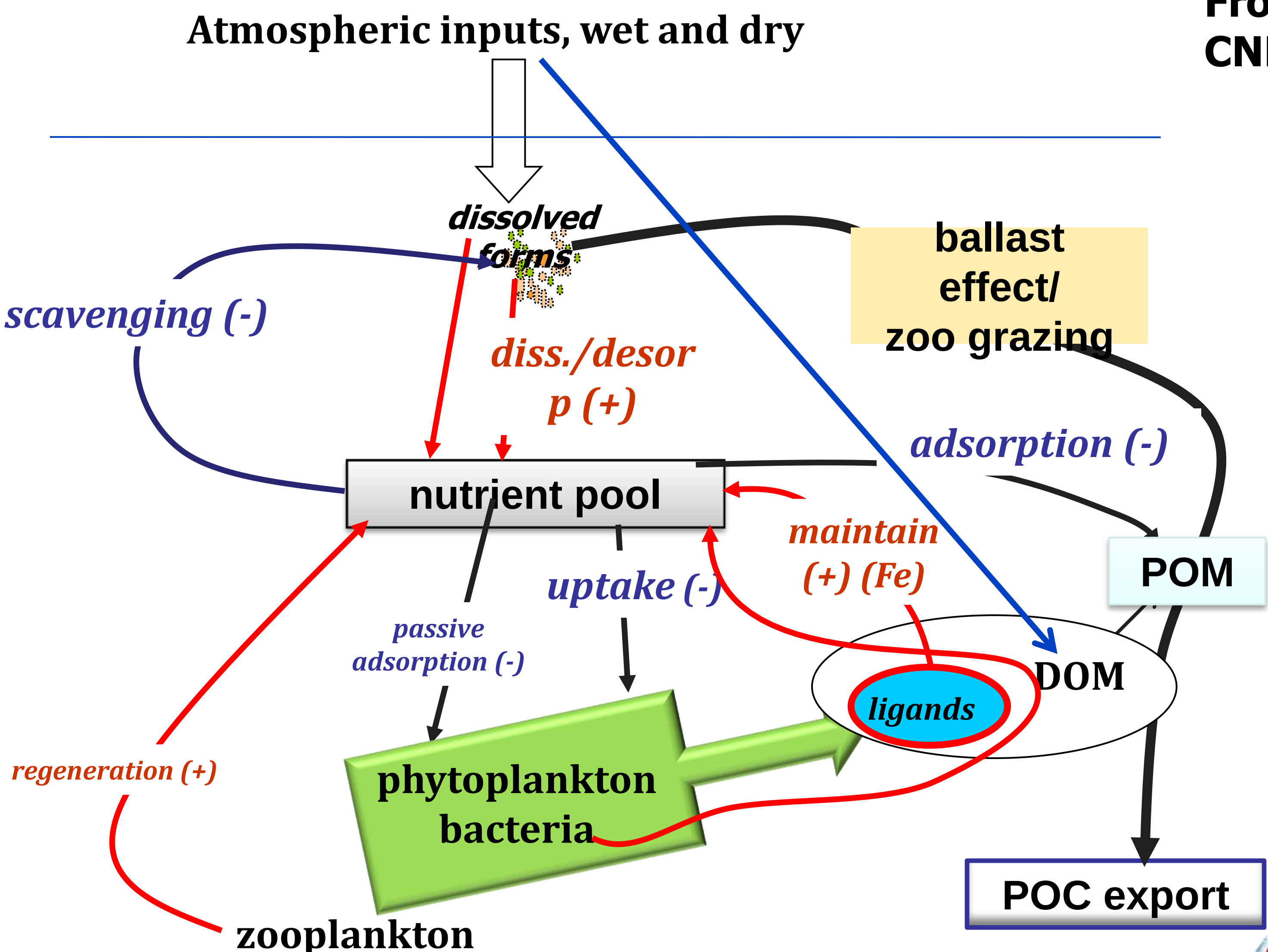
Oceanic control

- **Biological and nutrient state of the mixed layer**
- **Ocean Mixed Layer processes**

