LIMA: Liq. Ice Multiple Aerosols

A quasi 2-moment bulk scheme developed in the cloud-resolving mesoscale model MesoNH

Jean-Pierre Pinty(1), Benoît Vié(2),

and contributions from C. Barthe, S. Berthet and M. Leriche

(1) Lab. Aérologie, CNRS-Université de Toulouse, Toulouse, France
(2) Météo-France, Toulouse, France

Motivations:

- Steering cloud physics by 3D fields of aerosols (nCCN and mIFN)
- … but preserving enough computational efficiency to perform large meteorological simulations at high resolution

Introduction to
LIMA: Liq. Ice Multiple Aerosols

1-moment (bulk) microphysical schemes (4-5-6-7 Eqs): **ICE3/4**

- Advantage: adapted to NWP models => QPF, cloud radiative effects, scavenging of gas-aerosol, cloud electricity, …
- Drawbacks: no sensitivity to the aerosols, temperature-water vapor adjustment => no supersaturation, autoconversion cloud particles => hydrometeores => no physics: threshold & time scales to tune

2-moment (bulk) microphysical schemes (~2*****Eqs + aerosols Eqs):

- Advantage: remove preceeding drawbacks … but aerosol description is often too much simplified => **LIMA (new)**
- Drawbacks: assumed size-distributions of the particles, uncertain parameterization of autoconversion processes (droplets=>raindrops)

Detailed (bin) microphysical schemes (40-60 Eqs/water, ice & aerosol):

- Few assumptions => ref. schemes **(YES for water, but for ice ?)**
- Mass conservation (solved) and spectral diffusion (vapor cond/dep)
- Huge computational needs (transport & processes) for 3D numerical experiments over large domains

Introduction to LIMA: Liq. Ice Multiple Aerosols

<u>LIMA : a 2-moment microphysical scheme</u>

- 2 budget Eqs for each aerosol type (N_{free} & $N_{captured}$)
- Activation of a mixture of CCN => competition effect
- Nucleation by multiple IFN sources => V. Phillips scheme
- Scavenging by raindrops

$$n(D)dD = N\frac{\alpha}{\Gamma(\nu)}\lambda^{\alpha\nu}D^{\alpha\nu-1}\exp\left(-(\lambda D)^{a}\right)dD$$

$$M(p) = \frac{1}{N}\int_0^\infty D^p n(D)dD = \frac{\Gamma(\nu + p/\alpha)}{\Gamma(\nu)}\frac{1}{\lambda^p}$$

- N_{snow}, $N_{graupel}$, N_{hail} diagnosed
- Size distributions : *n(D)*
- *p*-moment : *M(p)*
  (α & ν are fixed)
- Aerosol modes are distributed lognormally

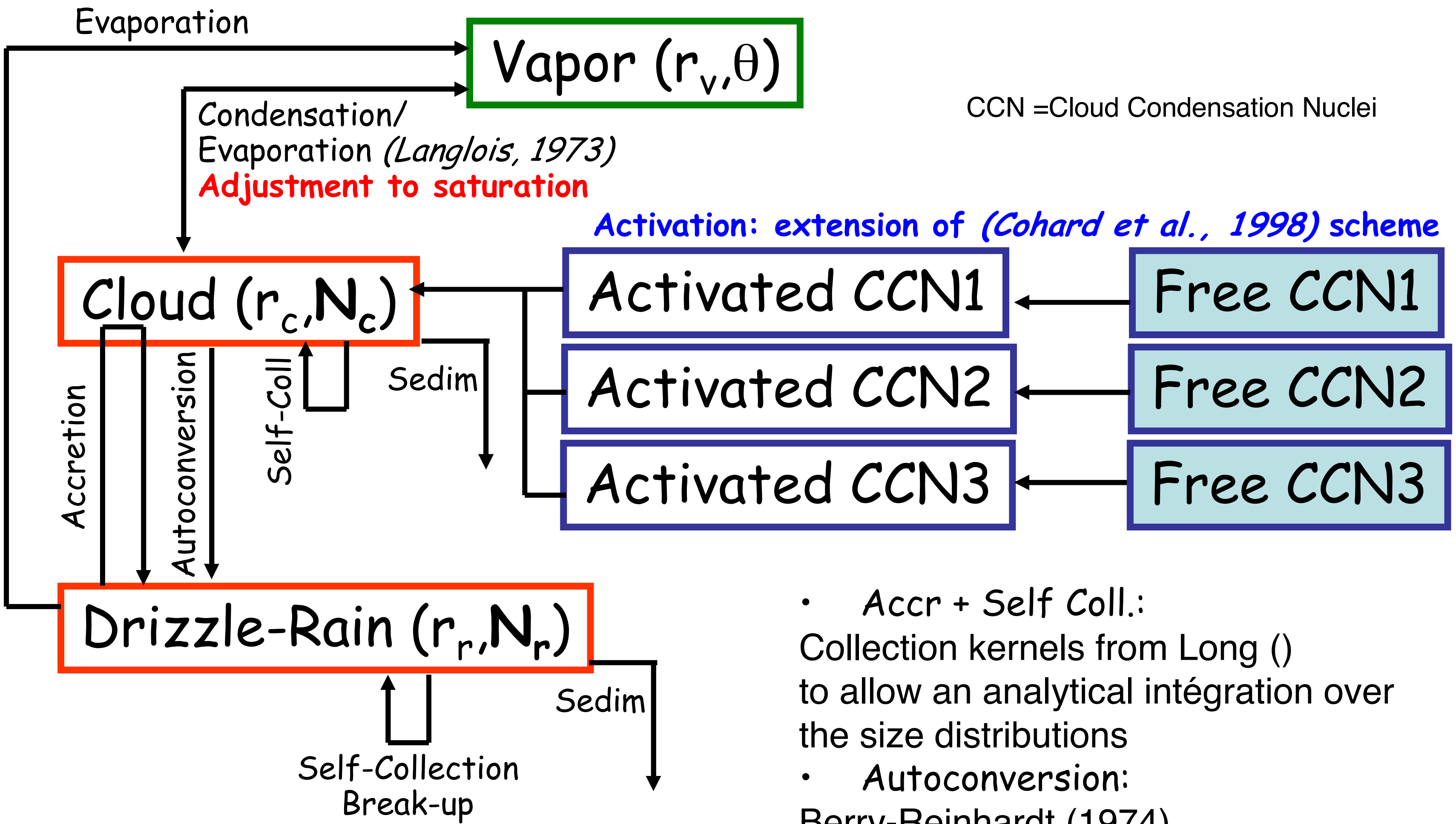
<u>LIMA : what is missing yet ?</u>

- Regeneration of the aerosols: surface processes, cloud processing
- Pristine ice crystal habits
- Transition particles : drizzling drops & «big» pristine ice crystals ?

