Aerosol / chemistry in RegCM4
some recent developments and results

Fabien Solmon

+

The RegCM4 developing team (ICTP and Abroad !)

The Abdus Salam
International Centre
for Theoretical Physics

Chemicals and aerosols in the climate system

Conservation of momentum:

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V}\cdot\nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega}\times\vec{V} + \nabla\cdot(k_m\nabla\vec{V}) - \vec{F}_d$$

Conservation of energy:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{dp}{dt} - \rho C_p (V\cdot\nabla)T - \nabla\cdot R + \nabla\cdot(k_T\nabla T) + C + S$$

Conservation of mass:

$$\frac{\partial \rho}{\partial t} = -(\vec{V}\cdot\nabla)\rho - \rho(\nabla\cdot\vec{V})$$

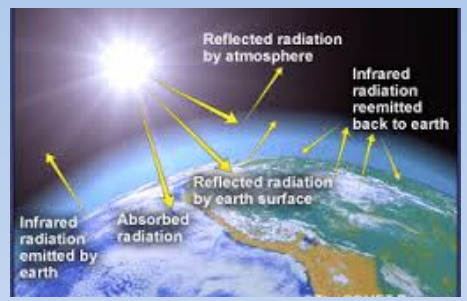
Conservation of H_2O (vapor, liquid, solid):

$$\frac{\partial q}{\partial t} = -(\vec{V}\cdot\nabla)q + \nabla\cdot(k_q\nabla q) + S_q + E$$

Equation of state:

$$p = \rho R_d T$$

Radiative transfers(SW / LW)



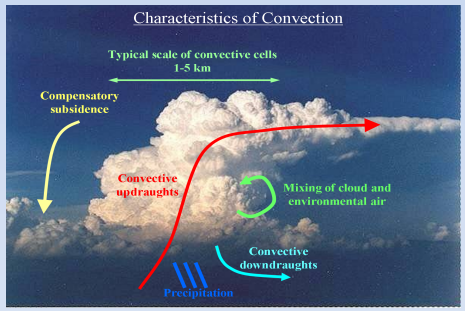
GHG

Direct effect

CHEM / AEROSOLS

Indirect effects

Clouds and Convection



Deposition of chemicals

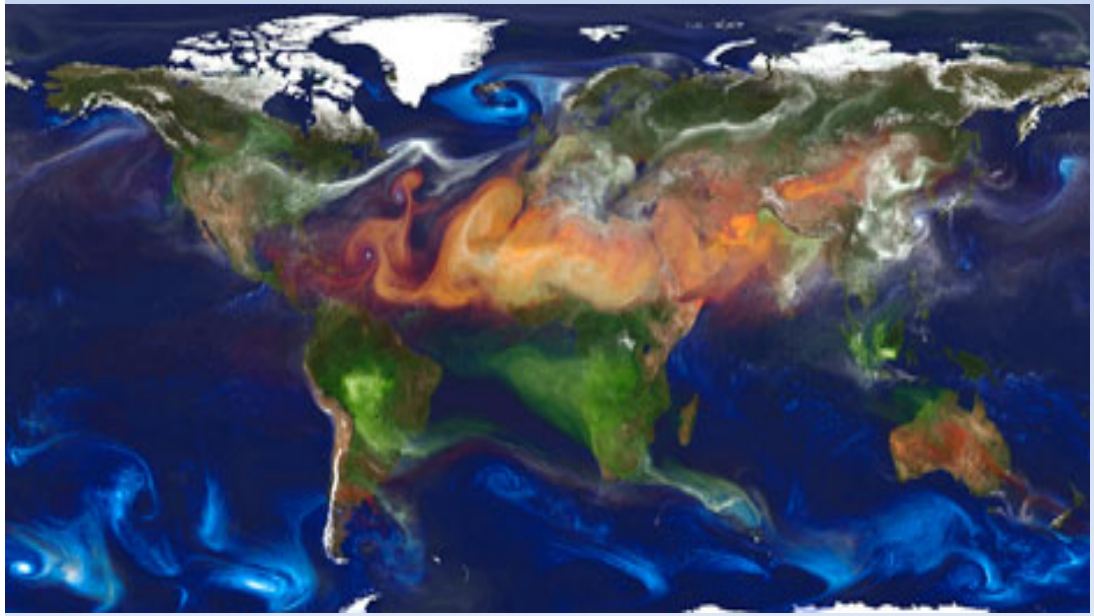
Turbulent diffusion

Surface processes Land /Oceans

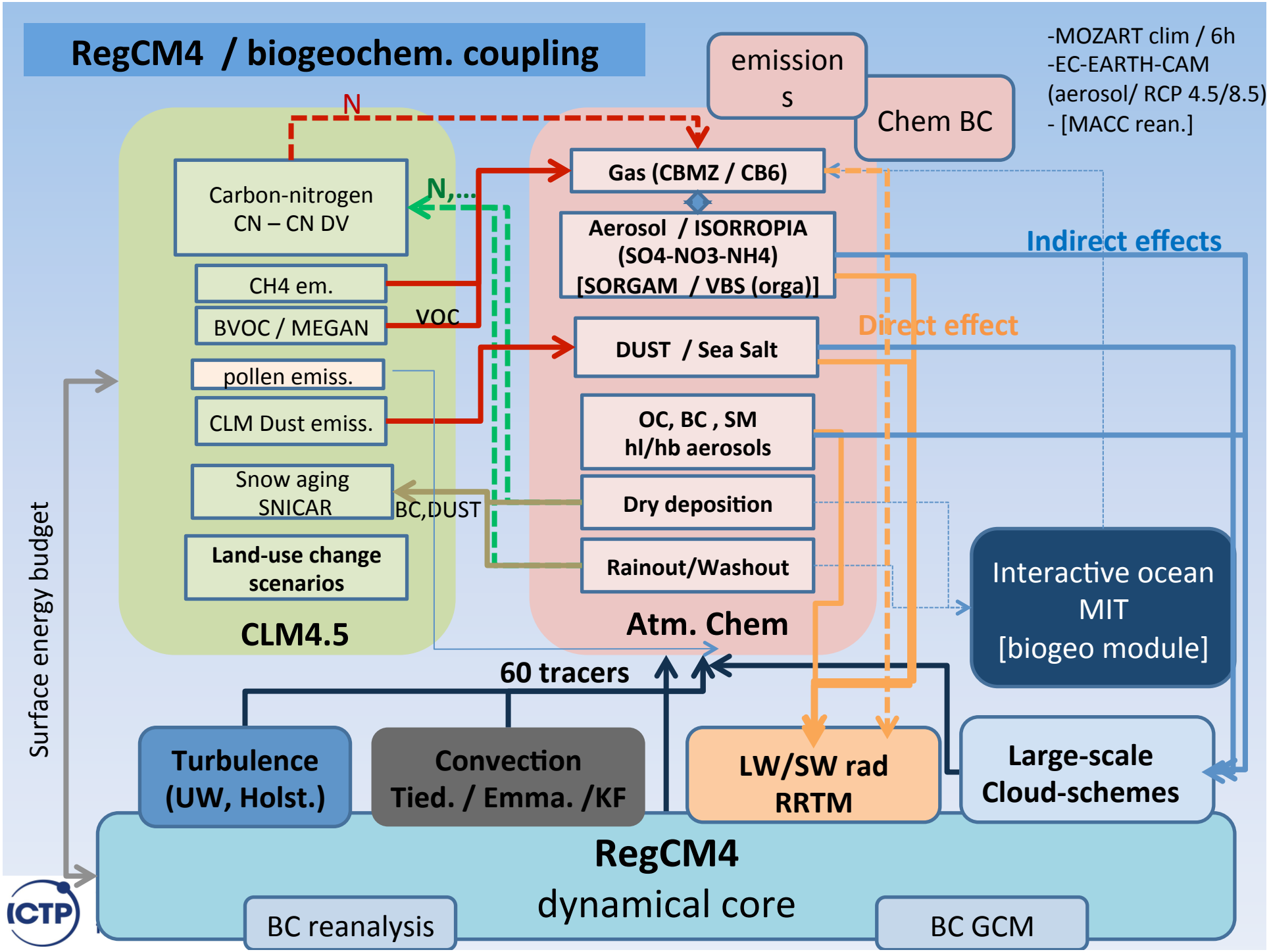
RegCM Coupled chemistry-climate model

Add prognostic tracer concentrations to the previous system …..