OCEAN MIXED LAYER PROCESSING

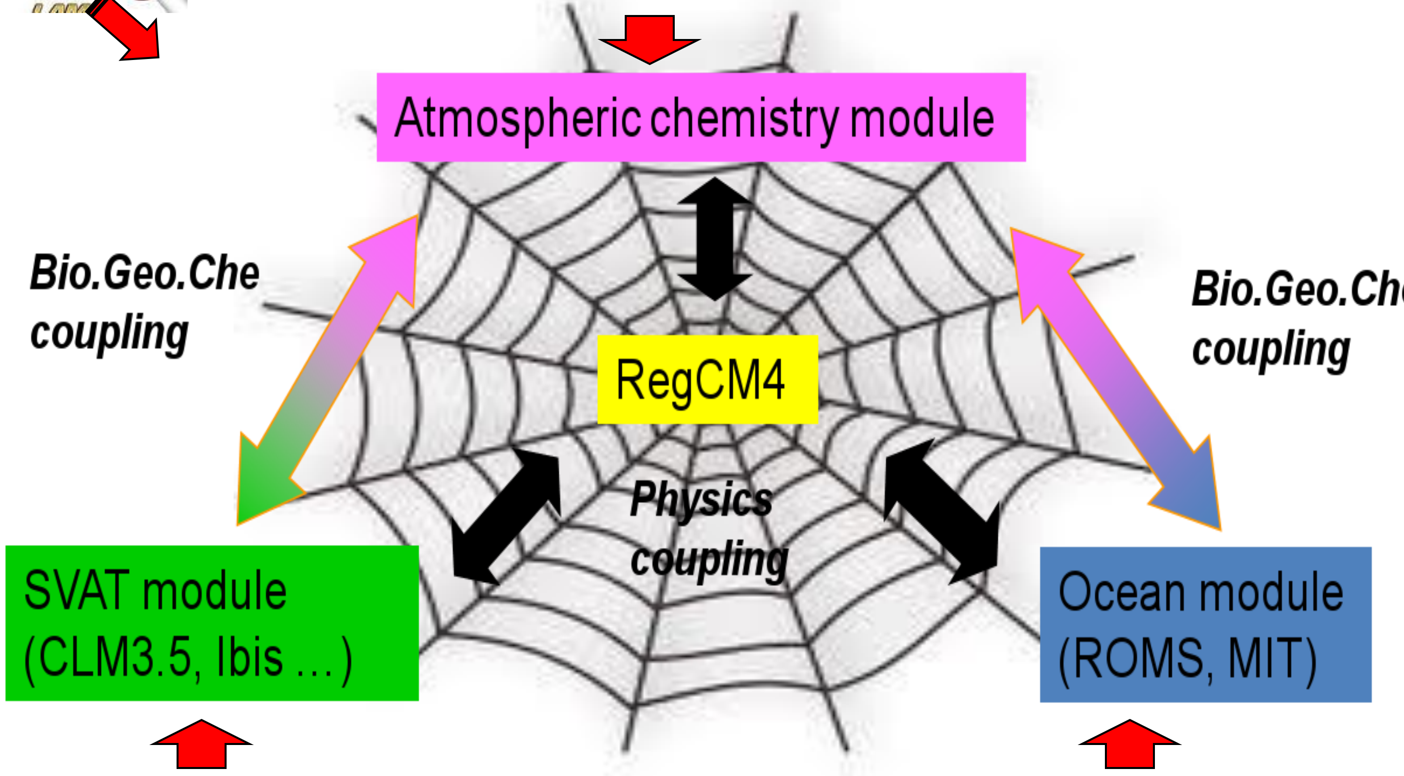
dissolved forms ~ bioavailable

From C. Guieu CNRS/LOV



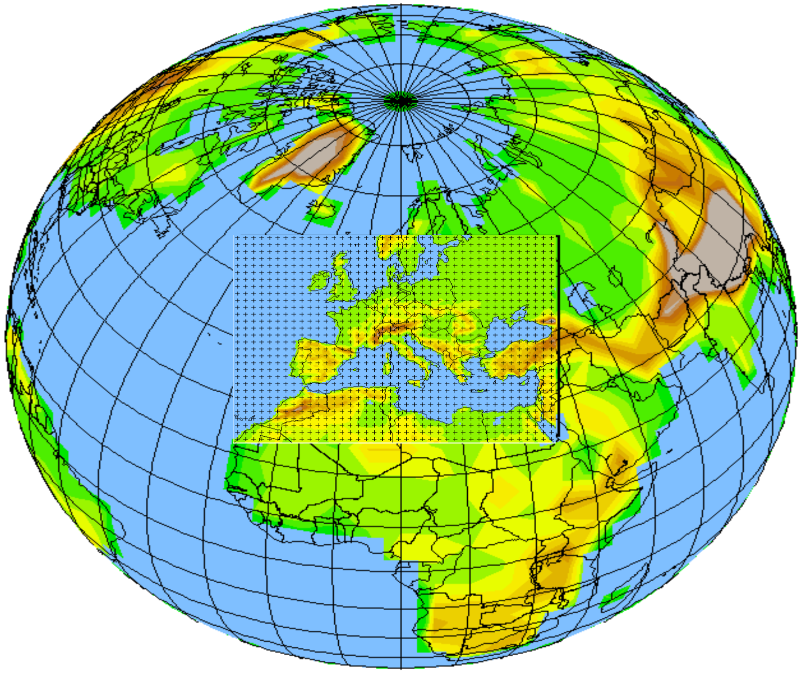
RegCM developments …

Anthropogenic pressures



Thank you

RegCM4 Regional Climate Model



High resolution / limited area / physical downscaling .

