Meso-NH physics

Present state, short and medium terms scientific plan

Christine Lac

Meteo-France (CNRM)

http://www.aero.obs-mip.fr/mesonh

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Meso-NH physics :
Present state, short and medium terms scientific plan

- General description of Meso-NH
- Turbulence
- Implicit Clouds in Meso-NH : Deep Convection, Shallow Convection, Subgrid condensation
- Explicit clouds : Microphysics
- Conclusion

General description of Meso-NH

A research model, jointly developped by Meteo-France and Laboratoire d'Aérologie (CNRS/UPS)

- Anelastic equations with the pseudo-incompressible system of Durran
- Vertical coordinate following the terrain : (Gal Chen and Sommerville, 1975) $z* = H \frac{z - z_S}{H - z_S}$
- Temporal discretization : Purely explicit leap-frog scheme
- Spatial discretization : Arakawa C grid
- Grid nesting : One-way/Two-way
- Initial fields and LBC (radiative open) from ECMWF/ARPEGE/ALADIN.

- Turbulence : 1.5 order closure Cuxart-Bougeault-Redelsperger (2000)
- Convection : Kain-Fritsch (1993) revised by Bechtold et al. (2001)
- Microphysical scheme : Bulk schemes at 1-moment or 2-moments. Up to 7 prognostic species: vapor (r_v), cloud (r_c), rain (r_r), pristine ice (r_i), snow (r_s), graupel (r_g), hail (r_h)
- Radiation : ECMWF package

Turbulence scheme

A prognostic equation for the TKE, e, while all the other 2nd order moments are diagnosed:

$$\frac{\partial e}{\partial t} = \underbrace{-\frac{1}{\rho}\frac{\partial(\rho \overline{u_i} e)}{\partial x_i}}_{Advection} \underbrace{-\overline{u'_i u'_j}\frac{\partial \overline{u_i}}{\partial x_j}}_{Dynamic} + \underbrace{\frac{g}{\theta_{vref}}\overline{w'\theta_v'}}_{Thermic} + \underbrace{\frac{1}{\rho_{ref}}\frac{\partial}{\partial x_i} C\rho_{ref} L\sqrt{e}\frac{\partial e}{\partial x_i}}_{Diffusion} \underbrace{-C_\varepsilon \frac{e^{3/2}}{L}}_{Dissipation\ \varepsilon}$$

$$\overline{w'\theta'} = -\frac{2}{3}\frac{L}{C_{p\theta}}\sqrt{e}\Phi_3 \frac{\partial \overline{\theta}}{\partial z}$$

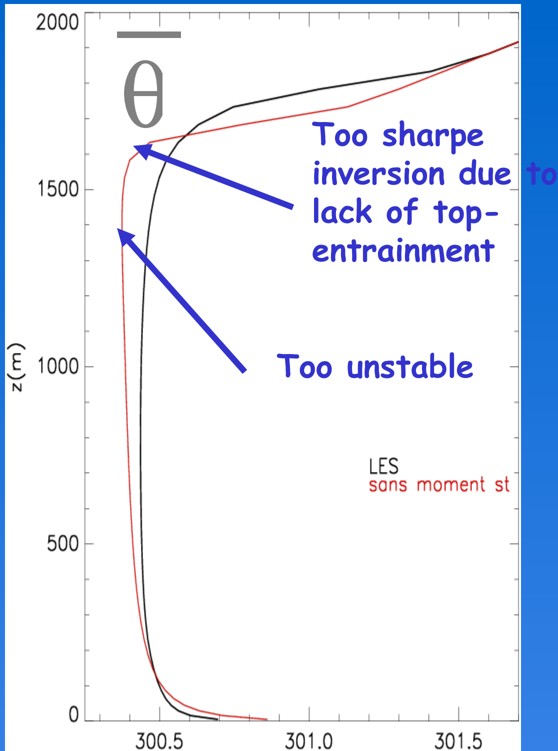
3rd order moments (TOM) are neglected

Closure through the mixing-length L

L = Size of the largest energetic eddies feeding the cascade of energy down to dissipation. Is the only parameter that varies from LES to mesoscale configuration.