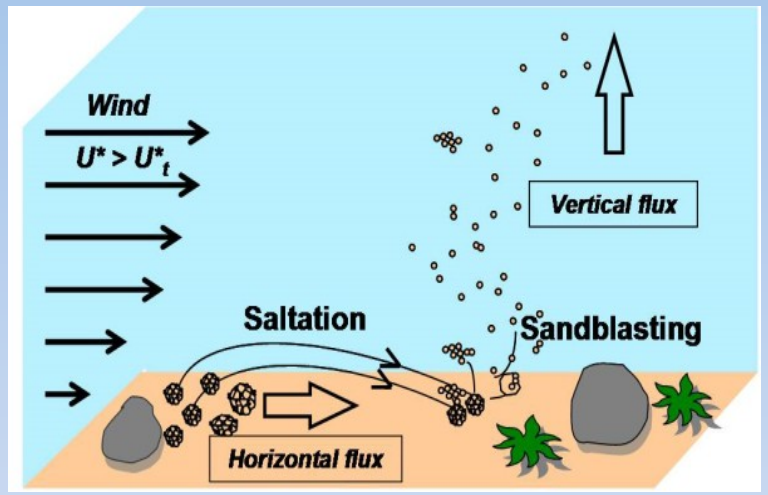
$$\frac{\partial \chi_i}{\partial t} = \underbrace{-\overline{V}\cdot\nabla\chi_i + F_H + F_V + T_{CUM}}_{\text{Transport}} + \underbrace{S_{\chi_i}}_{\text{Primary Emissions}} \underbrace{- R_{w,ls} - R_{w,cum} - D_{dep}}_{\text{Removal terms}} + \underbrace{\sum Q_{p_i} - Q_{l_i}}_{\text{Physico – chemical transformations}}$$

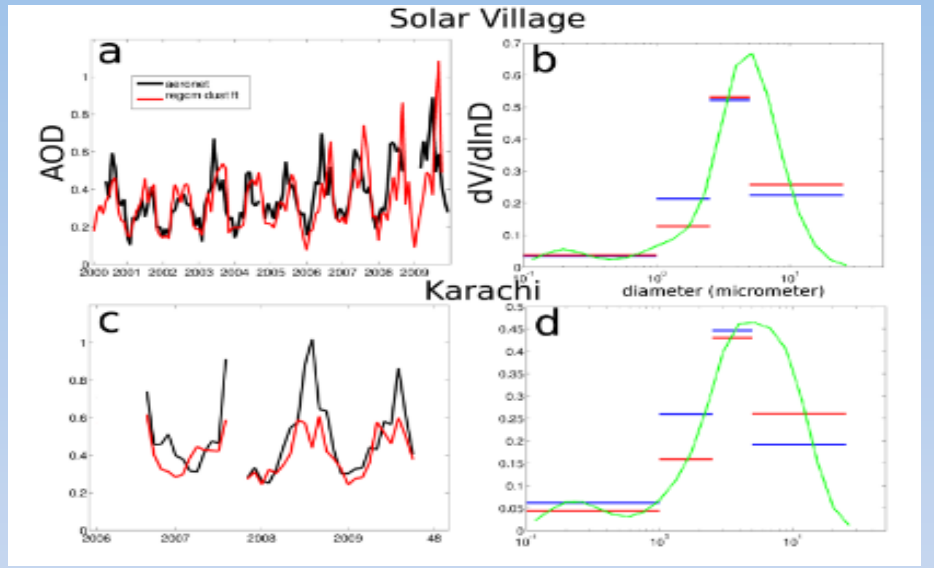


- **Anthropogenic aerosols**
- **Natural aerosols**
- **Photo-oxidant chemistry :**
  - O3 and precursors (anthropogenic, biogenic)
  - Secondary aerosols
- **Bio-aerosols (pollen)**

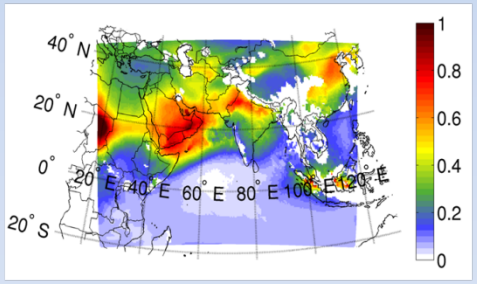

RegCM4 / biogeochem. coupling
emission s
Chem BC
-MOZART clim / 6h
-EC-EARTH-CAM
(aerosol/ RCP 4.5/8.5)
- [MACC rean.]
N
N,...
Carbon-nitrogen
CN – CN DV
CH4 em.
BVOC / MEGAN
VOC
pollen emiss.
CLM Dust emiss.
Snow aging
SNICAR
BC,DUST
Land-use change
scenarios
CLM4.5
Gas (CBMZ / CB6)
Aerosol / ISORROPIA
(SO4-NO3-NH4)
[SORGAM / VBS (orga)]
DUST / Sea Salt
OC, BC , SM
hl/hb aerosols
Dry deposition
Rainout/Washout
Atm. Chem
Indirect effects
Direct effect
Interactive ocean
MIT
[biogeo module]
Surface energy budget
60 tracers
Turbulence
(UW, Holst.)
Convection
Tied. / Emma. /KF
LW/SW rad
RRTM
Large-scale
Cloud-schemes
RegCM4
dynamical core
BC reanalysis
BC GCM
ICTP

Dust scheme

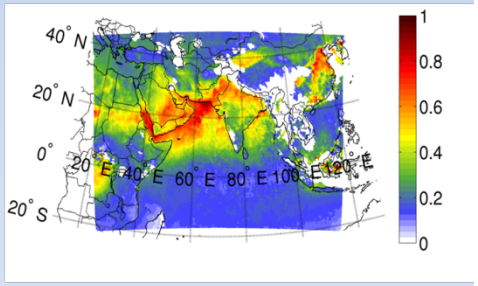




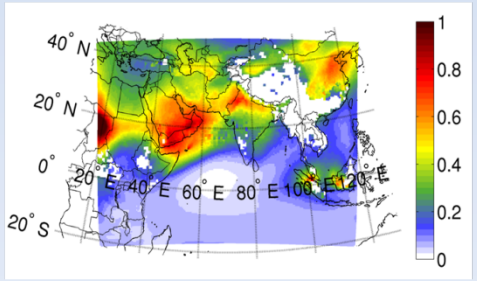
ReGCM (aer) JJA Composite average
(screened from monthly obs)



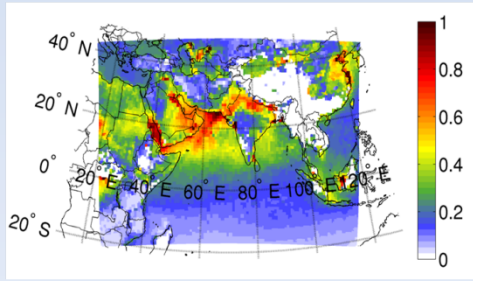
MISR JJA



- -Standard version : 4 bins (Zakey et al., 2006)
- -Revised version (soil texture and emission size distribution (Kok et al., 2011) + optical properties)



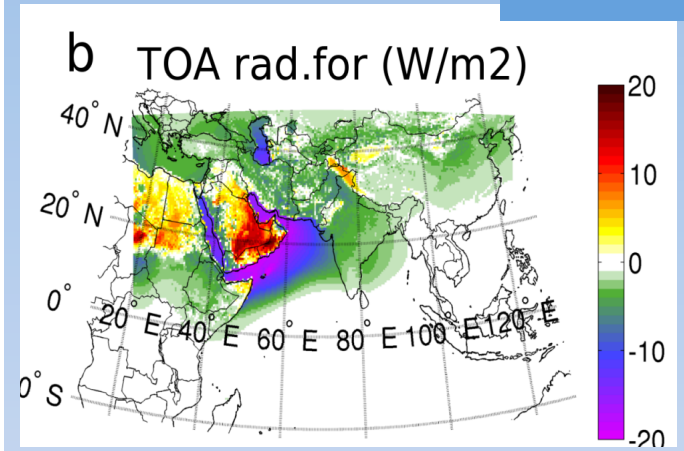
seawifs JJA

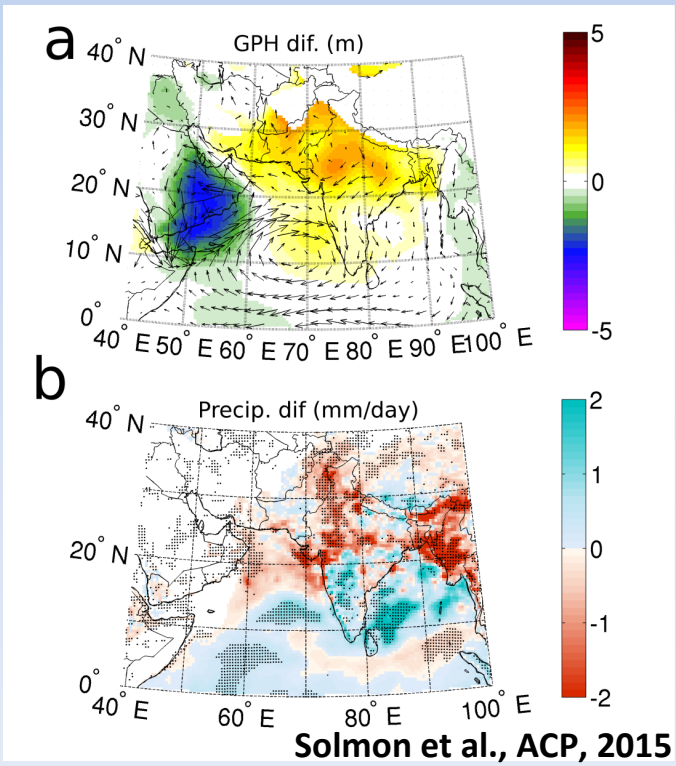


- -CLM4.5 emission dust scheme (Zender et al., 2001) enabled.
- -Somebody wants to test ?

