Experiments with the MésoNH-AROME microphysical scheme and evaluation by remote sensing tools

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HIRLAM Workshop, Tartu, Estonia, 24-26 January 2005

Outlook

- Introduction
- Common assumptions used in microphysical schemes
- The current scheme developed and used in MésoNH
- Some tools to evaluate the scheme
- Examples
- Conclusion and perspective

The explicit simulation of the Water Cycle is a major issue for many mesoscale studies and model applications.
Microphysical schemes are the key parametrisations to follow the evolution of the condensed phases

Introduction: from CRM to NWP

Some experience, gained by running standard and sophisticated microphysical schemes in mesoscale models, should benefit to NWP

The trend is now to develop operational forecast systems at high resolution (scales < 10 km): Unified **M**odel **(UK), L**okal **M**odel **(D), WRF (USA), AROME (F), ALARO (Aladin community), …**

➔ **New features in NWP models**

- **Non-hydrostatic dynamics, (3D) turbulence scheme**
- **Increased forcing by orography and surface conditions**
- **Resolution of new flow features: breezes, isolated storms, …**
- **Focus on the explicit resolution of clouds and precipitation**

Introduction: new features in CRM

Operational weather systems employ several techniques (½ lag. and ½ implicit schemes, data assimilation cycles) which are much less popular in mesoscale models.

➔ New aspects in Cloud Modeling

- **Numerics (from explicit, conservative, positive definite to 2TL implicit schemes with many interactions to integrate)**
- **Initialisation of microphysical fields ("clear sky" initial state → assimilation of satellite radiances & radar data, …)**
- **Verification tools (simulation of observations), update of forecast scores (nebulosity score ?)**

Explicit cloud modeling

There are many cloud types to simulate !
Fog, Extended cloud sheets, Cumulus clouds, Cirrus

Wide span of particle size: ~ 4 decades (μm -> cm)
of particle habit: many ice particle types

Microphysical fields are discontinuous and sparse.
Clouds have sharp boundaries.

Many interactions of the clouds and the precipitation:
Dynamics, Radiation, Surface, Aerosols, Chemistry, Electricity

Choice of microphysical variables

- **Variables: Mixing ratios (mass of water / mass of dry air) → assumptions about number concentrations (Aerosol Physics)**
- **Number of cloud and precipitation variables:**

2 water variables for warm clouds:

Cloud water (droplets),

Rain water (drops)

2, 3, 4, 5 ice variables for cold clouds:

Cloud ice (pristine crystals),

Snow (large crystals), Aggregates (assemblage of crystals),

Graupel (rimed crystals), Hail (large heavily rimed crystals)

General case → Mixed-phase microphysics

Common features of many microphysical schemes

Limited number of water species (~ 6): 1 vap. + 2 liq. + 3 ice

Size distribution:
Mathematical (parametric) distribution law [0 < D < ∞]

Mass-size and Fall speed-size relationships:
Power law → analytical integration

Uncertainties about bulk coefficients and about some processes:
- → **collision-sticking efficiencies of collection kernels**
- → **autoconversion processes (onset of precipitating particles)**
- → **adjustment to saturation (mixed-phase clouds)**

Description of the microphysical scheme of MésoNH

- **Size distribution (n(D)): Generalized Gamma law**

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

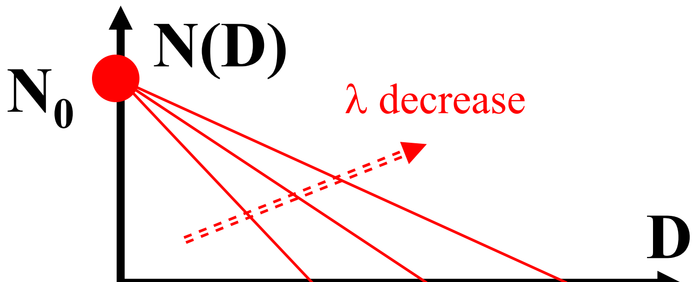
(α, ν) are free shape parameters (Marshall-Palmer law: $\alpha=\nu=1$)
λ is deduced from the mixing ratio
N is the concentration (g(D) is a normalized distribution law)

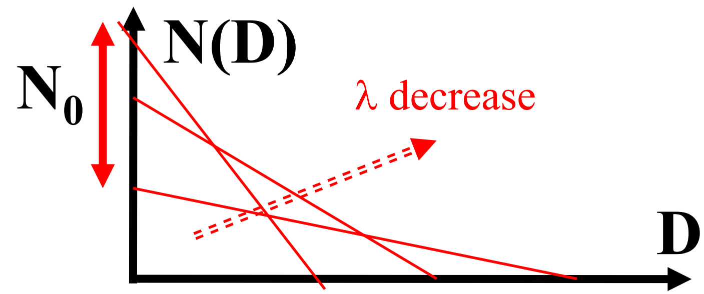
- **Useful p-moment formula**

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

Microphysical characteristics

- **Concentration: $N = C\lambda^x$ instead of a fixed $N_0 = N.\lambda$ value (M. P.)**