For mesoscale (>2-3km) or SCM, horizontal turbulent exchanges are not considered : TURBULENCE 1D (AROME) - BL89

Shortcomings of the turbulence scheme and ways of improvement



Dry CBL

The heat transport is <u>countergradient.</u>

In the eddy-diffusivity approach : $\overline{w'\theta'} = -K\left(\frac{\partial\theta}{\partial z} - \gamma\right)$

$$\gamma = \frac{\beta L_\varepsilon}{2C_{\varepsilon_\theta} e^{3/2}} \frac{\partial \overline{w'\theta'^2}}{\partial z} + \frac{3}{2e} \frac{\partial \overline{w'^2\theta'}}{\partial z}$$

When TOM for heat are kept during the derivation

These TOM are neglected in the budget of variance of θ:

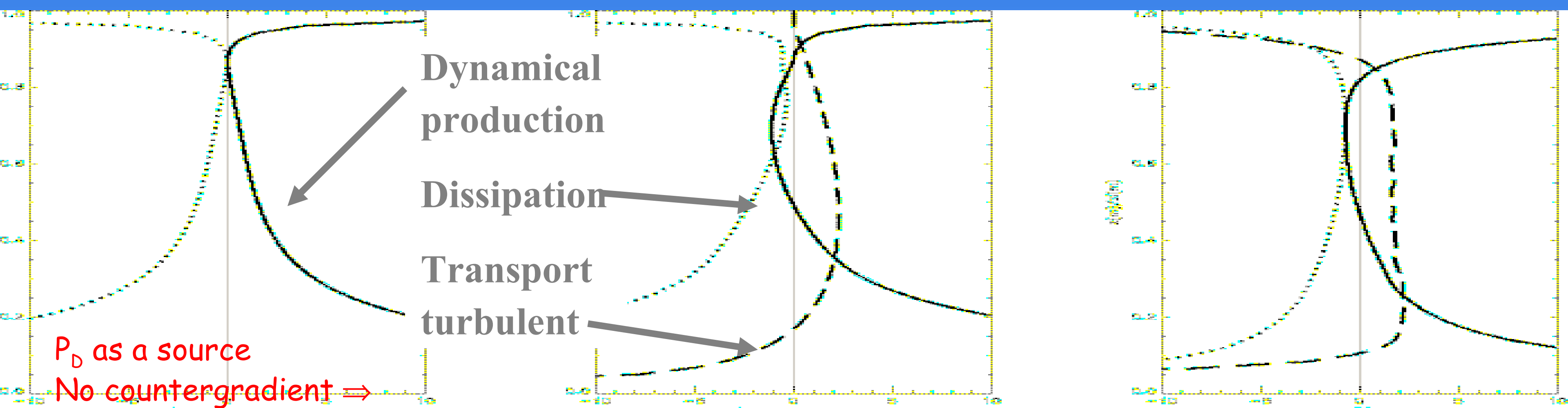
(Tomas and Masson, 2005)

$$\frac{\partial}{\partial t}\left(\overline{\theta'^2}\right) = \underbrace{-W\frac{\partial \overline{\theta'^2}}{\partial z}}_{Advection} \underbrace{-\frac{\partial \overline{w'\theta'^2}}{\partial z}}_{TOM} \underbrace{-2\overline{w'\theta'}\frac{\partial \theta}{\partial z}}_{P_D} \underbrace{-\varepsilon_\theta}_{Dis}$$

1D without moment

1D with moment

LES reference



P_D as a source

No countergradient ⇒ Excessive W to compensate

Shortcomings of the turbulence scheme and ways of improvement

- CBL :
  - First step (2005): TOM are fitted on reference LES simulation (S.Tomas)

$$\overline{w'^2\theta'} = f(w*, z/z_i), \quad \overline{w'\theta'^2} = g(w*, z/z_i)$$

Systematic improvement

  - Tune of L, Cet
  - Second step (2006-2007): To parametrize the TOM by a mass-flux formulation (Masson and Stein)

- Cumulus : Underestimation of the turbulence, at the transition cloud/clear sky $\Rightarrow$ Overestimation of the vertical velocity. Tests on SGCS.