LIMA is coupled to the radiative transfer scheme (effective radius or dim.)

LIMA: Warm part of the scheme

Based on Cohard and Pinty (2000)



- *Accr + Self Coll.:*

Collection kernels from Long ()
to allow an analytical intégration over the size distributions

- *Autoconversion:*

Berry-Reinhardt (1974)

State variables: N_{free1}, N_{free2}, N_{free3}, …, N_{act1}, N_{act2}, N_{act3}, …, N_c,r_c, N_r, r_r

LIMA: IFN nucleation (1)

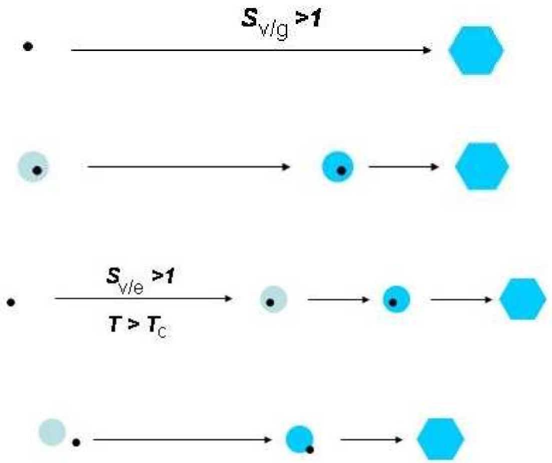
Based on Phillips et al. (2008, 2013)

Classical: Meyers et al.(1992), Diehl et al. (2004, 2006) but no IFN budget, no sensitivity to IFN type or to IFN size distributions

➔ « Empirical Parameterization » for multiple chemical species of IFN to homogenize the description of the heterogeneous nucleation process.

Species: X∈ {Dust, Black Carbon, Organics, Biogenics}

Processes:



Deposition

Immersion
Contact inside-out

Condensation/freezing

Contact outside-in

• Singular hypothesis: spontaneous *vs* probabilistic process => the largest IFN are nucleating first
• Importance of cloud chamber calibration *vs* theoretical modeling

LIMA: IFN nucleation (2)

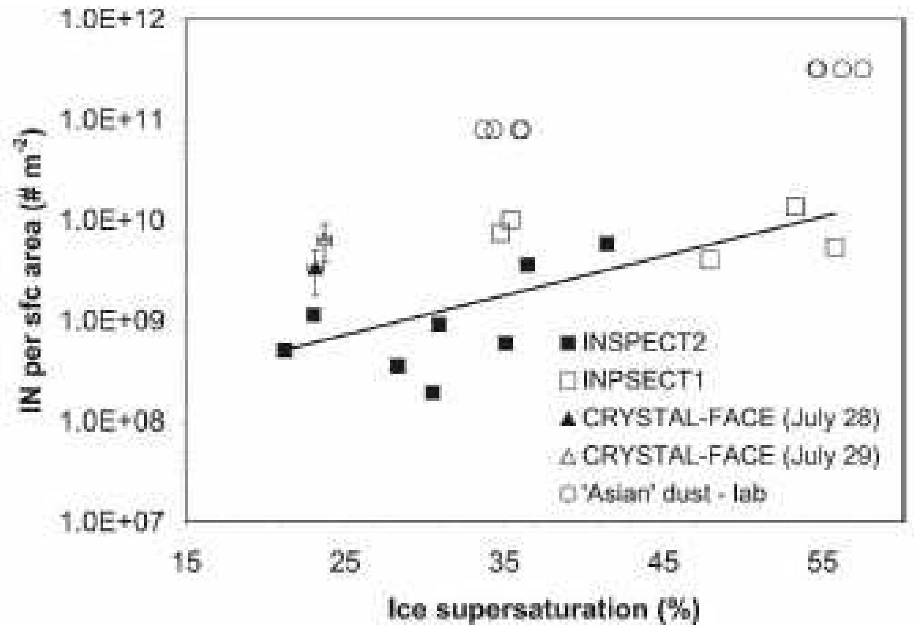
Based on Phillips et al. (2008)

The number of «nucleable» IFN for local *SSi* & *T* conditions is given by:

$$N^{*}_{IFN,i}\left(SSi,T\right)=\int_{0.1\mu m}^{\infty}\left[1-\exp\left(-\mu_{X}\left(d_{a},SSi,T\right)\right)\right]\times n_{a=IFN,i}\left(d_{a}\right)\mathrm{d}d_{a}$$

with $\mu_{X}=H_{X}\left(SSi,T\right)\left(\alpha_{X}n^{*}_{IFN}/\Omega^{*}_{X}\right)\times\pi d_{a}^{2}$

and where H_X is an interpolation factor to account for different {*SSi, T*} regimes, α_X is a fractional type contribution, $\Omega_X{}^*$ is the total surface of X-type IFN, $n_{IFN}{}^*$ is an IFN reference concentration.



IFN spectra are assumed to be lognomal:

$$\mathrm{d}N_{a}=\sum_{i=1}^{I}n_{ai}\left(d_{a}\right)\mathrm{d}d_{a}=\sum_{i=1}^{I}\frac{N_{ai}}{\sqrt{2\pi}\ln\sigma_{ai}}\exp\left(-\left(\frac{\ln\left(d_{a}/d_{ai}\right)}{\sqrt{2\pi}\ln\sigma_{ai}}\right)^{2}\right)\mathrm{d}\ln d_{a}$$

Integral involving size distributions $n_{IFN}(d_a)$ is computed analytically if exp(-μ) ~ 1- μ or performed with a Gauss-Hermite quadrature formula.