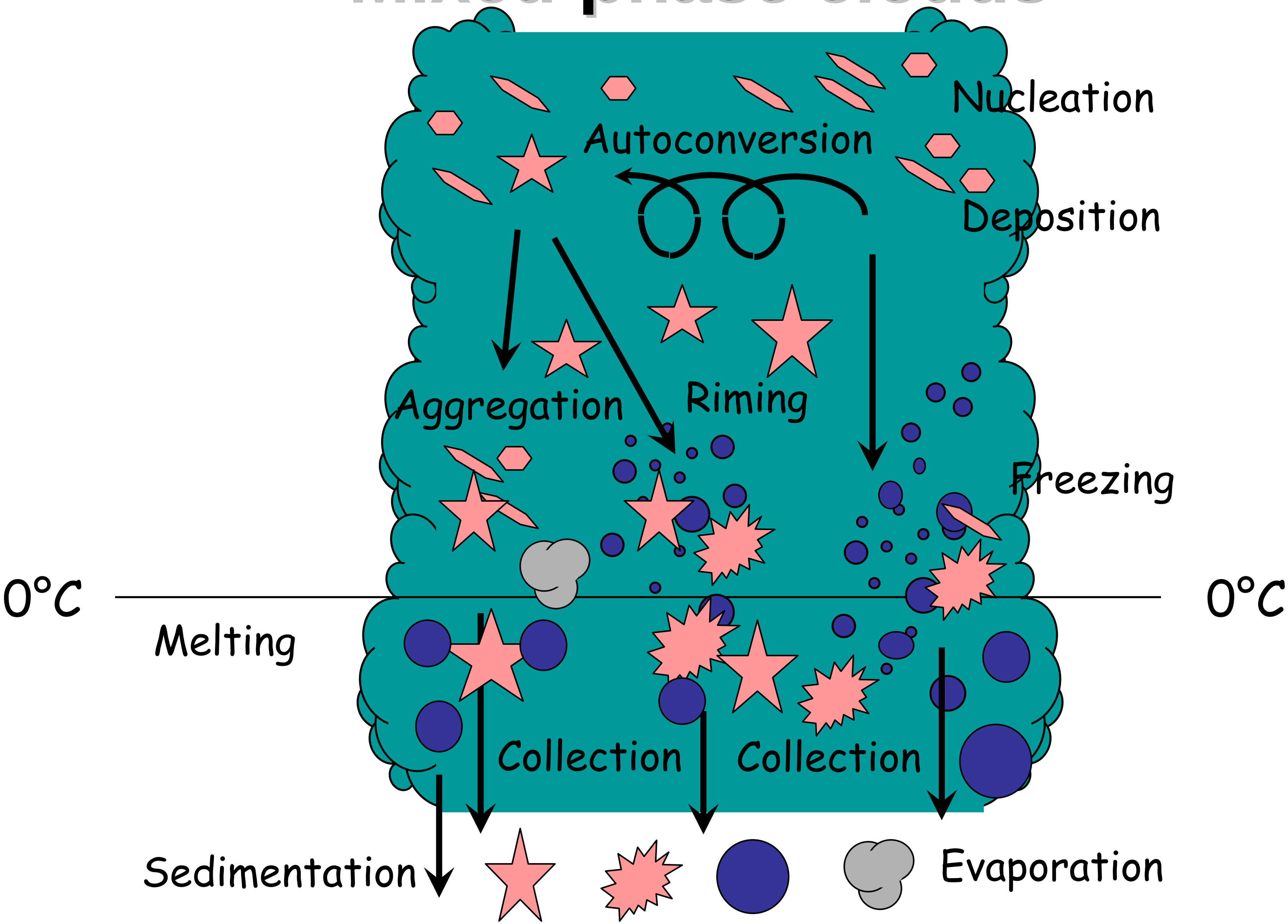




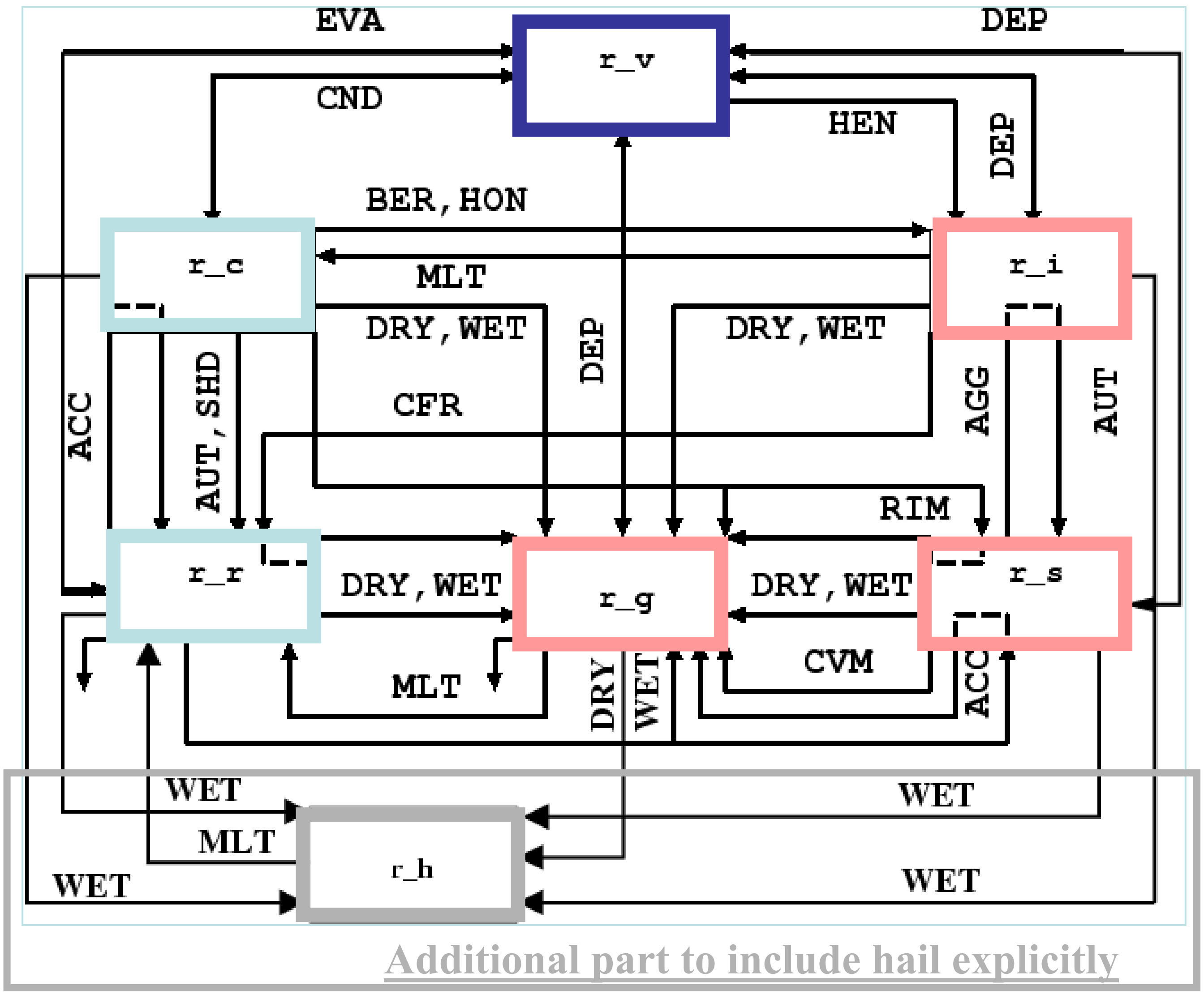
- **Mass-Size relationship: $m = aD^b$**
- **Fall speed-Size relationship: $v = cD^d \cdot (\rho_{00}/\rho)^{0.4}$**

Category → Parameters		Cloud water	Rain water	Cloud ice	Snowflake Aggregate	Graupel	Hail
mass	a	524	524	0.82	0.02	19.6	470
	b	3	3	2.5	1.9	2.8	3.0
speed	c	3.2e7	842	800	5.1	124	207
	d	2	0.8	1.00	0.27	0.66	0.64

Mixed-phase clouds



Microphysical Scheme diagram

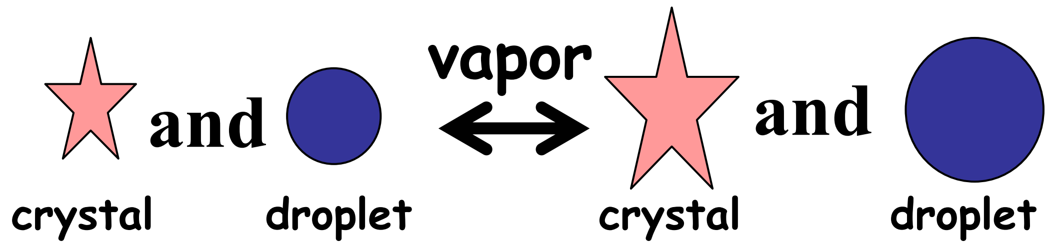


Implicit adjustment to saturation

Saturation mixing ratio:
using a barycentric formula
→ no supersaturation

$$r_{v,sat}^{w+i} = \frac{r_c^* \, r_{v,sat}^{w}(T) + r_i^* \, r_{v,sat}^{i}(T)}{r_c^* + r_i^*}$$

Cond/Evap+Dep/Subl rates:
Variational adjustment



$$F(T) = C_{ph}(T - T^*) + \left[L_{vw}(T) \frac{r_c^*}{r_c^* + r_i^*} + L_{vi}(T) \frac{r_i^*}{r_c^* + r_i^*} \right] \left(r_{v,sat}^{w+i}(T) - r_v^* \right)$$

$$1 - \textit{Find} \;\; T \;\; \textit{such} \;\; \textit{as} \;\; F(T) = 0$$

$$2 - \textit{Compute} \;\; \Delta r_v = r_v^* - r_{v,sat}^{w+i}(T)$$

$$3 - \textit{Get} \;\; \Delta r_c = \Delta r_v \frac{r_c^*}{r_c^* + r_i^*} \;\; \textit{and} \;\; \Delta r_i = \Delta r_v \frac{r_i^*}{r_c^* + r_i^*}$$

Collection processes

Collection processes: based on continuous collection kernels (geometrical swept-out concept)

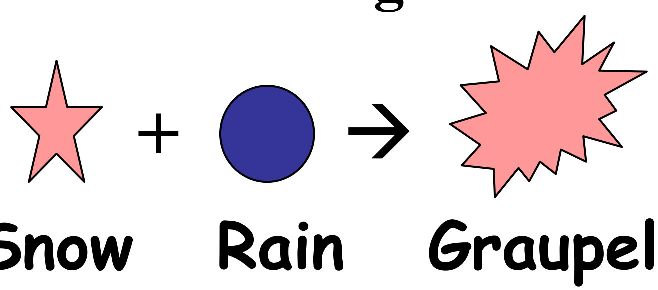
$$K(D_x, D_y) = \frac{\pi}{4}\left(D_x + D_y\right)^2 \left|v_x(D_x) - v_y(D_y)\right| E_{xy}$$

