Study of the aerosols role on the future climate over the Mediterranean region

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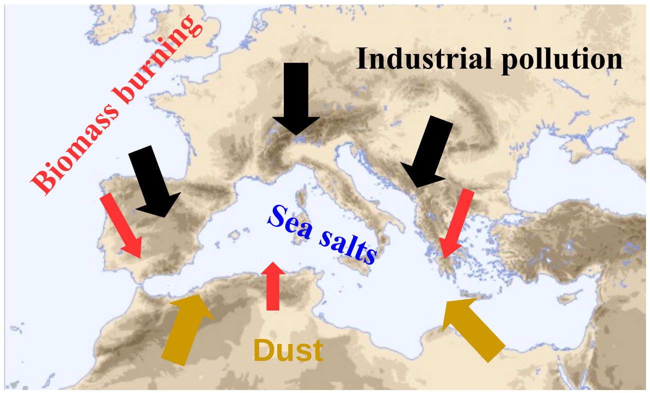
Aerosols :

Aerosols over the Mediterranean region



Mediterranean region :

– > Crossroads of air masses bringing aerosols from different sources (Lelieveld et al., 2002)

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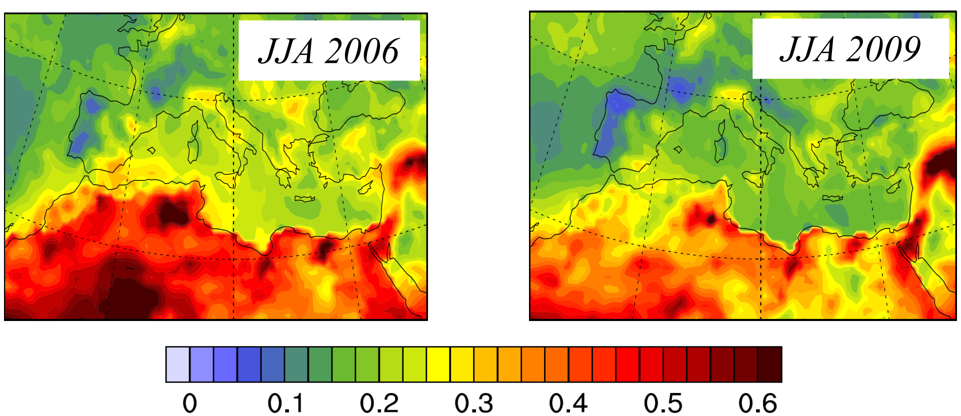
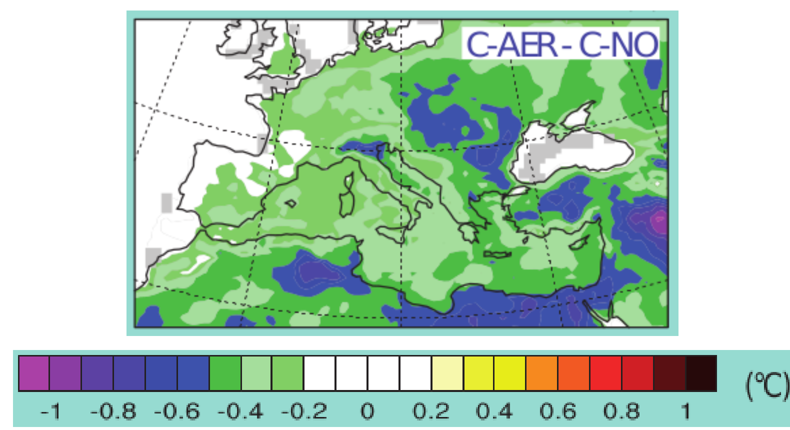
– > Very sensitive region to climate change (Giorgi, 2006)

Aerosol Optical Depth (AOD) of MODIS (average 2003/2013)



– > Aerosols = High spatio-temporal variability

Aerosol effects on temperature (average 2003/2009) (Nabat et al., 2015a)



– > Important impact on radiative budget and climate

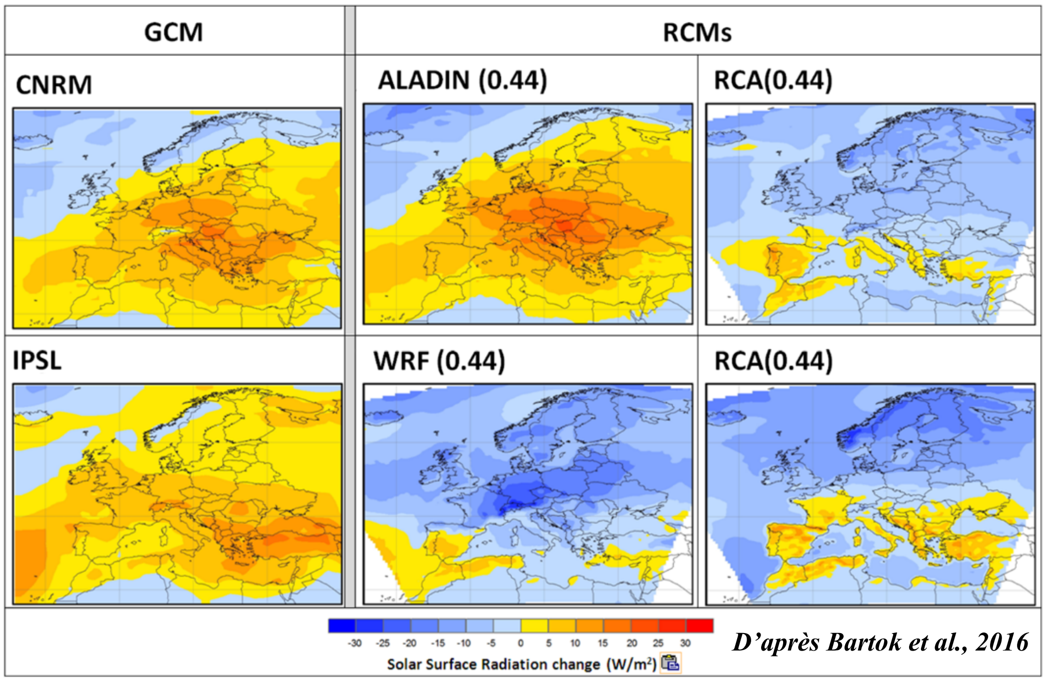
State of the art :

How aerosols are taken into account in climate modeling?