- Neutral BL : Improvement of L.

- Stable BL : Too weak mixing with weak wind (Fog) and in the inversions. Tests on L (introduction of local L). (T.Bergot)

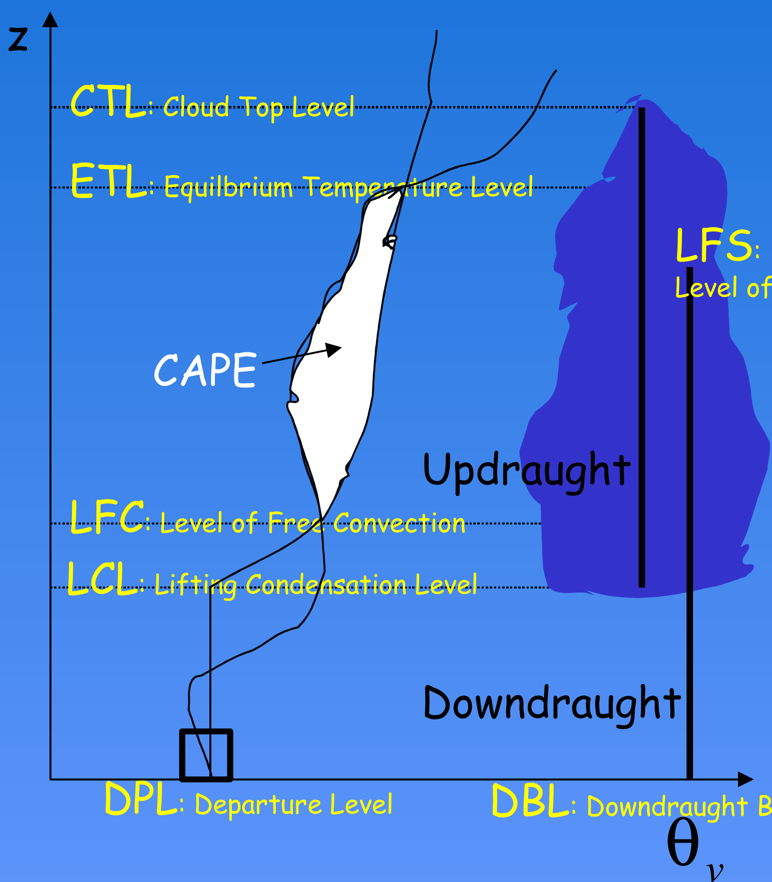
… and the transition stable/convective

Methodology : to compare LES and mesoscale simulations to improve 1D turbulence scheme

Convection scheme : Kain-Fritsch-Bechtold

A modified mass-flux scheme for deep and shallow convection (without downdraft and precipitation) – All computation are 1D

$$\frac{\partial\overline{\psi}}{\partial t} = -\frac{1}{\overline{\rho}}\frac{\partial(\overline{\rho}\,\overline{w'\psi'})}{\partial z} = \frac{1}{\overline{\rho} A}\left[\frac{\partial}{\partial z}(M^u + M^d)\overline{\psi} - (\varepsilon^u + \varepsilon^d)\overline{\psi} + \delta^u\psi^u + \delta^d\psi^d\right]$$



Trigger function : An air parcel, lifted to LCL, is unstable if: $\overline{\theta_v}^{mix} - \theta_v + \Delta T/\pi > 0$

+ ability to produce sufficient cloud depth (3km-500m)

Updraft and downdraft are computed assuming conservation of enthalpy and r_w with initial values M^u (LCL) et M^d(LFS)

Entrainment if B>0 for the mixed parcel. Detrainment if B<0. Functions of the supposed cloud radius.

Closure:Removing of the CAPE during an adjustment period (3h for SC, between 0.5 and 1h for DC)

Convection scheme

Short term scientific plan :

-Deep convection : No major evolution

- Shallow convection :

→ Current tests on the initial updraft mass flux Mu(LCL), acting on the closure assumption as a function of w_{LCL} (Stein et al.)