Collection+Conversion of precipitating particles: tabulated integrals

$$\left(\frac{\partial(\rho_a r_x)}{\partial t}\right)_{COLL} = -\int_0^\infty \left[\int_0^\infty K(D_x, D_y)\, m_y(D_y)\, n_y(D_y)\, dD_y\right] n_x(D_x)\, dD_x$$

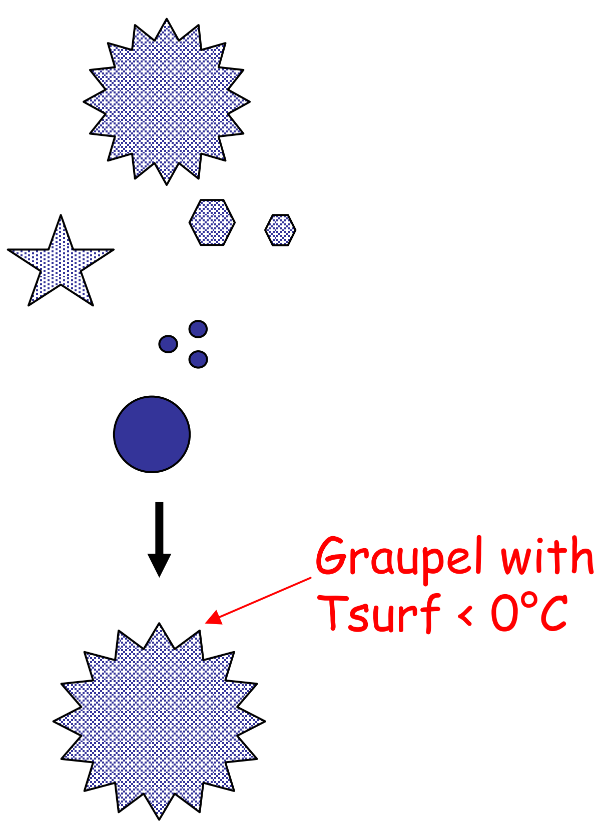
$$\left(\frac{\partial(\rho_a r_y)}{\partial t}\right)_{COLL} = -\int_0^\infty \left[\int_0^\infty K(D_x, D_y)\, m_x(D_x)\, n_x(D_x)\, dD_x\right] n_y(D_y)\, dD_y$$

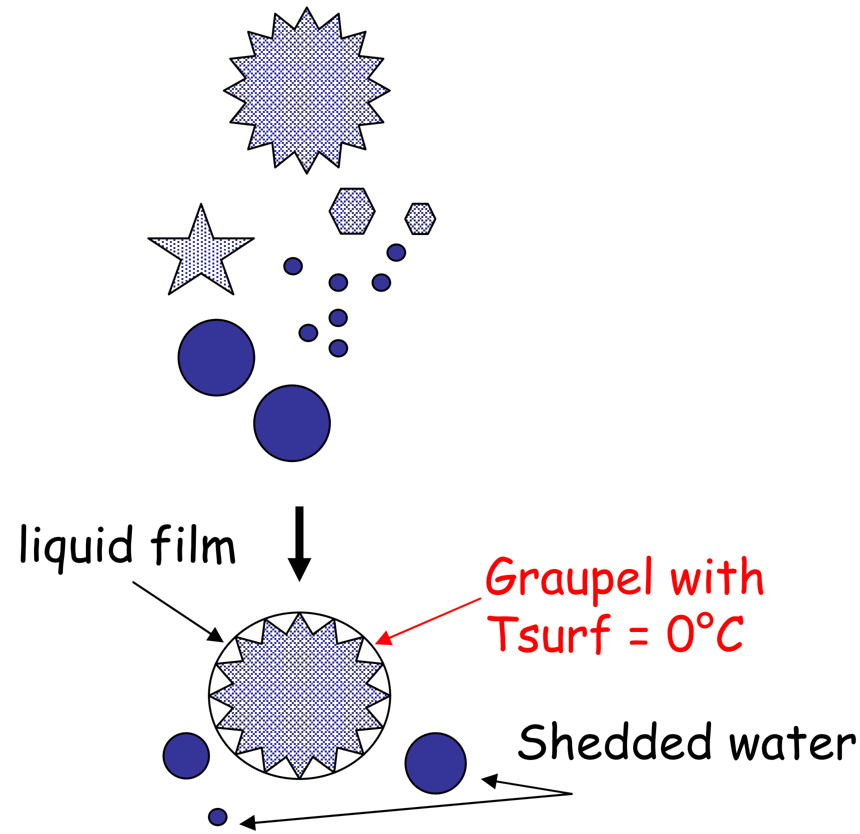
$$\left(\frac{\partial(\rho_a r_z)}{\partial t}\right)_{COLL} = \left(\frac{\partial(\rho_a r_x)}{\partial t}\right)_{COLL} + \left(\frac{\partial(\rho_a r_y)}{\partial t}\right)_{COLL}$$



… but the treatment is even more complicated in the case of partial conversion (function of particle size)

Graupel growth: other effects





Dry growth (→ Graupel)
(Sum of collection rates)

Wet growth (→ Hail)
(Heat balance equation)

The minimum growth rate *must* be taken

Microphysical Scheme of MésoNH

Summary

- **Warm processes (Kessler scheme)**
- **Light and Heavy riming rates of the snowflakes (by the cloud droplets and by the rain drops) and their conversion into graupel particles**
- **Wet/Dry growth mode of the graupels**
- **Melted particles are considered as graupels**

- **Sedimentation (1st order upstream scheme)**
- **Processes are integrated one-by-one after carefully checking the availability of the sinking categories**
- **On-line budgets**

Present uncertainties …

- **Onset of precipitating drops and precipitating ice:**

➔ **Simulation of extended cloud sheets of moderate lifetime (Sc, Ci) ?**

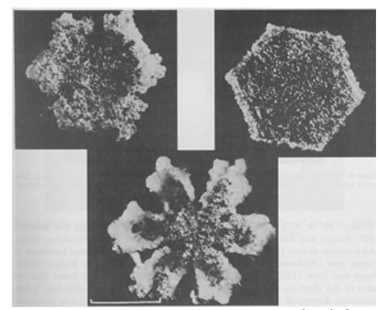
- **Physics of the ice phase:**

➔ **Collection efficiencies ?**

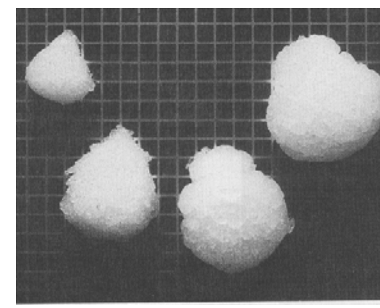
➔ **Supercooling of water ?**

➔ **Ice nucleation ?**

snow



graupel



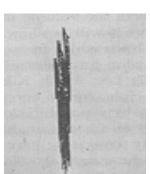
1-10 mm

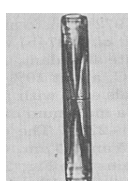
(Pruppacher and Klett, 1997)