Solmon et al., ACP, 2015

Dust regional climate interactions



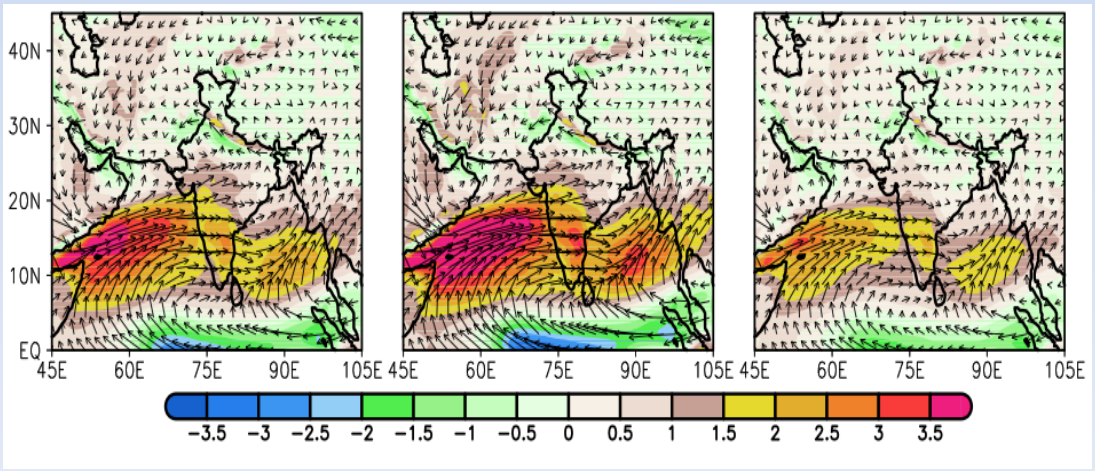


Solmon et al., ACP, 2015

Importance of "interactive" ocean (here we implemented a slaboc option – Interest to use fully coupled version)

Optical properties / source variability

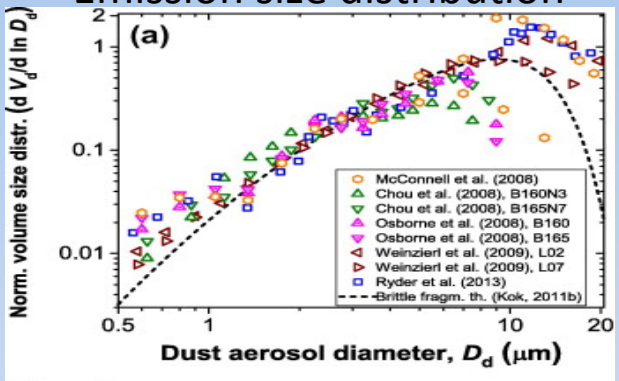
e.g. change in dust ssa, impact the response

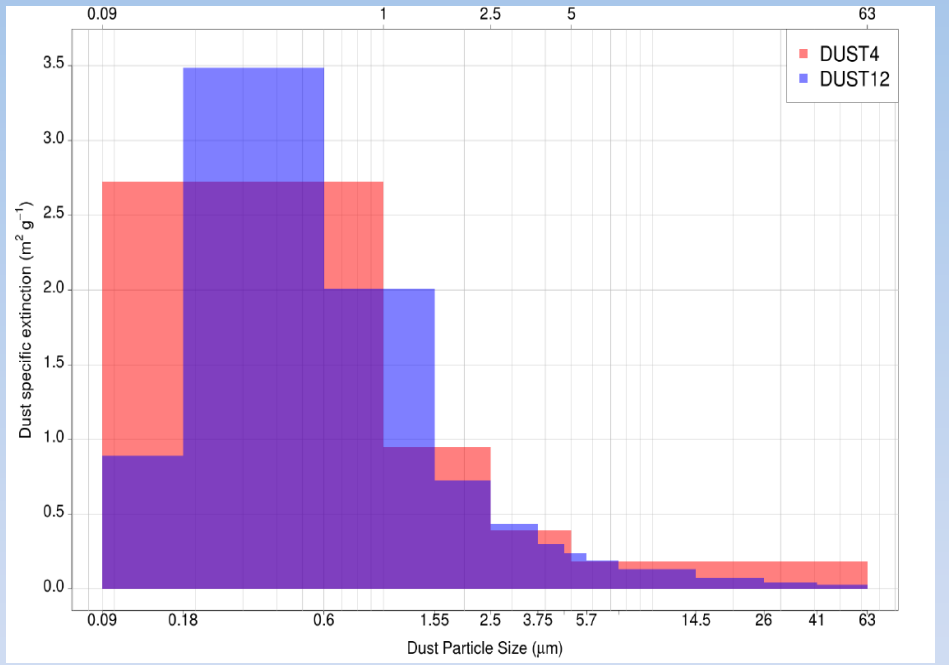


Das et al., JGR, 2015

Dust : towards a more detailed option …

Emission size distribution



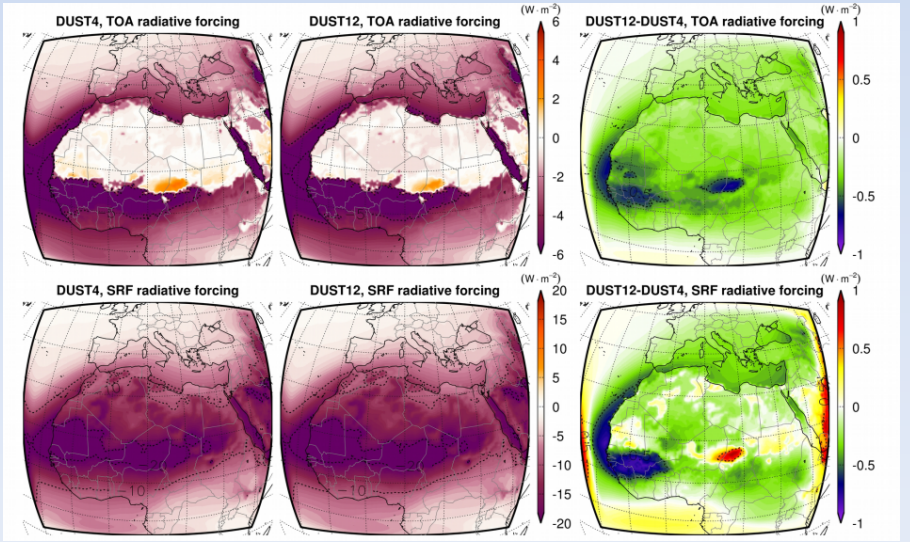


"iso –gradient" discretisation:

12 bins : Foret et al. 2006

Optical properties
Calculated using sub-bin
distribution of Kok et al., 2011

Next step :
Dust mineralogical composition



Tsikerdekis et al., ACPD, 2016

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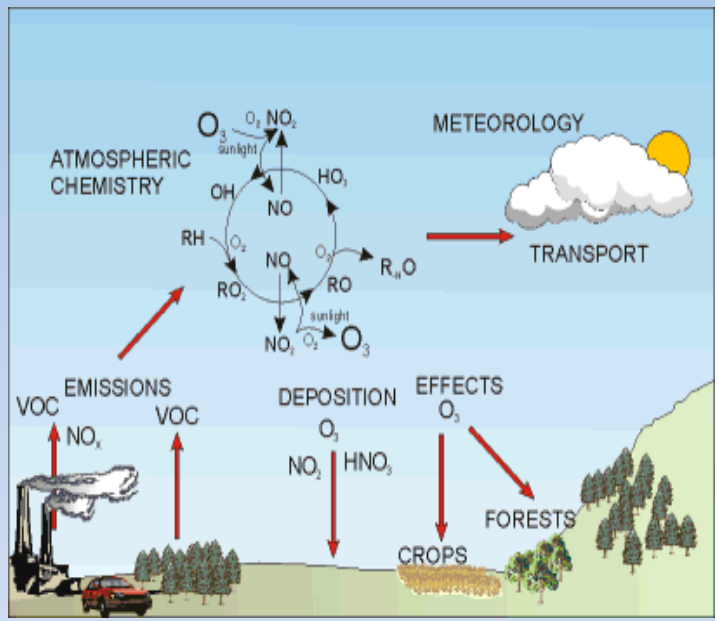
Gas phase chemistry

- **CBMZ / initially Shallaby et al., GMD, 2012**

  ODE Solver : now use KPP
  (check wikipedia ..)

  More tracer transported (SL adv)

  Boundary conditions :
  MOZART –clim 2000-2007
  MOZART 6h : for the period 2000-2009
  … soon to come : MACC reanalysis at 6h
  … MOCAGE / ARPEGE / hist +RCP at 6h



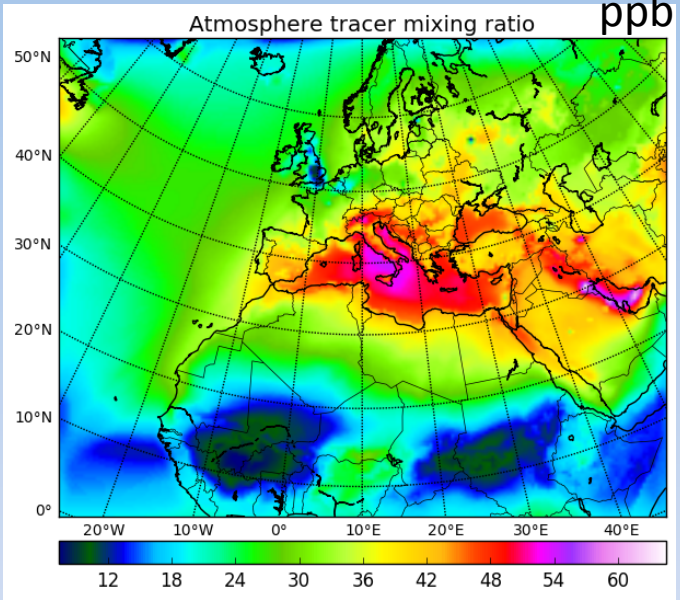
- **Developing branch :**

  CB6r2 / J. Ciarlo's PhD : allows a better representation of SOA precursors
  …. Yet to be merged … (try to catch up with Graziano …)