Boundary forcing :

Re-analysis :

ERA-I , NCEP

GCM outputs (scenarios) :
In the context of CMIP5/CORDEX
EC-EARTH
HadGEM
ARPEGE
CSIRO
GFD

for RCP4.5, 8.5

Chemistry/ aerosols in RegCM4

- **Tracer model / RegCM4**

$$\frac{\partial \chi}{\partial t} = -\overline{V} \cdot \nabla \chi + F_H + F_V + T_{CUM} + S_{\chi} - R_{w,ls} - R_{w,cum} - D_{dep} + \sum Q_p - Q_l$$

Transport	Primary Emissions	Removal terms	Physico – chemical transformations
$-\overline{V} \cdot \nabla \chi + F_H + F_V + T_{CUM}$	S_{χ}	$R_{w,ls}$, $R_{w,cum}$, D_{dep}	$\sum Q_p - Q_l$

- **Particles and chemical species considered**

Simple aerosol scheme

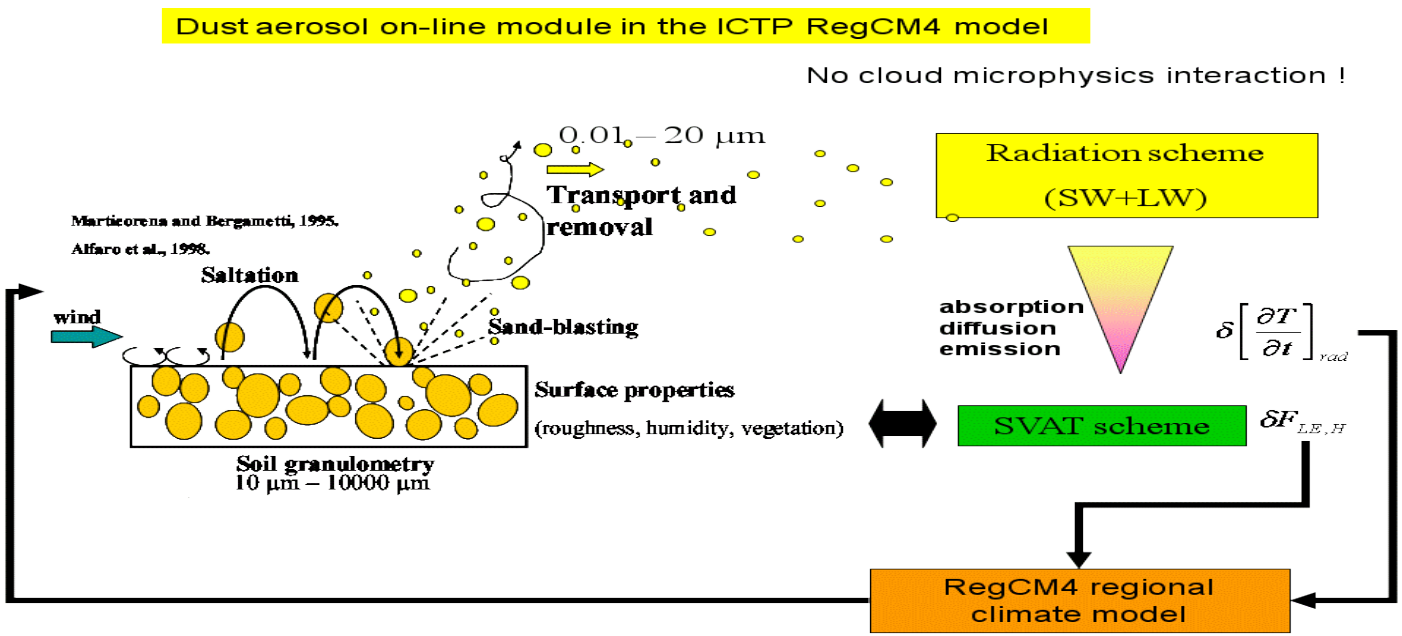
SO_2	SO_4^{--}	BC (soot)		OC (total organic carbon)		DUST (4 bins)				SEA SALT	
Aqueous and gazeous conversion (Qian et al., 2001)		Hydrophilic (20% at emission)	Hydrophobic (80%at emission)	Hydrophilic (50%at emission)	Hydrophobic(50%at emission)	0.01-1 µm	1-2.5 µm	2.5-5 µm	5-20 µm	fine 0.6	coarse 6