➔ **Which ice crystal characteristics to choose ?**

10-100 μm

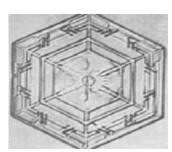
needle



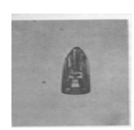


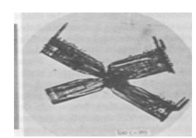
column

plate

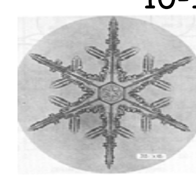


bullet



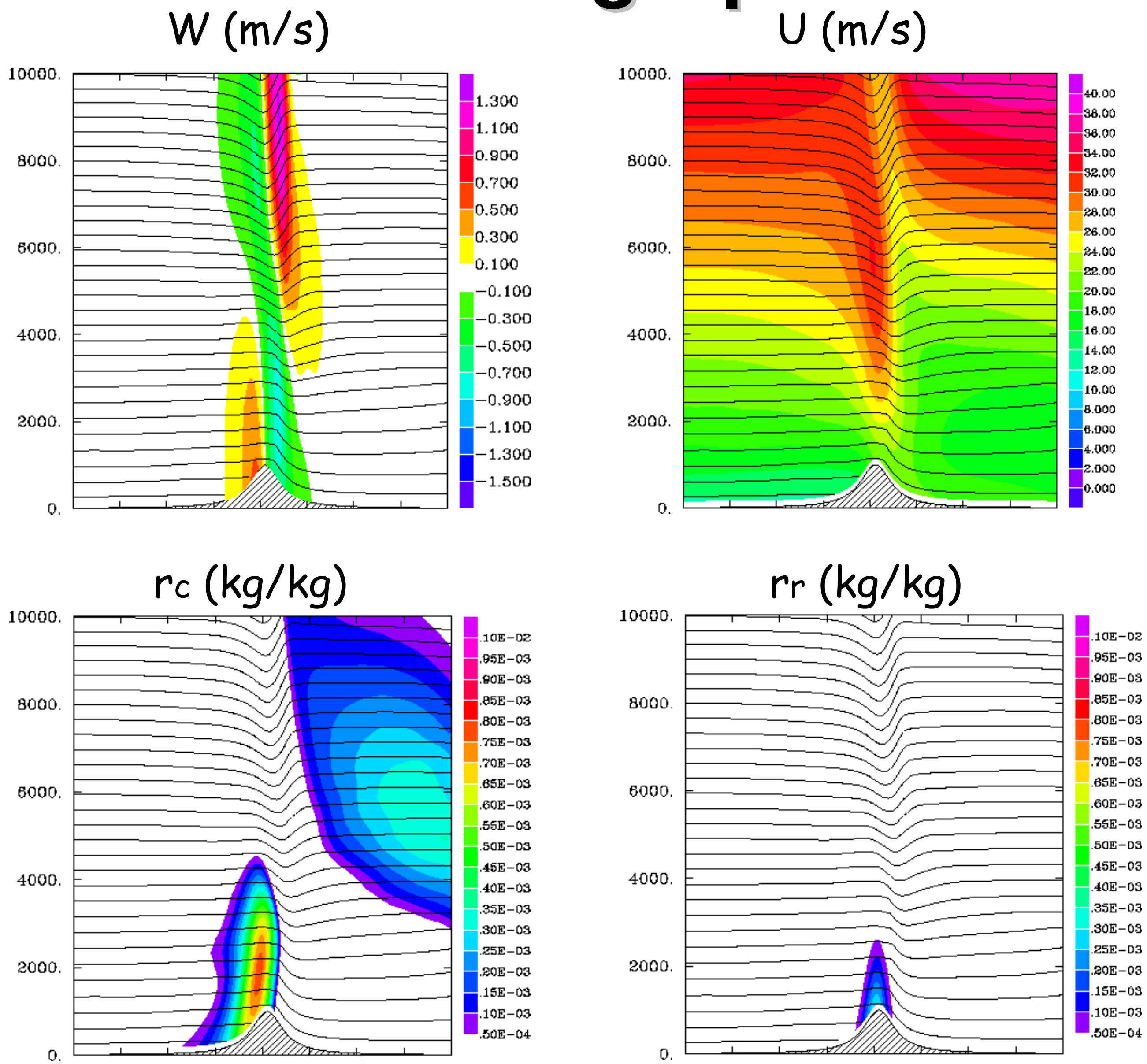


rosette

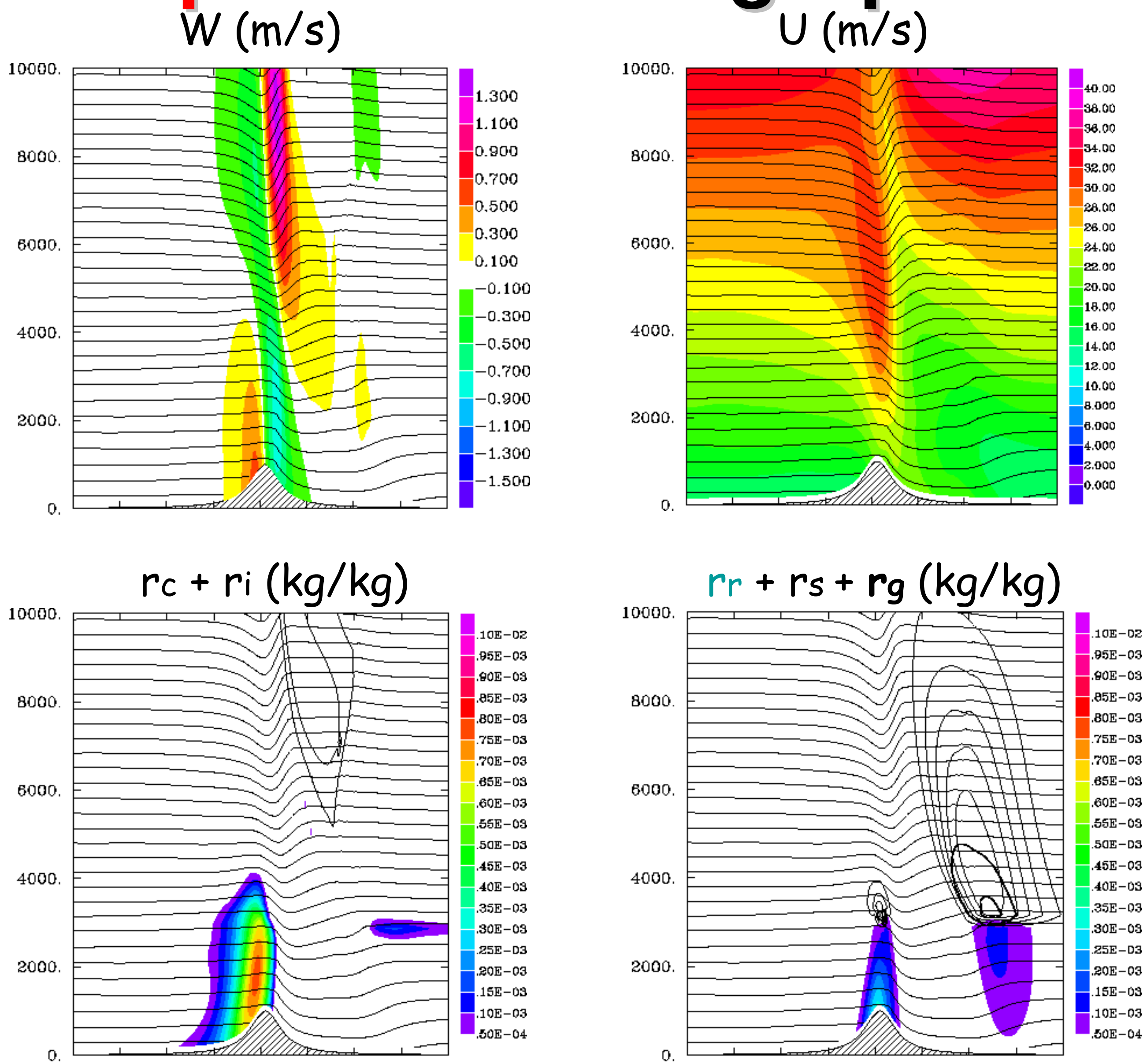


dendrite

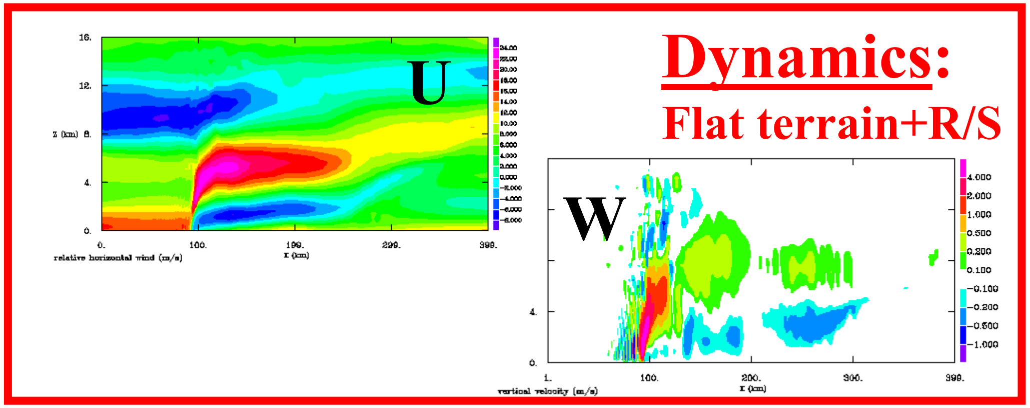
Warm 2D Orographic Cloud