→ Contribution to the SGCS (Malardel et al.)

→ Implementation of the mass flux scheme of Soares et al. (2004) (Summer 2005) (the eddy-diffusivity is CBR).

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + M(\phi_{up} - \overline{\phi})$$

Introduction of effects of thermals (non-local turbulent transport)

Subgrid condensation scheme (SGCS)

Fractional cloudiness and cloud condensate in subsaturated regions – To attenuate numerical shocks between cloudy and non cloudy grid cells.

1. First SGCS available in Meso-NH : Moist turbulence of mixed-phase clouds (Sommeria and Deardorff, Bougeault):

$$N = \int_{-Q_1}^{\infty} G(t)dt, \quad Q_1 = \overline{S} / \sigma_S$$

$$\frac{r_c}{2\sigma_S} = \int_{-Q_1}^{\infty} (Q_1 + t) G(t) dt$$

$$\frac{\overline{S' r'_C}}{2\sigma_S} = \int_{-Q_1}^{\infty} t (Q_1 + t) G(t) dt$$

N = Cloud fraction

Q_1 = Normalized saturation deficit

S = combination of (r_{np},θ_l)

σ_s= variance of S

G(t)=G(q_l, r_{np}) a probability distribution function

Directly linked with the turbulence scheme through 2nd-order turbulent moments

Limitation : Misrepresents the shallow convective cloudiness

Subgrid condensation scheme (SGCS)

2. Other option available in Meso-NH (Bechtold and Chaboureau, 2002):

Originally developed for non-precipitating clouds, extended for all cloud types (deep, cirrus)

$$\sigma_S^2 = \sigma_{S\,TURB}^2 + \sigma_{S\,CONV}^2$$

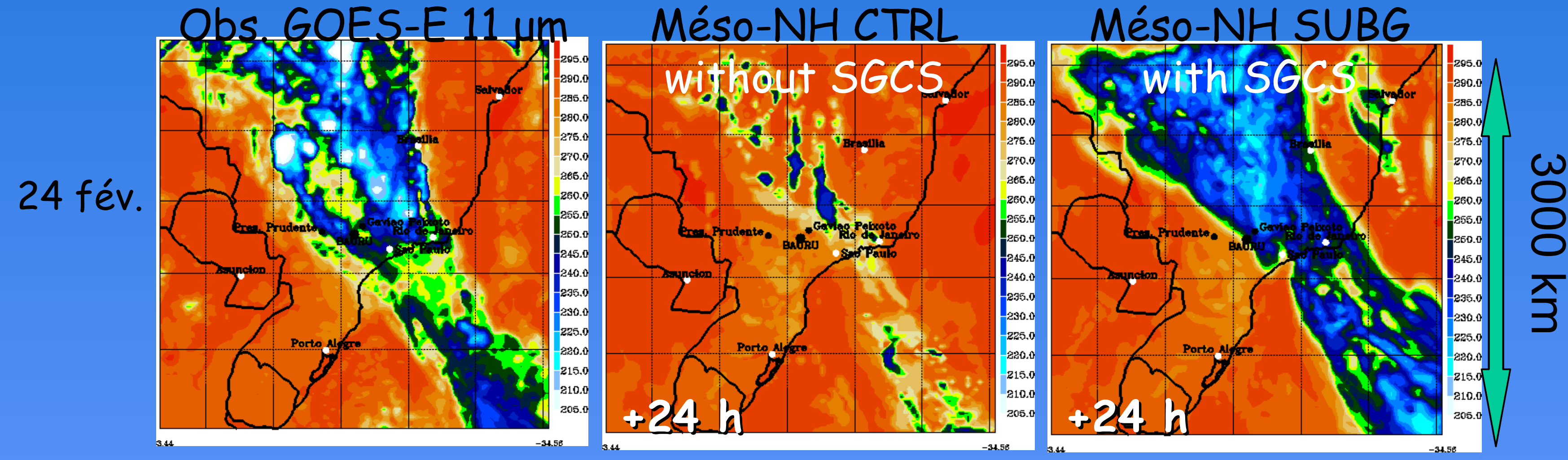
$\sigma_{S\,TURB}$ diagnosed with 1st order turbulent closure

$$\sigma_{S\,CONV} \approx M \frac{s^c - s^e}{W_* \rho}$$

From the KFB scheme

M =Mass flux

W_* = Convective velocity scale



(JP.Chaboureau)

