CLOSING OF THE PHYSICS SESSION

The known weaknesses of the Meso-NH physics for AROME and the plans of improvement

1st AROME training course, Poina Brasov, November 21-25, 2005

Cirrus clouds

Depends on convective systems (anvils). Turbulence ice improves the life cycle.
Improvement with tuning of microphysics.

Deep clouds

Mainly driven by dynamics. Mixed-phase microphysics
Good results with AROME (no excessive W)
Numerical improvements. Impact of hail.

BL clouds : Sc

Larger cloud fraction. Variety of turbulence and stability profiles - Importance of entrainment.
Impact of vertical resolution - Mixing length -
Aerosol effects -

BL clouds : Cu

-The CBR scheme insufficient to produce BL clouds.
Countergradient (TOMs) insufficient for top-cloud entrainment.
Improvement : Tuning of KFB, Introduction of Soares,
Subgrid condensation with ED+MF contribution

Dry CBL

Transition to BL clouds. Turbulent mixing dominated by large-eddy transport and entrainment at the top.

Improvement : Countergradient (TOMs) versus EDMF (Siebesma and Soares)

Fog

Stable BL and transition to neutral for the dissipation.
Improvement : Sedimentation of small drops. Mixing length. Influence of aerosols.

PLAN

Inventory, Ways of improvement and Plan for:

1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus
7. Chemistry

Fog

∃ just a few studies with Meso-NH . A PRIORITY for AROME

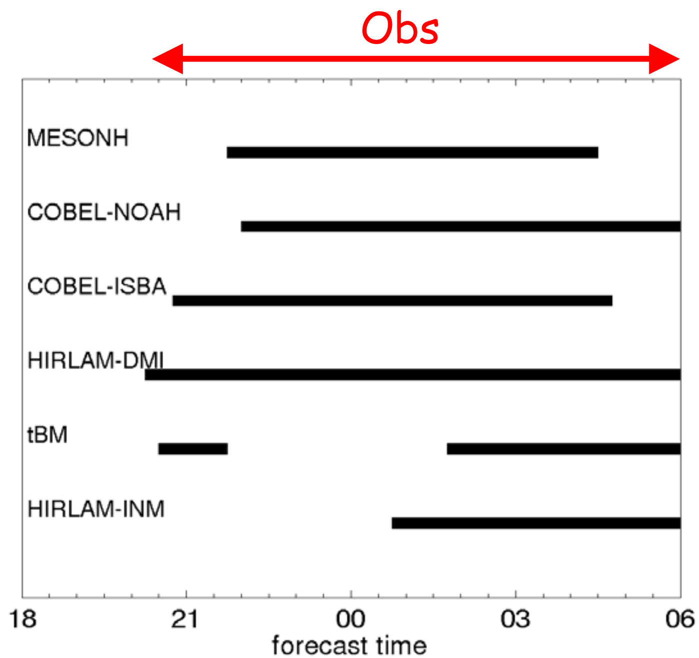
Bergot et al., 2005, submitted :
Intercomparison of 1D numerical models for prediction of the fog ($\neq \mu\pi$, $\neq$turbulence, $\neq\Delta z$)

2 events at Paris-CdG. 4 sets of initial conditions (RS): 18UTC (onset), 21 (thickening), 00 (mature) and 03 (disspation)

Scientist	Model	Levels <50m	Levels <200m
E.Terradellas	**Hirlam-INM (1D version used in Spain)**	1	3
O. Liechti	**tBM**	2	7
N.W. Nielsen	**Hirlam-DMI**	13	20
T. Bergot	**Cobel-Isba**	13	20
M. Mueller	**Cobel-Noah**	18	30
J.Cuxart/A.Mira	**MesoNH**	50	89

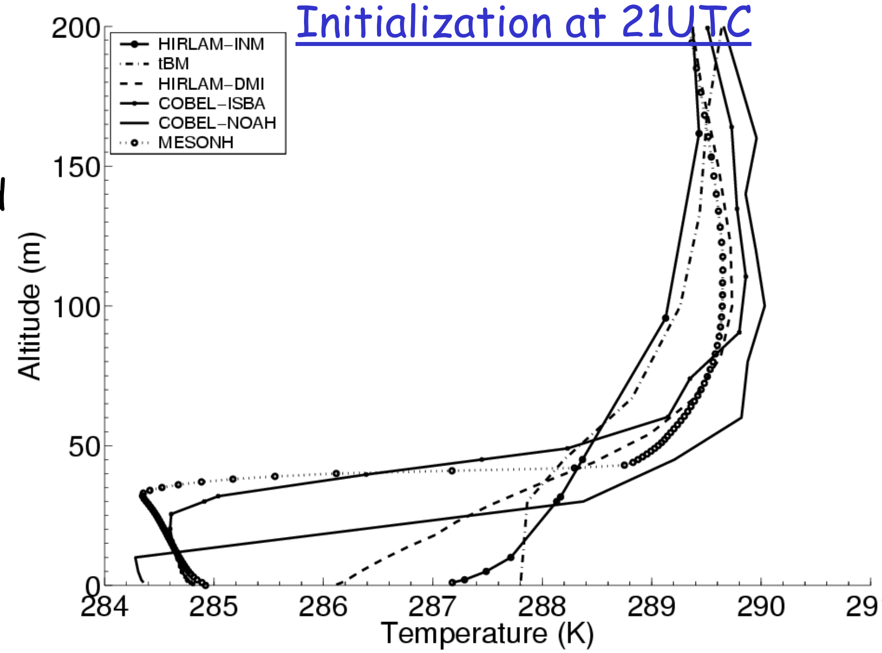
Fog

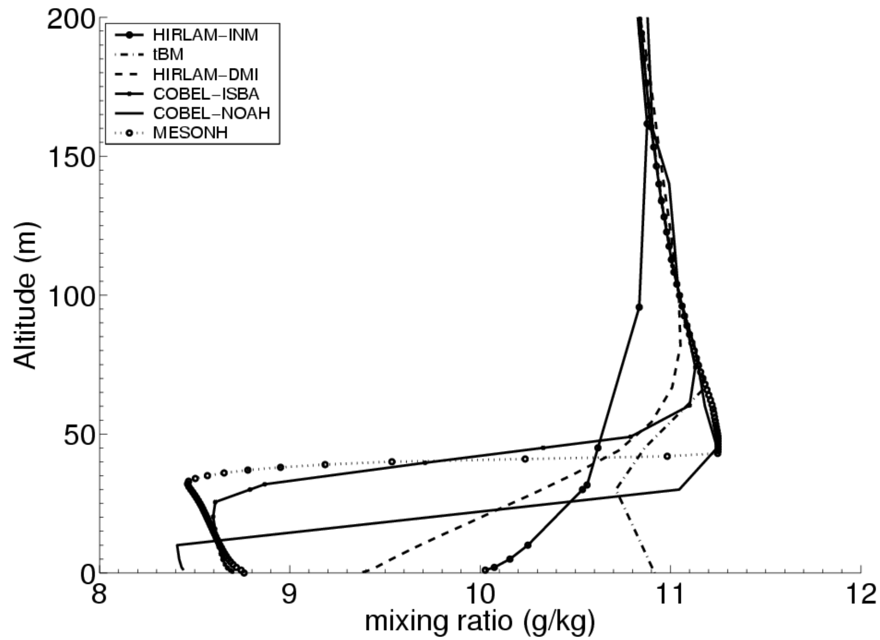
1st case : Radiation fog with weak wind



Forecasted occurrence of fog with **initialization at 18UTC**.

Initialization at 21UTC

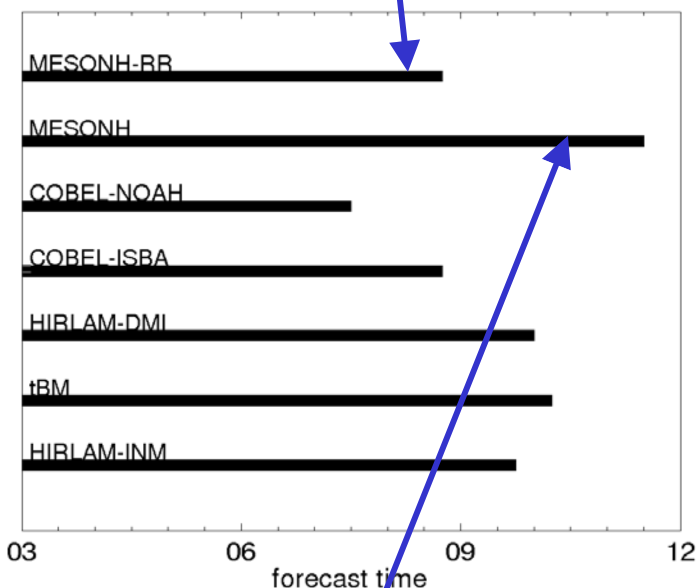




Bergot et al., 2005, submitted

Fog

Crude test : Modification of the autoconversion threshold

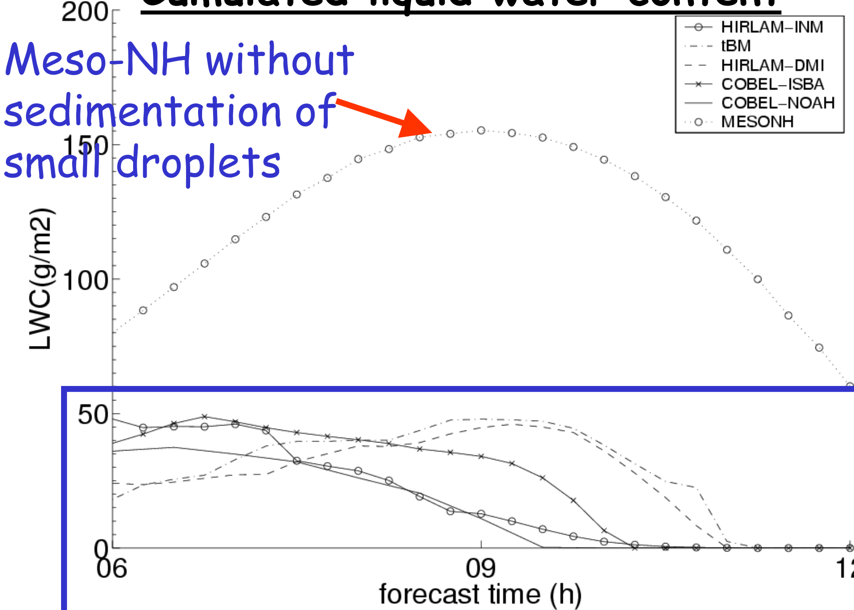


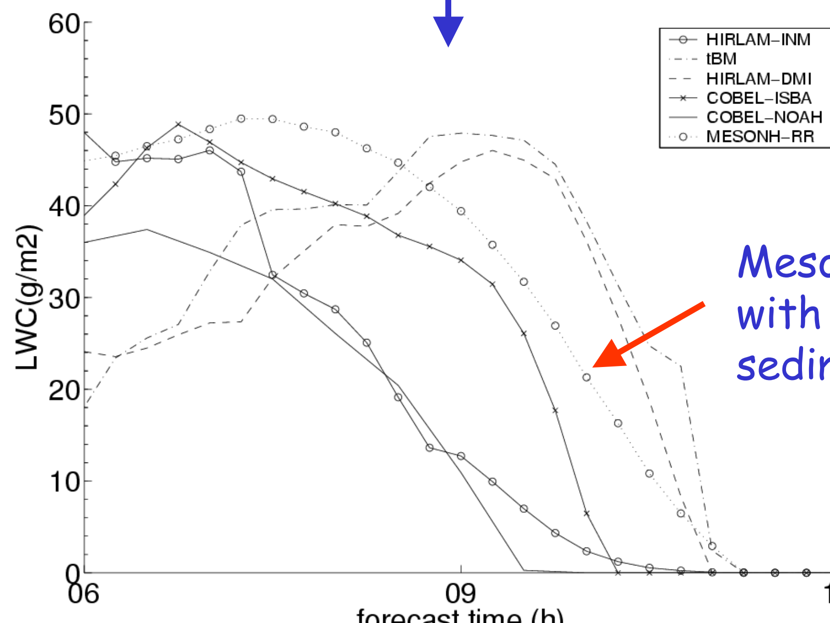
Initialization at 03UTC

Late dissipation due to excessive r_c : lack of gravitational settling

Cumulated liquid water content

Meso-NH without sedimentation of small droplets





Meso-NH with sedimentation

Bergot et al., 2005, submitted

Fog : Plan for 2006

1. Microphysics : Implementation of the sedimentation for small droplets
2. Tests on the sensitivity to vertical resolution → Additional levels to L41 ? (Cobel-Isba with L41 shows degradation)
3. Evaluation on CAPITOUL and on several international airports. Run of AROME on Ile-de-France on winter 2005 and in 1D on Casablanca and Varsovie (to be confirmed)

PLAN

Inventory, Ways of improvement and Plan for:

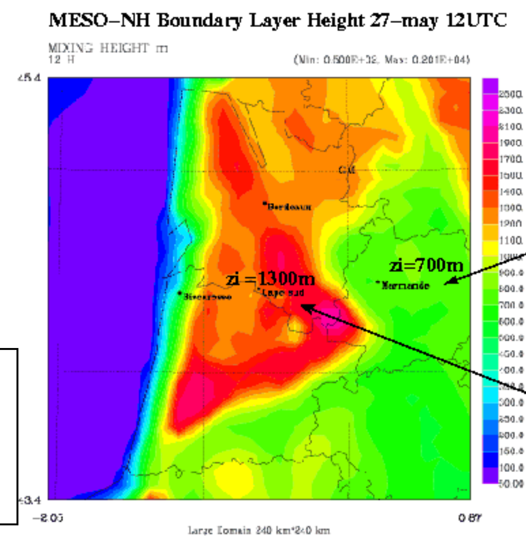
1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus

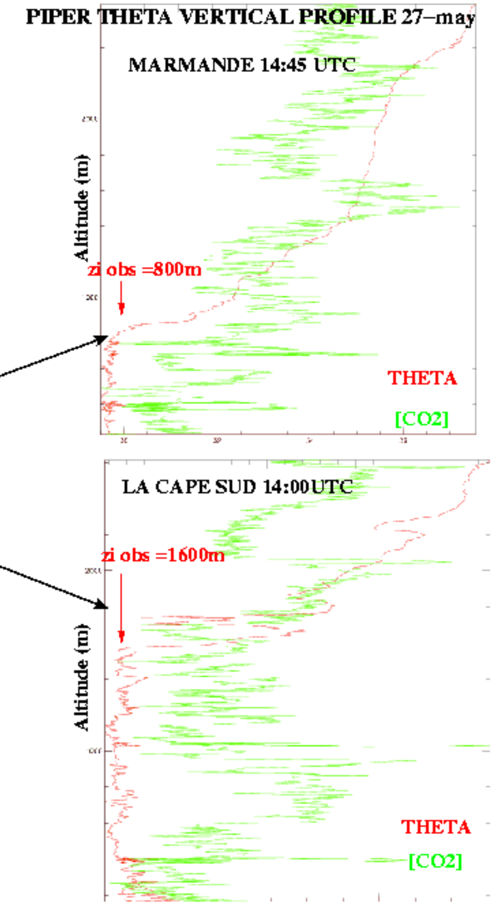
7. Chemistry

Dry CBL

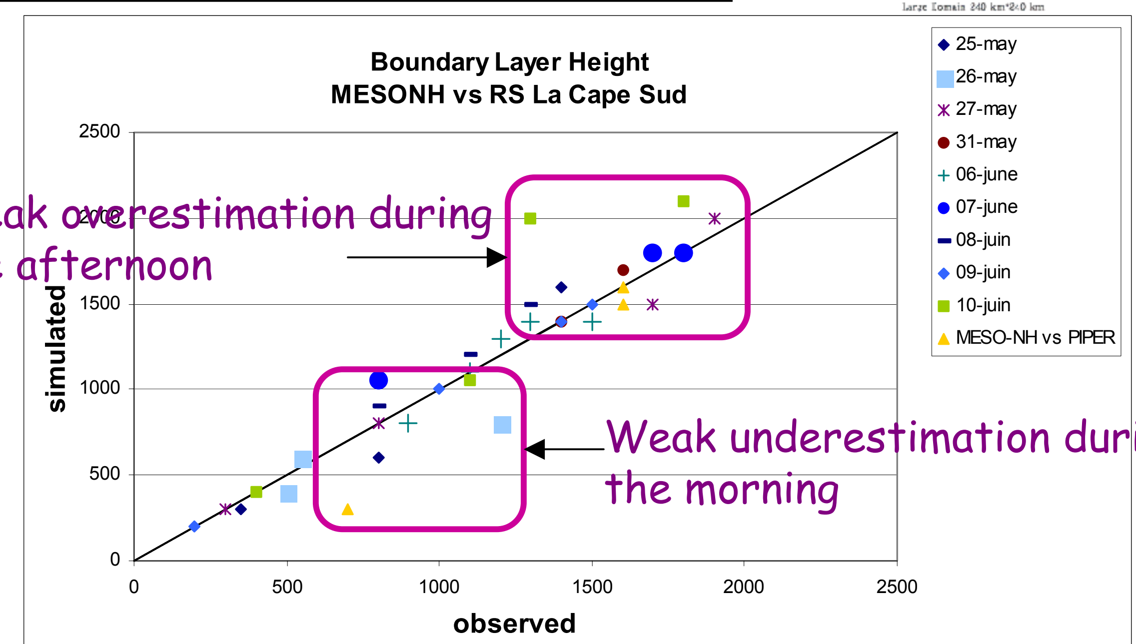
Evaluation CARBOEUROPE

Forecasts of Meso-NH (8km) in an operational mode during the experiment





La Cape Sud : Comparison Meso-NH/RS of BL height (parcel method) between 6 and 17UTC