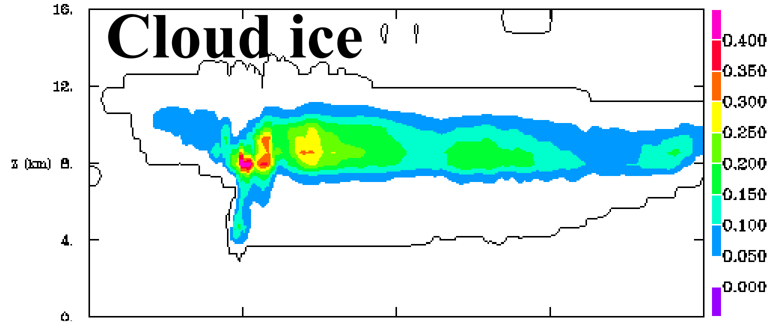


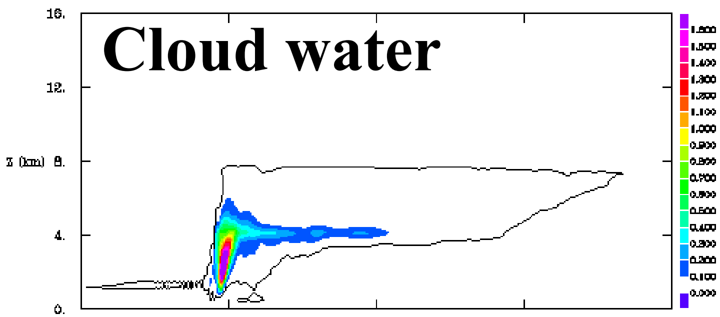
Mixed-phase 2D Orographic Cloud

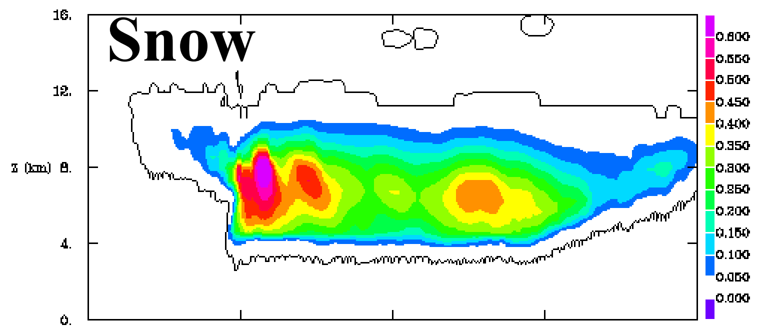


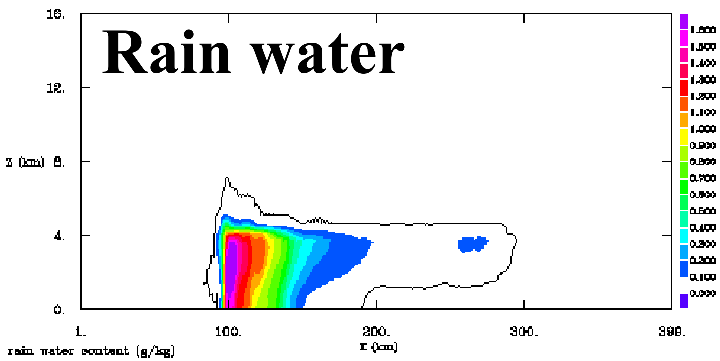
2D Tropical Squall Line

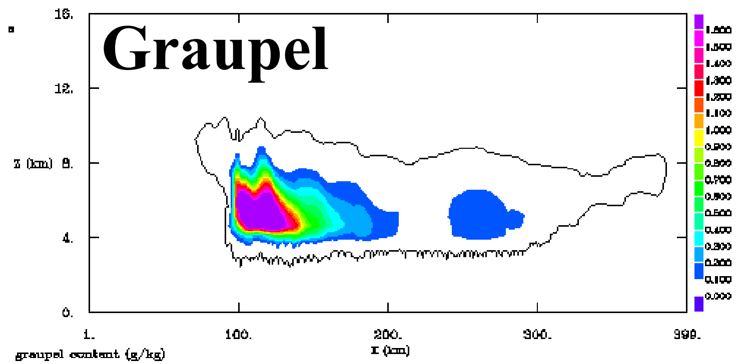








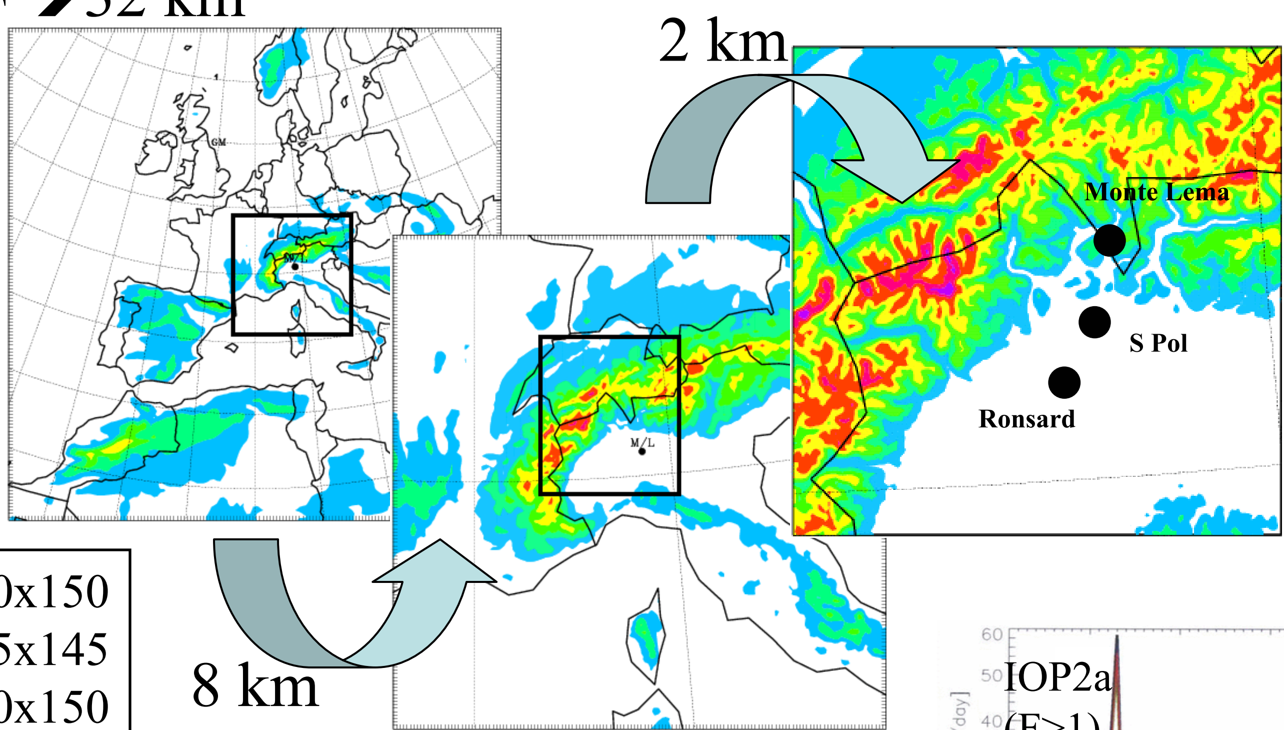




3D Orographic precipitation (MAP)

How does the flow over complex terrain modify the growth mechanisms of precipitation particles?