Global scale: often taken into account.

Regional scale: rarely (especially nitrate and ammonium).

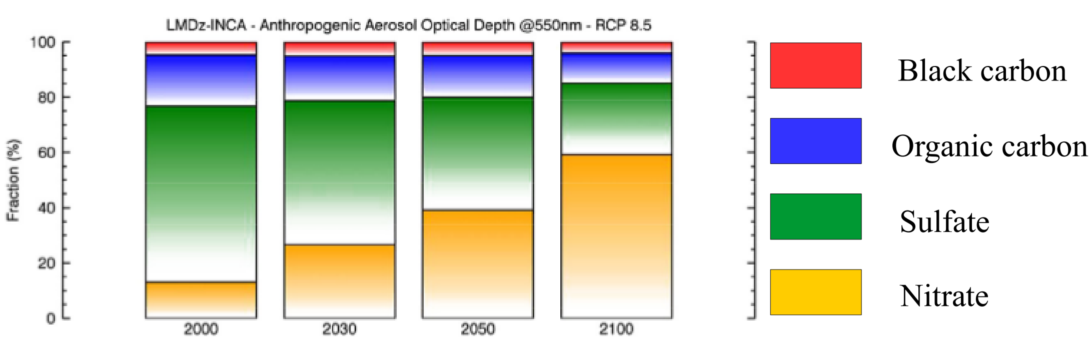
Surface radiation (RCP 8.5) : 2071/2100 – 1971/2005



D'après Bartok et al., 2016

– > Strong differences between GCM and RCM (radiation scheme, aerosols, clouds).

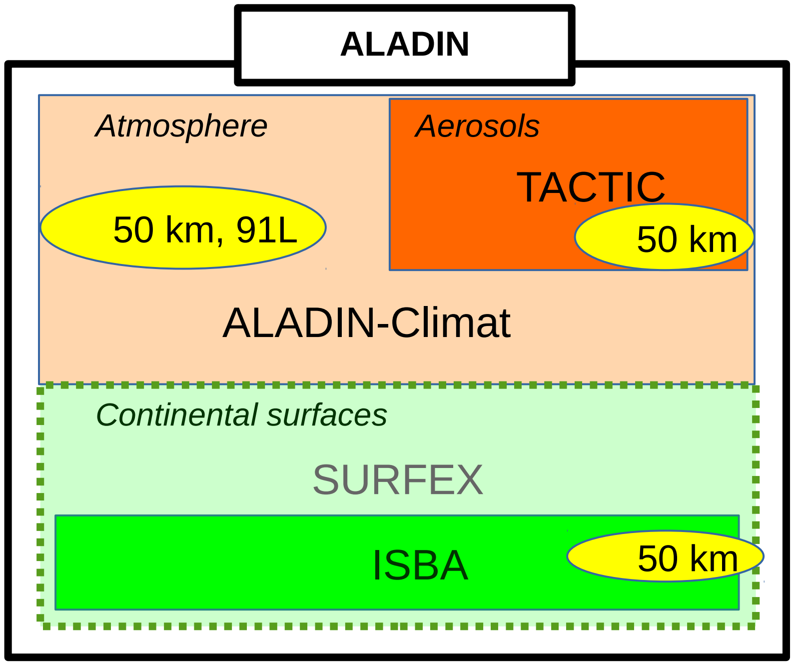
Global average contribution of aerosols to the total aerosol anthropogenic optical depth (Hauglustaine et al., 2014)



– > Increase of the nitrate contribution.

Objectives of the thesis:

– > Study and quantify the role of different aerosols in regional climate projections.



<u>Three step approach:</u>

- Implementation of a nitrate and ammonium aerosol module in ALADIN,
- Evaluation of the new aerosol scheme,
- Realization and analysis of coupled regional climate simulations.

Aerosols (dust, sea salt, black carbon, organic carbon, sulphate) are represented in the TACTIC prognostic scheme and are coupled with radiation (direct, semi-direct and indirect effect).

Methodology:

Implementation of the nitrate and ammonium aerosol module:

– > 2 bins of nitrate, 1 bin of ammonium and 1 variable for NH_3

Ammonium and nitrate formation by reactions (accumulation mode):

First formed specie: ammonium sulfate due to the low vapor pressure of sulfuric acid:

$NH_3\,(g) + H_2SO_4\,(g) \rightarrow (NH_4)HSO_4(s)$
$3NH_3(g) + 2H_2SO_4\,(g) \rightarrow (NH_4)_3H(SO_4)_2(s)$
$2NH_3(g) + H_2SO_4(g) \rightarrow (NH_4)_2SO_4(s)$

➡ Three possible reactions to form ammonium sulfates, according to the relative concentration of ammonia and sulfate in the atmosphere.