CBMZ gas phase

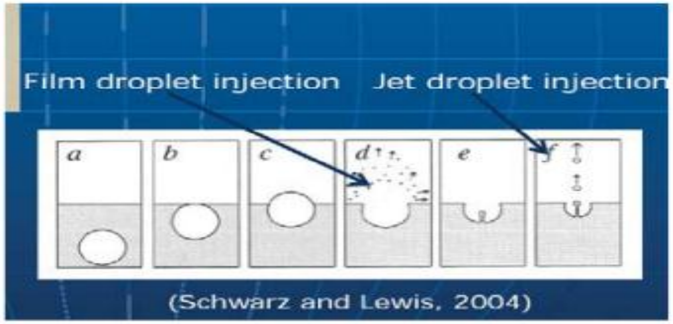
'SO2',‘SO4','O3','NO2','NO','CO','H2O2‘,'HNO3‘,'N2O5','HCHO','ALD2',‘ISOP','C2H6', 'PAR','ACET','MOH','OLT','OLI','TOLUE','XYL','ETHE','PAN','CH4','MGLY','CRES','OPEN','ISOPRD','ONIT','HCOOH','RCOOH’,'CH3OOH','ETHOOH','ROOH','HONO',‘HNO4','XO2'

Natural emissions

DUST



Sea-salt



Biogenic (isoprene)

MEGAN / CLM3.5

Anthropogenic emissions

CMIP5 emissions historical and RCPs

Chemical boundary conditions

EC-EARTH / CAM runs for RCP4.5, 8.5

Pollen modelling ?

STEP 1 : (fast)

❖ Use of IPSL/ LSCE emissions prescribed directly to RegCM (period and frequency to be determined) .

❖Implementation of a pollen tracers : sizing and relevant parameters (affective diameter, hydrophilic character, etc) to be defined

STEP 2 : (longer + post-doc required)

❖ Implementation of on-line emission modelling.

- two paths possible

 1: activation of CLM 4 interactive vegetation / coupling of phenology dependant functions (same parameterisation than used in IPSL approach).

 2 : coupling of ORCHIDEE with RegCM

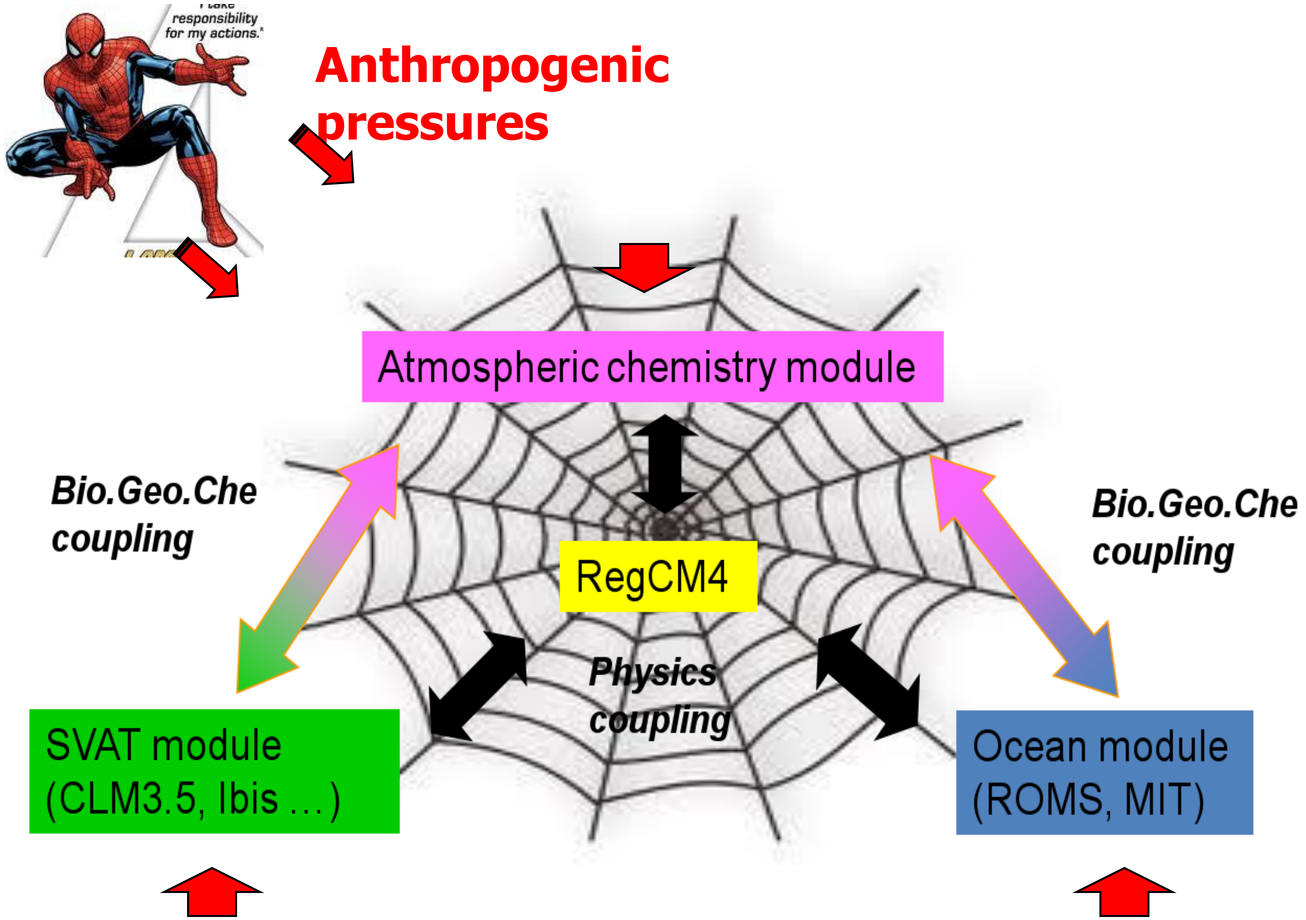
⟹ I would tend to support 1 for intercomparisons