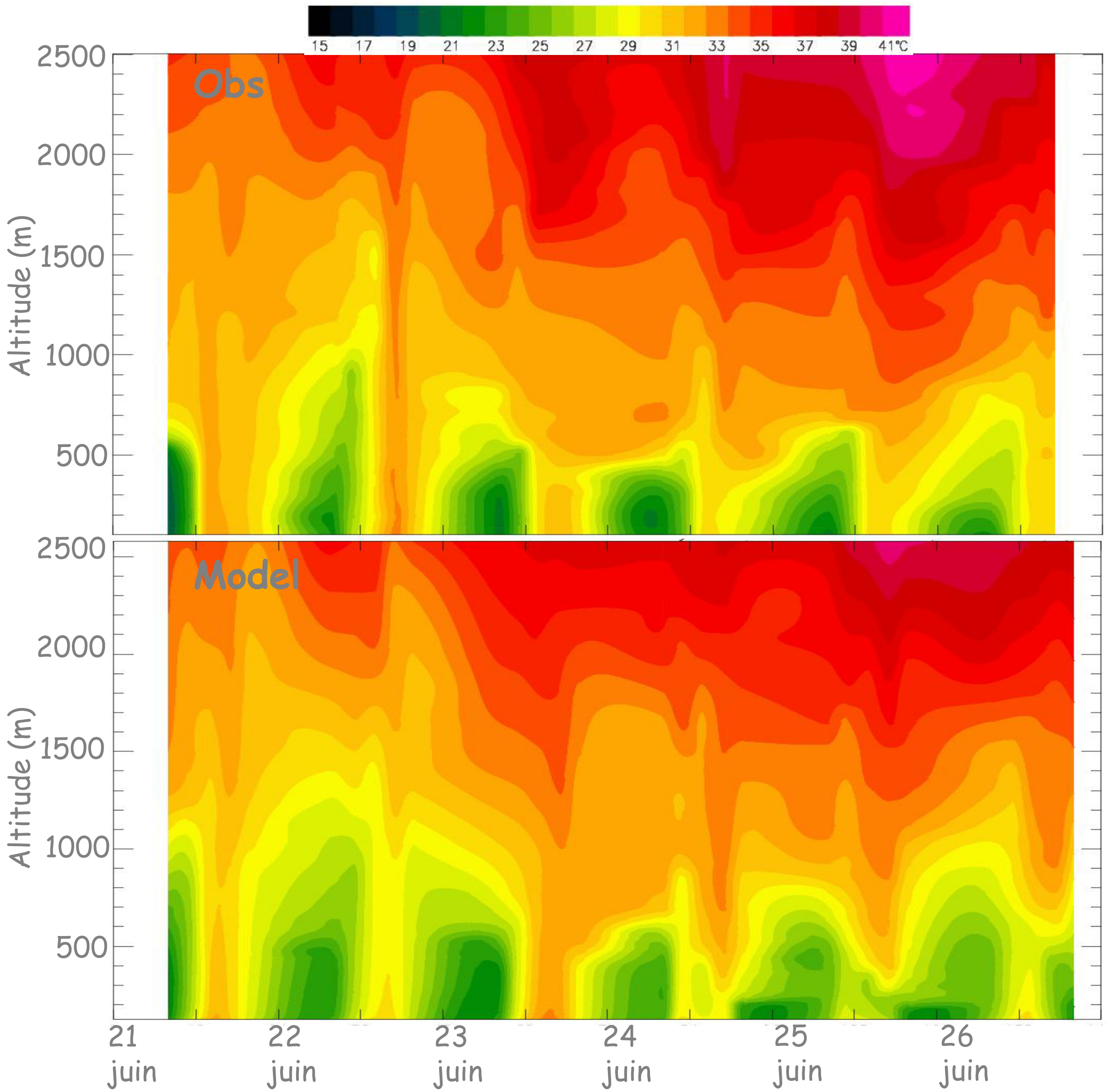


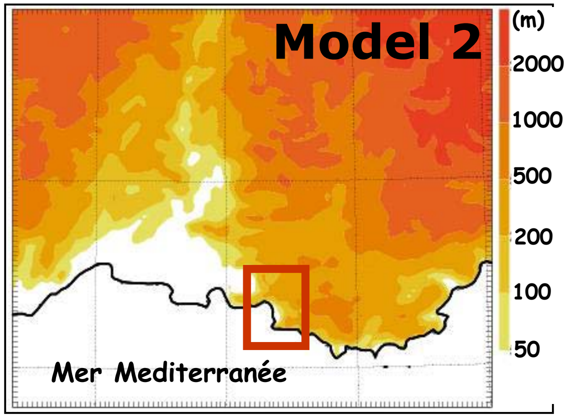
Weak overestimation during the afternoon

Weak underestimation during the morning

Dry CBL

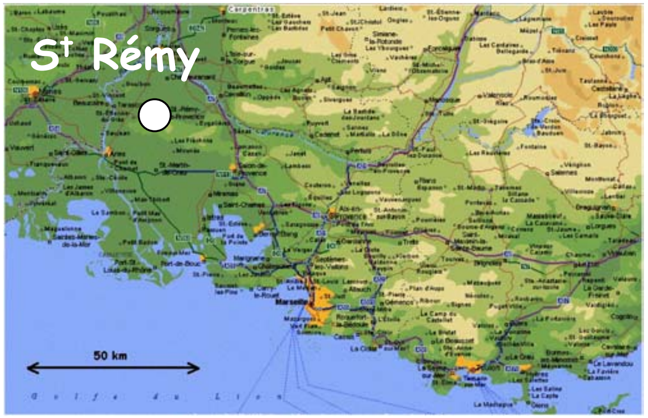
Evaluation Escompte (Meso-NH 3km)





Radiosoundings

S^t Rémy de Provence



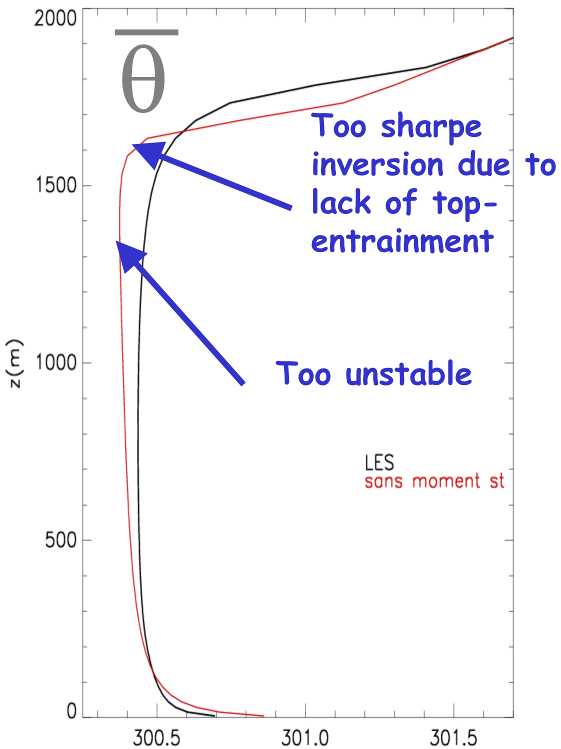
Lemonsu, Bastin et al., 2005b

Dry CBL

BUT limitations are well-known, inherent to Eddy-diffusivity

Eddy-diffusivity (local) :

$$\overline{w'\theta'} = -K \frac{\partial \theta}{\partial z} \quad \text{with} \quad K = \frac{2}{3C_{p\theta}} L \sqrt{e}\phi_3$$



1. The K-diffusion doesn't take into account countergradient.

2. Entrainment is not treated explicitly in the K-diffusion approach.

3. But diffusion remains necessary, for transition to neutral or stable BL.

Dry CBL

To take care of the non-local transport

1. The eddy-diffusivity with a countergradient : $\overline{w'\theta'} = -K\left(\frac{\partial\theta}{\partial z} - \gamma\right)$

   a. $\gamma = a\frac{w^*}{\sigma_w^2 z^*}\overline{w'\theta'}^*$ (*=BL height) *(Cuijpers and Holtslag, 1998)*

   b. Third-order moments (TOM) for heat :

1 $$\gamma = \frac{\beta L_\varepsilon}{2C_{\varepsilon_\theta} e^{3/2}}\frac{\partial\overline{w'\theta'^2}}{\partial z} + \frac{3}{2e}\frac{\partial\overline{w'^2\theta'}}{\partial z}$$ *(Tomas and Masson, 2005)*

2. The eddy-diffusivity /mass-flux parameterization (EDMF)

2 $$\overline{w'\theta'} = -K\frac{\partial\theta}{\partial z} + M(\theta_u - \overline{\theta})$$ *(Siebesma et al., 2000)*

Implemented by Soares (2004)

Old version of Meso-NH

In the dry CBL, the MF acts as a countergradient

In the cloud-top BL, it corresponds to the usual mass-flux closure

Dry CBL

1. Countergradient with Third order moments

- In a first step, TOMs not expressed to higher order closure but fitted on the TOMs of LES .

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

zi=Inversion height, previously diagnosed
w*=Vertical convective scale
θ*= θ convective scale

- Sufficient in dry CBL with weak winds (Nieuwstadt, 1993) but insufficient with strong fluxes :

✓ Tuning of the mixing length :

$$L = L_\varepsilon = \frac{1}{\sqrt{1/(2.8 l_{up})^2 + 1/(2.8 l_{down})^2}}, 2L$$

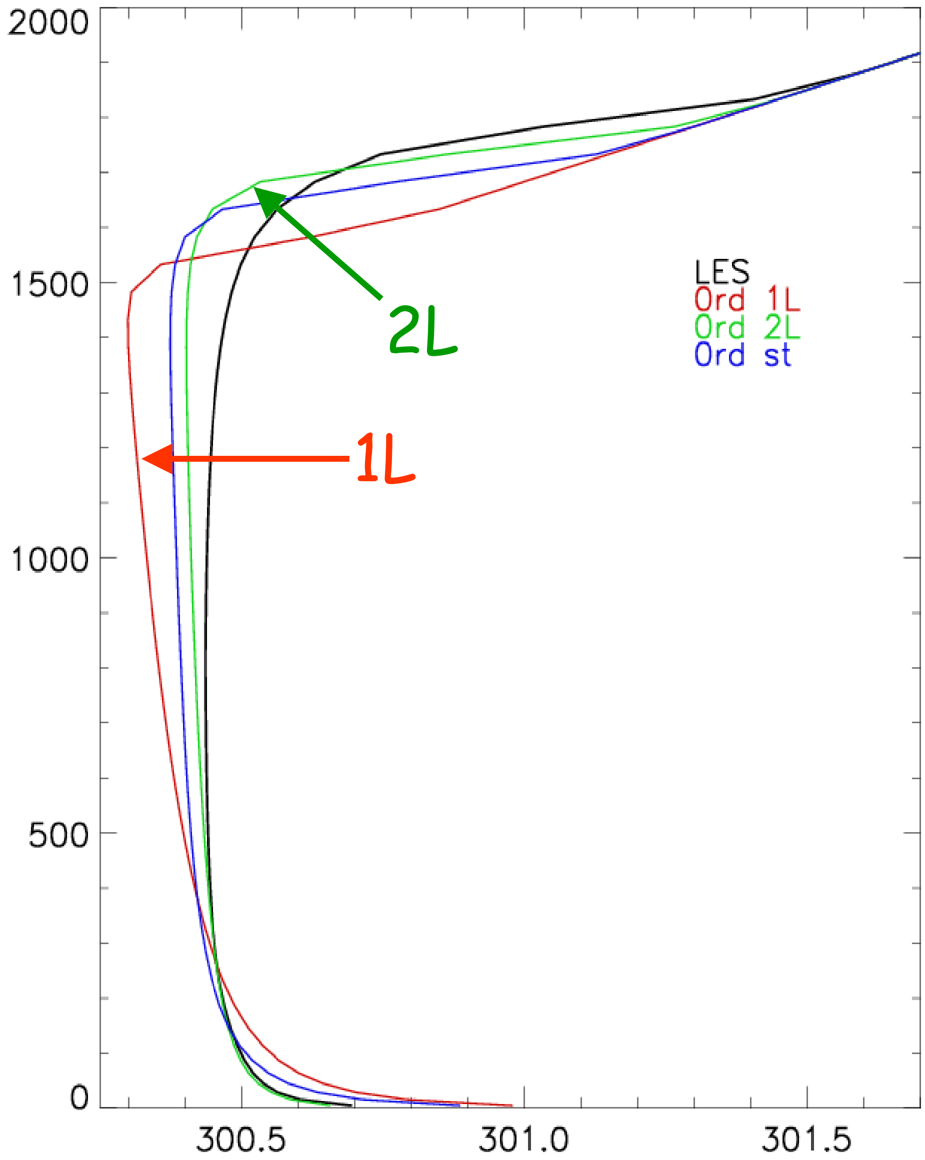
✓Tuning of turbulent exchange coefficient :

$$\overline{w'e'} = -l\sqrt{e}C_{TKE}\frac{\partial e}{\partial z}, \quad C_{TKE} = 0.2 \; or \; 0.4$$

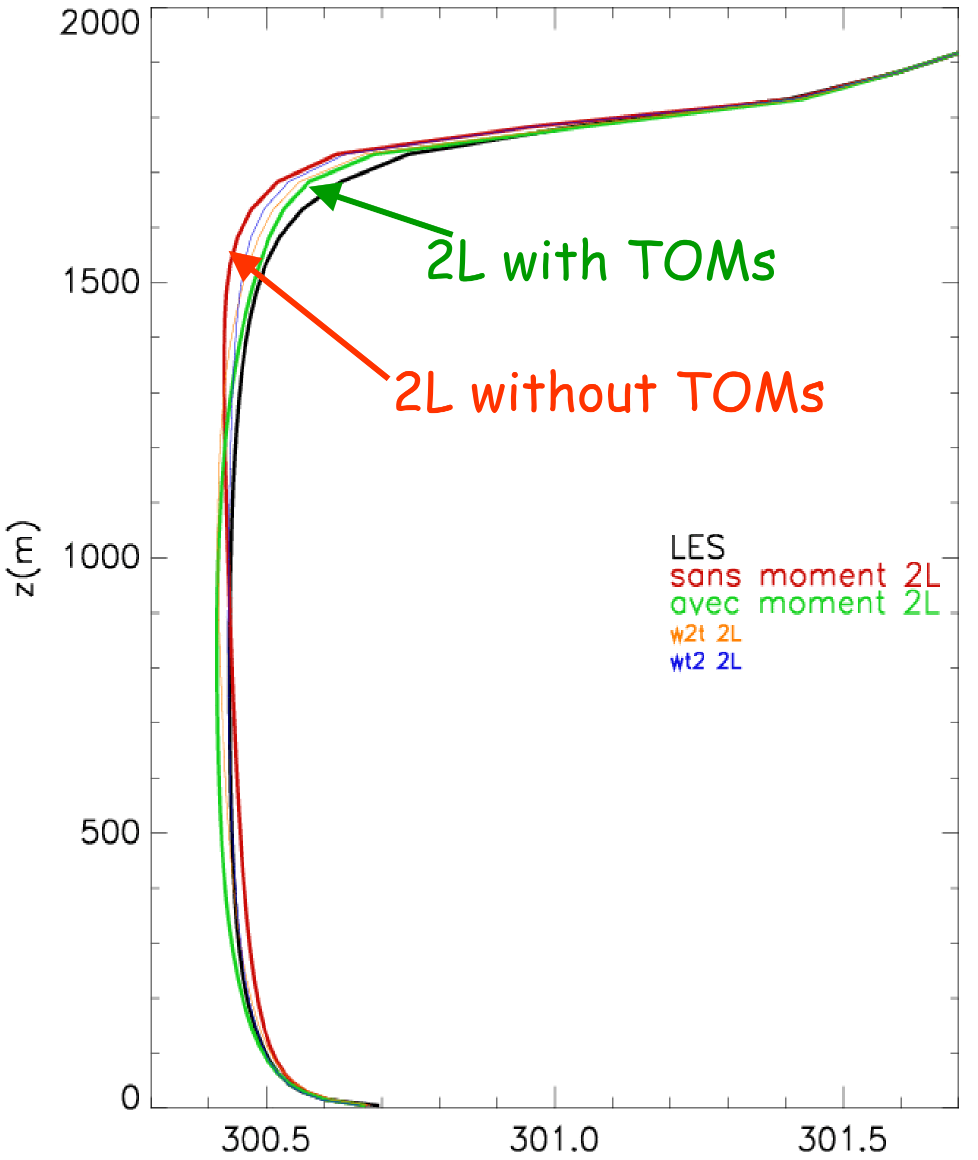
Dry CBL

1. Countergradient with Third order moments

On L



On the TOMs



Dry CBL

1. Countergradient with Third order moments

With the eddy-diffusivity, these TOM are neglected in the budget of variance and flux of θ :