Second formed specie: ammonium nitrate:

- If all free ammonia (NH_3) is consumed – > no ammonium nitrate formation.
- If free ammonia (NH_3) persists – > ammonium nitrate production by:

$$HNO_3(g) + NH_3(g) \longleftrightarrow NH_4NO_3(s)$$

Nitrate formation by uptake (coarse mode):

– > occurs from calcite (dusts) and sea salts according to the equations:

$HNO_3(g) + NaCl(s) \rightarrow NaNO_3(s) + HCl(g)$
$2HNO_3(g) + CaCO_3(s) \rightarrow Ca(NO_3)_2(s) + H_2CO_3(g)$

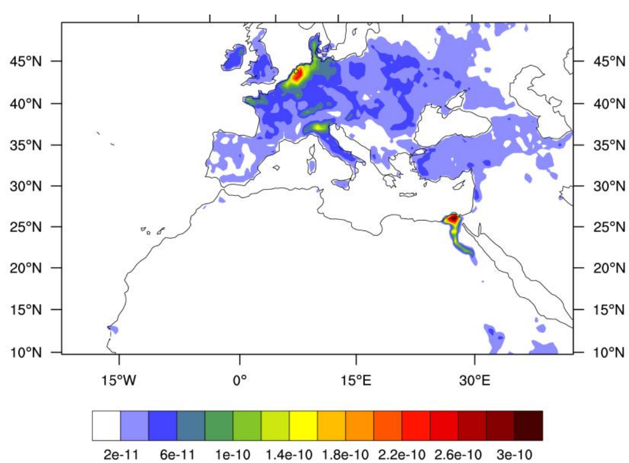
– > It is assumed that Ca^{2+} constitutes 5% of the total mass of dusts (Fairlie et al., 2010).

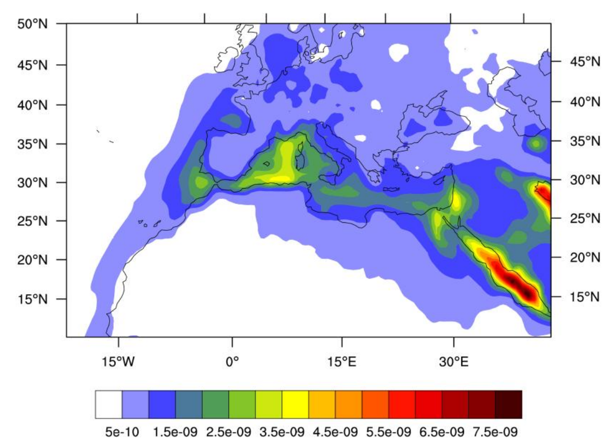
HNO_3: Climatology coming from the European center with a seasonal cycle based on observations

NH_3: CMIP6 emissions with a seasonal cycle based on MACCity data

NH_3 emissions (kg m^{-2} s^{-1}) (average 1979-2016)

– > Agriculture (fertilizer) and livestock



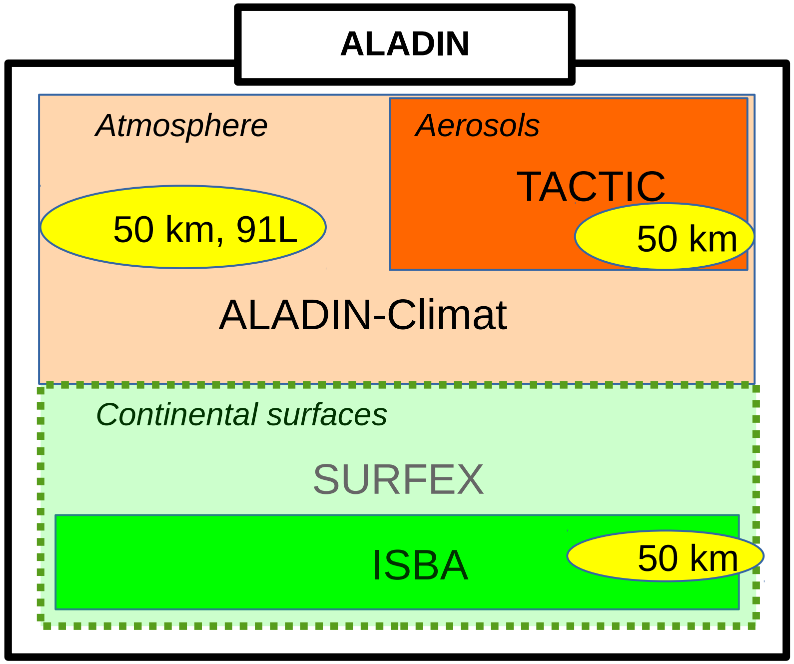


HNO_3 concentration (Kg/Kg) (average 2003 - 2015)

– > Fossil fuel combustion
– > land use practices
– > soil emissions

I – Evaluation of the aerosol scheme

Method of evaluation of the aerosol scheme:



– > Two simulations forced by ERA-Interim over the period 1979-2016:

REF
(All aerosols except nitrates and ammonium).

/

NIT
(All aerosols)