TROCCINOX 2004 Δx=30 km

Subgrid condensation scheme (SGCS)

2. Other option available in Meso-NH (Bechtold and Chaboureau, 2002):

Applied to shallow and deep convective clouds, cirrus

$$\sigma_S^2 = \sigma_{S\,TURB}^2 + \sigma_{S\,CONV}^2$$

$\sigma_{S\,TURB}$ diagnosed with 1st order turbulent closure

$$\sigma_{S\,CONV} \approx M \frac{s^c - s^e}{W * \rho}$$

From the KFB scheme
M =Mass flux
W_* a convective velocity scale

3. Other ideas of improvement (in test at current time) (Lenderink and Holtslag, 2004):

$$\overline{r'_w{}^2} = (\overline{r'_w{}^2})_{TURB} + (\overline{r'_w{}^2})_{CONV}$$

$$(\overline{r'_w{}^2})_{CONV} = -\frac{M(r_{w_{UP}} - r_w)l_{Cu}}{W_{Cu}} \frac{\partial r_w}{\partial z}$$

From the KFB scheme :
M =Mass flux
l_{Cu} the depth of cloud layer
W_{cu} a convective velocity scale (Grant)

Microphysics

<u>Main assumptions</u> :

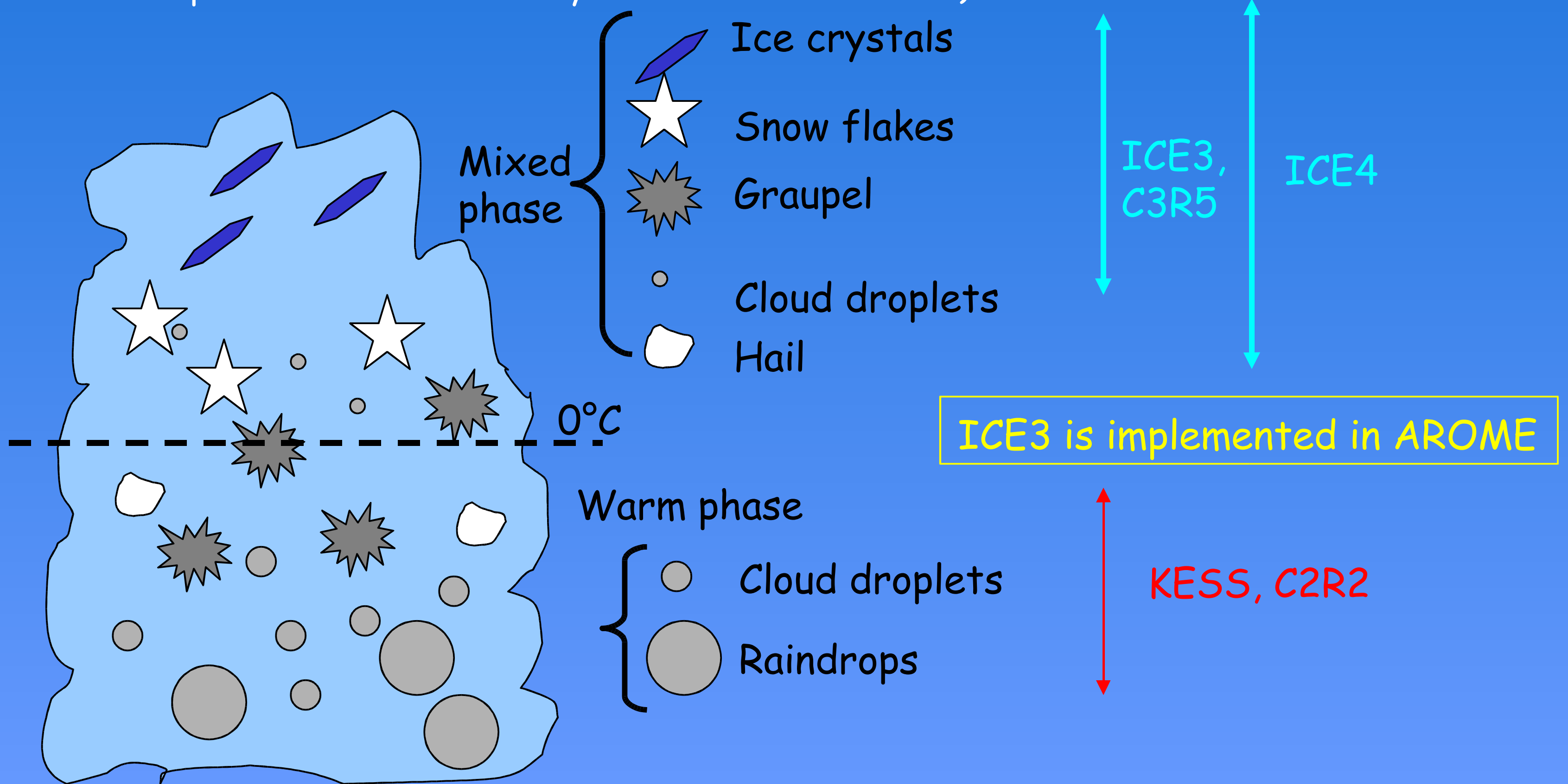
-Precipitating particles are distributed according to Gamma function (Marshall Palmer for raindrops : $N(D)dD = N_0 \exp(-\lambda D)dD$)