LIMA: coated IFN activation/nucleation

Heterogeneous nucleation by immersion

Coated IFN: insoluble core + encapsulated by sulfate material

Coated IFN (aging effect) are treated separately:

1. First, a CCN activation effect ➔ droplets with IFN inside. These droplets are tagged.
2. Then IFN nucleation by immersion: droplet freezing ➔ pristine ice crystal

According to Phillips et al. (2008) the same formula of the Empirical Parameterization can be used

LIMA: Other sources of pristine ice (w/o IFN)

Hallett-Mossop, droplet homogeneous freezing, haze freezing

Hallett-Mossop process (splintering or ice multiplication)

- HM process occurs when droplets are riming on graupel particles. The process is efficient in the range T=[-3℃, -8℃] (triangular function). A splinter is produced each time 200 droplets with size>25μm are riming (Mossop, 1976; Beheng, 1987). This is computed using the incomplete Γ function.

Homogeneous freezing of the cloud droplets

- Homogeneous nucleation occurs when T<-35℃ at least and no more droplet exist when T<-42℃ . The freezing probability is proportional to the droplet volume and to the freezing rate taken in Pruppacher (1995).

Haze (wet aerosol) freezing

- The freezing of wet aerosols occurs at very low temperature (T<-40℃). The parameterization of Kärcher and Lohmann (2002) is used here. No size and aerosol type dependence is accounted for.

LIMA: water vapor ⇔ cloud droplets & water vapor ⇔pristine ice

<u>Adjustment to saturation for the liquid phase and explicit deposition or sublimation rates for the ice phase</u> (thanks to prediction of N_i)

3 cases:

• Liquid only: **equilibrium ➔** pure adjustment to saturation ($SSw = 0$)

• Ice only: **out of equilibrium ➔** computation of an explicit deposition growth rate function of SSi and T (SSi is not constrained to saturation)

• Mixed-phase (both droplets and ice crystals are present): **tradeoff ➔** analytical scheme of Reisin et al. (1996) but no supersaturation allowed over liquid droplets

In addition, …

• Deposition/sublimation rates computed explicily for snow/aggr. and for graupel

• Evaporation rate is computed explicitly for the raindrops

LIMA: Pristine ice to snow/aggr. conversion

Scheme of Harrington et al (1995)

The conversion rate of the pristine ice crystals into the «snow/aggregate» category depends on the water deposition rate on pristine ice.

<u>Assumption</u>: Transfer rate of pristine ice ➔ snow/aggr. is taken equal to the deposition growth rate of the ice crystals larger than d_i=125 µm.

$$-\left.\frac{\partial N_i}{\partial t}\right|_{\mathrm{CNVIS}} = \int_{d_{CNVIS}}^{\infty} \left.\frac{\partial n_i(d_i)}{\partial t}\right|_{\mathrm{DEP}} \mathrm{d}d_i = \int_{d_{CNVIS}}^{\infty} \frac{\partial}{\partial d_i}\left(\left.\frac{\mathrm{d}d_i}{\mathrm{d}t}\right|_{\mathrm{DEP}} \times n_i(d_i)\right)\mathrm{d}d_i = \left.\frac{\mathrm{d}d_i}{\mathrm{d}t}\right|_{\substack{\mathrm{DEP}\\ d_i=d_{CNVIS}}} \times n_i(d_{CNVIS})$$

$$-\rho_{air}\left.\frac{\partial r_i}{\partial t}\right|_{\mathrm{CNVIS}} = \rho_{air}\left.\frac{\partial r_s}{\partial t}\right|_{\mathrm{CNVIS}} = \int_{d_{CNVIS}}^{\infty} \left.\frac{\partial\left(m_i(d_i)n_i(d_i)\right)}{\partial t}\right|_{\mathrm{DEP}} \mathrm{d}d_i$$

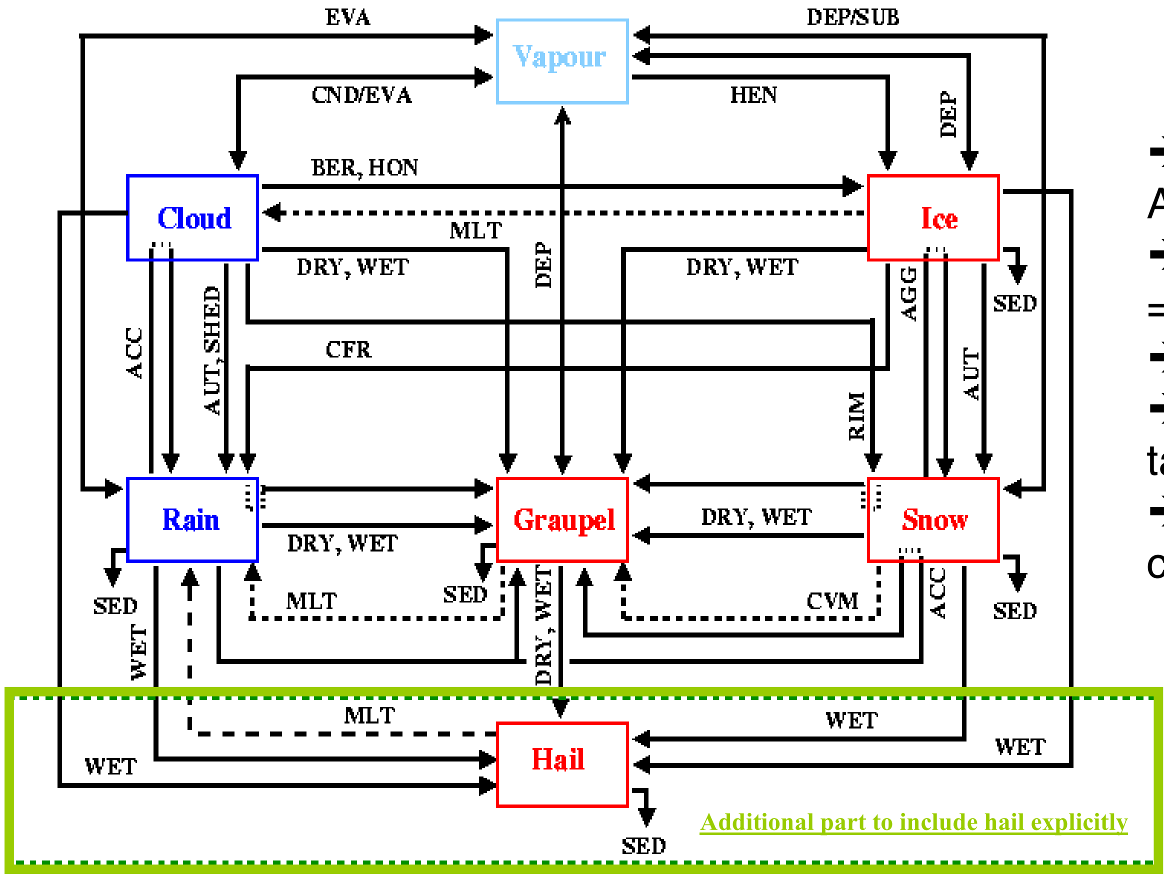
$$= m_i(d_i)\left.\frac{\mathrm{d}d_i}{\mathrm{d}t}\right|_{\substack{\mathrm{DEP}\\ d_i=d_{CNVIS}}} \times n_i(d_{CNVIS}) + \int_{d_{CNVIS}}^{\infty} \left.\frac{\mathrm{d}m_i(d_i)}{\mathrm{d}t}\right|_{\mathrm{DEP}} n_i(d_i)\mathrm{d}d_i$$