Last point :

Activities for ATOPICA workshop in Trieste

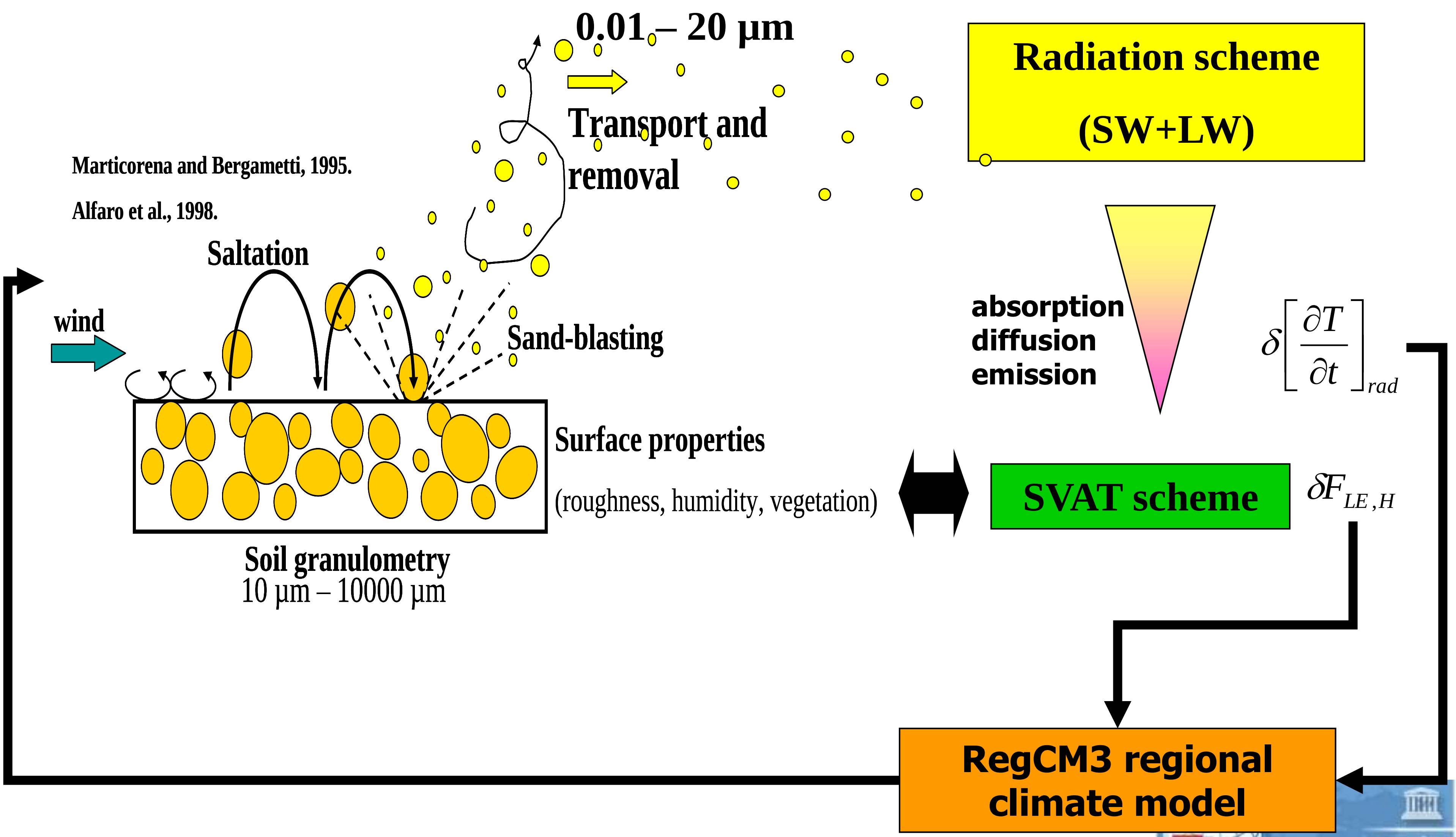
-RegCM
-Chimere
-… ?