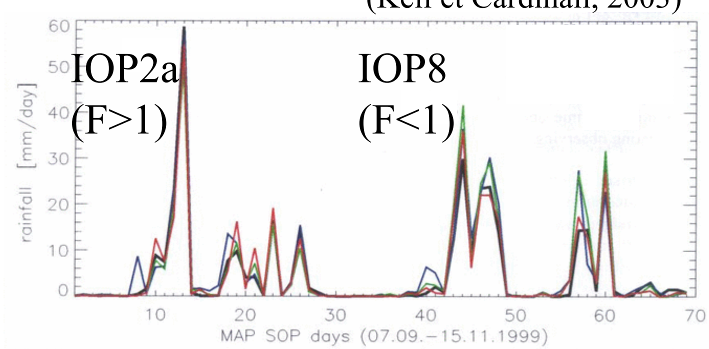
ECMWF→32 km



3 Doppler radars (●)

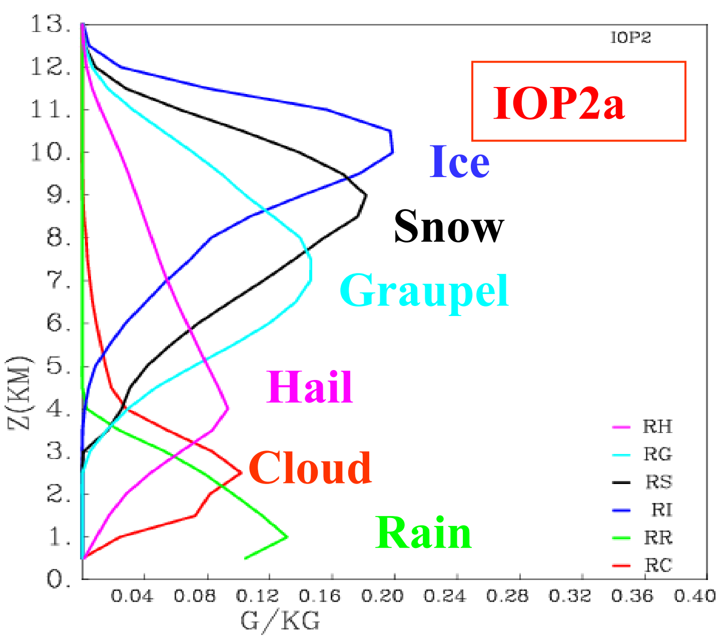
32km : 150x150
8km : 145x145
2km : 150x150
over 51 levels

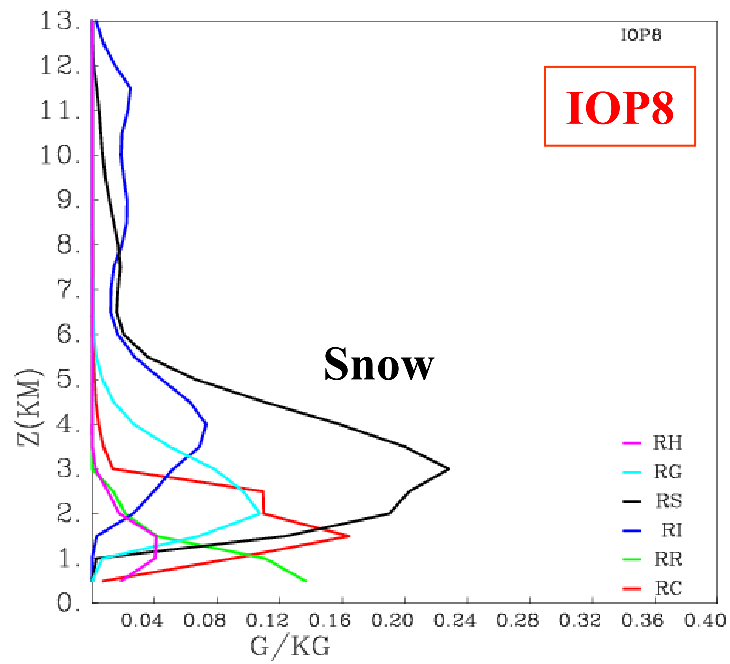
(Keil et Cardinali, 2003)



3D Orographic precipitation (MAP)

Mean vertical distribution of the hydrometeors





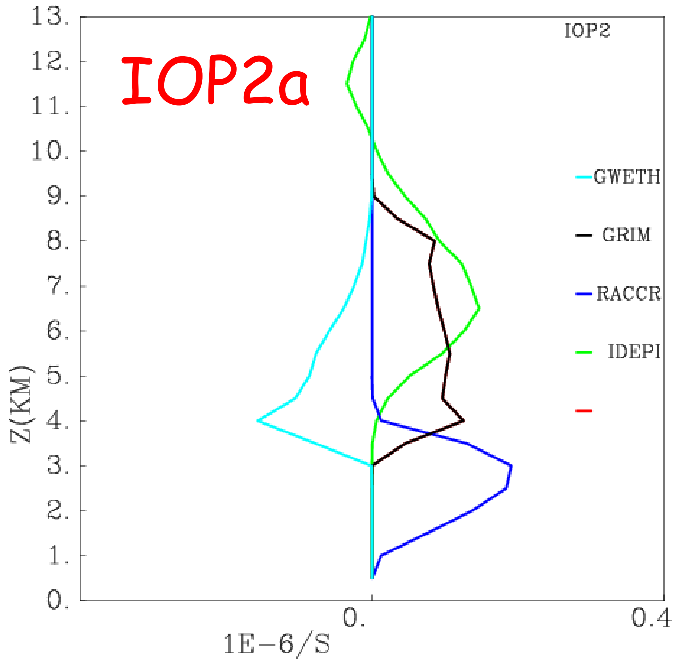
IOP2a (Strong convection)
- Deep system
- Large amount of hail and graupel

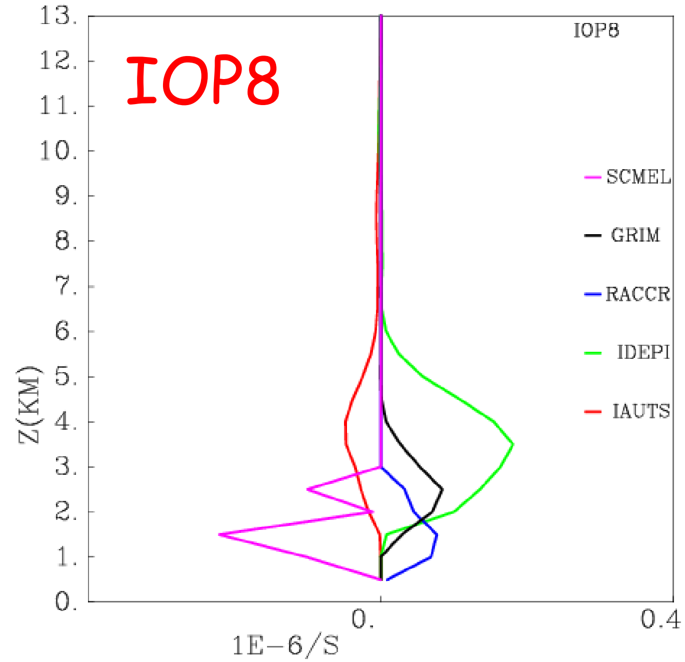
IOP8 (Stratiform event)
- Shallow system
- Large amount of snow

Explained by analysing the dominant microphysical processes

3D Orographic precipitation (MAP)

Bugdets → dominant microphysical processes





Growth of graupel by RIMING

ACCRETION of cloud droplets by raindrops

MELTING-CONVERSION of the snow (into graupel)

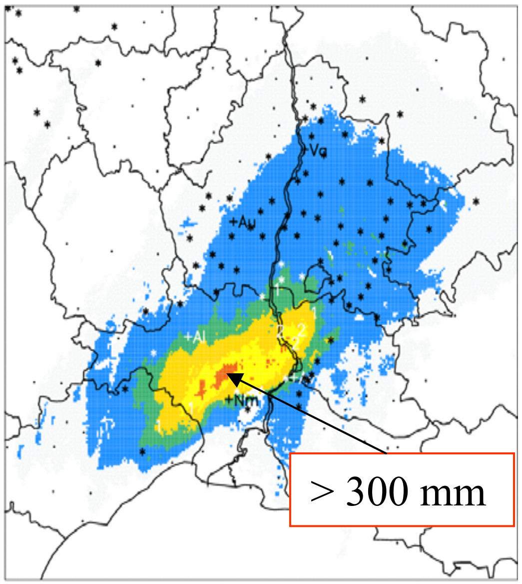
DEPOSITION on ice (and sublimation)