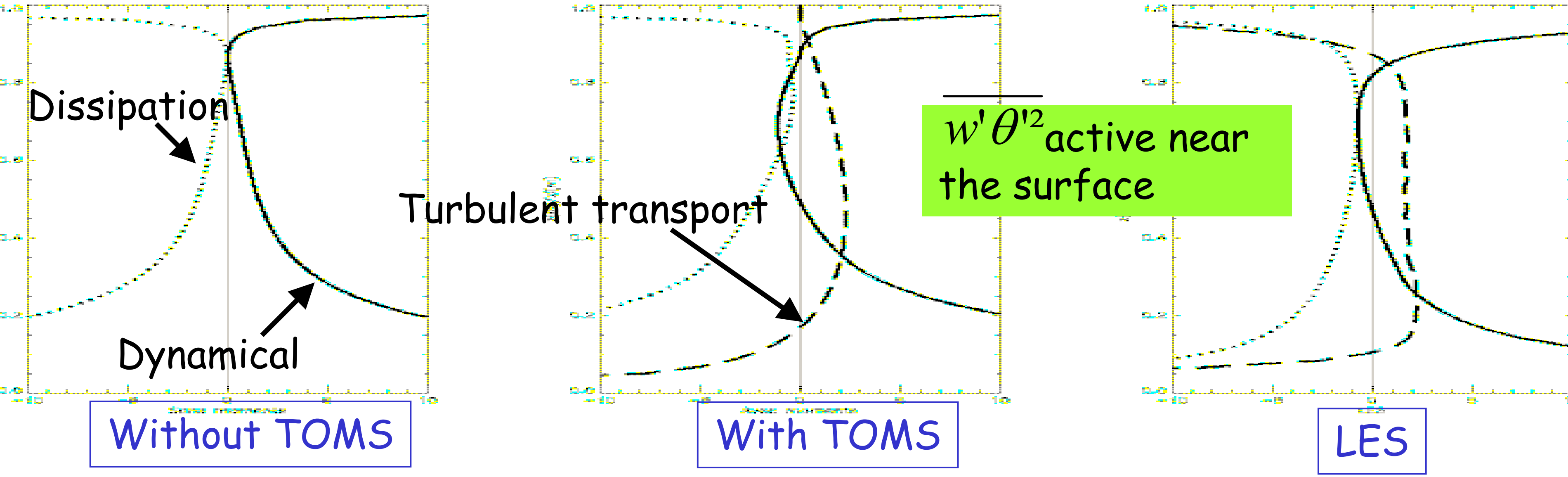
$$\frac{\partial}{\partial t}\left(\overline{w'\theta'}\right) = \underbrace{-W\frac{\partial \overline{w'\theta}}{\partial z}}_{Advection} \underbrace{-\frac{\partial \overline{w'^2\theta'}}{\partial z}}_{TOM} - \underbrace{\overline{w'\theta'}\frac{\partial W}{\partial z}}_{Dynamical\ production} \underbrace{-\overline{w'\theta'}\frac{\partial \theta}{\partial z} + \beta\overline{\theta'\theta_v'}}_{Buoyancy} - \underbrace{P_\theta}_{\Pr esso}$$

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

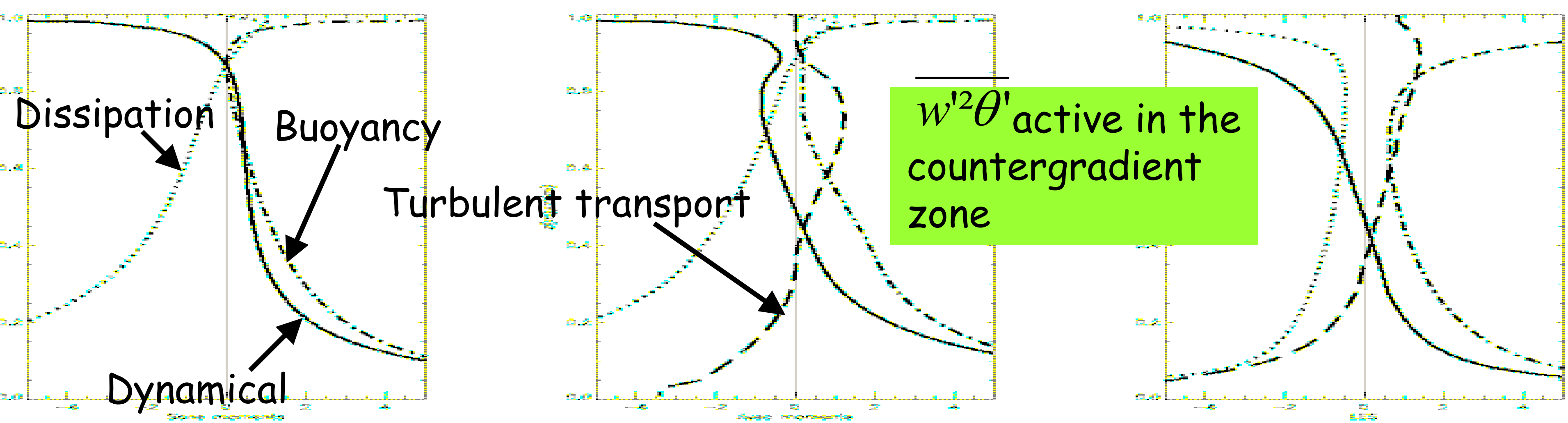
Transport (the TOM terms)

Budget of $\overline{\theta'^2}$

REFERENCE



Budget of $\overline{w'\theta'}$

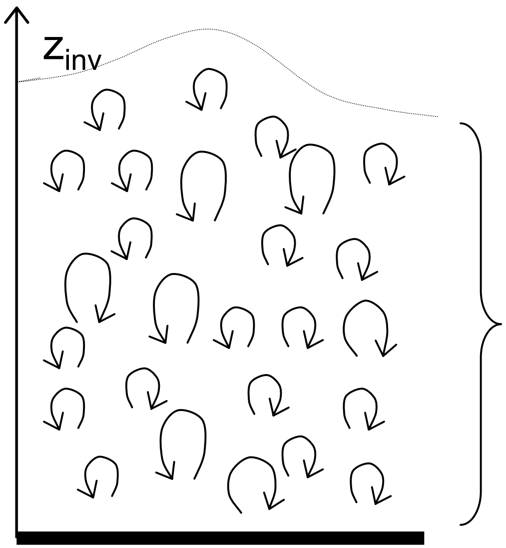


CBL

2. Eddy-diffusivity/Mass-flux (EDMF)

$$\frac{\partial \overline{\phi}}{\partial t} \cong -\frac{\partial}{\partial z}\left(\overline{w'\phi'}\right) + \overline{S}$$

$$\overline{w'\phi'} \cong -K\frac{\partial \overline{\phi}}{\partial z} + M(\phi_u - \overline{\phi})$$

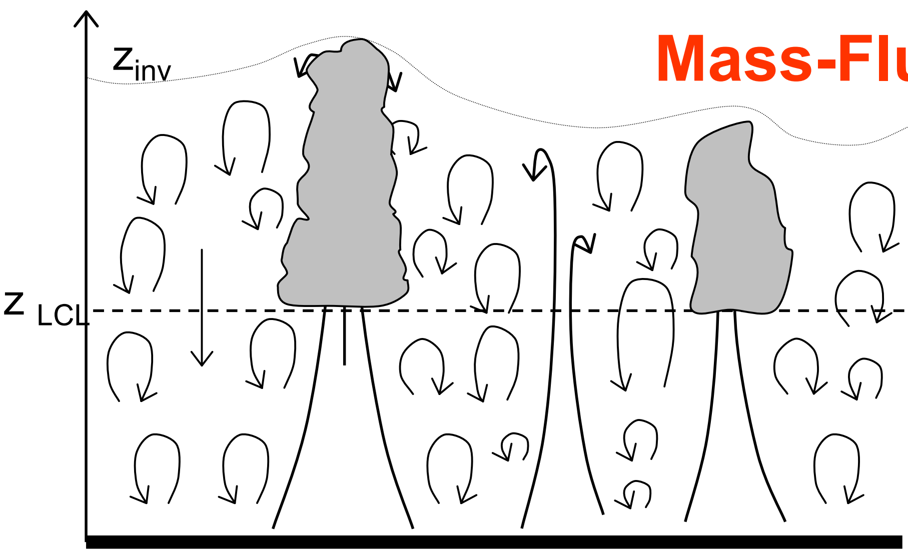


Eddy-Diffusivity (ED) : CBR scheme

$$\overline{w'\phi'} \cong -K\frac{\partial \overline{\phi}}{\partial z}$$

ED represents mixing of the mean profile

Mass-Flux (MF)



$$\overline{w'\phi'} \cong M(\phi_u - \overline{\phi})$$

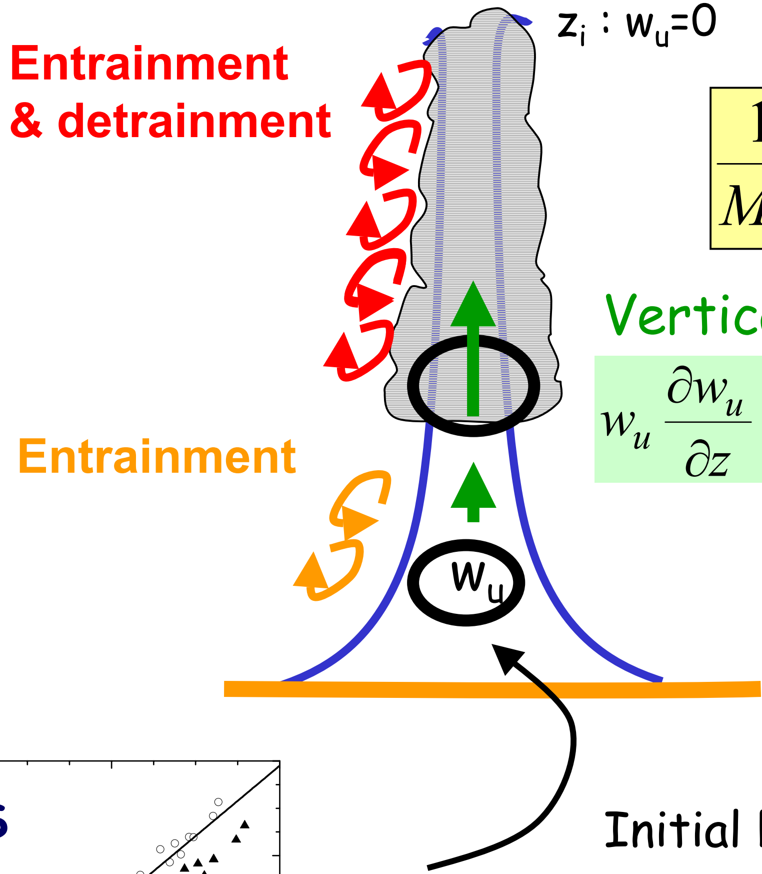
MF represents the interaction between the strong thermals and the mean environment

Soares et al., 2004

CBL

2. Eddy-diffusivity/Mass-flux (EDMF)

Ascending parcel
$$\frac{\partial \theta_{lu}}{\partial z} = -\varepsilon\left(\theta_{lu} - \overline{\theta}_l\right)$$



Cloud

$$\frac{1}{M_c}\frac{\partial M_c}{\partial z} = \varepsilon - \delta$$

$$\varepsilon = 2\times 10^{-3}\, m^{-1};$$
$$\delta = 2.7\times 10^{-3}\, m^{-1}$$

Vertical speed (Simpson and Wiggert)

$$w_u \frac{\partial w_u}{\partial z} = -b\varepsilon w_u{}^2 + aB$$

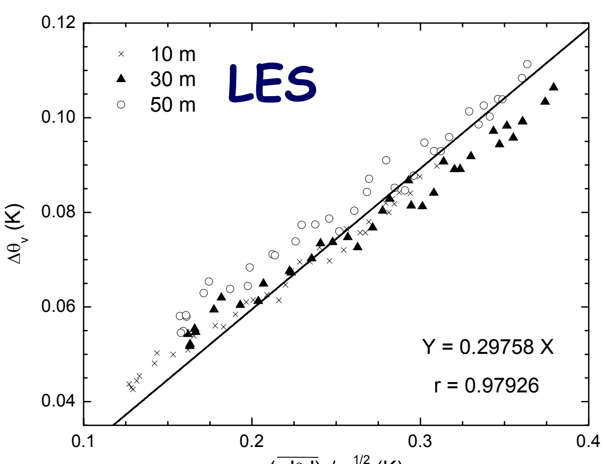
Sub-cloud

$$M = a_u w_u$$

$$\varepsilon = c_\varepsilon\left(\frac{1}{z} + \frac{1}{z_i - z}\right)$$

Initial buoyancy

$$\Delta\theta_v(z_i) = b\frac{\overline{w'\theta'_v}_s}{e^{1/2}(z_i)}$$



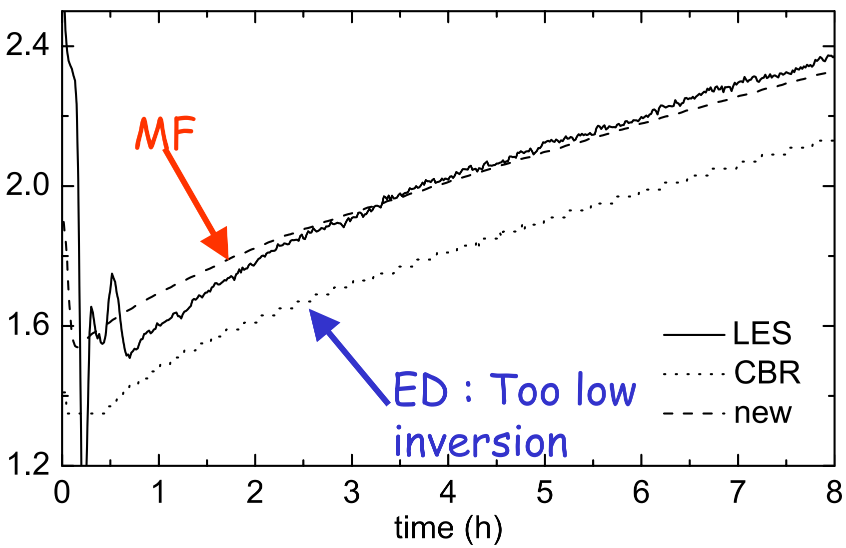
Soares et al., 2004

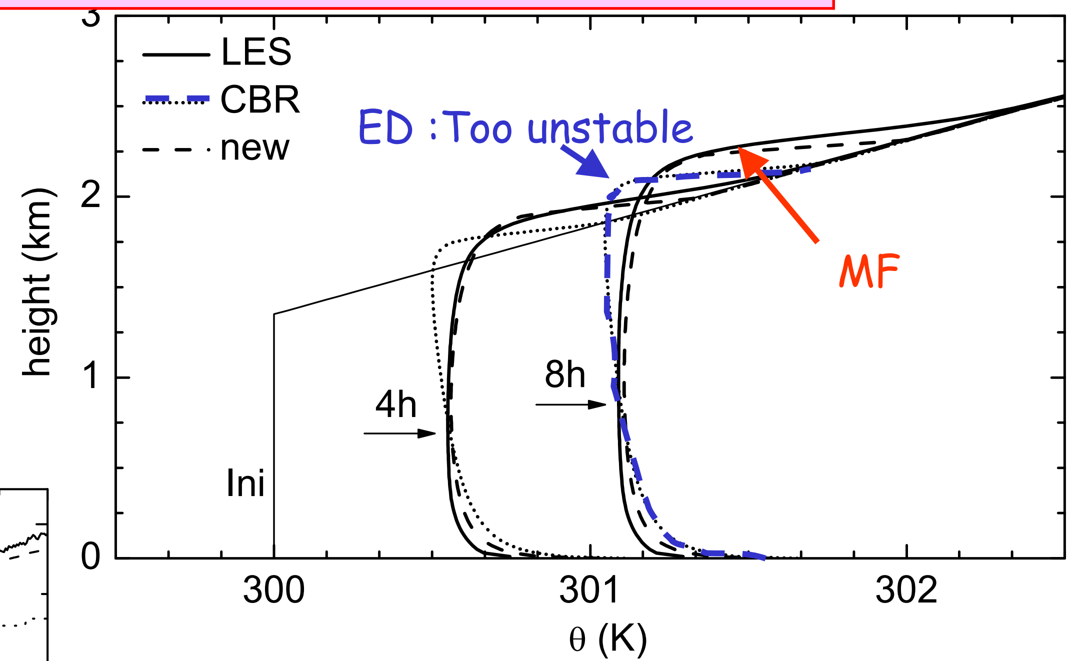
Dry CBL

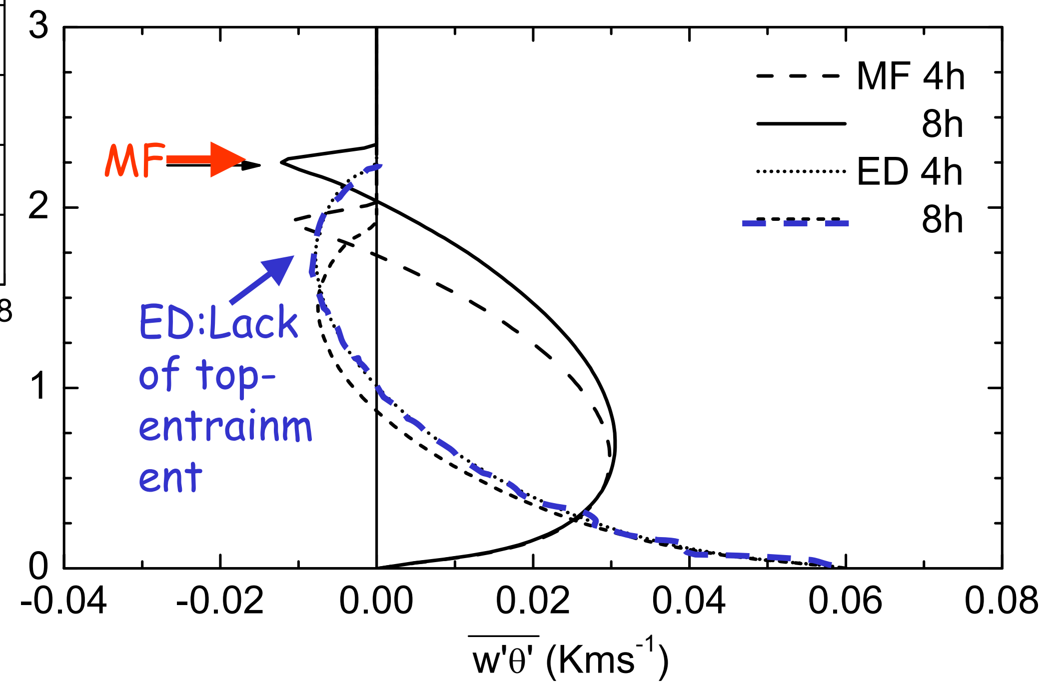
EDMF - Nieuwstadt *et al.* (1992)