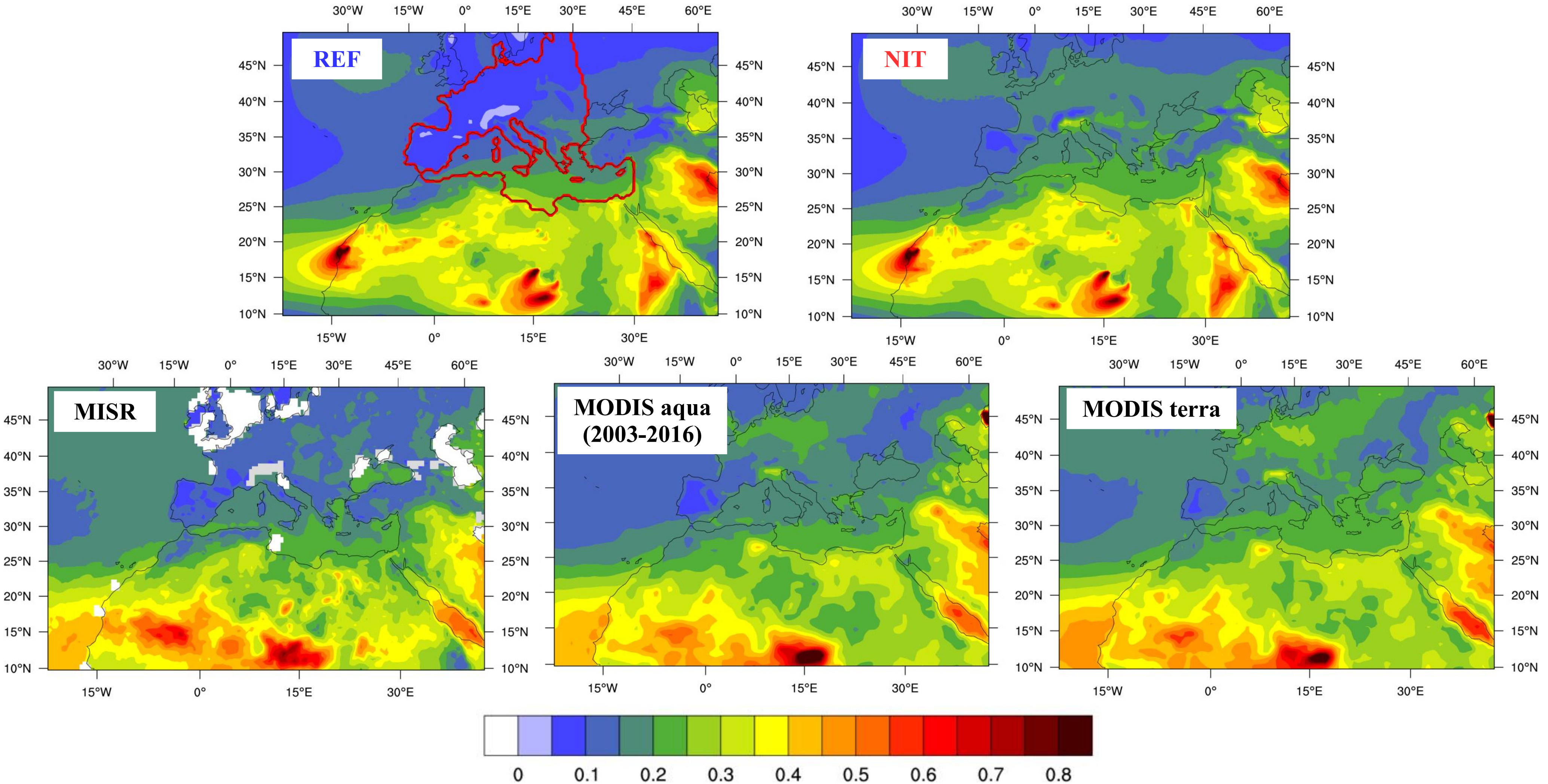
– > Comparison of these simulations with:

- satellite data MODIS and MISR (AOD),
- EMEP stations (surface concentration).

I – Evaluation of the aerosol scheme

1 – Comparison with MODIS and MISR

Aerosols AOD (average 2001-2016)

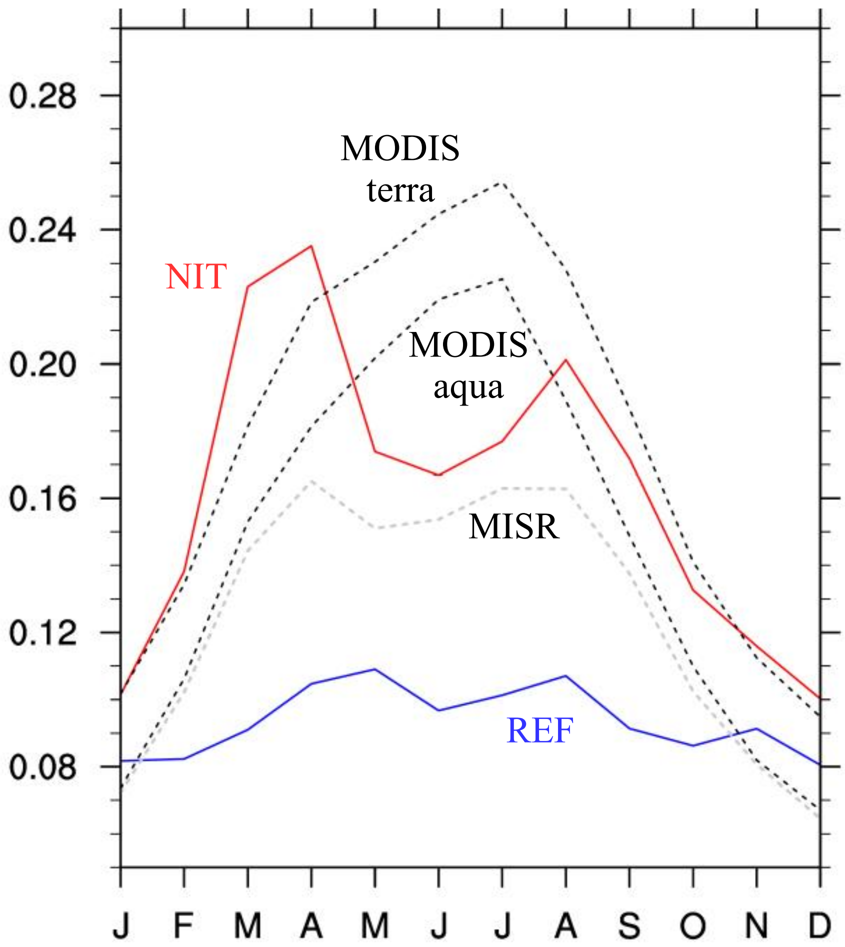


	REF	NIT	MISR	MODIS aqua	MODIS terra
Europe	0.09	0.16	0.13	0.17	0.19
Mediterranean Sea	0.19	0.22	0.20	0.20	0.22