AUTOCONVERSION of pristine ice

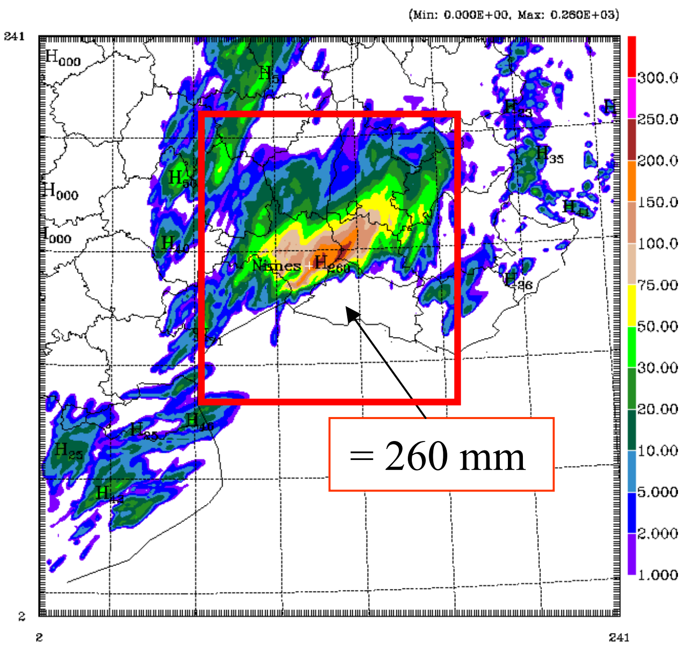
Depletion of graupel by WET GROWTH of hail

« Gard » flash flood (8 Sept. 2002)

12-22 TU Nîmes radar cumulated rainfall



MesoNH with grid_nesting (V. Ducrocq)



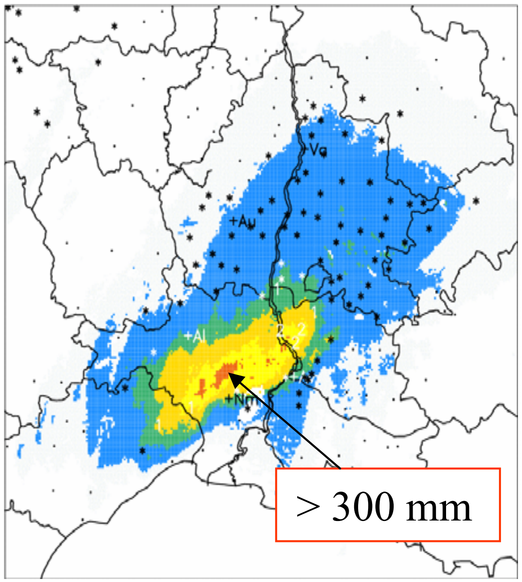
Arpège-> MésoNH 10km -> MésoNH 2.5km

IC : Mesoscale surface data reanalysis

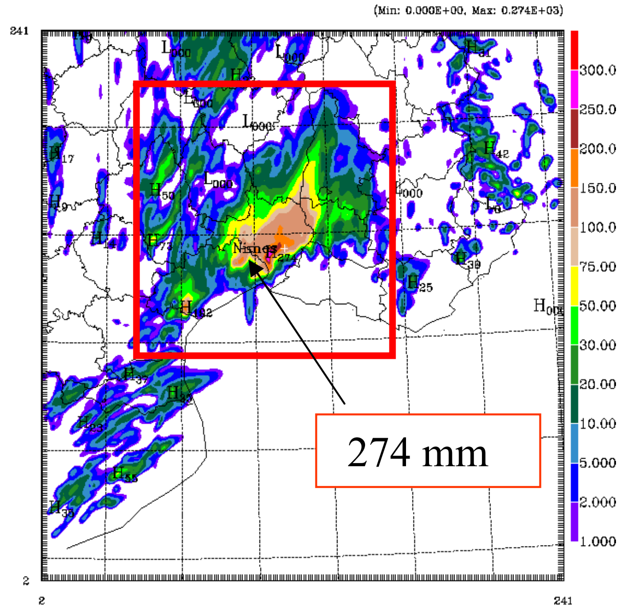
BC : Aladin 3h Forecasts

« Gard » flash flood (8 Sept. 2002)