The reverse mechanism is used to transfer snow/aggr. into pristine ice when snow sublimates (loss of «snow » and gain of pristine ice).

LIMA: Overview of the whole scheme

Cohard & Pinty (2000), Pinty & Jabouille (1998)

Microphysical Scheme diagram

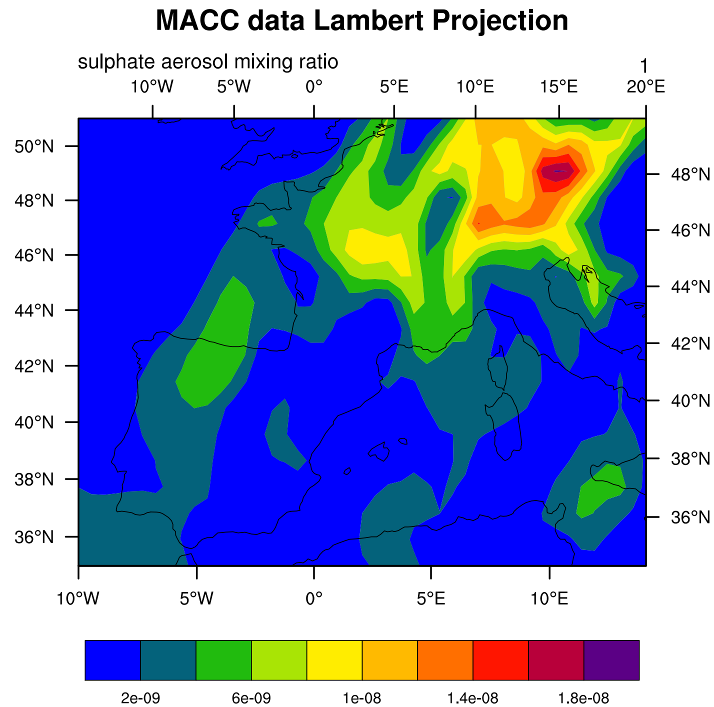


➔«Long» kernels to compute ACC, SELF (warm processes)
➔Snow ConVersion/Melting => graupel
➔Graupel Melting => rain
➔WET/DRY graupel growth, tabulated collection kernels
➔w or w/o separate «hail» category