Meso-NH 1D : Comparison
ED/EDMF

BL Height







Positive impact EDMF vs ED

Soares et al., 2004

Dry CBL

EDMF versus COUNTERGRADIENT

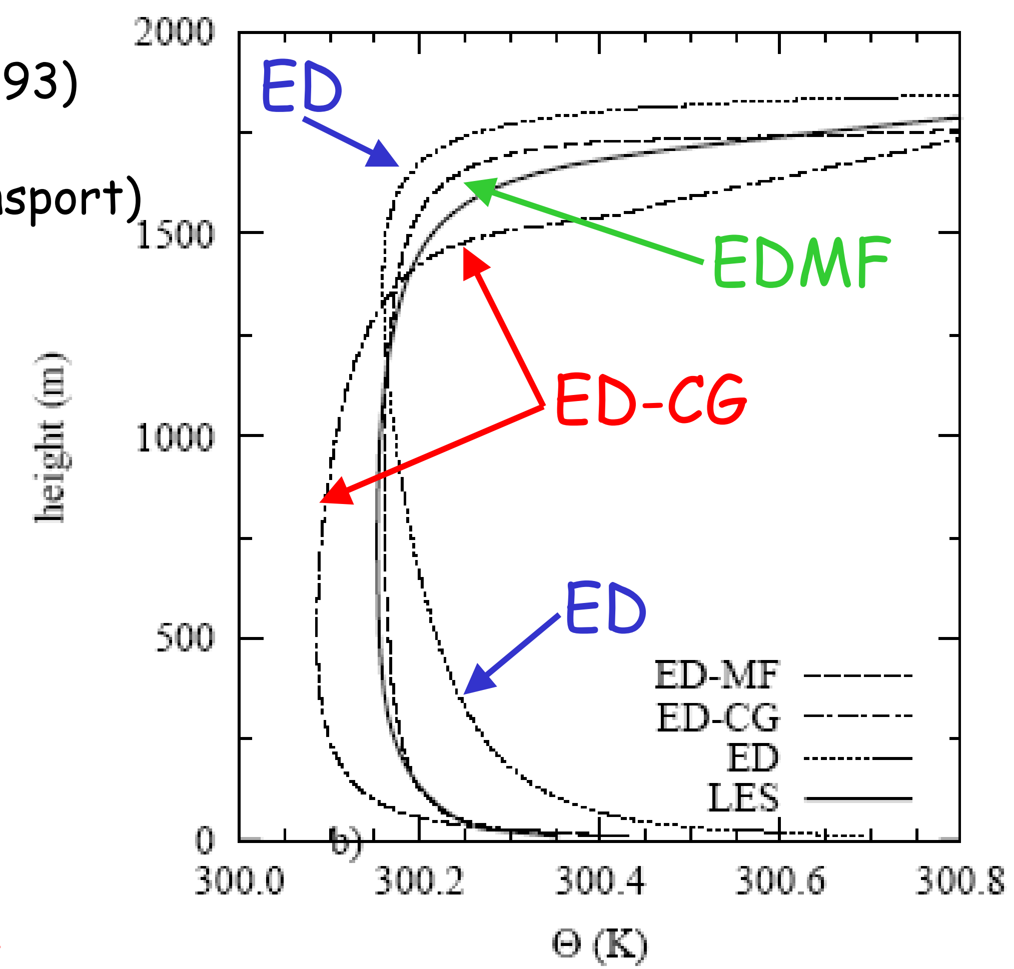
Siebesma et al., 2005

Comparison on Nieuwstadt et al. (1993)

1. Eddy-diffusivity (non-local transport)
2. EDMF
3. ED-CG : $\overline{w'\theta'} = -K\left(\frac{\partial\theta}{\partial z} - \gamma\right)$

with $\gamma = a\frac{w*}{\sigma_w^2 z*}\overline{w'\theta'}*$

(Cuijpers and Holtslag, 1998)



Main limitation of ED-CG :
Inhibition of the top-entrainment

Dry CBL

For AROME in 2006

1. TOMs on heat momentum fitted on LES already implemented in Meso-NH → evaluation of the impact for AROME on CBL (needs of evaluation on test cases, impact on unreal rolls ?)

2. EDMF scheme : evaluation of the impact in Meso-NH during the 1st sem.2006 (In collaboration with P.Soares)

3. Comparison EDMF/TOMS on the same cases

Under development in Meso-NH (2006-2008)

1. Improvement of EDMF scheme : entrainment, extension to momentum transport (In collaboration with P.Soares in 2006)

2. Parametrization of TOMs with an entraining plume used to find the mass-flux.

3. Improvement of the BL89 mixing length in the same way (V.Masson)

PLAN

Inventory, Ways of improvement and Plan for:

1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus

7. Chemistry

BL clouds : Cu

What we know :

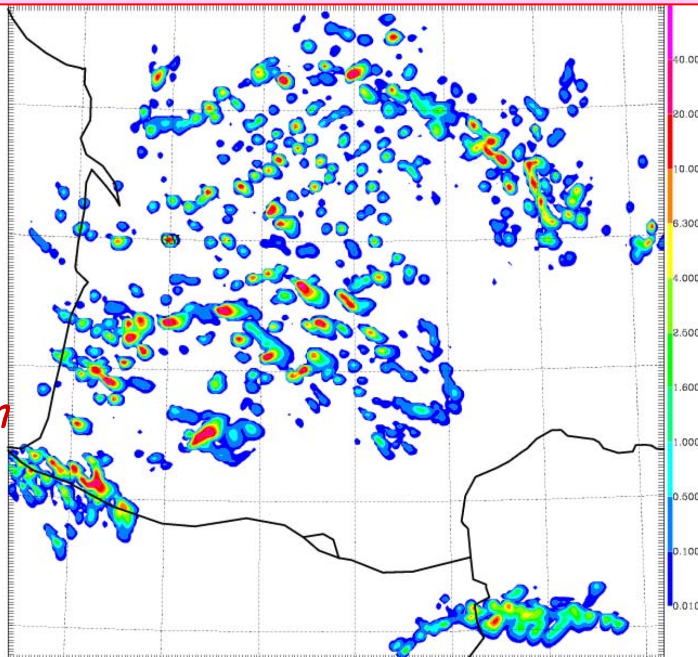
1. The turbulent CBR scheme is insufficient to produce clouds in the BL $\rightarrow$ a mass-flux approach is necessary

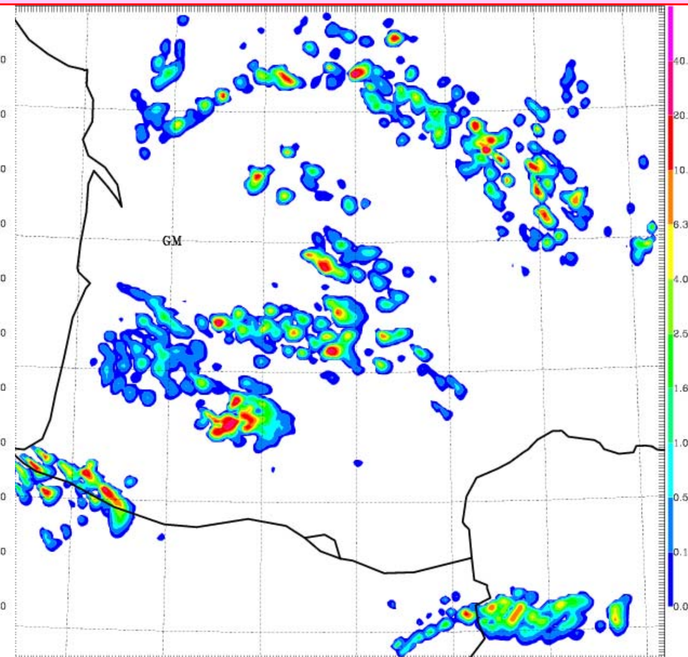
2. KFB scheme treats shallow convection but the closure assumption (to control the intensity of convection), based on the removal of the CAPE during an adjustment period (3h by default), is limited.

3. SG condensation scheme : Necessity to combine mass flux with the statistical diffusion scheme

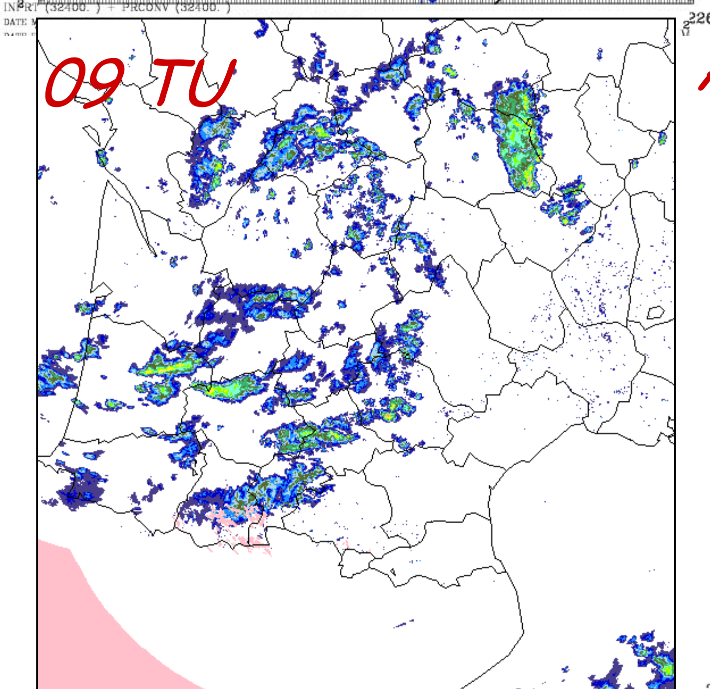
Example of AROME run on 2005/08/20

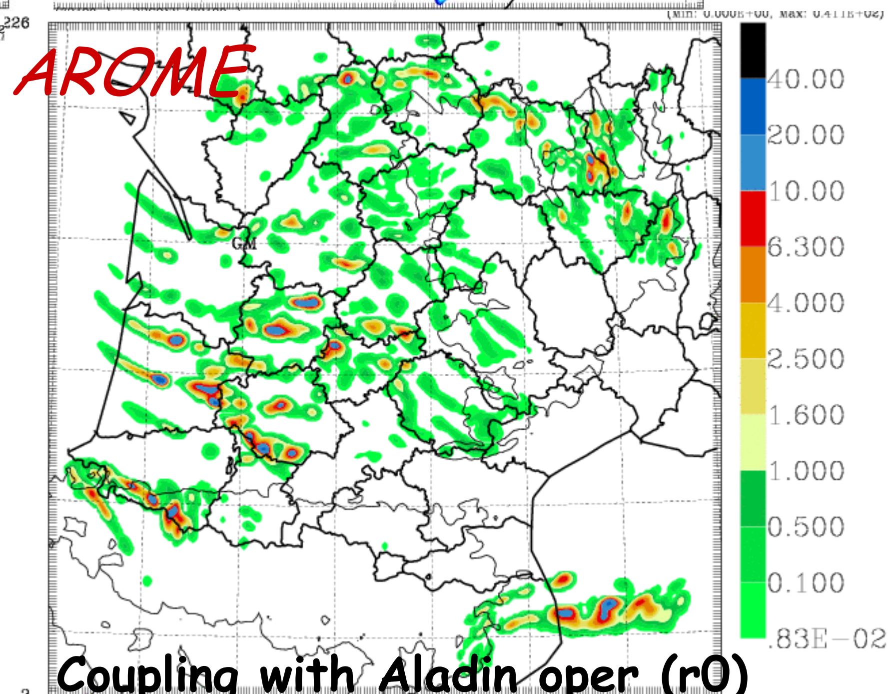
Meso-NH with SUBGRID COND + SHALLOW : *Adjustment time of 3h in the closure*



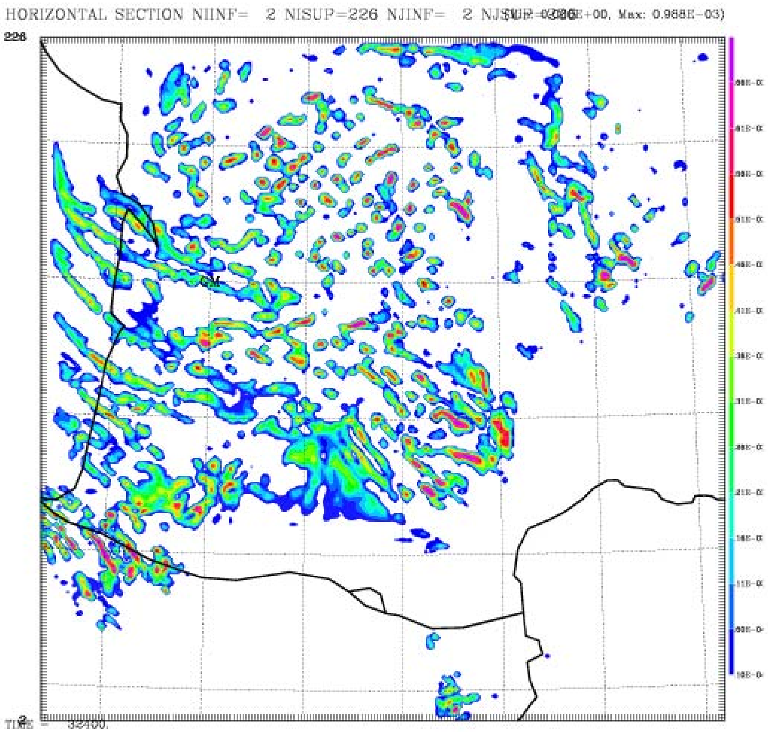


Meso-NH with SUBGRID COND + SHALLOW 30min : *Adjustment time of 30min*

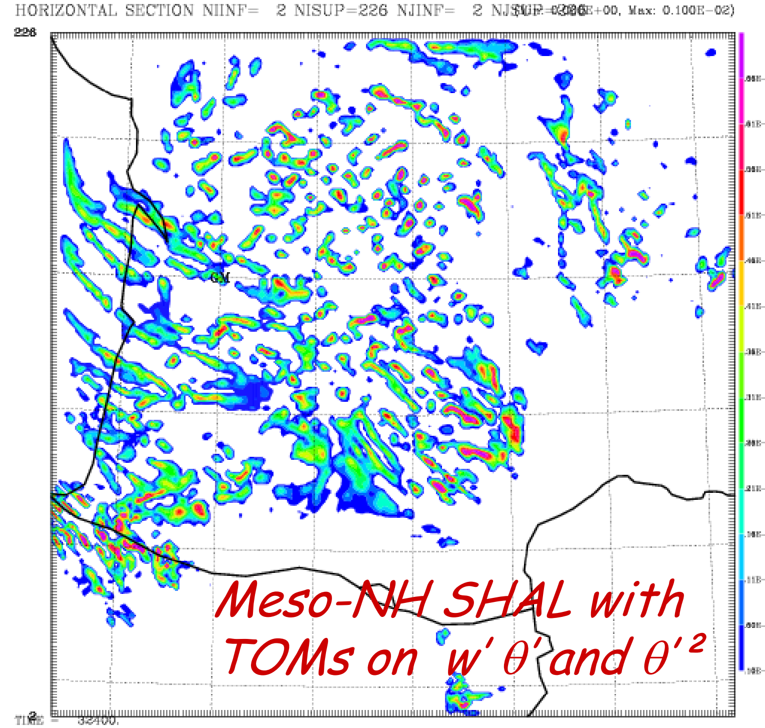




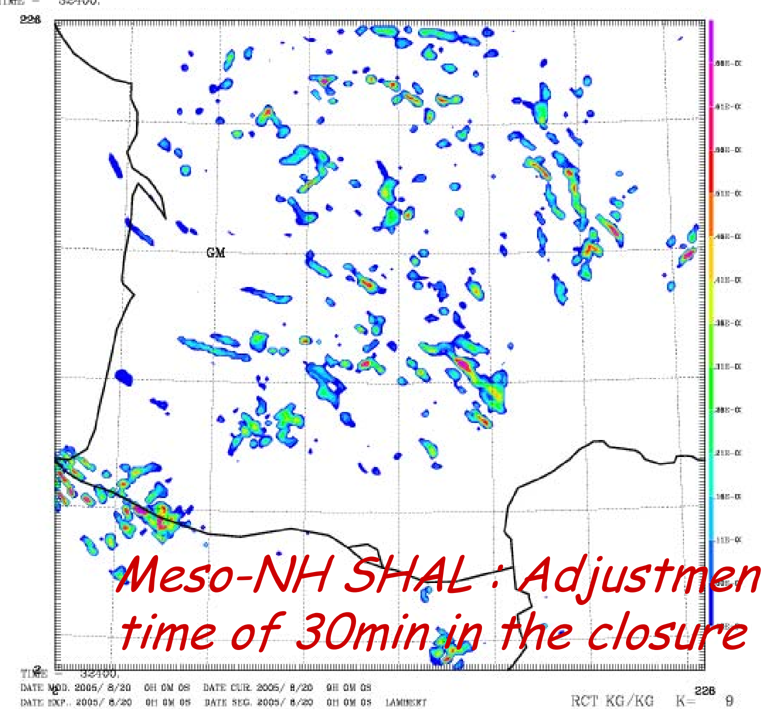
9H Cloud mixing ratio at z=800m



Meso-NH SHALLOW : Adjustment time of 3h in the closure



Meso-NH SHAL with TOMs on $\overline{w'\theta'}$ and $\overline{\theta'^2}$



Meso-NH SHAL : Adjustment time of 30min in the closure

BL clouds : Cu

For AROME in 2006

January 2006 : New runs AROME on a 2 week past period

1. Removal of KFB closure assumption by W_{LCL}=W* (from turbulent scheme) : Mass flux is not modified in the closure to remove the CAPE. Good results in 1D on BOMEX and ARM (Examples Sylvie).