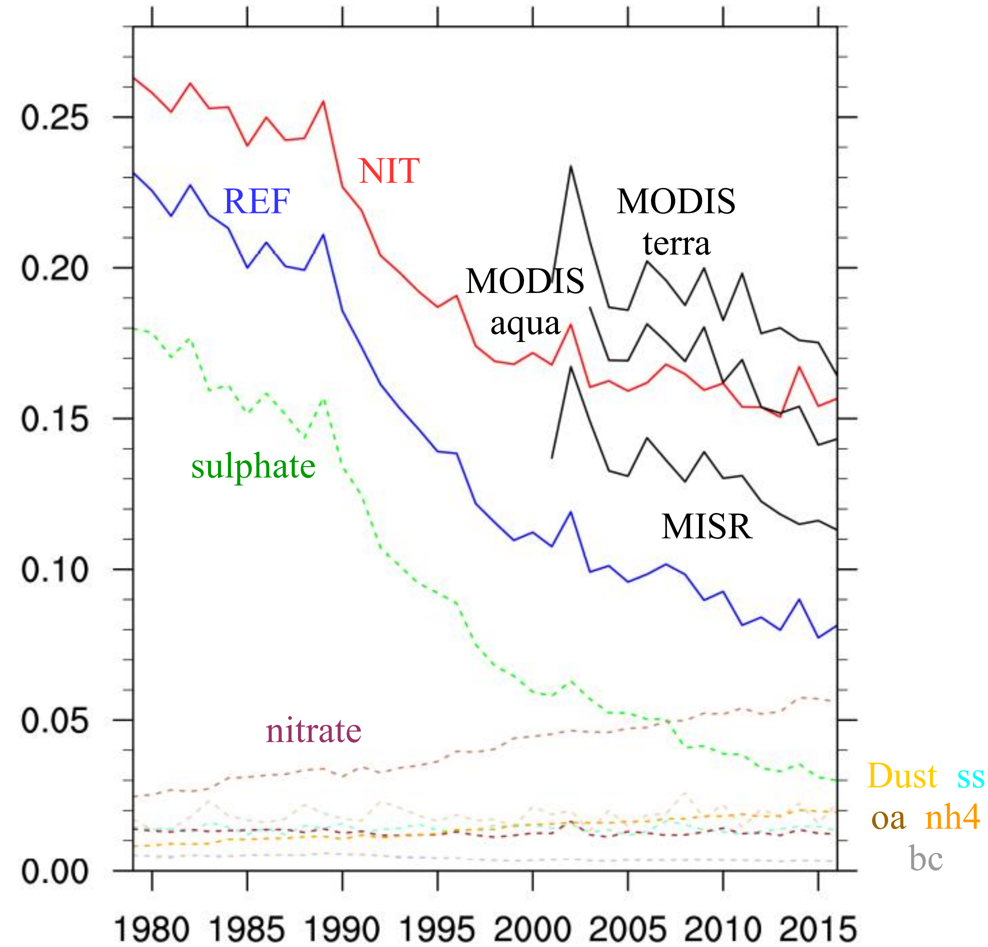
– > Underestimation of the AOD without nitrates and ammonium (Europe and Mediterranean Sea).

AOD nitrates + ammonium ≃ 40% of the total aerosols AOD (Europe)

Average seasonal cycle of AOD on Europe over the period 2001-2016 (2003-2016 for MODIS aqua)



AOD evolution over Europe



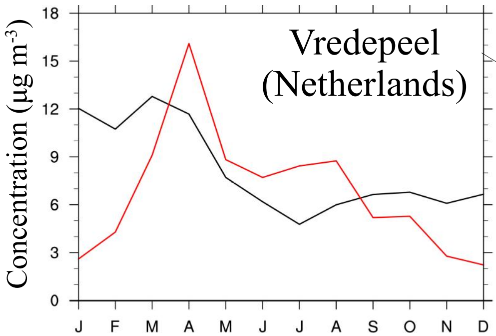
–> Improvement of the seasonal cycle and evolution of total aerosol AOD.