MACC analyses à ECMWF

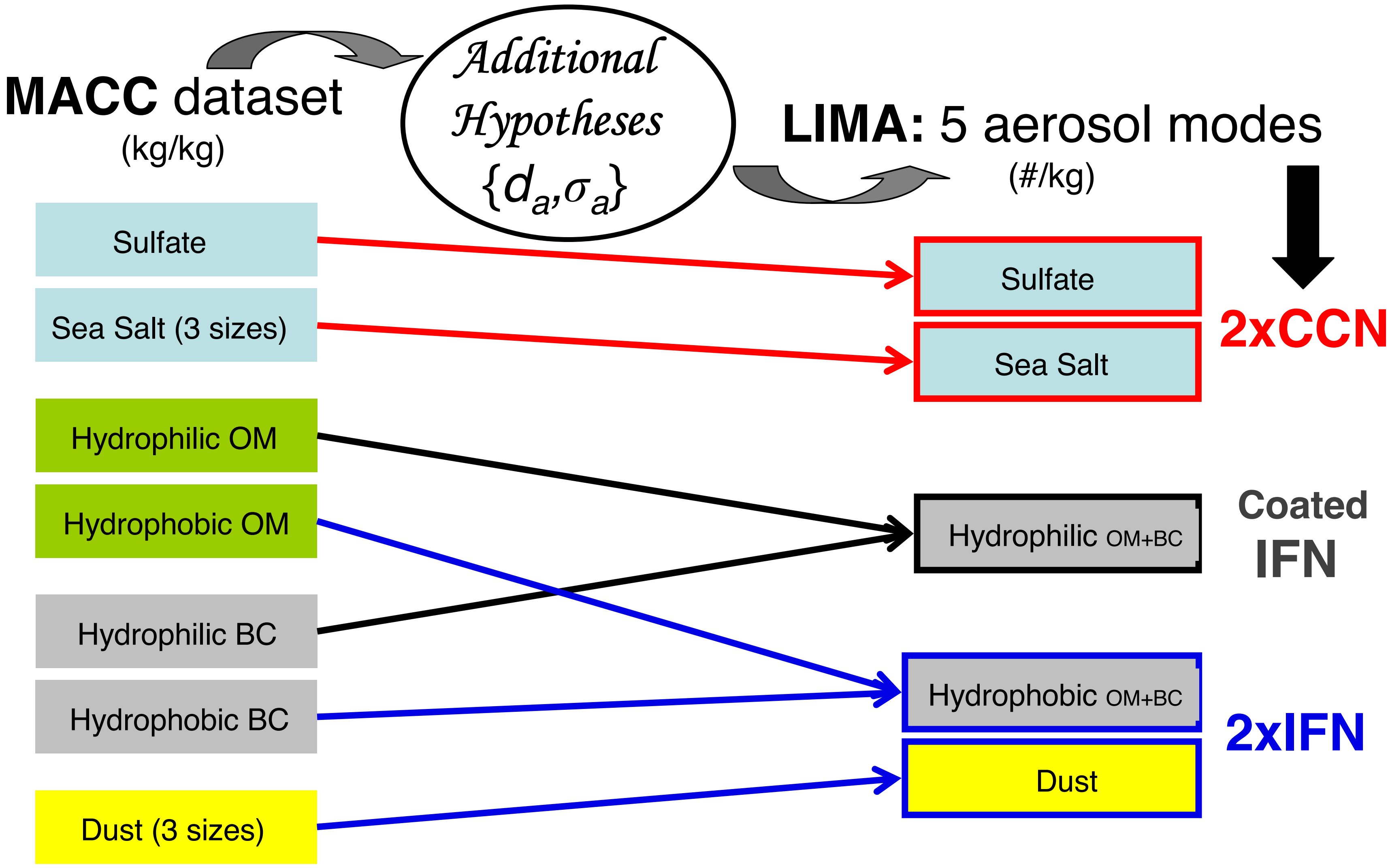
MACC page

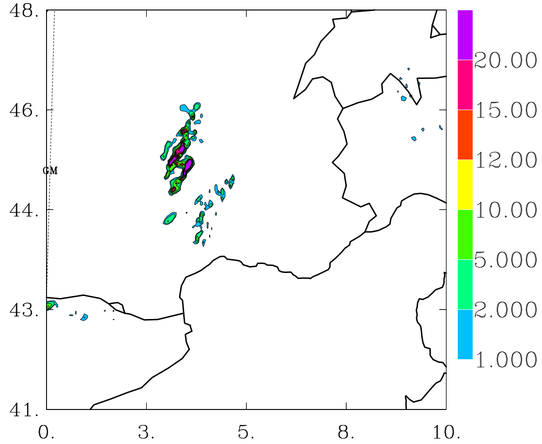
Flexible files.nc: up to 13 mixing ratios of different aerosol type/size to select.



MACC analyses adapted to LIMA

Aerosol initialization using MACC 3D analyses @ ECMWF

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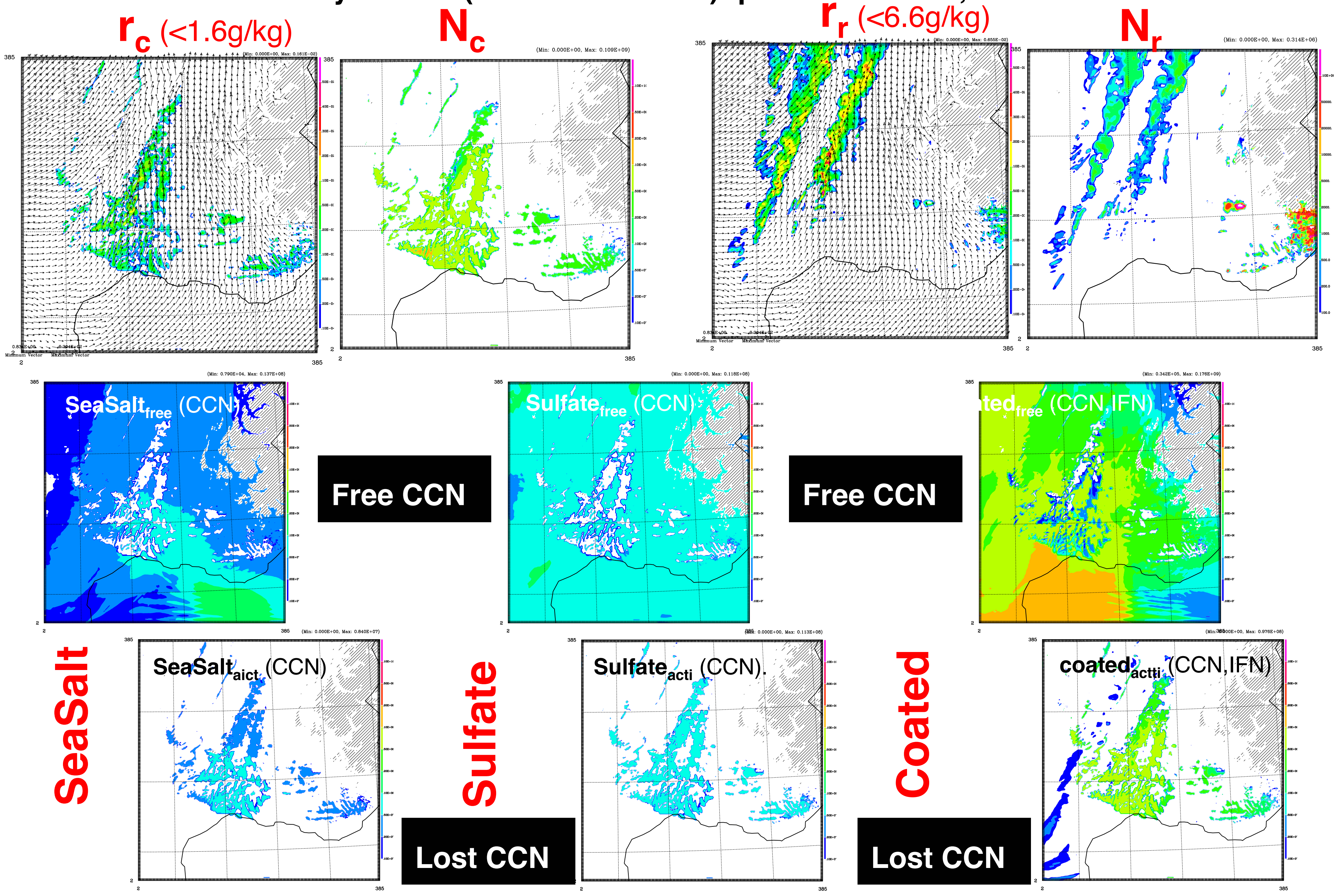
HyMeX IOP6: 24th Sept 2012 @ 03UTC