2. SG condensation scheme combining mass flux with the statistical diffusion scheme

   - 1st test : (Lenderink and Holstslag, 2004)

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

$$\overline{\theta'_l{}^2} = (\overline{\theta'_l{}^2})_{TURB} + (\overline{\theta'_l{}^2})_{CONV}$$

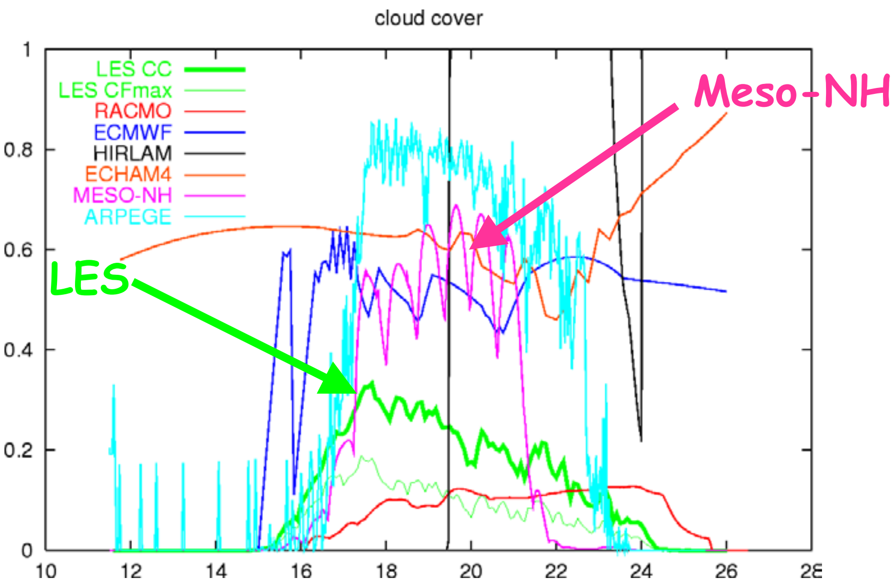
$$(\overline{r'_w{}^2})_{CONV} = -\frac{M(r_{w_{UP}} - r_w) l_{Cu}}{W_{Cu}} \frac{\partial r_w}{\partial z}$$

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

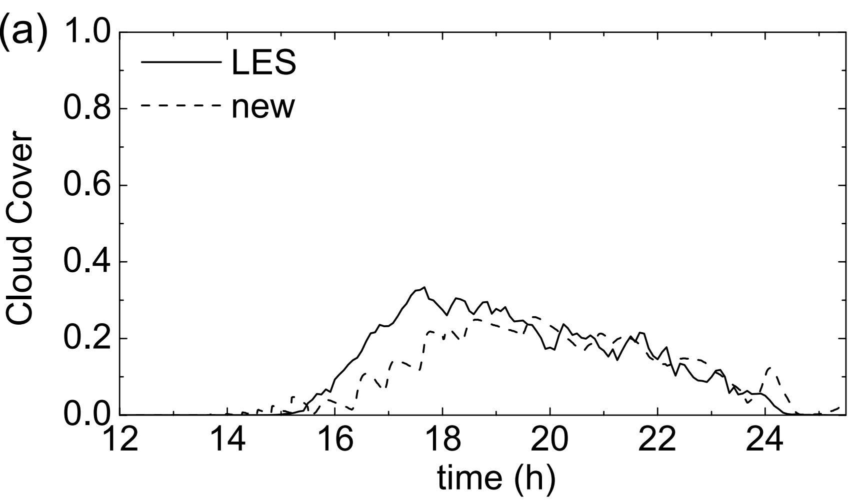
   - 2nd test : Calculate a convective cloud fraction in KFB

3. Test of EDMF Soares scheme in Meso-NH (Beginning 2006)

Shallow Cu BL – ARM : Test of EDMF (old version of Meso-NH)



Meso-NH with CBR+ KFB schemes + turbulent SG condensation :
Too large cloud cover and too small cloud liquid water

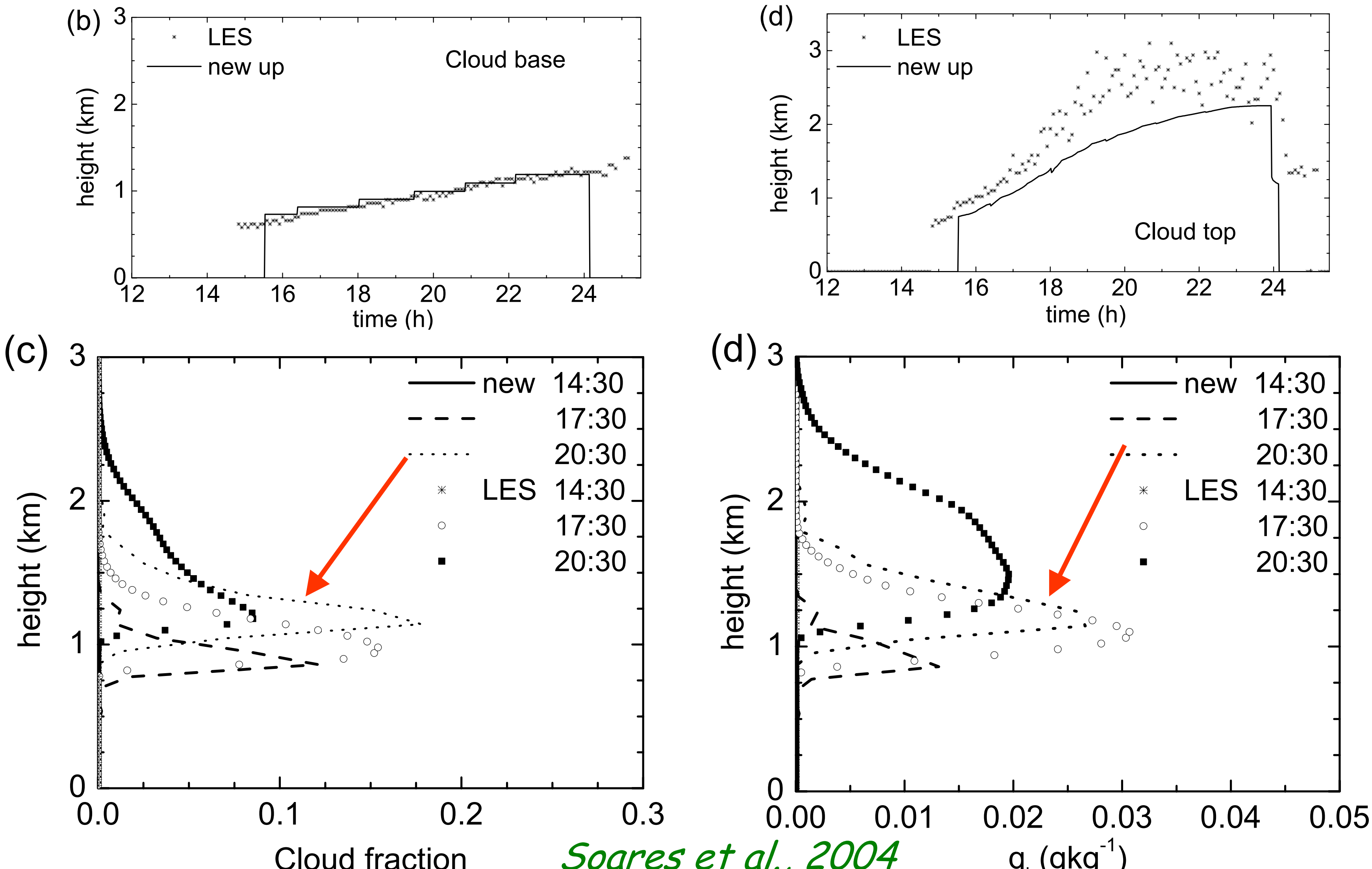


Meso-NH with EDMF scheme (CBR+MF) and (turbulent+MF) SG condensation : *mainly due to a better estimate of the variance*

Soares et al., 2004

Shallow Cu BL – ARM : Diurnal cycle of cumulus cloud over land

Good representation of the sub-cloud layer but insufficient transport into the cloud layer



Soares et al., 2004

PLAN

Inventory, Ways of improvement and Plan for:

1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus

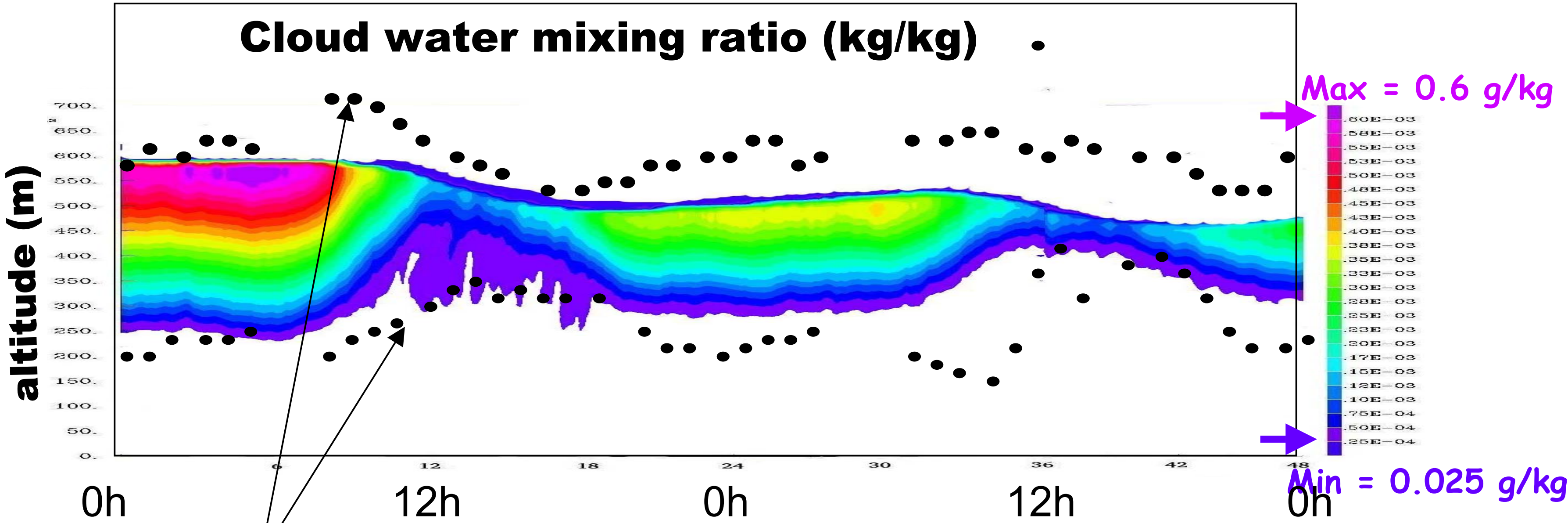
7. Chemistry

Stratocumulus : Capped BL

Beneath strong capping inversions in regions of LS subsidence

FIRE 1 case of EUROCS : Forcing terms : a LS subsidence + cooling ($d\theta_l/dt<0$) and moistening ($dq_t/dt>0$) under the inversion to balance the subsidence

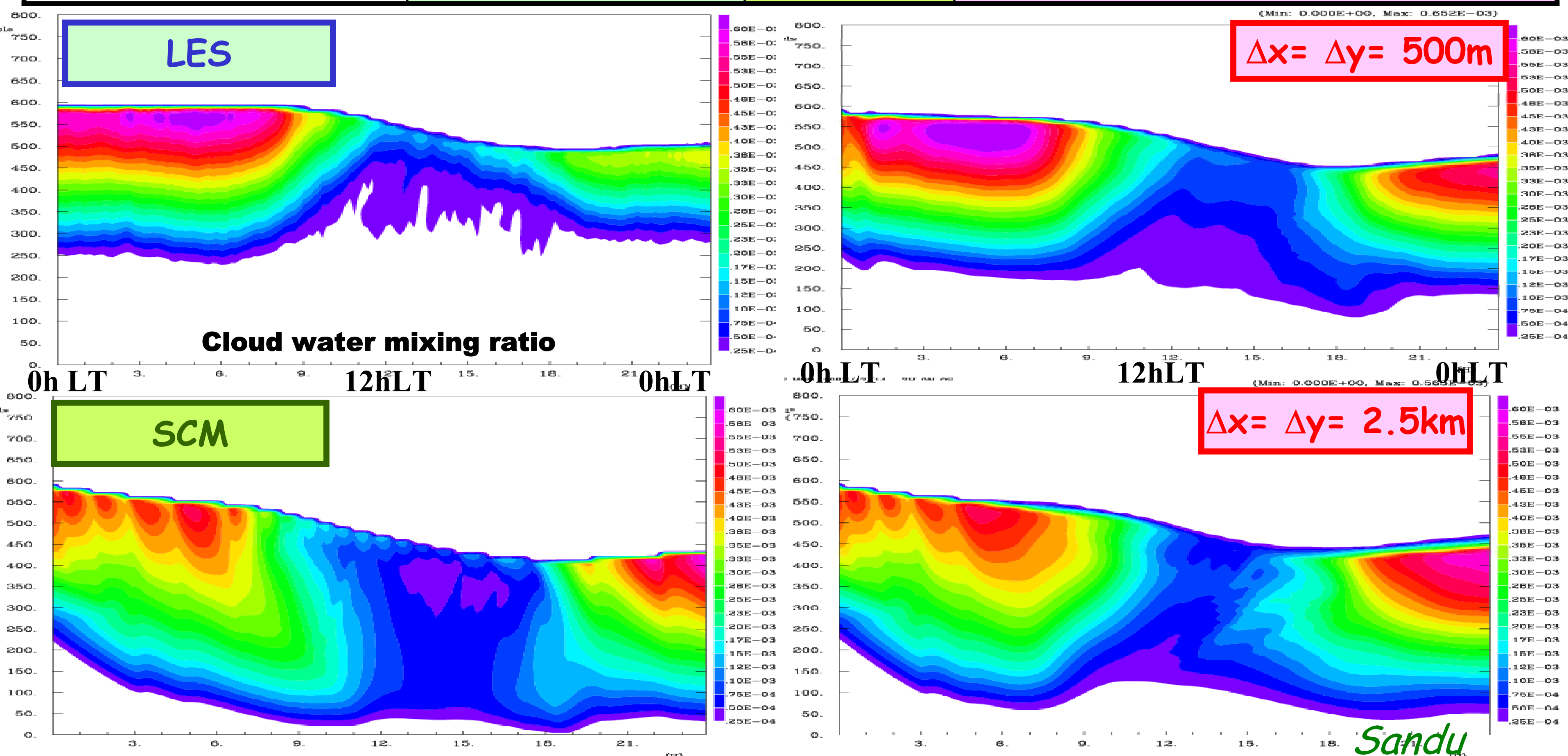
First : LES simulation of the diurnal cycle (Δx=50m)