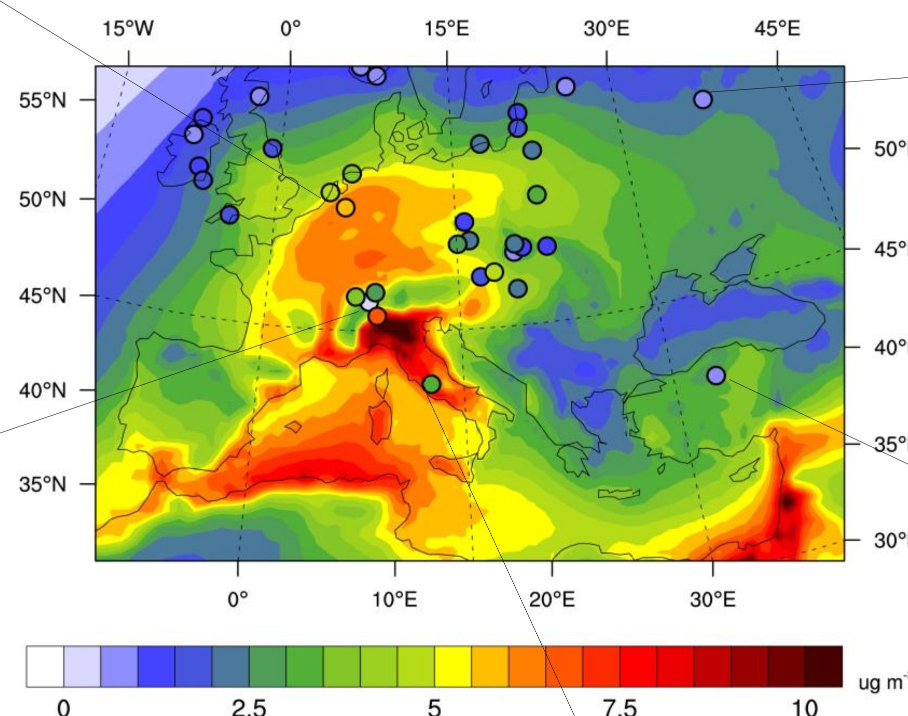
I – Evaluation of the aerosol scheme

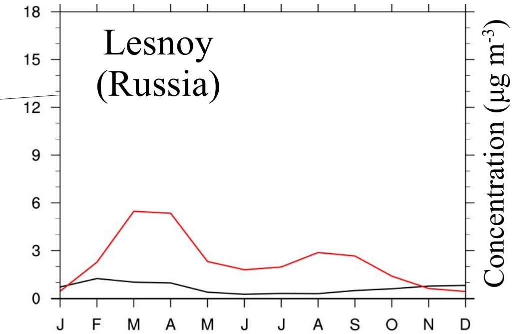
1 – Comparison with MODIS and MISR

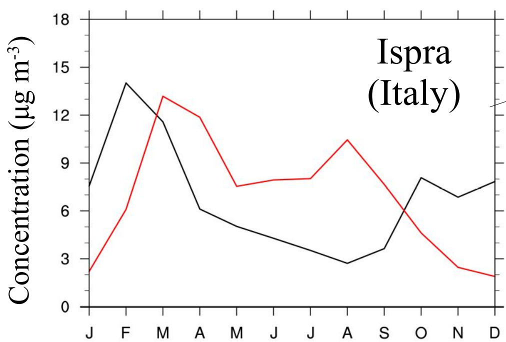
2 – Comparison with EMEP stations

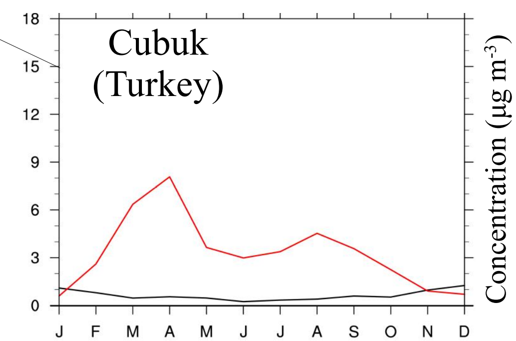
Seasonal cycle of nitrate concentration (fine and coarse mode) vs EMEP stations (1994-2014)

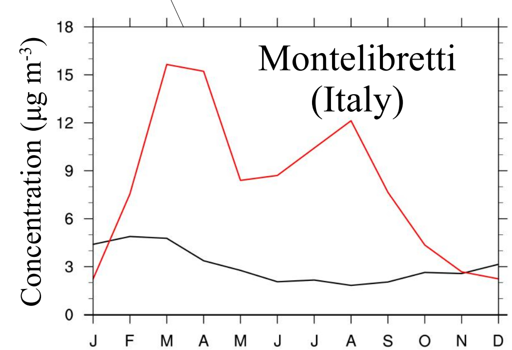


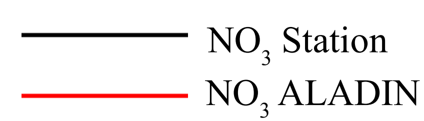












Representativeness of EMEP stations data?

– > Stations **don't have continuous data** over the period 1994-2014 (on the other hand, only the stations with a minimum of 5 years of data have been retained).

– > The concentration of the model corresponds to the simulated concentration at the first model level with a **50km horizontal resolution**.