Preliminary results (1 km horiz. scale): plots after T=9h, @ Z=1500m



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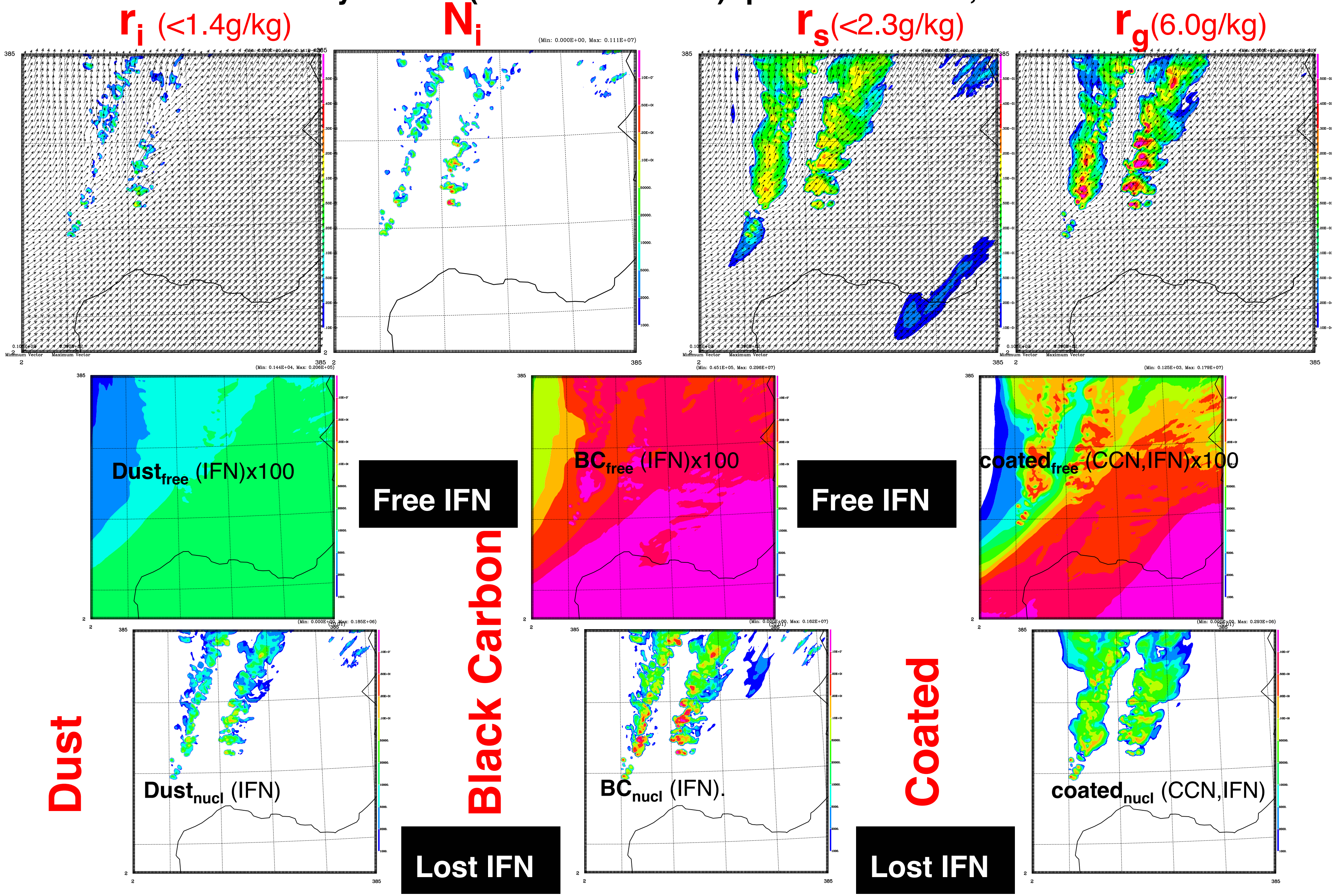
Preliminary results (1 km horiz. scale): plots after T=9h, @ Z=8000m