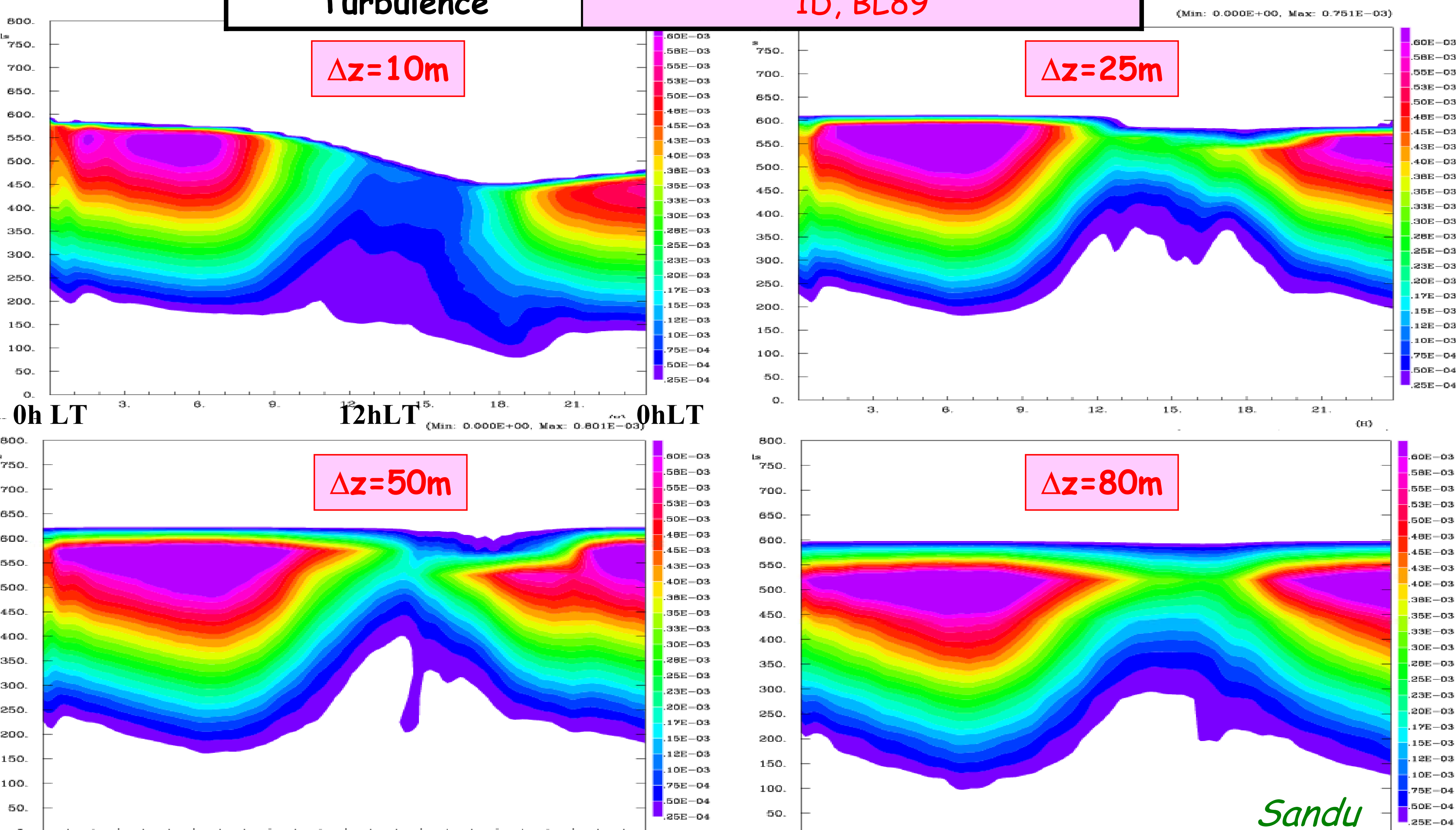
Sandu et al., 2006

Stratocumulus : What's about the resolutions of AROME ?

	LES (3D)	SCM (1D)	Meso-scale simulation
Horizontal resolution	Δx= Δy= 50m (50pts X 50pts)		1. Δx= Δy= 500m (40pts X 40pts) 2. Δx= Δy= 2.5km (20pts X 20pts)
Time step	Δt=1s	Δt=5s	Δt=5s
Vertical resolution	Δz=10m	Δz=10m	Δz=10m
Turbulence	3D, L= Deardorff	1D, BL89	1D, BL89



	Meso-scale simulation
Horizontal resolution	$\Delta x = \Delta y =$ 500m (40pts X 40pts)
Time step	Δt=5s
Vertical resolution	Δz=10m, Δz=25m, Δz=50m, Δz=80m
Turbulence	1D, BL89

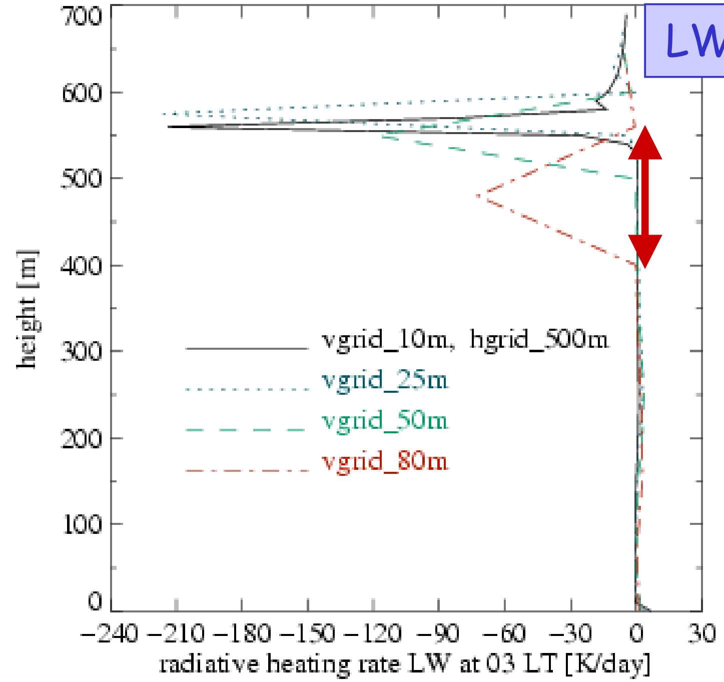


Radiative heating rate (K/day)

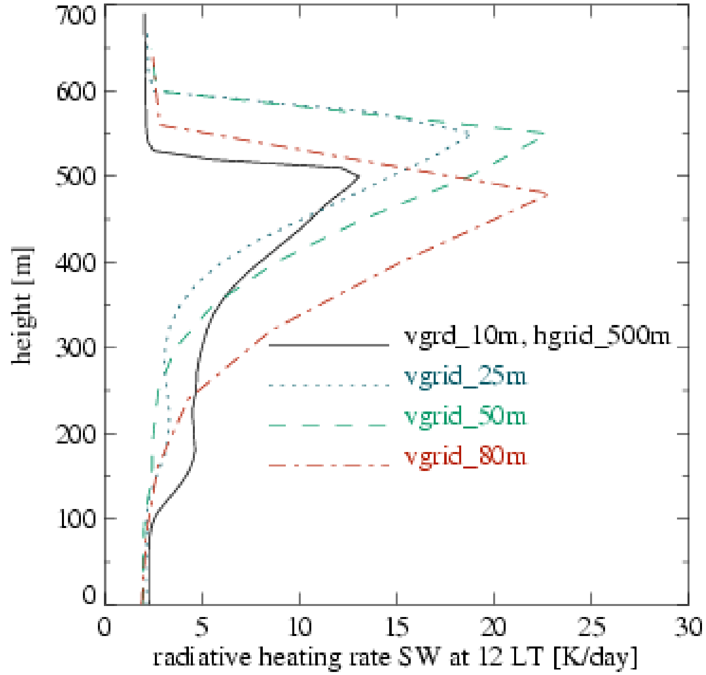
Δx= Δy= 500m

Insufficient resolution of the radiative cooling in the vicinity of the cloud top → systematic biases in estimates of entrainment.

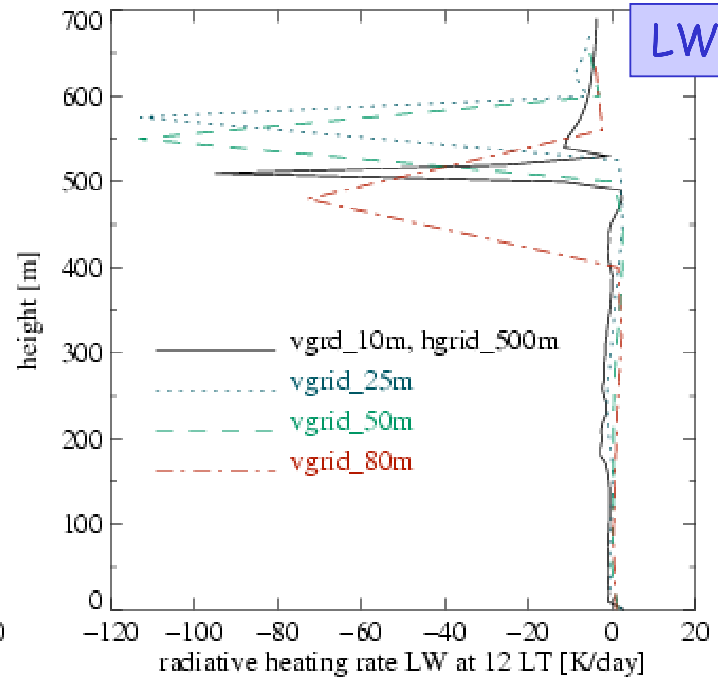
LW 3h LT (K/day)



SW 12h LT (K/day)

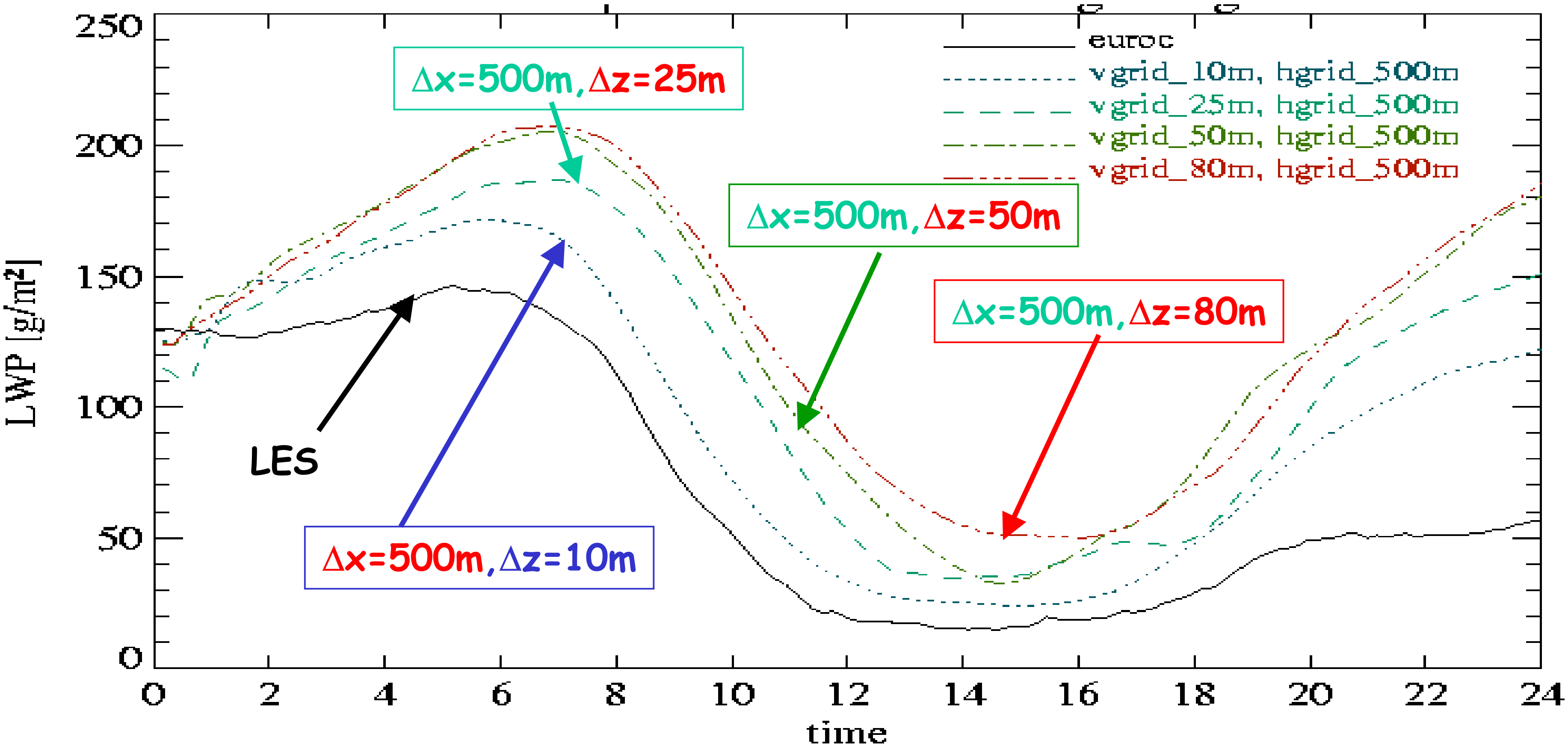


LW 12h LT (K/day)



BL clouds : Sc

Liquid Water Path



I. Sandu

BL clouds : Sc

Preliminary tests in Meso-NH at the resolutions of AROME

1. Diurnal cycle of Sc is maintained.
2. LWC more sensitive to lower Δz than lower Δx
3. Main impact of lower Δz at the top of Sc (entrainment) than beneath

Further tests of Sc with AROME

1. Preliminary tests with AROME : Influence of Δt and advection (Lenderink and Holstlag, 2000)
2. Sensitivity tests on vertical resolution for cloud-top entrainment$\rightarrow$Additional levels to L41?
   Interest of an entrainment parametrization (Lock, 2001, 2004. ARPEGE-Climat).
3. Tests on the microphysics scheme, in comparison with 2-moment scheme (Cohard and Pinty, 2000; Khairoudinov and Kogan, 2003). Influence of drizzle.
4. Impact of climatology of aerosols.

BL clouds : Sc

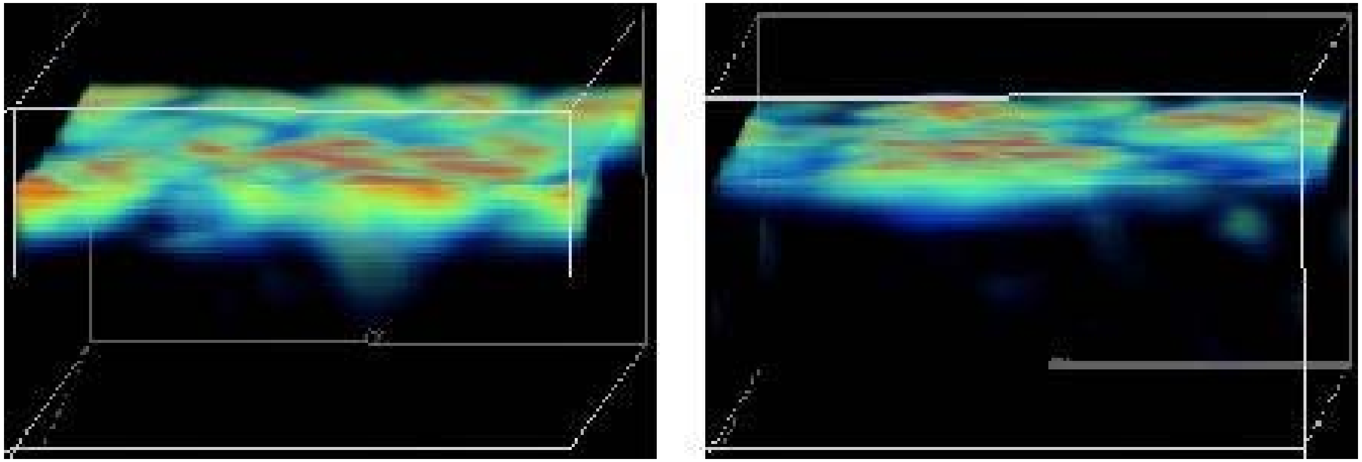
Influence of aerosol on SW . Aerosol climatology

Sc mostly controlled by absorption of SW by cloud droplets
→ Precise diagnostic of the cloud droplet single scattering albedo (SSA)

Fouquart et al., 1986 : Strong fraction of Black Carbon, not representative of marine clouds → Overestimation of absorption for marine cases

New parametrization of Chuang et al. (2002) with SSA containing BC inclusions for different types of aerosols : improvement in Meso-NH (Sandu et al., 2005) with a 2-moment $\mu\pi$ scheme

Sandu et al., 2005 **11 UTC** *Fouquart et al., 1986*



Included in SURFEX 1.1

PLAN

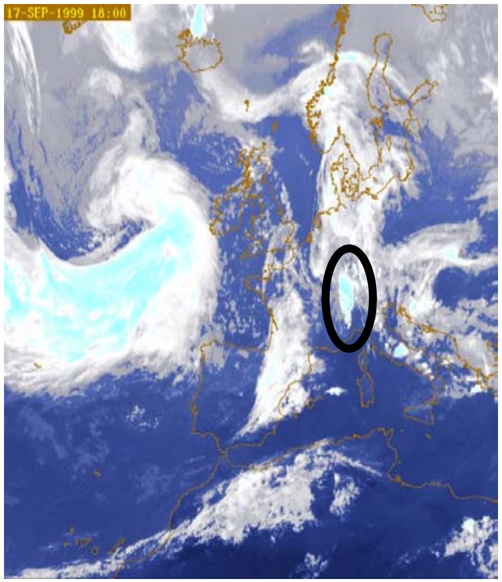
Inventory, Ways of improvement and Plan for:

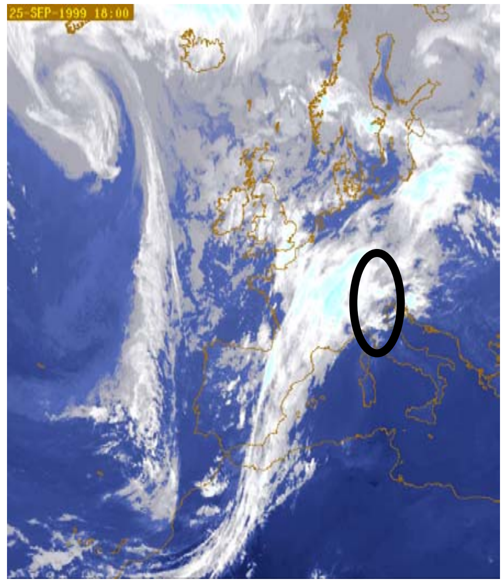
1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus

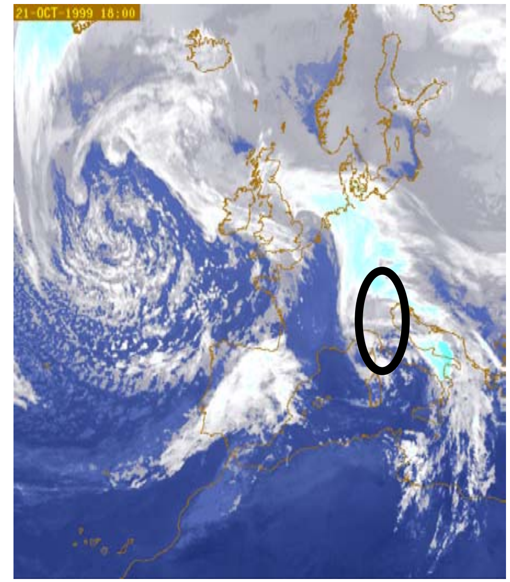
7. Chemistry

Deep clouds

Three contrasted MAP cases







IOP 2A

Strong Convection

IOP 3

Moderate Convection

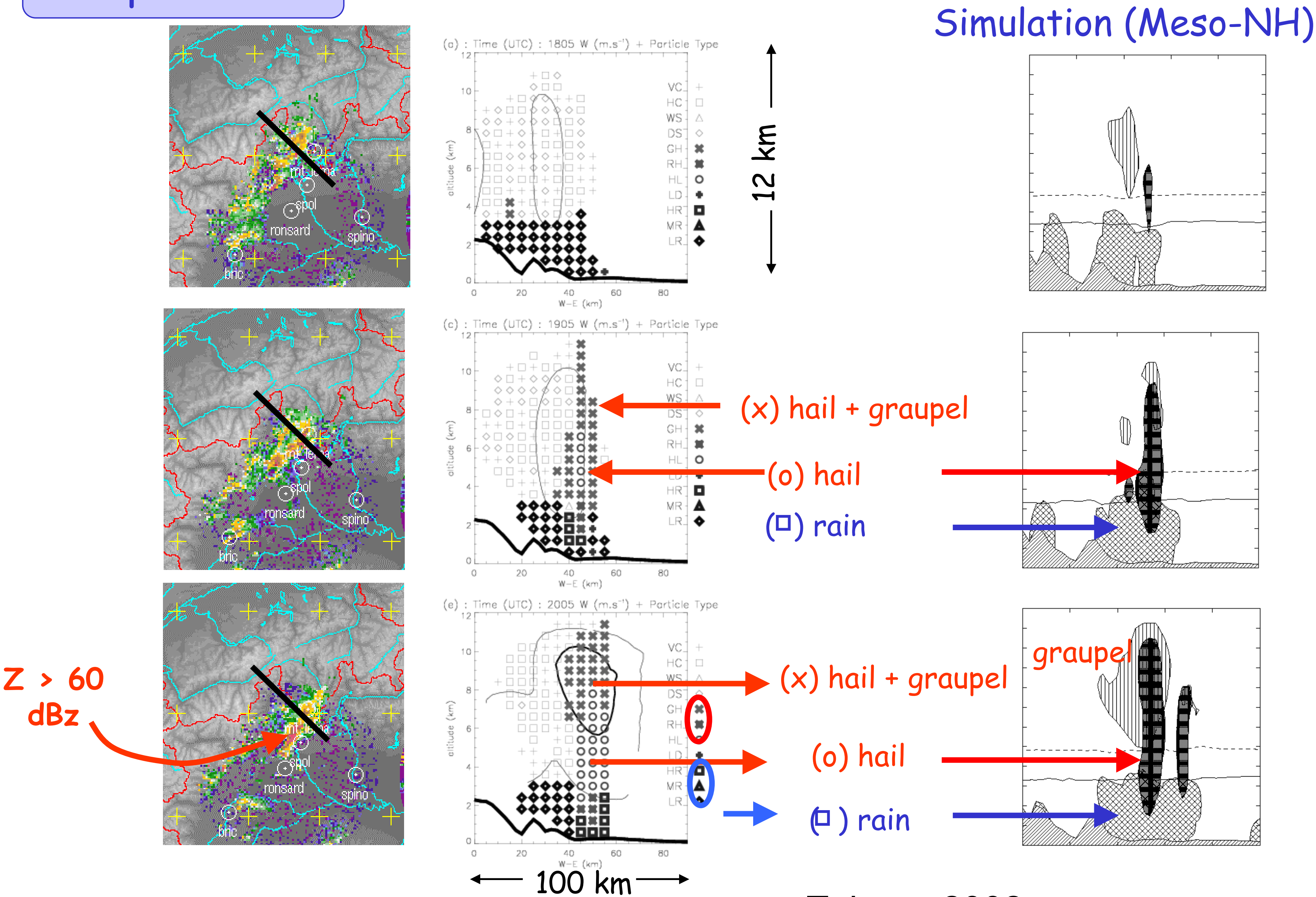
IOP 8

Stratiform rain

Lascaux and Richard, 2006

Deep clouds

Microphysical retrievals : IOP 2A (intense convection)

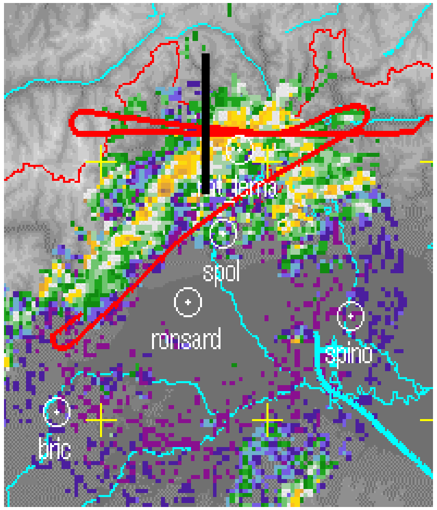


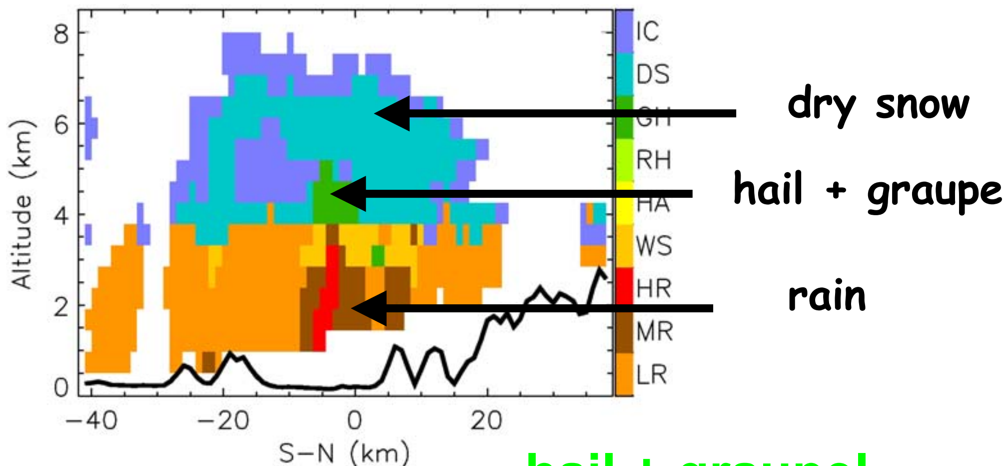
Tabary, 2002

Deep clouds

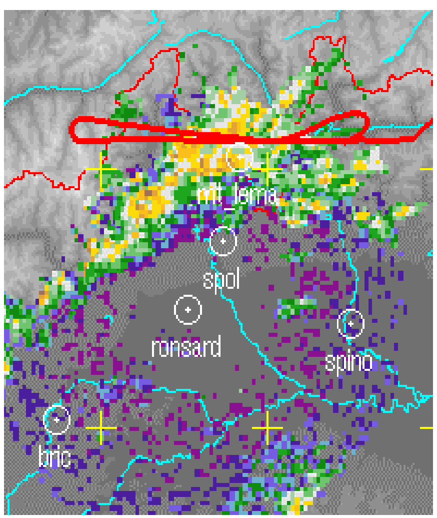
Microphysical retrievals : IOP 3 (moderate convection)

18:10 UT

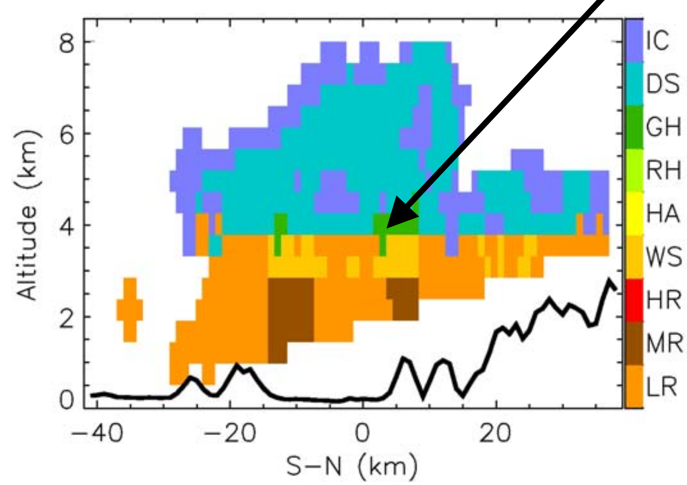


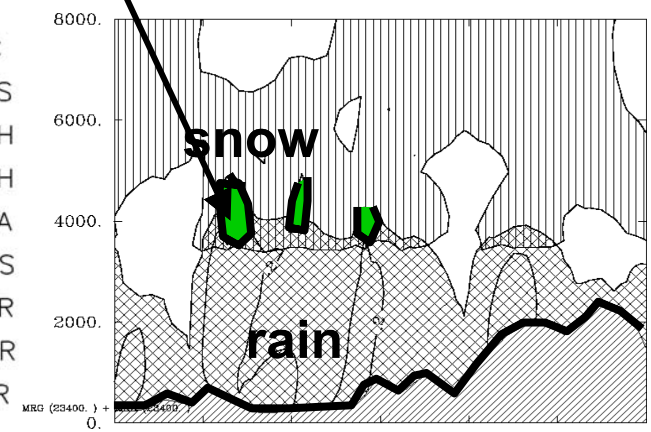


18:30 UT



hail + graupel





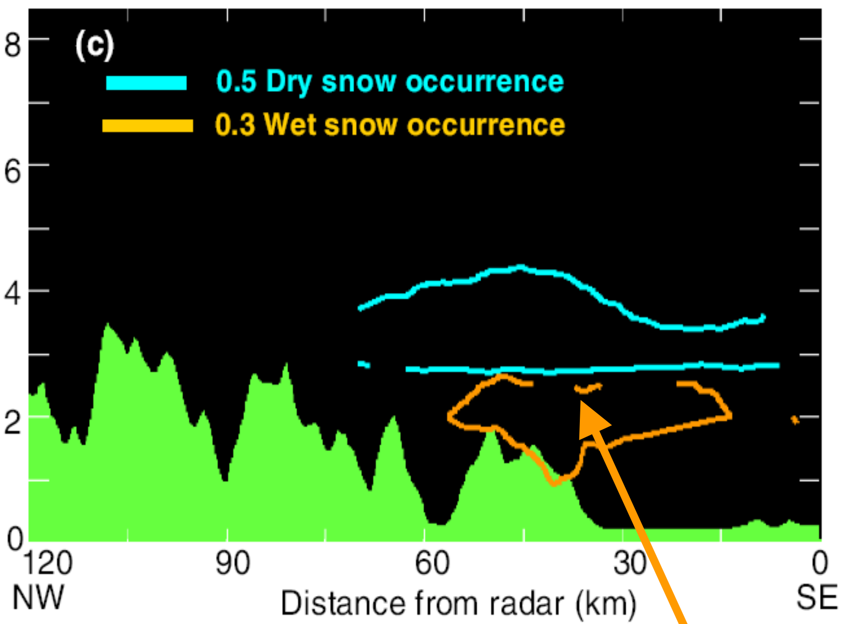
Meso-NH simulation

Pujol et al., 2005

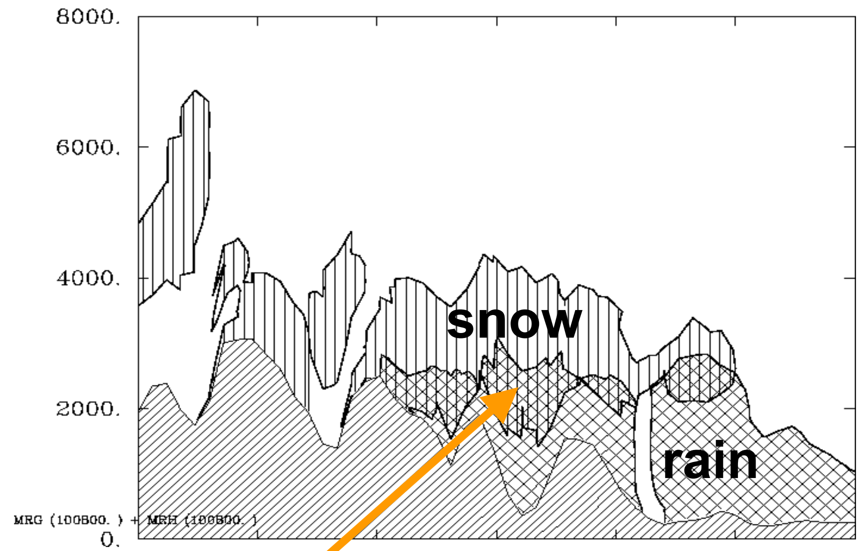
Deep clouds

Microphysical retrievals : IOP 8 (stratiform)

S-Pol retrieval



Meso-NH simulation



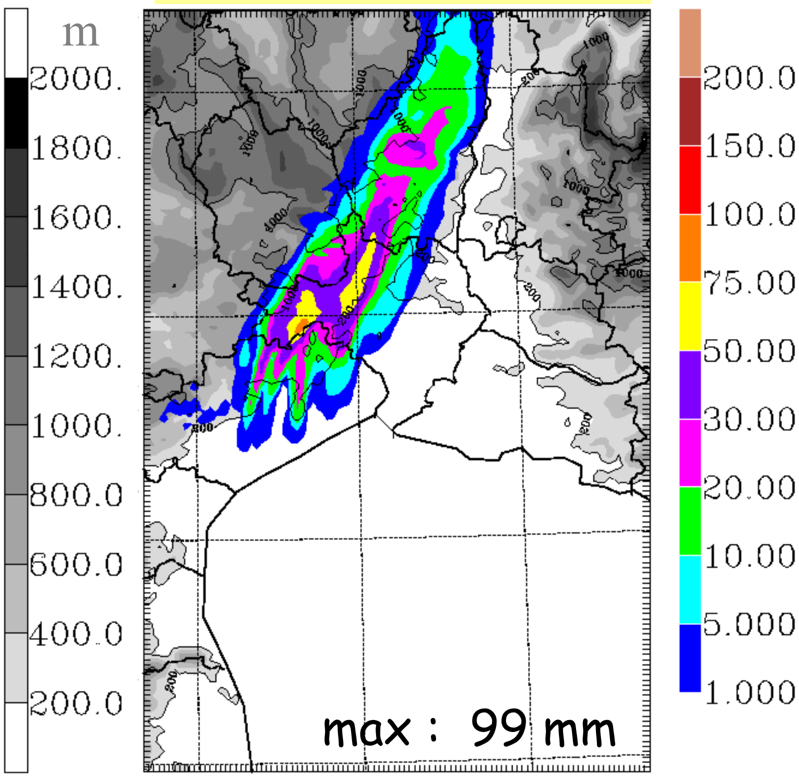
melting snow

Medina et Houze, 2003

Deep clouds

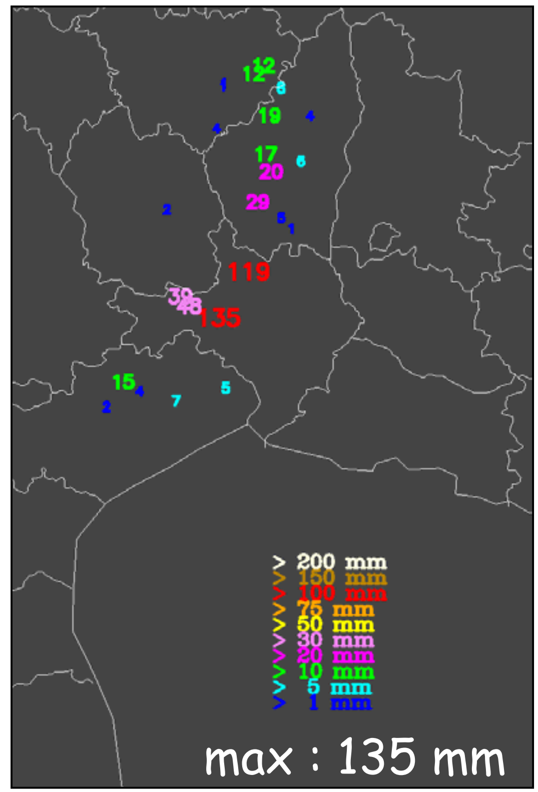
Quasi-stationnary MCS 13-14 Oct. 1995

MESO-NH, Δx=2.5km

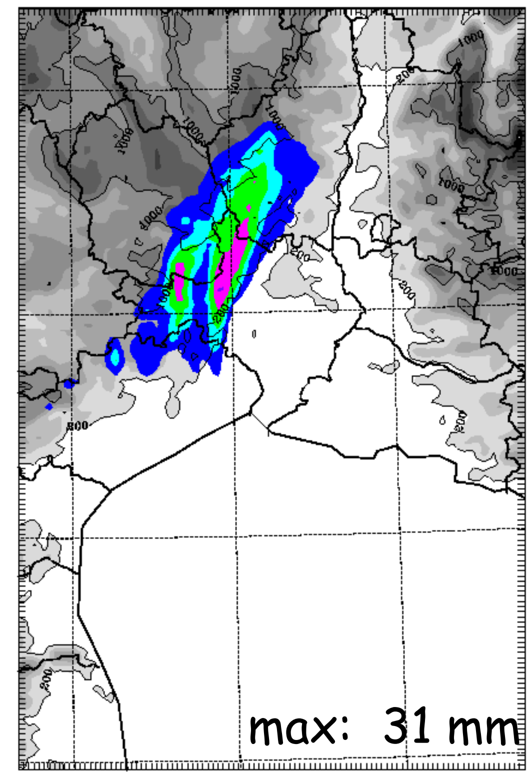


Initialisation Ducrocq *et al* (2000)'s

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)