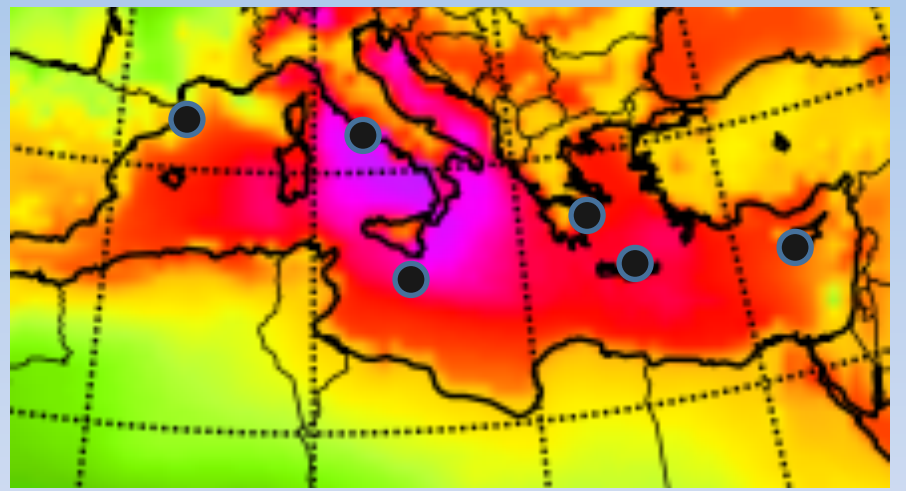
Gas phase chemistry
Surface ozone simulations (JJA)

- 50km
- ERAI
- MOZART CBC
- IIASA ECLIPSE

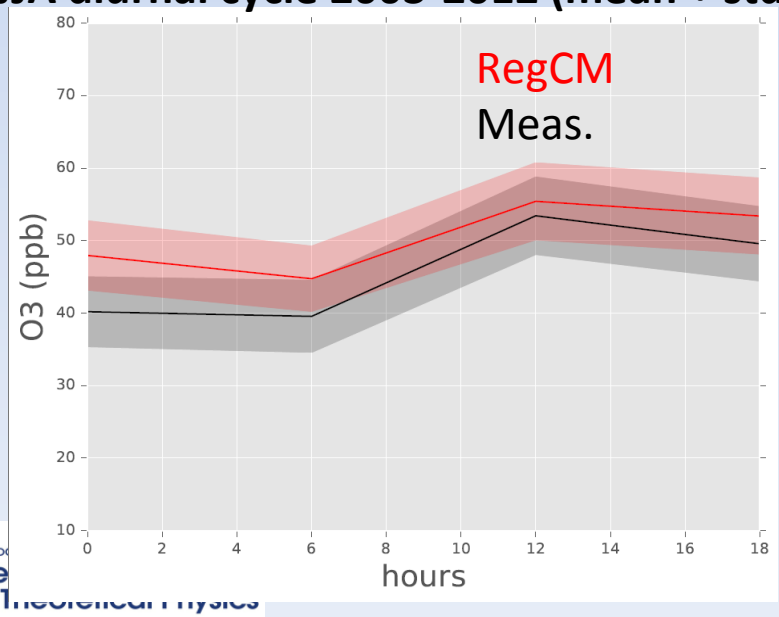
2003-2012



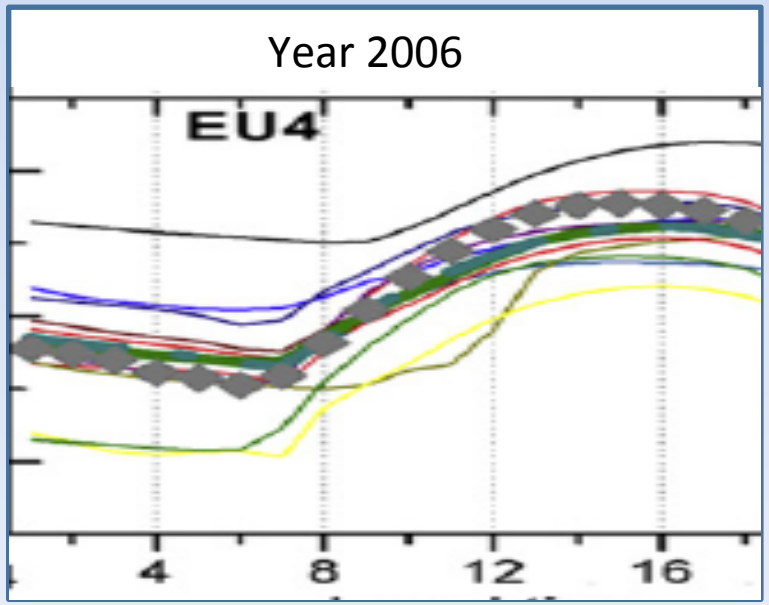
- MED stations / EMEP - Katragkou et al., 2015



JJA diurnal cycle 2003-2012 (mean + std)



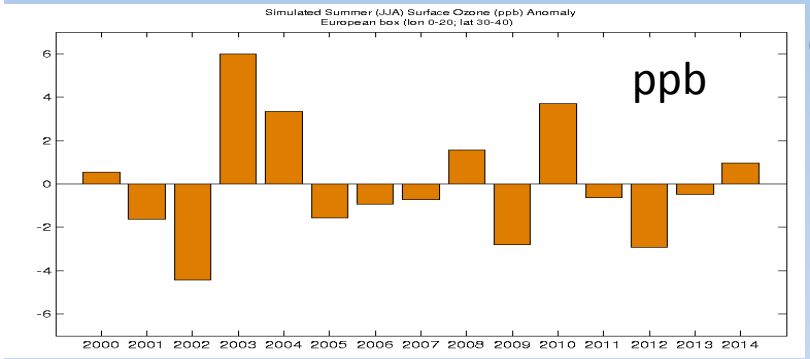
AQMEI(Solazzo et al., 2012)



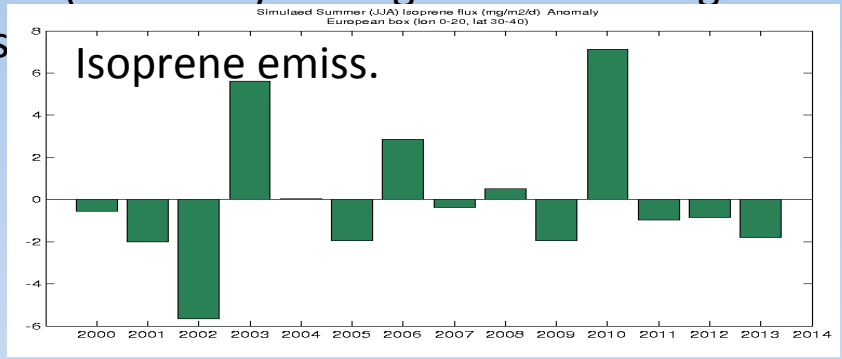
Simulated Interannual variability (2000-2014)