I – Evaluation of the aerosol scheme

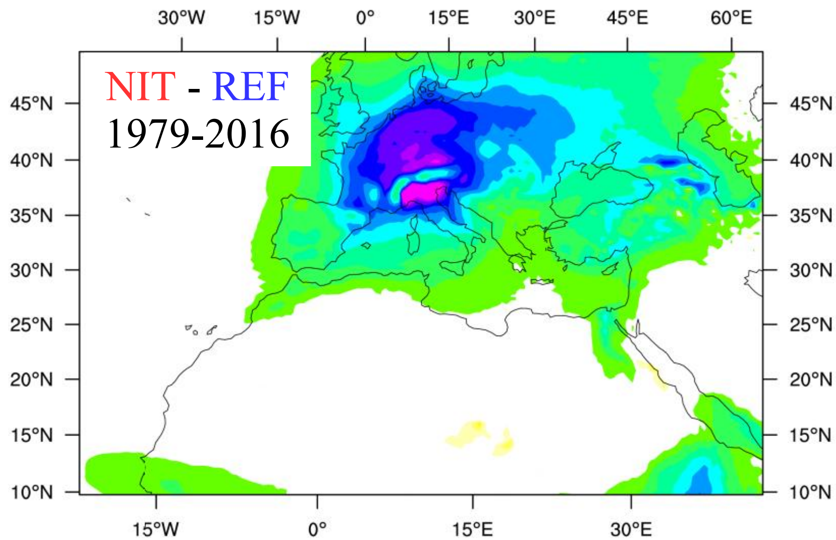
1 – Comparison with MODIS and MISR

2 – Comparison with EMEP stations

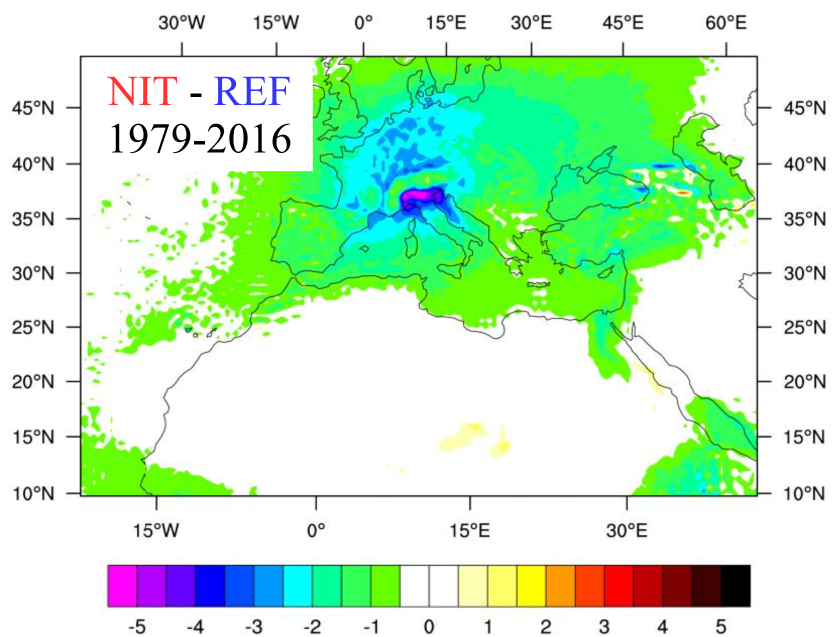
II – Nitrate impacts on climate (radiation, temperature,...)

Nitrate and ammonium surface radiation (W m^{-2})