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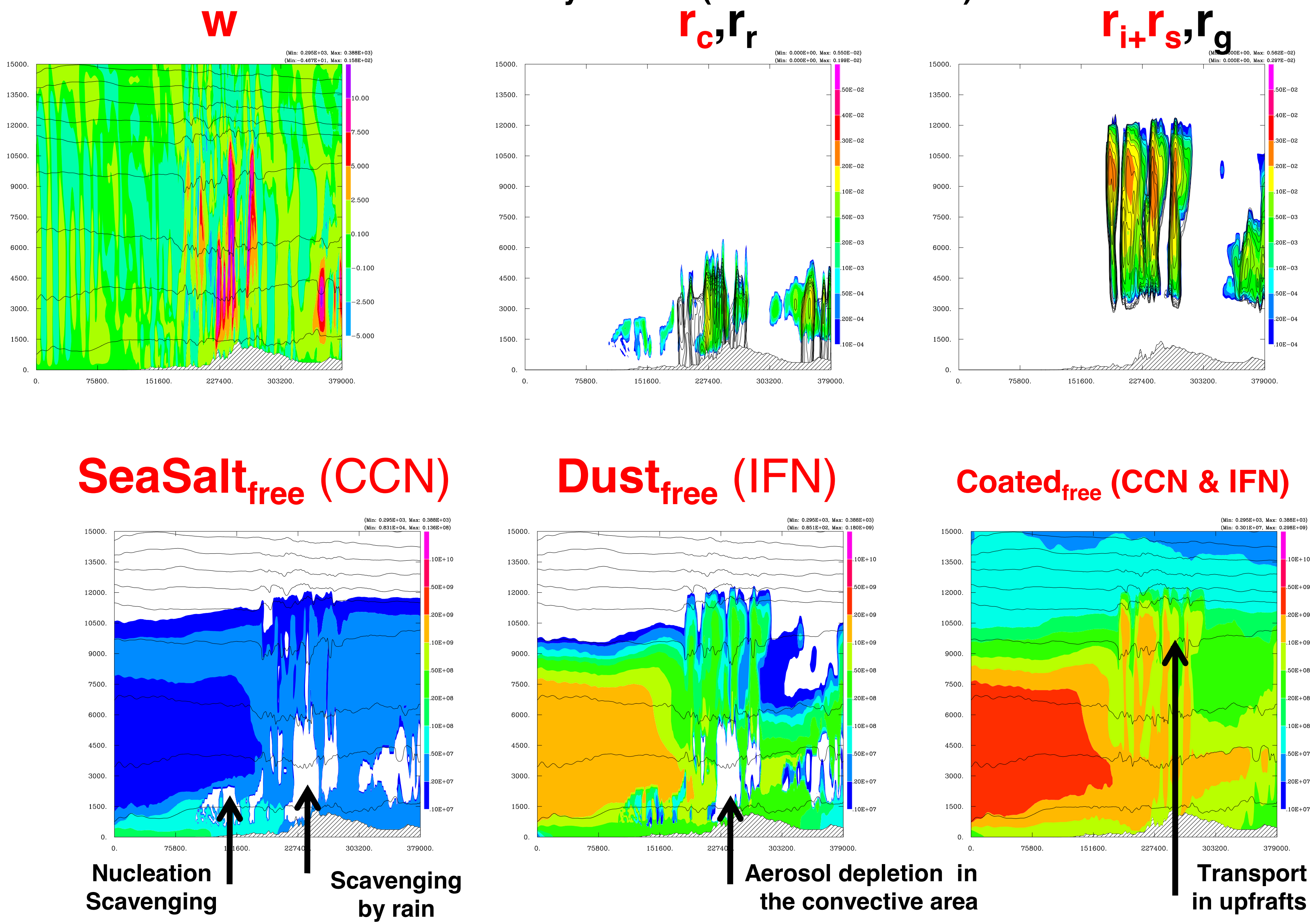
Preliminary results (1 km horiz. scale)



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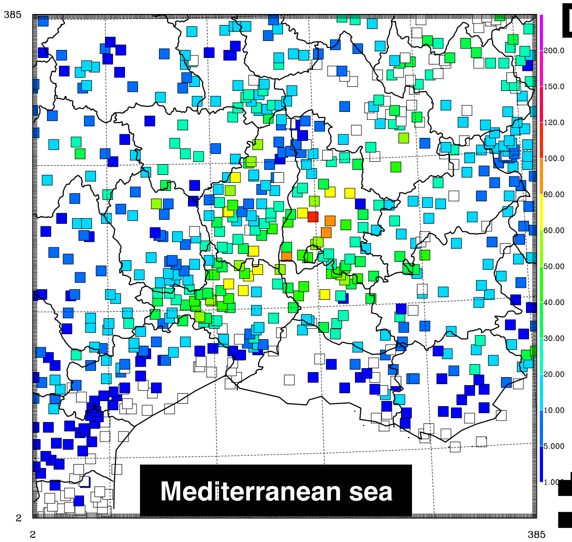
Preliminary results (1 km horiz. scale)



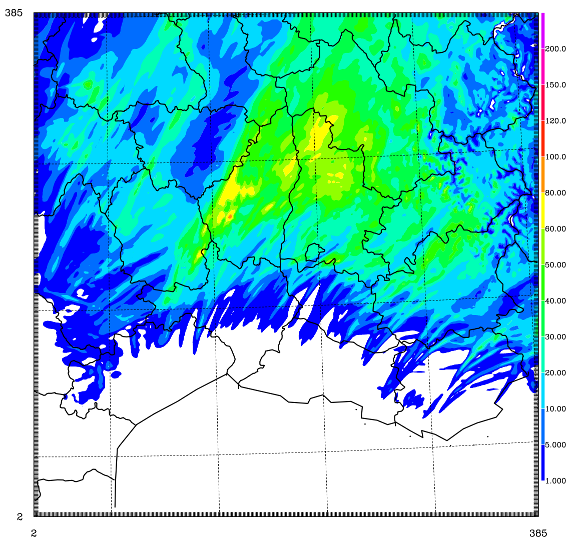
DATA raingauges

18 h rain

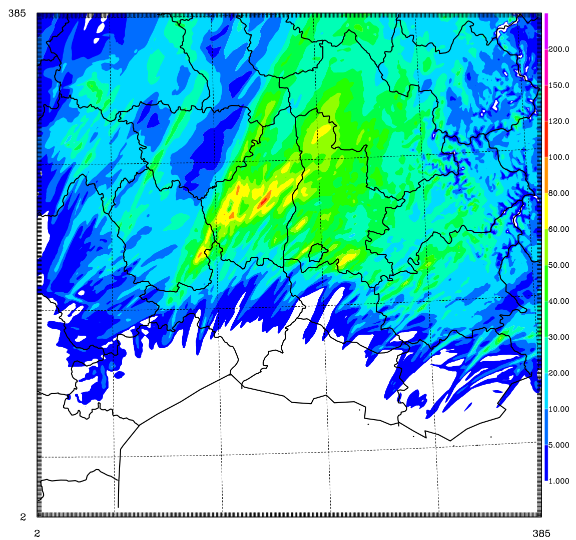
(Max=100mm)