- Mass-diameter ($m=aD^b$) and fall velocity-diameter ($V=cD^d$) relations as power laws

- Concentrations : * 1-moment scheme $N_i = C\lambda_i^x, i = \{r, s, g, h\}$ KESS ICE3, ICE4

  * 2-moment scheme : Integration of $\partial N_i / \partial t$ C2R2 C3R5

(attractive for topics like cloud chemistry and radiative transfer)



Microphysics

Ordering the processes : example for warm cloud :

2. Advection (+Turbulence) + Check for positivity
3. Rain sedimentation (time splitting)
4. Accretion of cloud droplets by raindrops
5. Autoconversion of cloud droplets into raindrops
6. Rain evaporation
7. Saturation adjustment

(2–6) Slow processes – Explicitely computed

(7) → Very fast process – Implicitely computed

Many questions concern the treatment of the autoconversion processes that govern the onset of precipitation

Improvement of ICE3 for cirrus :

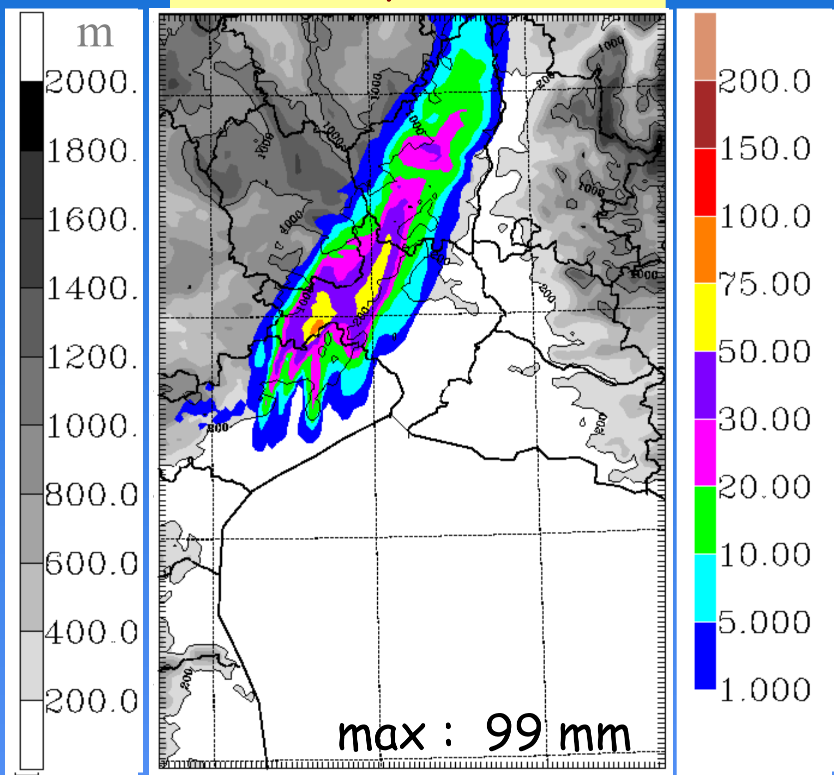
$$\left.\frac{\partial r_S}{\partial t}\right|_{AUT} = K_{IS} Max(0, r_i - r_i^*) , \quad r_i^* \in [0.1,1] g/m^3$$