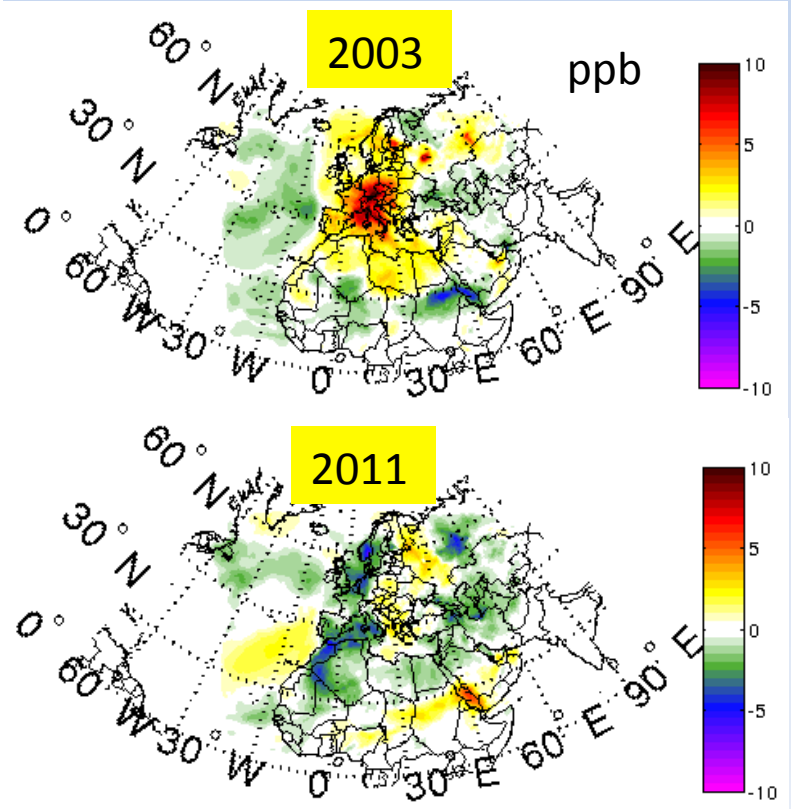
RegCM4 – 2000-2014

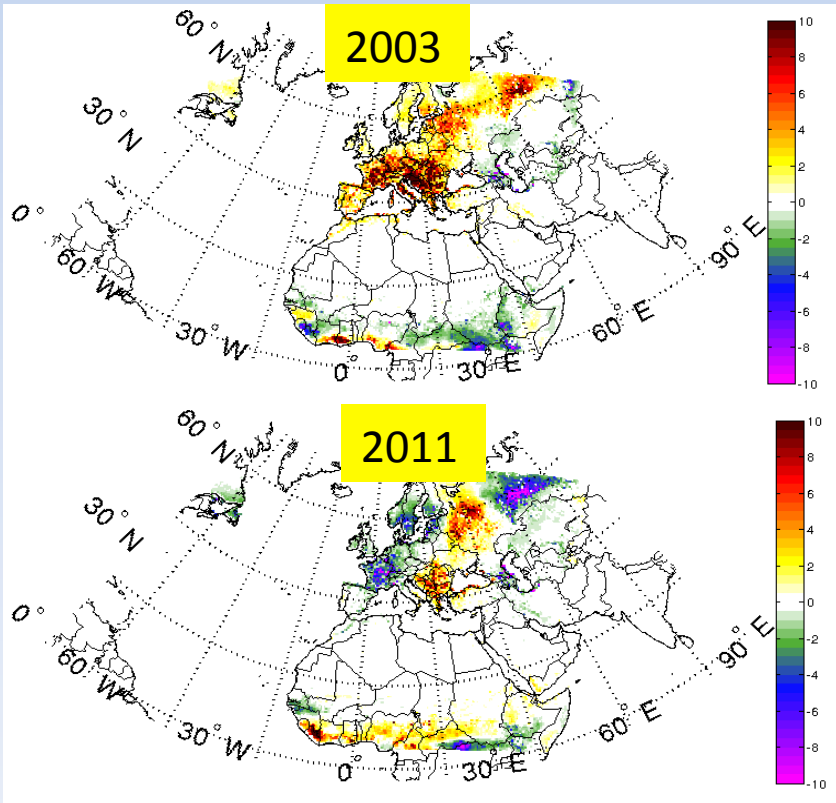
Simulated JJA surface ozone anomaly



2003 heat wave and high regional ozone levels in Europe: (sensitivity to stagnation and biogenic voc emiss

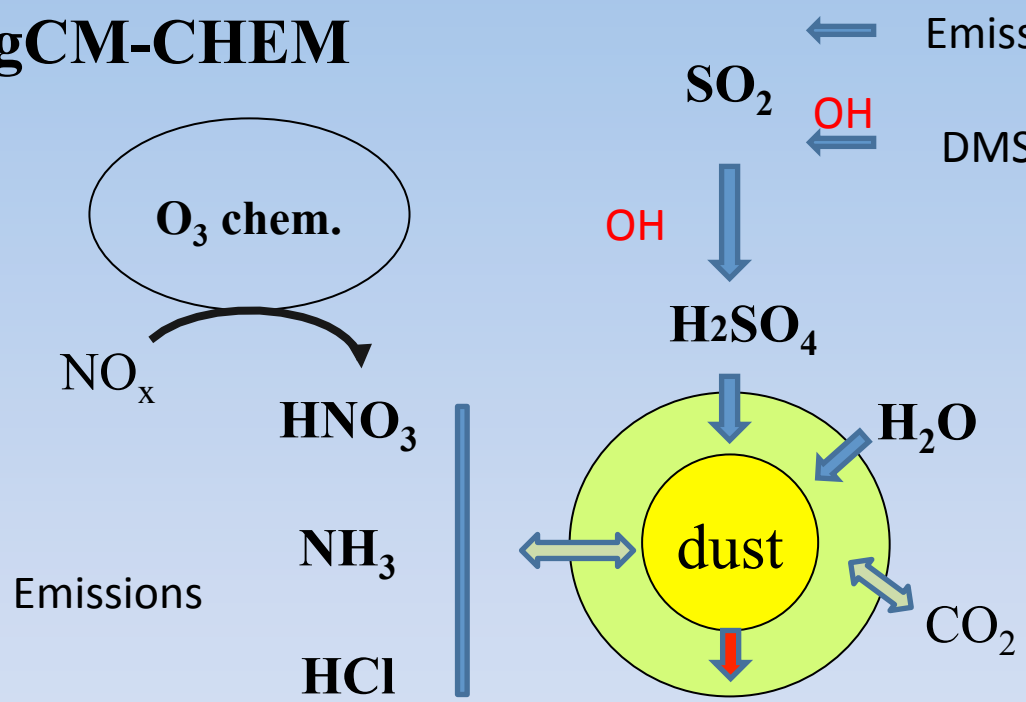






Sulfate-Nitrate-Ammonium formation via thermo equilibrium

RegCM-CHEM



1: Formation of H2SO4

2: ISORROPIA (Nenes et al.)

determine thermodynamical <u>equilibrium</u>

- semi-volatile compounds partition

- Speciation of the solution e.g. ammonium nitrate) + pH

Scavenging of gas (SO2/NOx) by the dust or sea salt particle

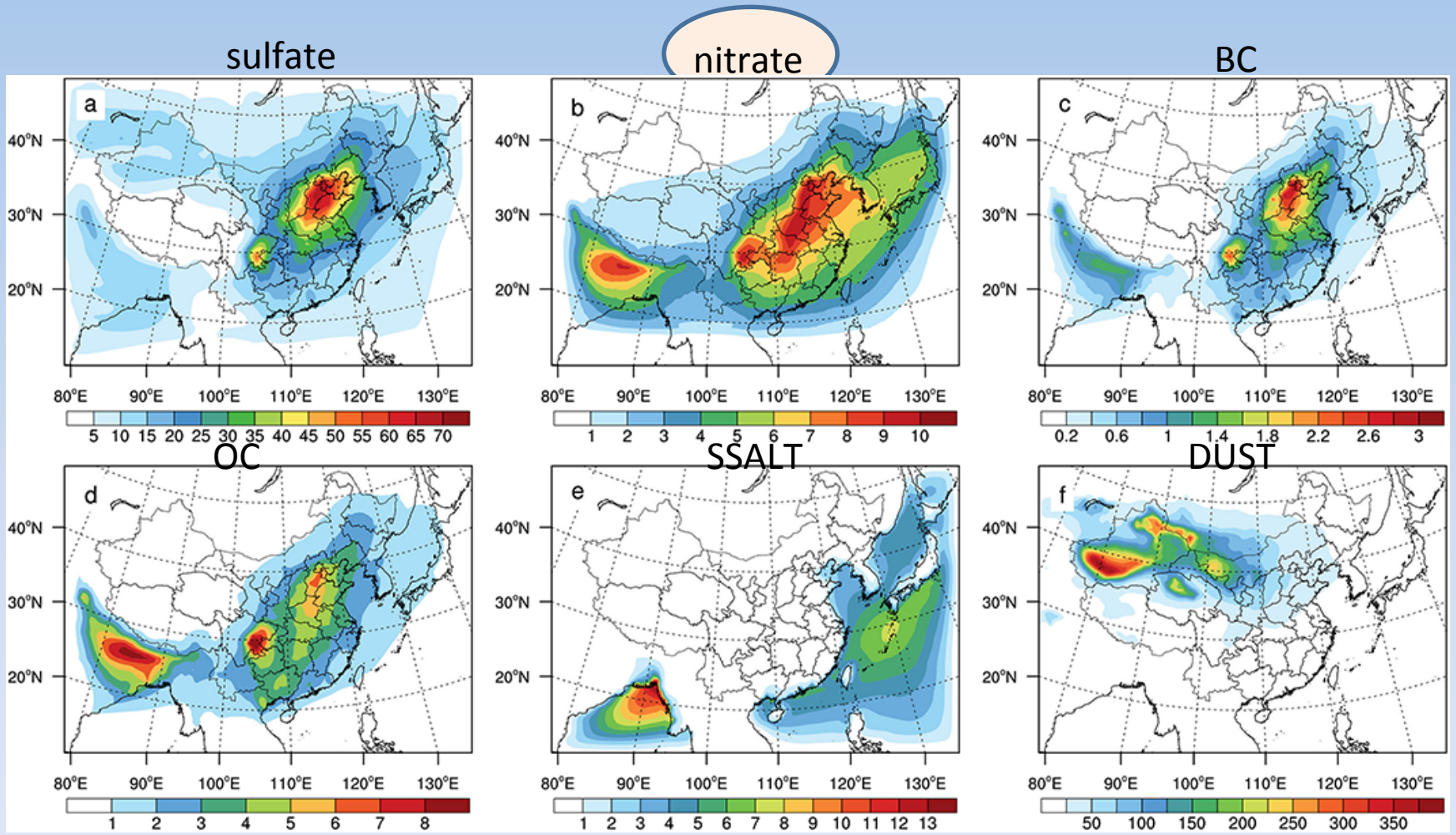
Dissolution kinetic of minerals : cations (Ca2+, K+, NA+) : new tracers

New thermodynamical equilibrium

Not yet implemented

Perspective biogeochem. coupling e.g. Fe

Secondary aerosols : inorganics

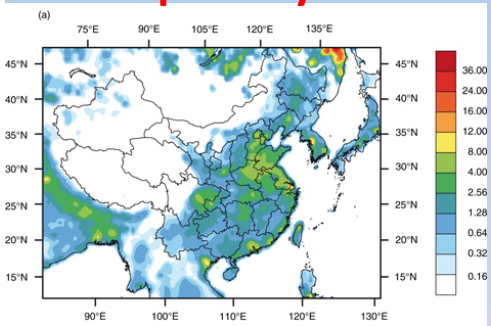


Shu et al., JGR, 2016
(REQUA)

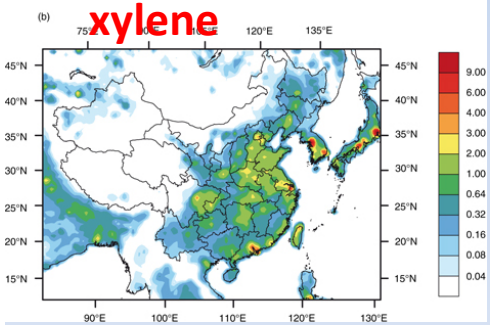
Secondary organic aerosols

Emissions JJA
(mg/m2/day)