from 23th Sept 2012
@ 18UTC
to 24th Sept 2012
@ 12UTC

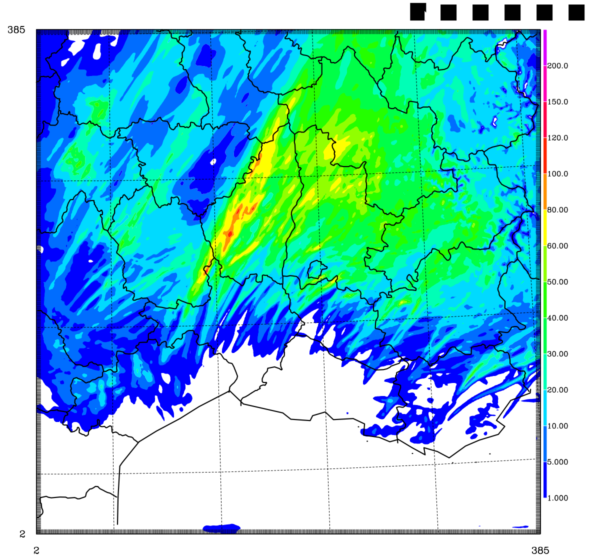
LIMA 2-moment
with **hail** **(soon)**



ICE3 1-moment



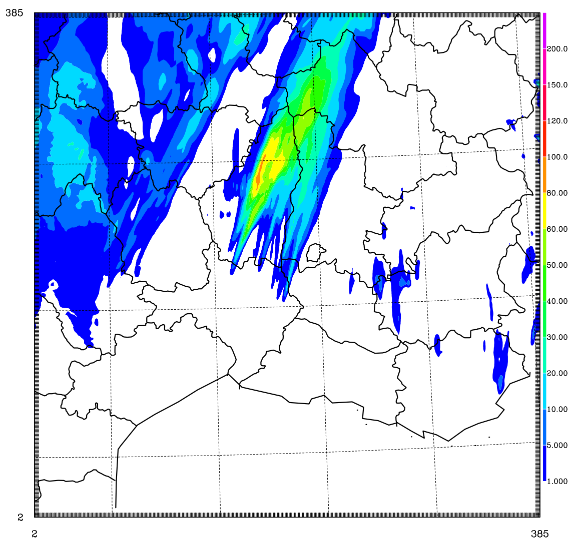
ICE4 1-moment
with **explicit hail**



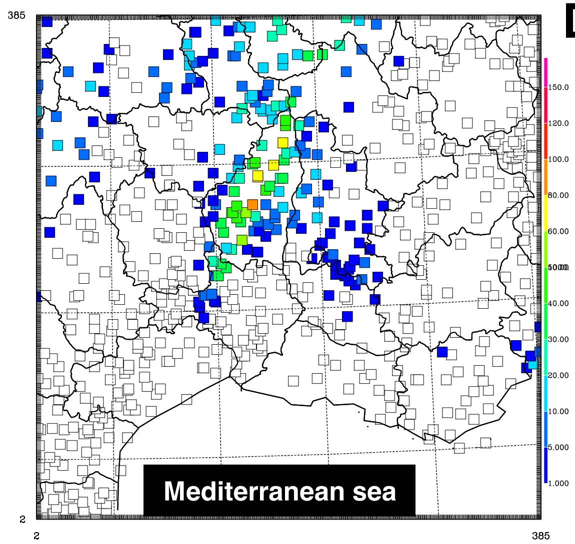
LIMA 2-moment
with **explicit CCN & IFN**

HyMeX IOP6: 26th Sept 2012

Preliminary results (1 km horiz. scale)



ICE3 1-moment

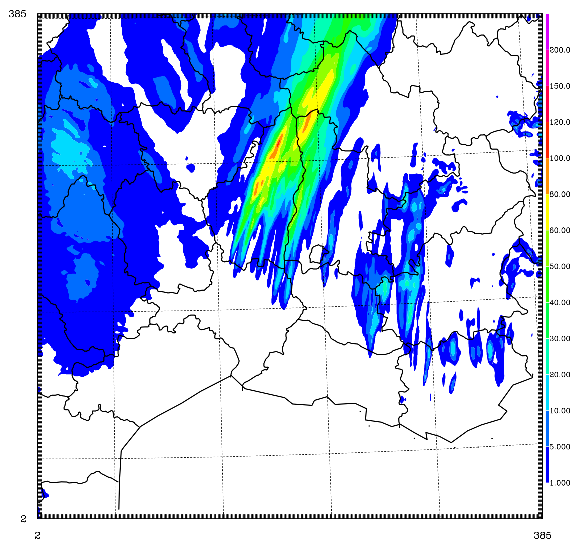


DATA raingauges

8 h rain

(Max=89 mm)

from 26th Sept 2012
@ 18UTC
to 26th Sept 2012
@ 12UTC



LIMA 2-moment
with **explicit CCN & IFN**

Summary and conclusion

- **2-moment microphysical scheme LIMA** in MesoNH
  - realistic representation of the aerosols
    - Lognormal modes, spatially heterogeneous population
    - Aerosols: CCN, IFN and coated_IFN: first CCN then IFN
  - interaction between aerosols, cloud particles and raindrops
    - multimodal CCN activation and IFN nucleation
    - impaction scavenging by rain
  - **3D prognostic budget equations** in LIMA
    - Mixing ratios (kg/kg): r_c, r_r, r_i, r_s, r_g … r_h (hail to include)
    - Concentrations (#/kg): n_c, n_r, n_i
    - Aerosol concentrations (#/kg per mode): n_{free}, $n_{act/nucl}$

- **Simulation of precipitating systems at high resolution**
  - Aerosols of MACC II analyses ➔ CCN, IFN, coated IFN
  - Quantitative evaluation of cloud μphysics (RR, radar, lidar, RTTOV)
  - Additional developments to integrate (crystal shape, …)
  - Long-term integrations with full aerosol regeneration (future)