(Chaboureau et al., 2002)

Model to satellite approach

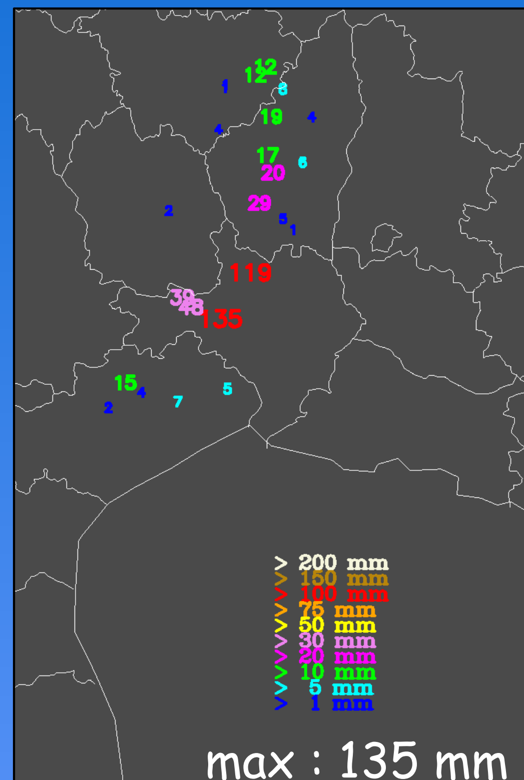
Quasi-stationnary MCS 13-14 Oct. 1995

MESO-NH, Δx=2.5km

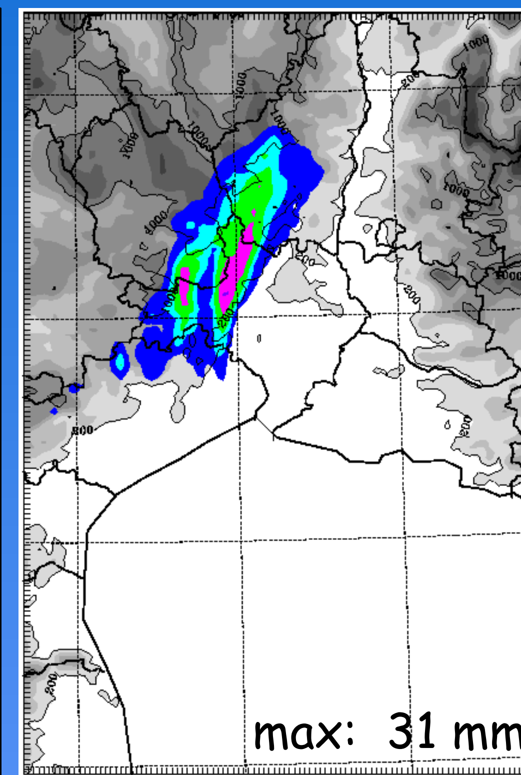


Initialisation Ducrocq et al (2000)'s

OBSERVATIONS



MESO-NH, Δx=2.5km



Initial conditions: ARPEGE analysis at 18UTC

Cumulated precipitation 01 UTC to 06 UTC the 14th Oct. 1995

(Ducrocq et al, 2002)