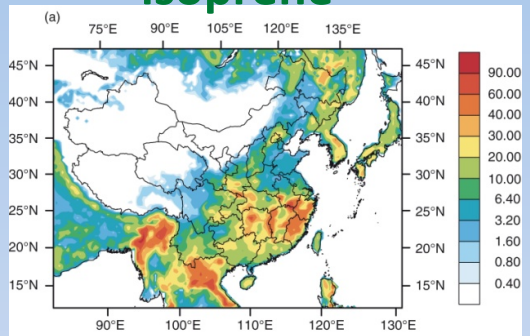
OC primary



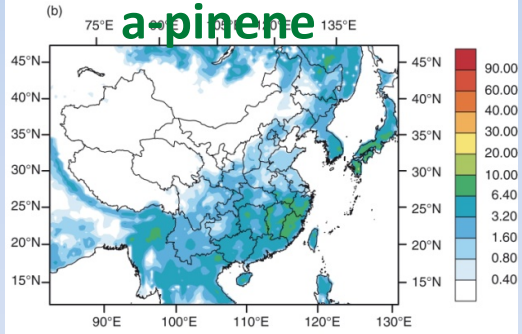
xylene



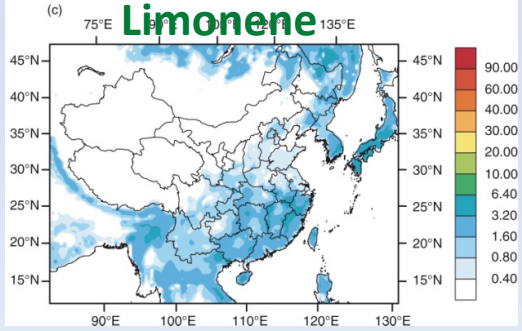
isoprene



a-pinene



Limonene



CLM / MEGAN

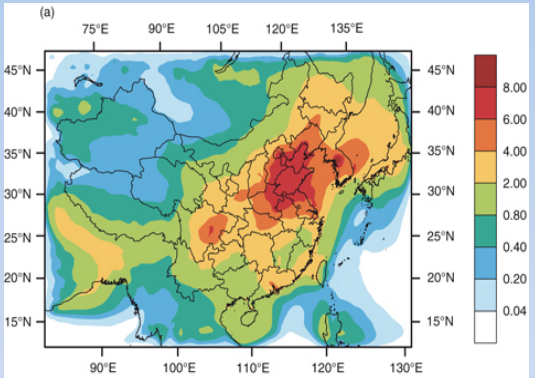
CBMZ

VBS

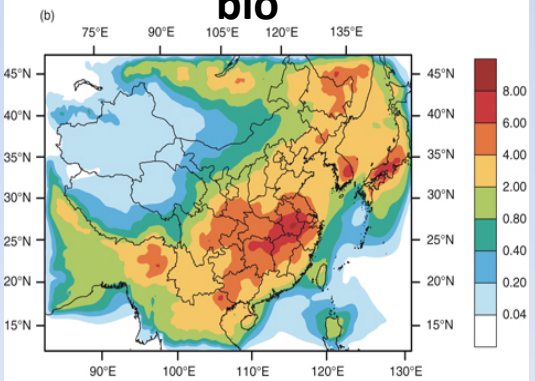
SOA formation from gas phase semi-volatile precursors

SOA

anthro



bio



Yin et al., Tellus B, 2015 (REQUA)

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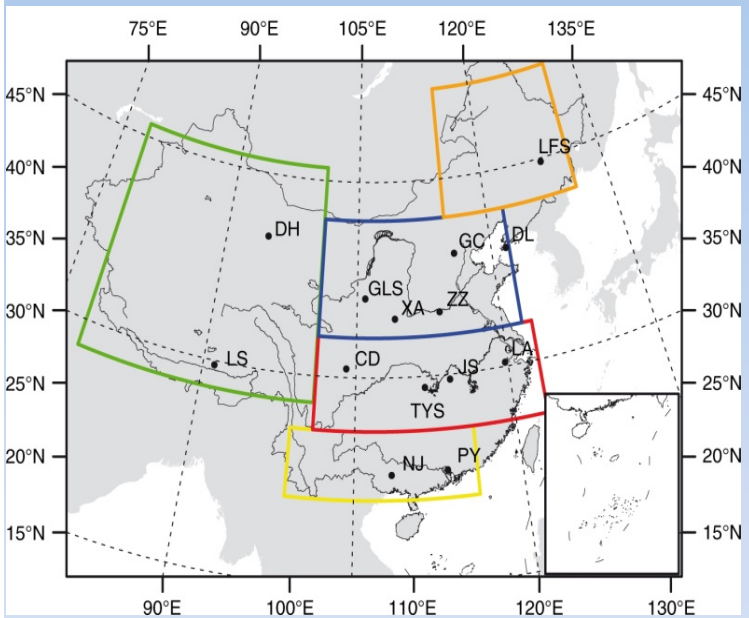
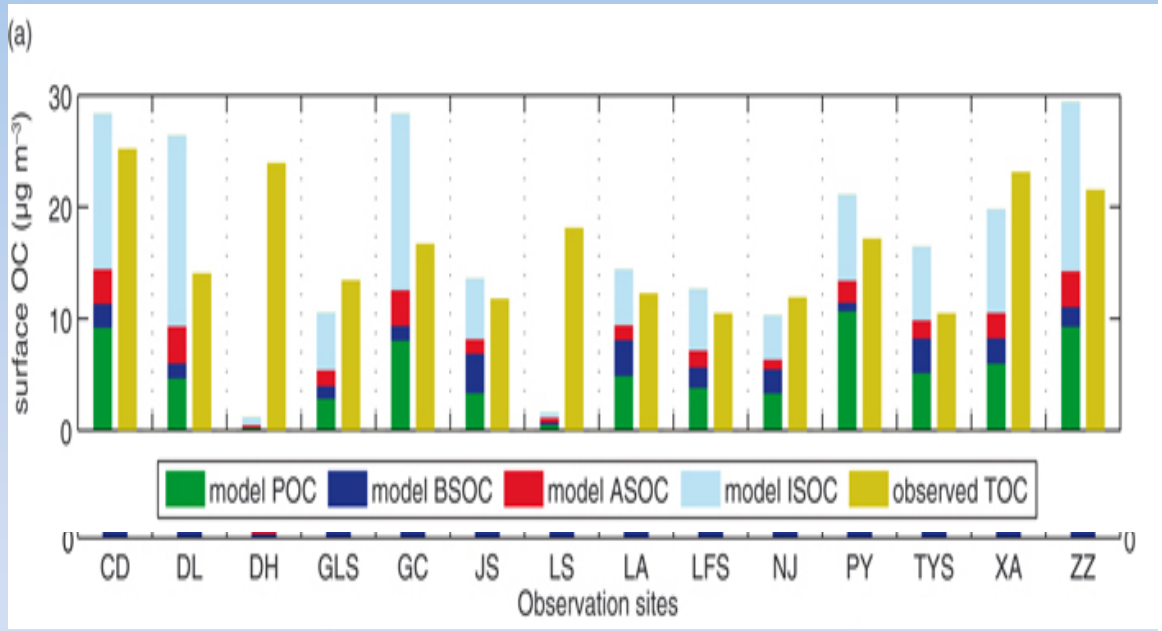
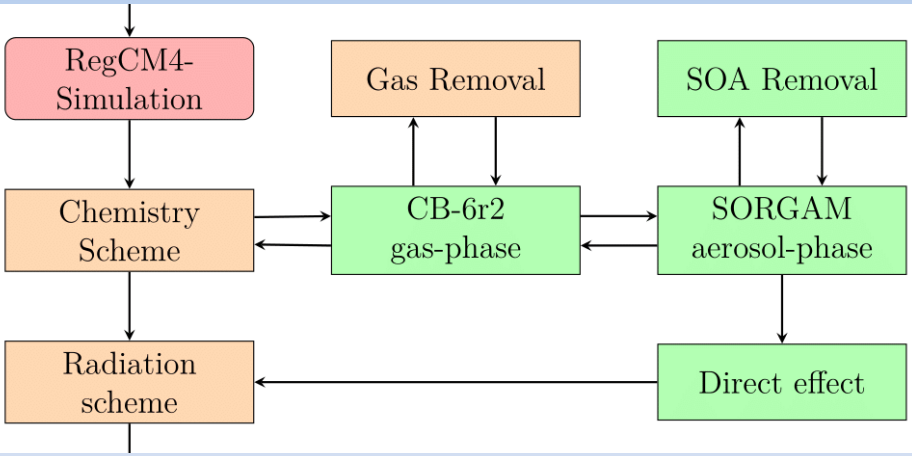
Secondary organic aerosol