Deep clouds

For AROME in 2006

- Good results with no excessive vertical velocity

- First time : To use diagnostics to better evaluate precipitating events. To multiply case studies.

- First time : Adaptation of numerical aspects of the sedimentation parametrization (time splitting) to longer time steps (> 60s)

- Second time : Test of the impact of hail with Meso-NH on a lot of cases (will be done in LA)

PLAN

Inventory, Ways of improvement and Plan for:

1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus
7. Chemistry

Cirrus

Meso-NH with ICE3, deep convection (for anvils) and the inclusion of ice in turbulence allows to reproduce cirrus and its life cycle.

A tunable parameter of a bulk $\mu\pi$ scheme is the ice to snow autoconversion threshold

$$Autoconversion \quad rate: \quad R_{iauts} = k_{is} Max(0, r_i - r_i^*)$$

Chaboureau et al., 2002 : Thick cloud regime over Atlantic : (currently in AROME)

$$r_i^* = 2.10^{-5} kg.kg^{-1}$$

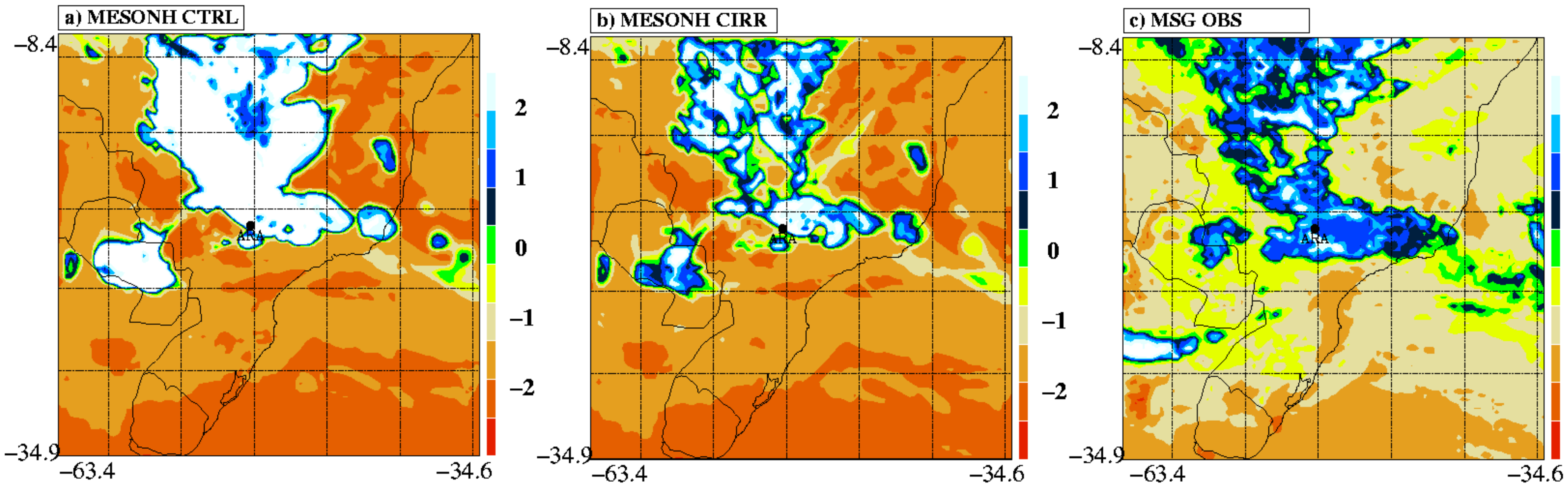
To better control thin cold cirrus sheets, Ryan (2000) proposed :

$$r_i^* = \min(2.10^{-5}, 10^{0.06(T-273.16)-3.5})$$

Chaboureau and Pinty (2005) tested an improvement on tropical cirrus (TROCCINOX) by Model to Satellite approach (MSG)
Could be rapidly tested in AROME, but with diagnostics Model → Satellite .

Chaboureau and Pinty (2005) : Use of radiative transfer RTTOV to MSG

Δx=30 km



PLAN

Inventory, Ways of improvement and Plan for:

1. Fog
2. Dry Convective Boundary Layer
3. Shallow cumulus BL
4. Stratocumulus Capped BL
5. Deep clouds
6. Cirrus

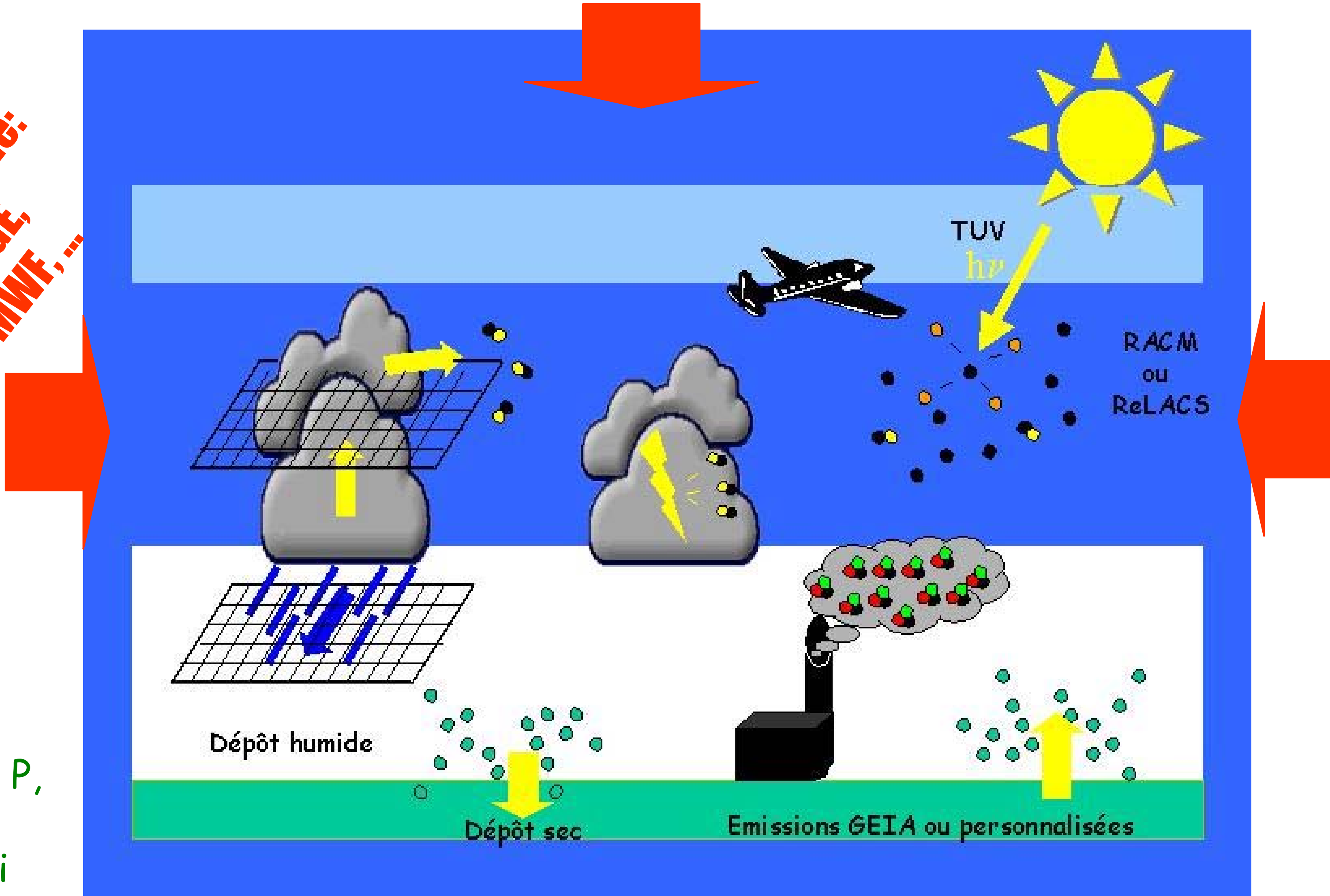
7. Chemistry

All the Meso-NH-Chemistry integrated in AROME (with SURFEX)

Tulet.P and Y.Seity

In Meso-NH and SURFEX :

large-scale: MOCAGE, ECMWF, ...



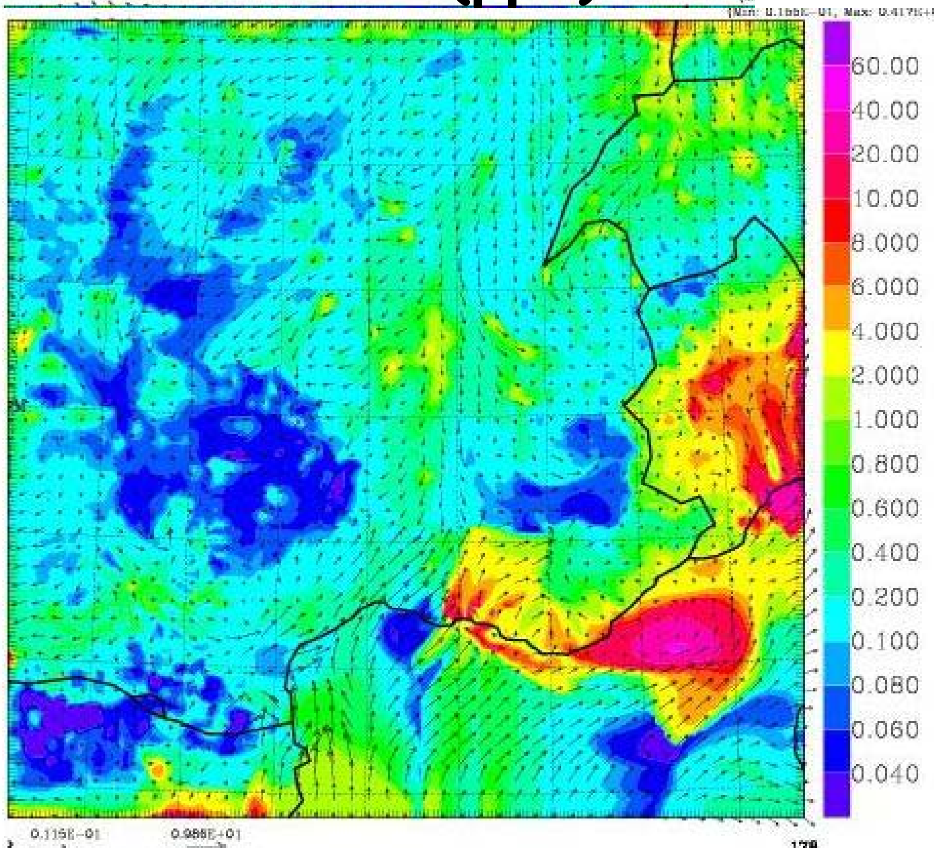
Tulet, P, and C.Mari

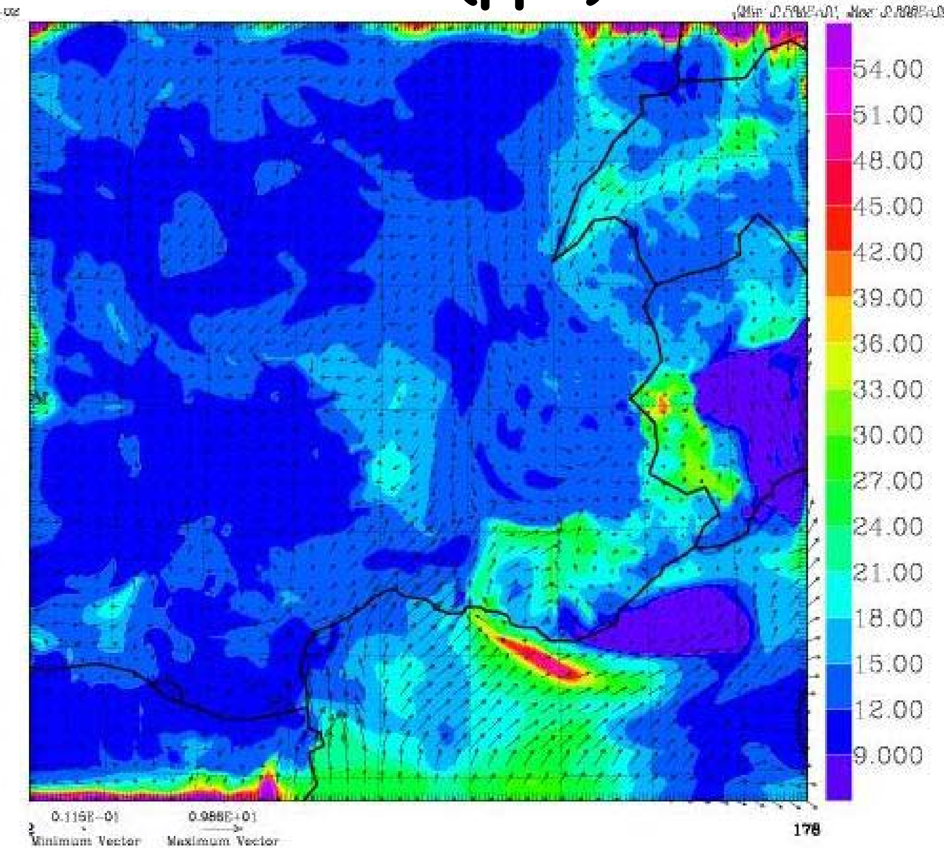
- Initialization 24 Juin 2001 at 00UTC (POI2B ESCOMPTE)
- O3 initial = 10 ppb
- NO et NO2 initial = 0.01 ppb
- CO = 30 ppb
- Emission GENEMIS + ESCOMPTE (zone PACA)

- RUN : 18H
- DOMAIN: 180*180*43 . 4 km de résolution
- Cost: 3000 s for 1h : 30 times less expensive than Meso-NH-Chemistry

Tulet.P and Y.Seity

NOx (ppb) 18 UTC O3 (ppb)





Priority fo AROME
BUT with DIAGNOSTICS

Cirrus clouds	Depends on convective systems (anvils). Turbulence ice improves the life cycle. Improvement with tuning of microphysics.
Deep clouds	Mainly driven by dynamics. Mixed-phase microphysics Good results with AROME (no excessive W) Impact of hail.
BL clouds : Sc	Larger cloud fraction. Variety of turbulence and stability profiles - Importance of entrainment. Impact of vertical resolution - Mixing length - Aerosol effects -
BL clouds : Cu	-The CBR scheme enables to produce BL clouds. Countergradient (TOMs) insufficient for top-cloud entrainment. Improvement : Tuning of KFB, Introduction of Soares, Subgrid condensation with ED+MF contribution
Dry CBL	Transition to BL clouds. Turbulent mixing dominated by large-eddy transport and entrainment at the top. Improvement : Countergradient (TOMs) versus EDMF (Siebesma and Soares)
Fog	Stable BL and transition to neutral BL. Improvement of Mixing length. Sedimentation of small drops and influence of aerosols.