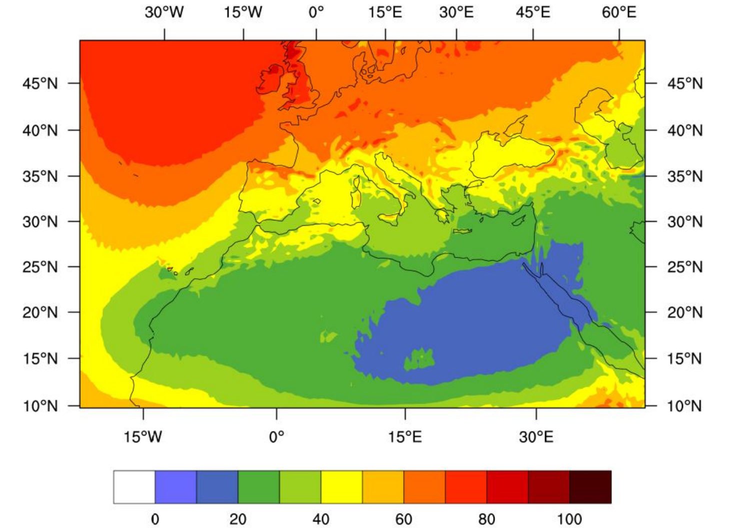
Clear sky



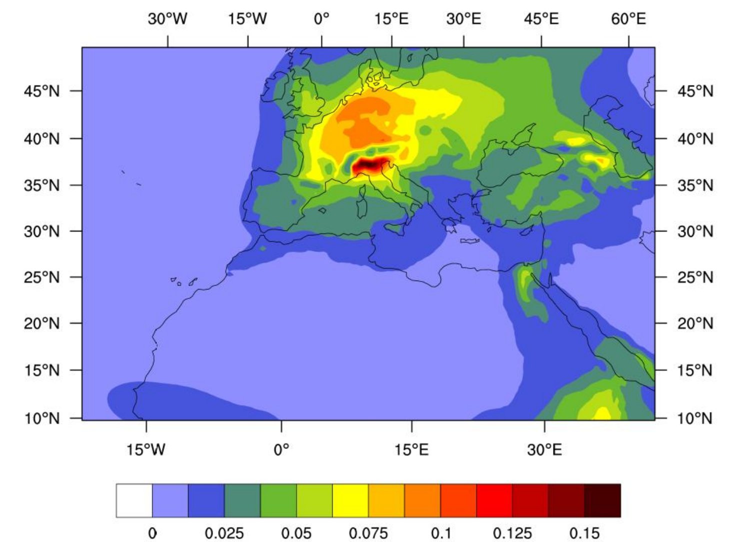
All sky



Total cloud cover (%) over the period 1979-2016



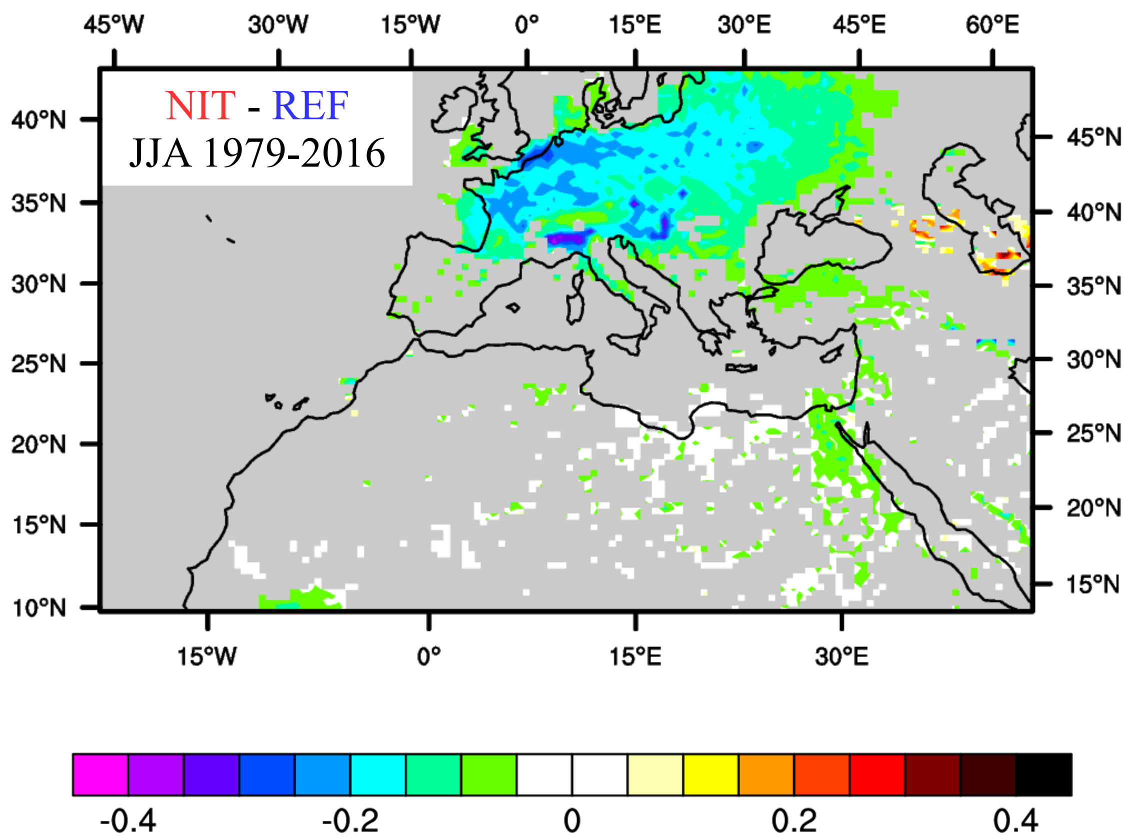
Nitrate and ammonium AOD over the period 1979-2016



– > All sky radiation weaker than clear sky radiation (cloud cover).

– > Significant effects on Italy, Croatia, southern France and the Mediterranean (North-West South-East radiation gradient).

Significant difference in temperature between NIT and REF



–> Significant temperature decrease of - 0.2°C over Europe.

Conclusion :

Model evaluation

First results

Addition of nitrate and ammonium aerosols in TACTIC:

– > Improvement of the seasonal cycle of total AOD in Europe,

– > Nitrate concentrations relatively well represented despite an overestimation.

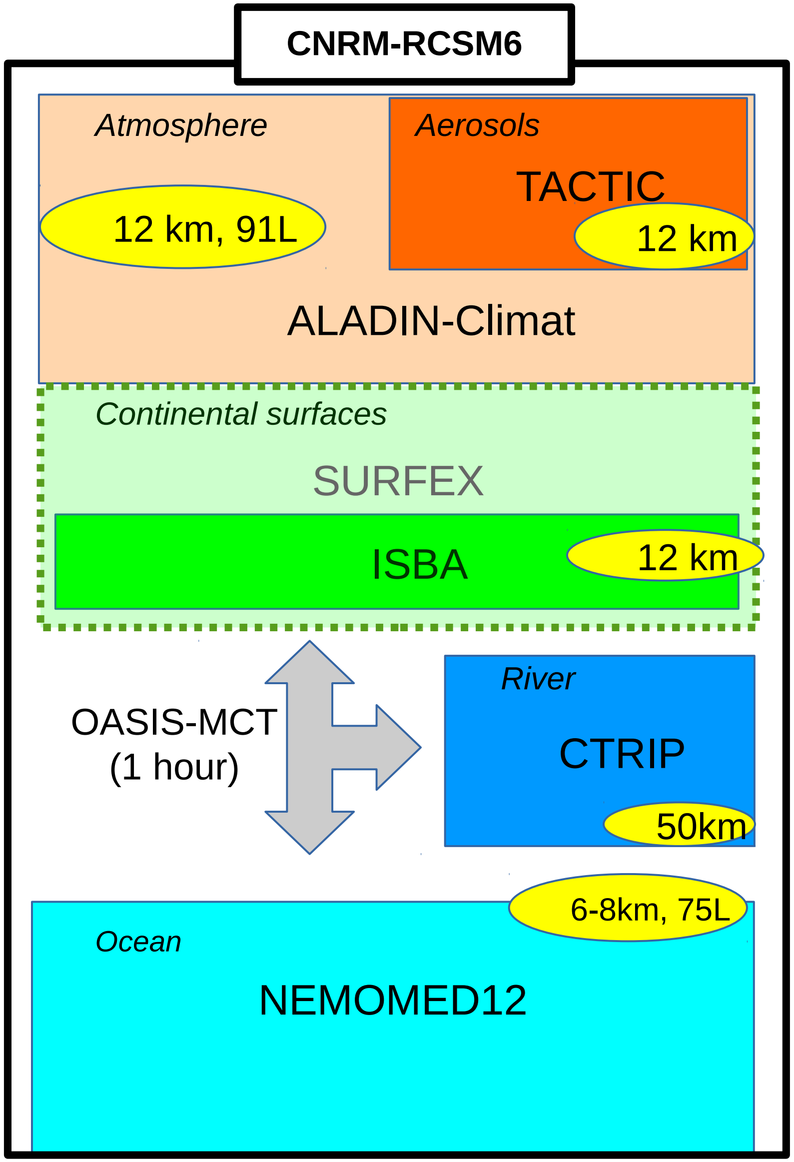
– > Significant nitrate impact on radiation (20% of aerosols radiative forcing) and on temperatures: around -2W/m² in Europe causing cooling (- 0.2°C at the surface during the summer).

Perspectives :

- Realization of regional climate simulations to estimate the impact of different aerosols on the future climate over the Mediterranean region (CNRM-RCSM6),

- Taking into account the indirect effects of nitrates on cloud microphysics,

- Comparison of the results with the models available in the Med-Cordex program.



Thank you for your attention !