Thank you !

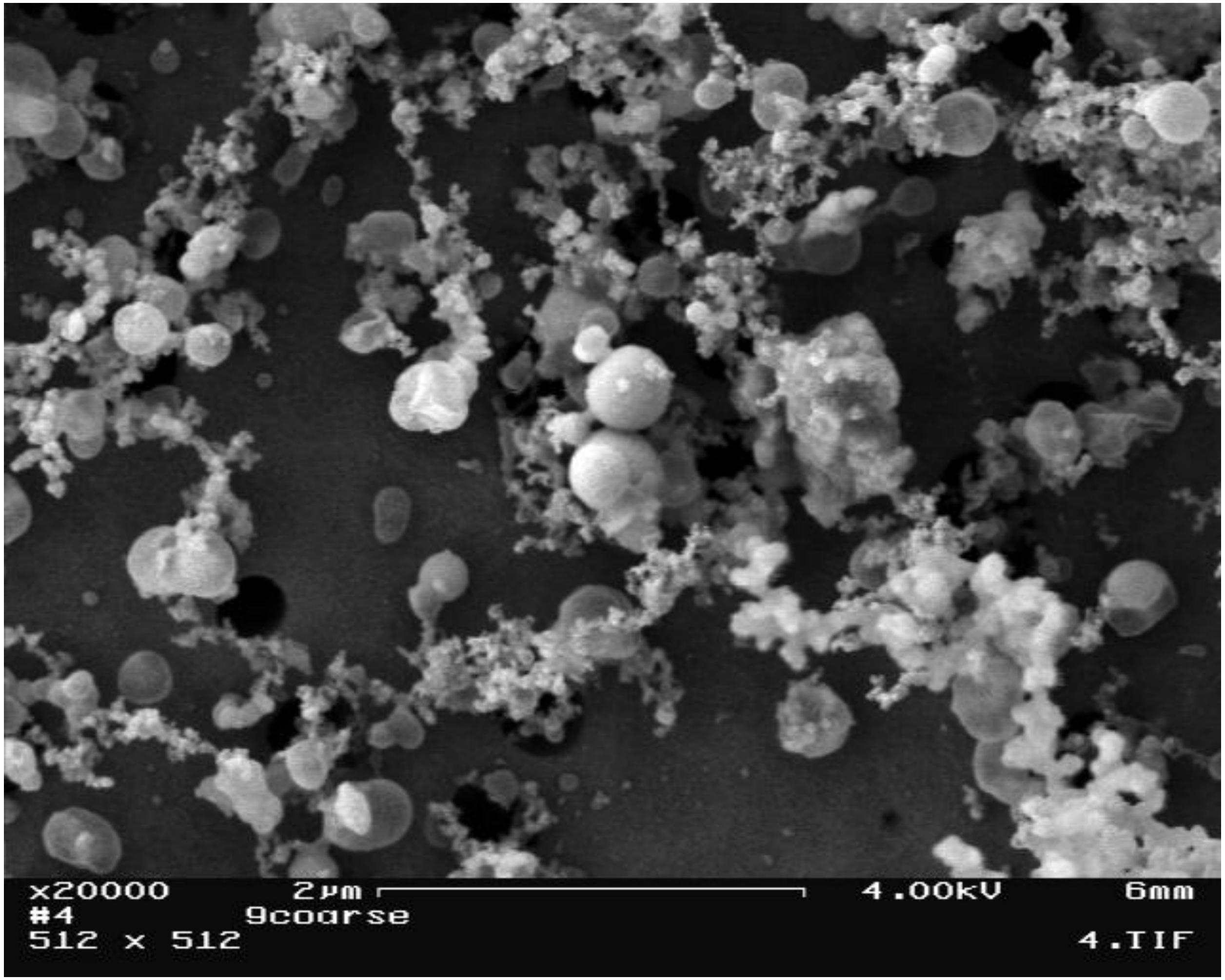

responsibility
for my actions."
Anthropogenic pressures
Atmospheric chemistry module
Bio.Geo.Che coupling
RegCM4
Bio.Geo.Che coupling
Physics coupling
SVAT module (CLM3.5, Ibis …)
Ocean module (ROMS, MIT)

Dust aerosol on-line module in the ICTP RegCM3 model