Microphysics : Stratocumulus

Perspectives of improvement for Stratocumulus prediction :
Instead of C2R2, the Khairoudinov-Kogan developped for Marine Sc, in hand of implementation (O.Geoffroy)

- -auto-conversion
- -accretion
- -condensation/evaporation (C2R2)
- -Drizzle sedimentation

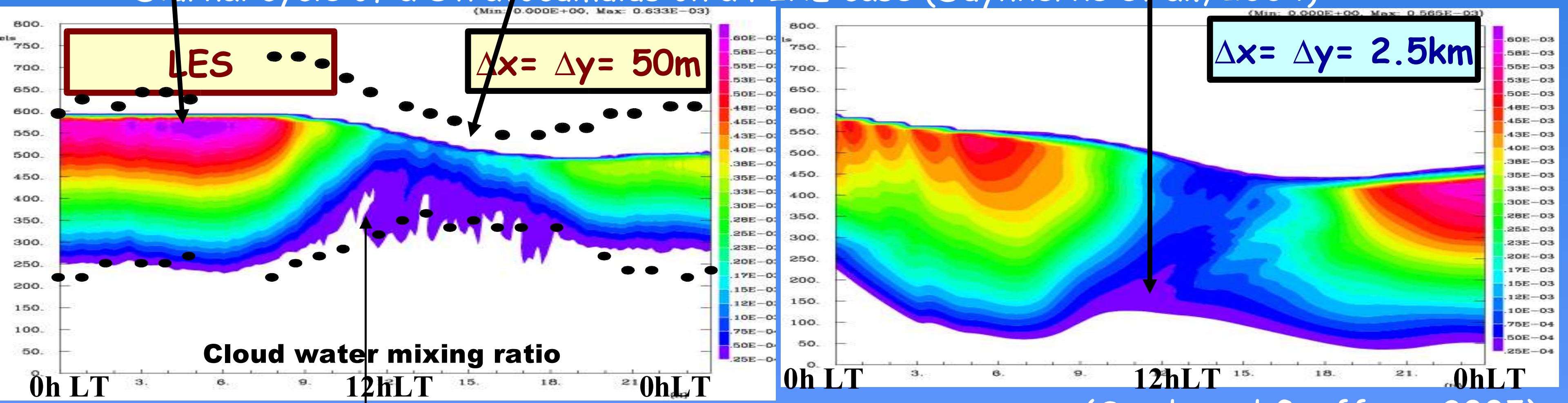
N_{CCN} → **Activation (Cohard et al. 1998)** → **N_a** → **q_c, N_c** → **Rain parametrization (KK2000)** → **q_r, N_r**

Turbulence driven by LW radiative cooling near the top of the Sc. Vertically well-mixed.

Heating by SW + entrainment of warm and dry air → stable stratification → Decoupling with PBL

Underestimation of the decoupling, due to overestimation of explicit turbulence to compensate insufficient SG TKE. Large moistening rate ↔ Small entrainment rate

Diurnal cycle of a Stratocumulus on a FIRE case (Duynkerke et al., 2004)



(Sandu and Geoffroy, 2005)

Too early decoupling due to overestimation of the absorption. **Improvement of the SSA** by taking into account chemical composition and dimensions of the droplets (Sandu et al., 2005)

CONCLUSION : Objectives of Meso-NH physics

1. To supply to AROME the best possible physics.
   Improvements during the next 2 years especially on turbulence, on the link turbulence-convection-SGCS (Shallow cumulus), on the microphysics (Cirrus, Sc, Fog)

   ALARO and HIRLAM communities are welcome !

2. To remain a research tool and a numerical laboratory for meso-scale (grid-nesting) to LES studies, including assimilation data tests

   With a range of advanced diagnostics : on-line budgets for each water category, LES budgets, simulated parameters (radar, Doppler, satellite …)

3. To favour adjacent research, broadening the user's community : on-line chemistry/aerosol, electricity (implicite, explicite), hydrology …