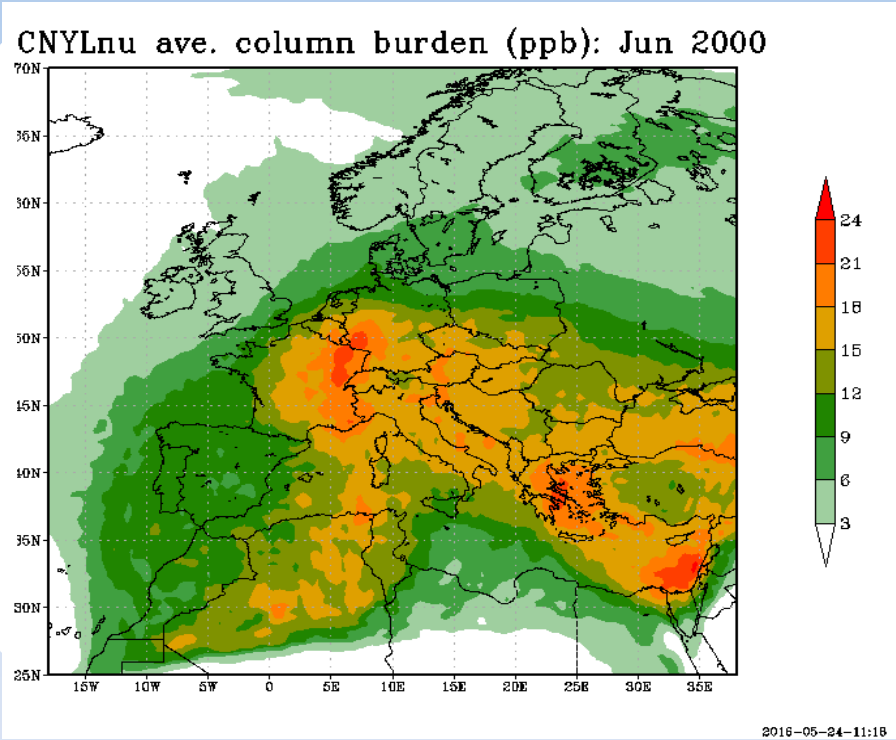




- **Importance for CCN**
- **Importance for certain region : e.g. Mediterranean regions (SOA = 20 % of PM1)**

Developing branch CB-6r2 + SORGAM
J.Ciarlo

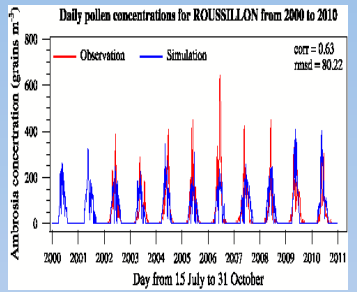


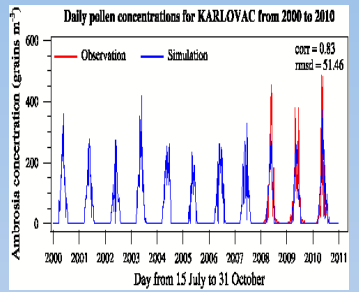


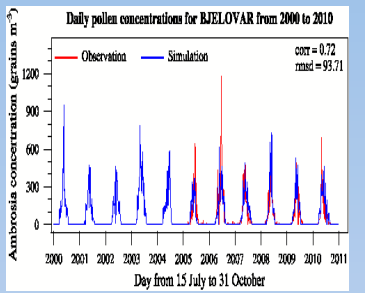
Pollen modelling

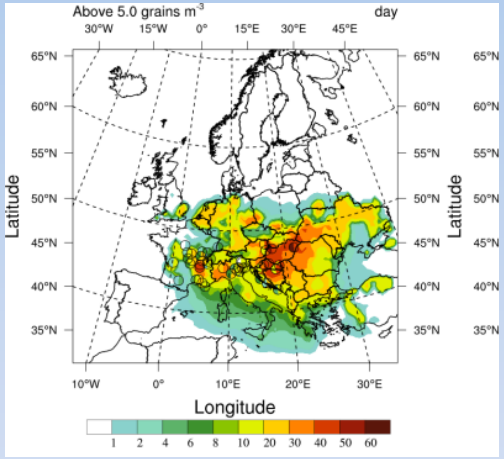
Ambrosia

atopica
atopic diseases in changing climate, land use & air quality

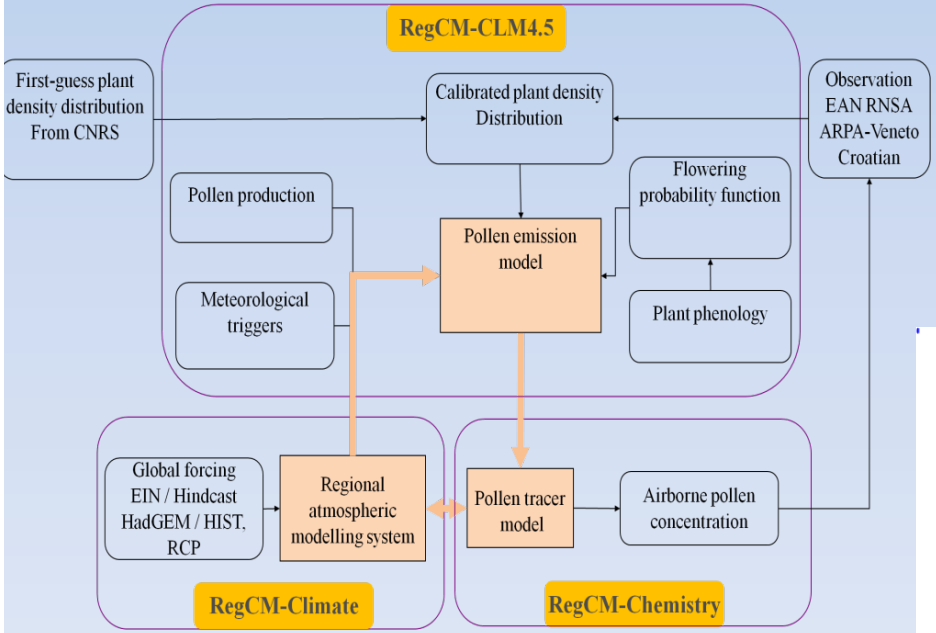




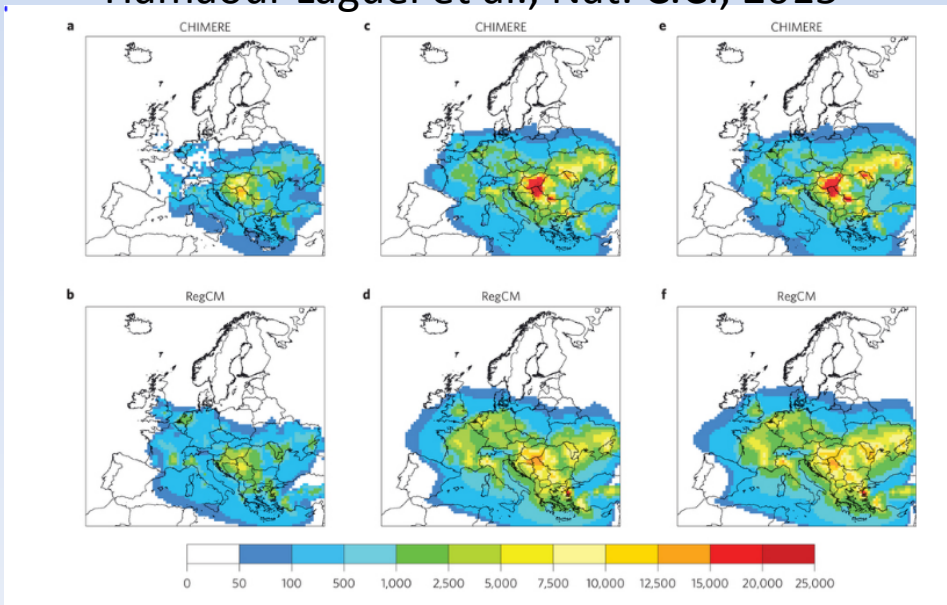




Hamaoui-Laguel et al., Nat. C.C., 2015



Liu et al., GMD, 2016



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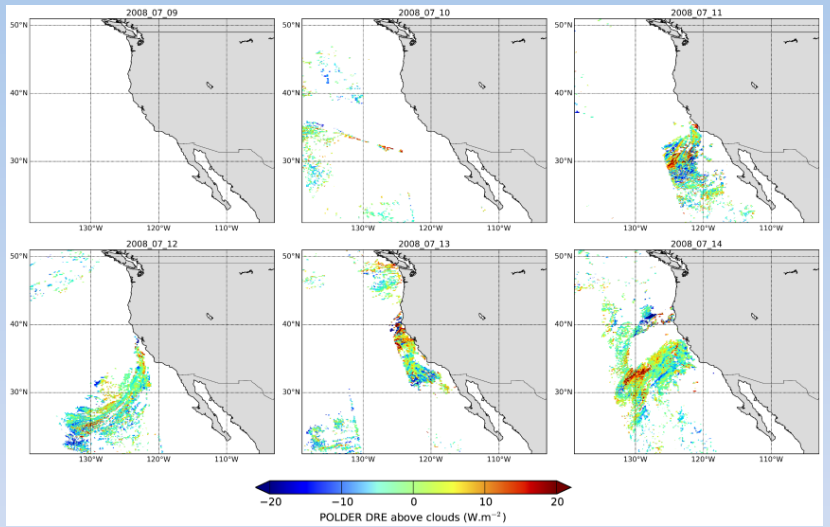
Semi-direct effects of smoke aerosol on Stratocumulus