No cloud microphysics interaction !

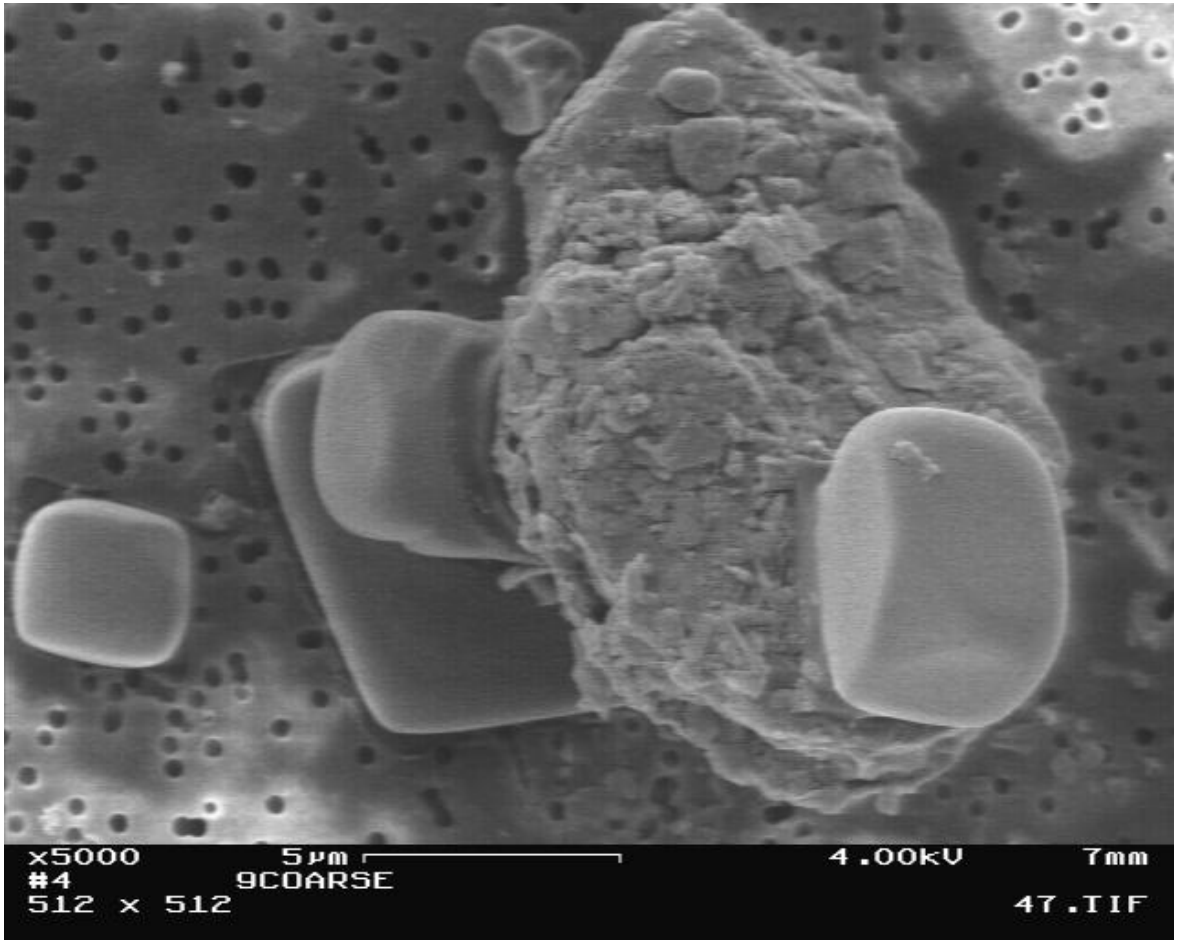


A close up of a field of view of Fine Particles collected on the East Mediterranean Shore. Most particles are either <u>spherical sulfates</u> (similar to ammonium sulfates in appearance) or short <u>aggregates of diesel particles</u>.