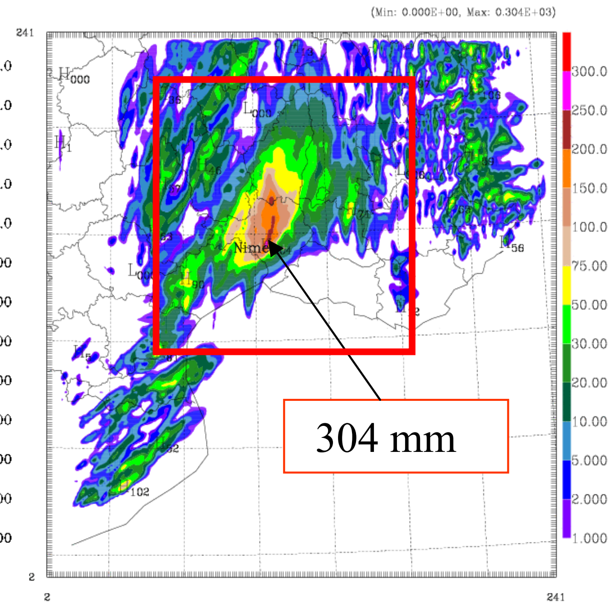
12-22 TU Nîmes radar
cumulated rainfall



MésoNH 4s



Arome 60s



Single model 2.5Km

IC : Mesoscale surface data reanalysis

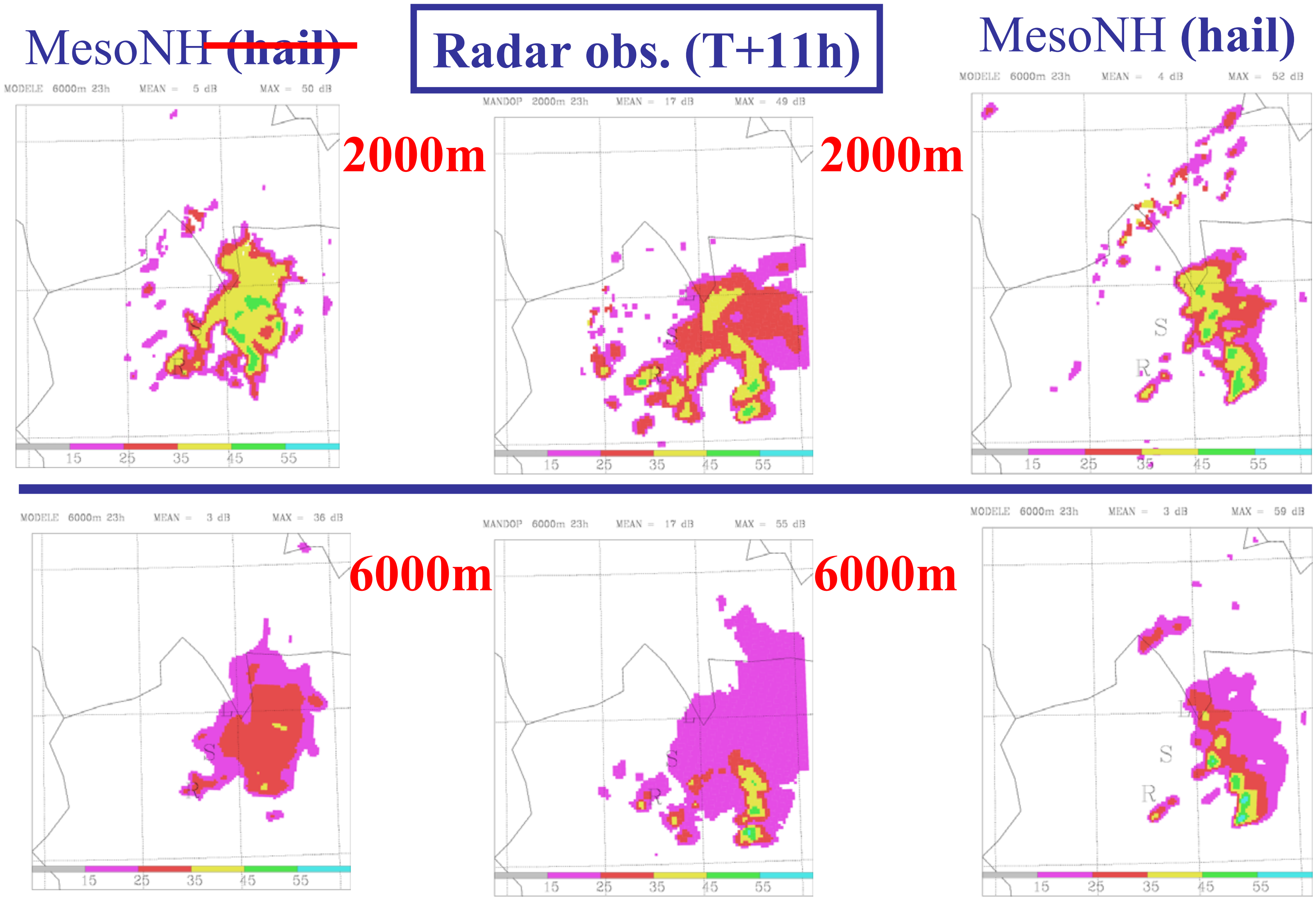
BC : Aladin 3h Forecasts

MésoNH verifying toolbox

- **Simulation of radar observations (Z_e, V_{Dop}, ZDR, …): based on the Rayleigh diffusion approximation $Z \sim ND_e^6$**

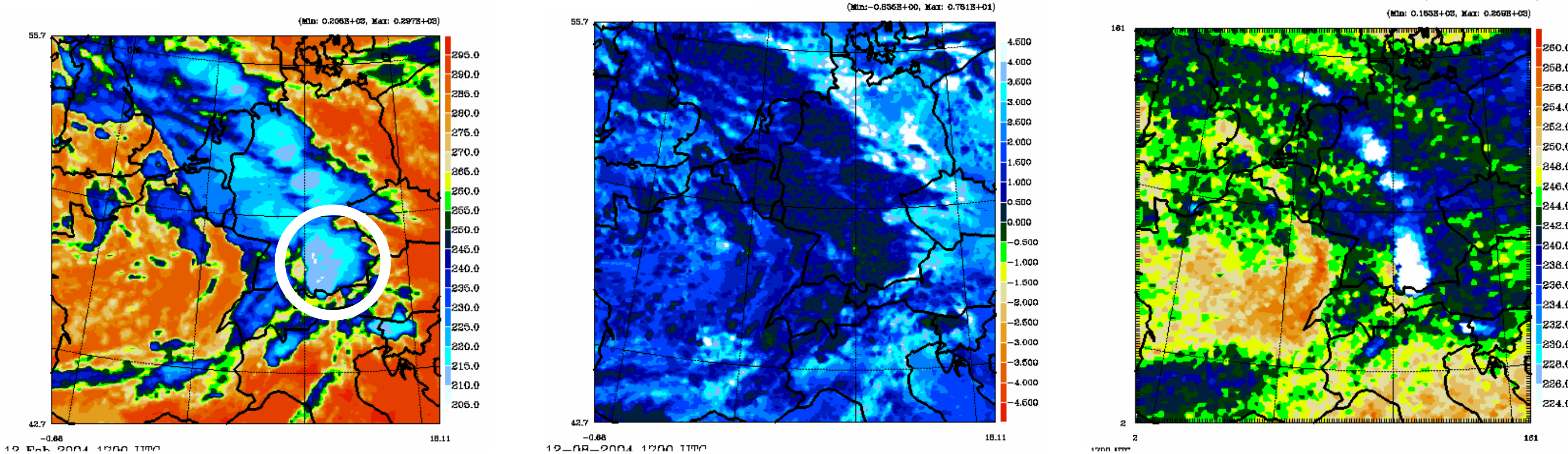
- **Simulation of satellite radiances and BTs (VIS, IR, MW): based on highly accurate radiative transfer scheme coupled to Mie/T-matrix diffusion codes or using a fast algorithm such as RTTOV**

Radar reflectivities (MAP IOP2a 2 km)

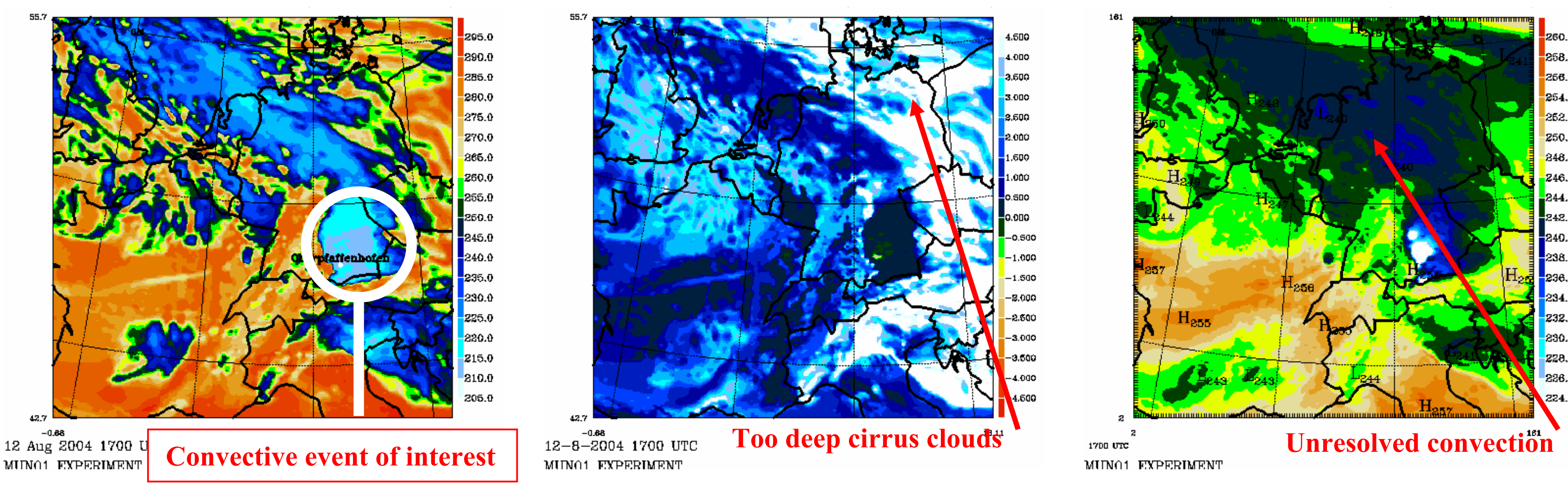


Satellite analysis of storms over Germany

SEVIRI **10.8 µm** BT (MSG) | SEVIRI **10.8-12 µm** BT (MSG) | AMSUB **183+/- 1 GHz** (NOAA15)



MesoNH simulation (Δx=10km) with RTTOV results after 17 hours



Conclusion

- **The simulation of cloud cover and precipitation fields seems promising at high resolution even without a sophisticated initialization procedure.**

- **Cloud schemes still need to be improved and tested for the purpose of operational applications (this should be a new concern of the cloud modeling community!)**

- **There is a great interest in using routine radar & satellite data to show up cloud scheme deficiencies.**

Perspectives

- **Fractional cloud cover and precipitation.**

- **Interactions between convection schemes (implicit clouds) and microphysical schemes (explicit clouds) to simulate the lifetime of anvil outflow.**

- **Should microphysical schemes be scale dependent ?**

- **Careful evaluation and calibration of microphysical schemes using ground radar and satellite observations.**