Courtesy of
M. Mallet
LA / CNRS

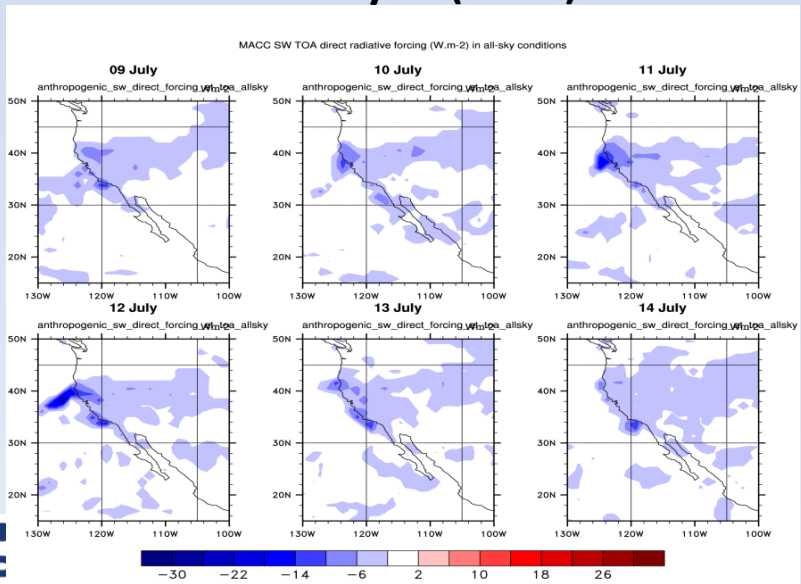
Smoke aerosol advected over a Sc deck

Polder OBS
TOA All sky radiative foircing (ASRF)

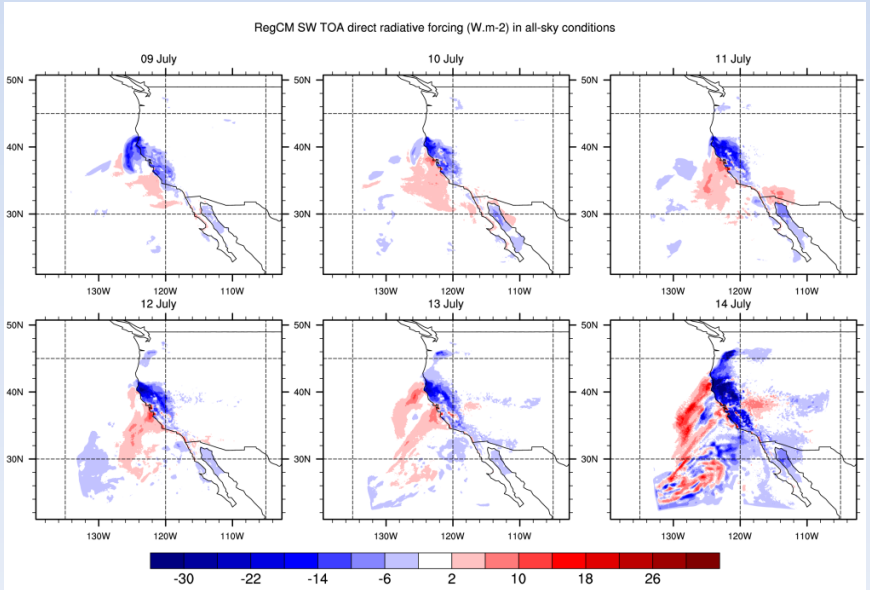


Smoke/ RRTM

MACC reanalysis (ASRF)



RegCM (ASRF)



Indirect effects

First indirect effect :

Cloud eff. radius modified in function of CCN number CLWC and type of cloud (e.g. Martin et al., 1994). Different param according to aerosol nature (sulfate vs smoke) . Assume aerosol size distribution / use empircal relation ships to calculate CCN number from aerosol number.

Second indirect effect :

modification of cloud to rain water autoconversion rate in function of CCN number, depending on aerosol – simple approach -

N. Kaffashzadeh
A. Tompkins

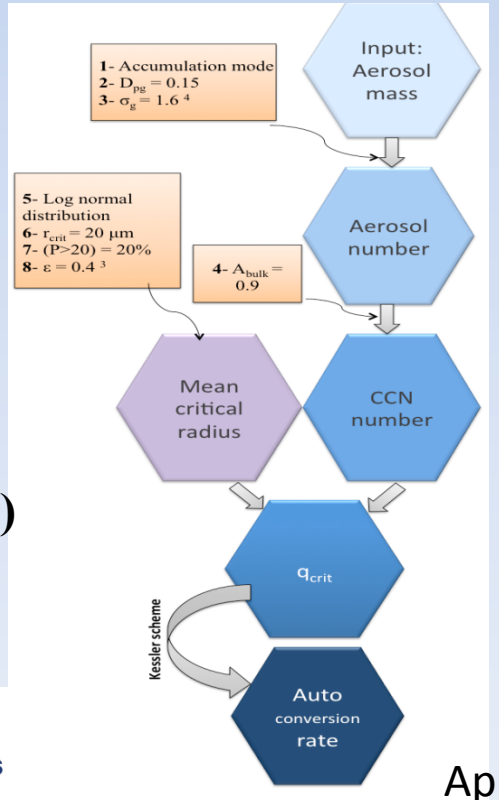
Kessler scheme

$$dq/dt = c\,(q - q_c)$$

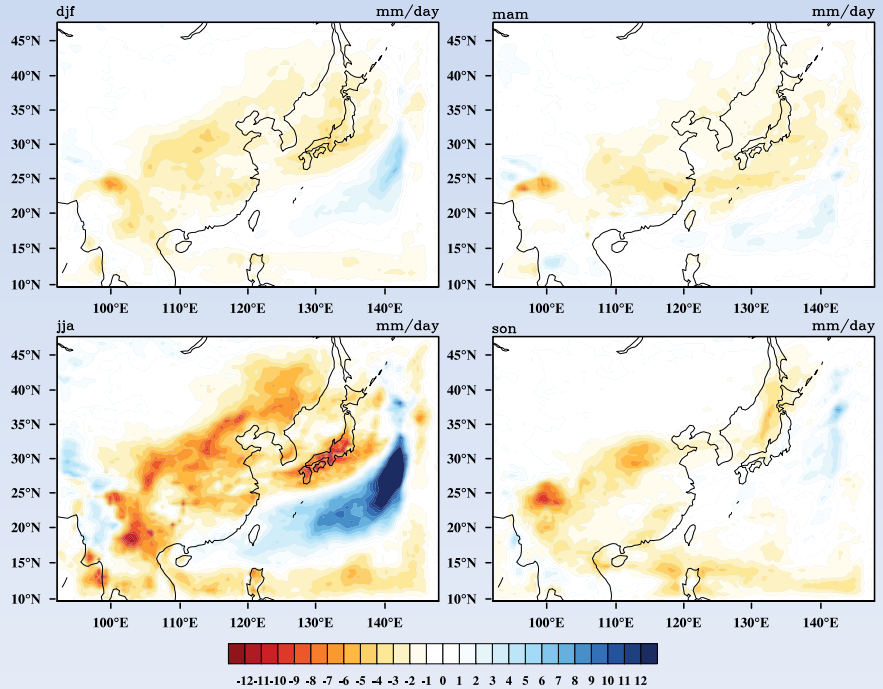
q_c : critical liquid water content

$$q_c = N_{ccn}\,(4/3\,\pi\,r^3_{cm}\,\rho)$$

r_{cm} : mean critical radius for efficient auto-conversion



Prcip dif : indirect - ctrl



Applied to large scale precip and Tiedke conv precip

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perspectives

Other sources (marine organics, aviation, generalized pollens, on line fire modelling)

Full aerosol model (prognostic size evolution)
+ more detailed of indirect effects

High resolution

Spectral nudging (impact studies)

Thanks

Ozone in the Earth system

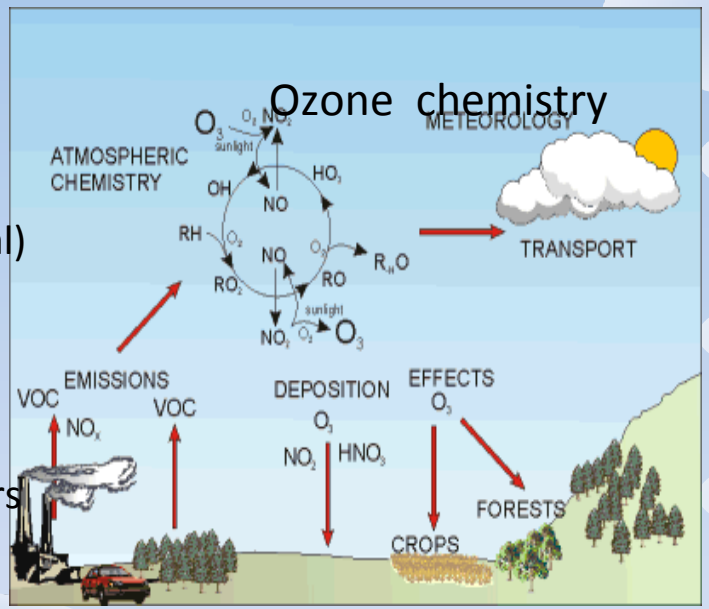
Climate change

Biogenic emissions
(marine / continental)

Land-use change

Emissions of precursors

Anthropogenic activity



Air quality

Atm. Ox. Capacity and Acidity

Impacts on agro/ecosystems
- Biogeochemical cycles

Climate : radiative forcing

Climate : connections to secondary aerosols
(e.g. sulfate and organics)

Regional scale experiment (e.g. MINOS, ..)

Chemistry Aerosol Mediterranean Experiment

http://www.atmos-chem-phys.net/special_issue334.html

http://charmex.lsce.ipsl.fr

CHARMEX

MISTRALS

CharMEX WP7 –
Future climate- chemistry conditions over the Med. Basin

Model intercomparison study

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