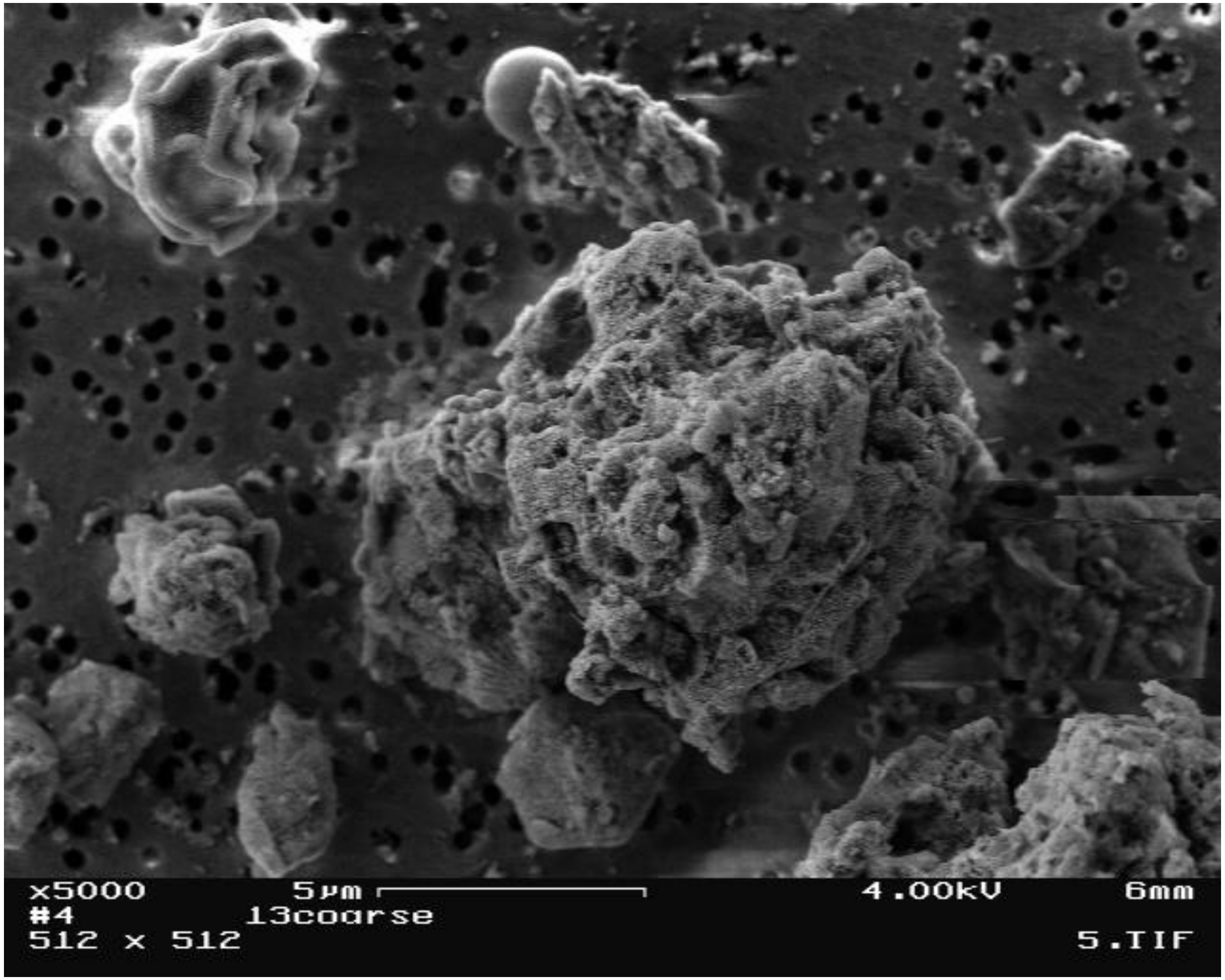


Thanks to Prof. Mamane

Cubes of 3-7 µm sea salt particles, attached to a mineral, from the coarse fraction. Sea salt (Na, Cl) particles were found at both particle size fractions.



Typical Irregular Mineral with very rough porous surfaces collected at the coarse fraction. A spherical 1.5 µm <u>coal fly ash</u> is seen at the top, and a <u>"crushed" spore</u> at the upper left corner.



Oil Combustion Cenosphere rich in Ni and V collected in the coarse fraction. These are typical particles emitted from combustion of heavy oil.