EDMF developments in the operational global model ARPEGE

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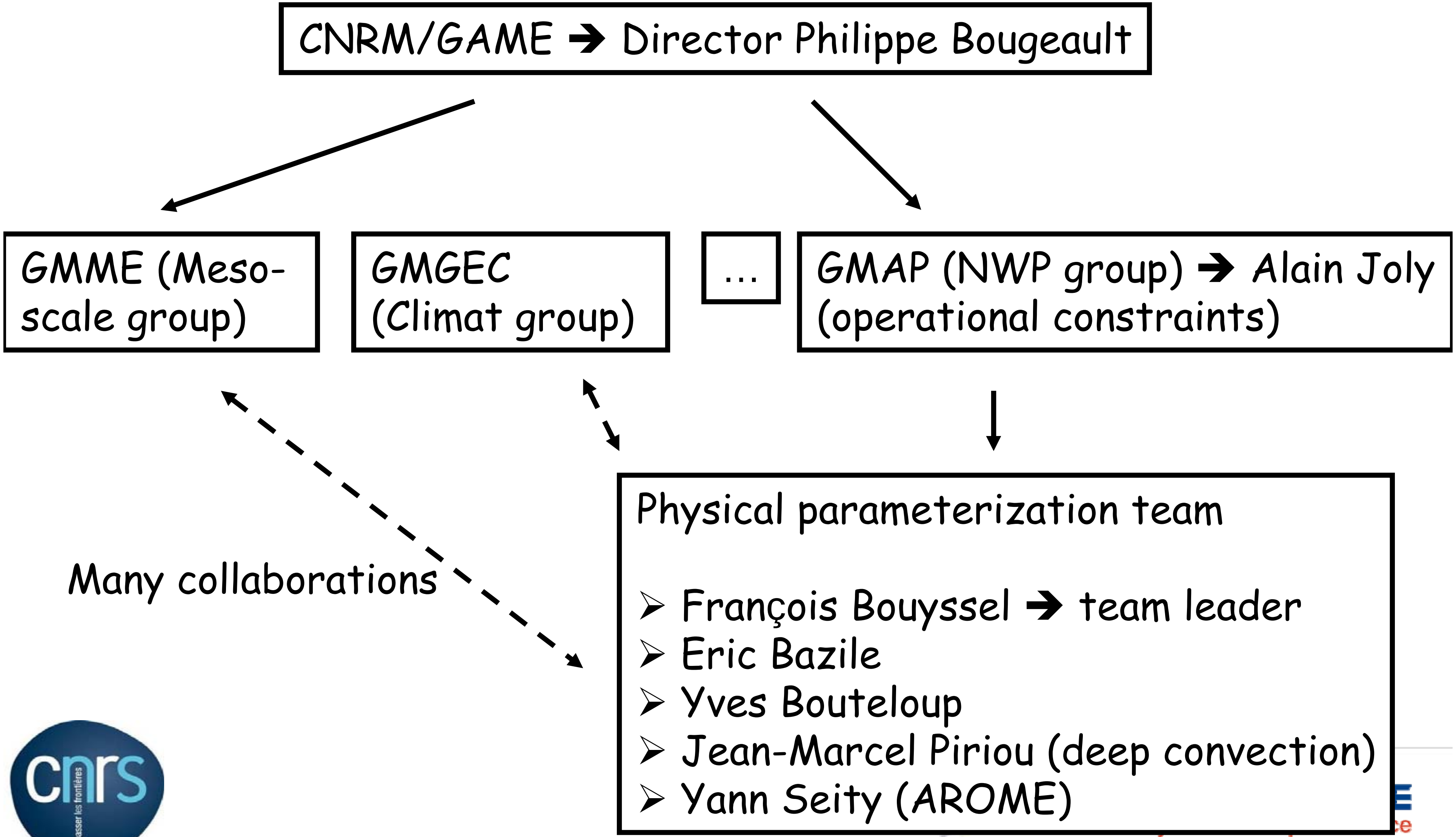
NWP in the CNRM/GAME



CNRM/GAME ➔ Director Philippe Bougeault

GMME (Meso-scale group)

GMGEC (Climat group)

…

GMAP (NWP group) ➔ Alain Joly (operational constraints)

Many collaborations

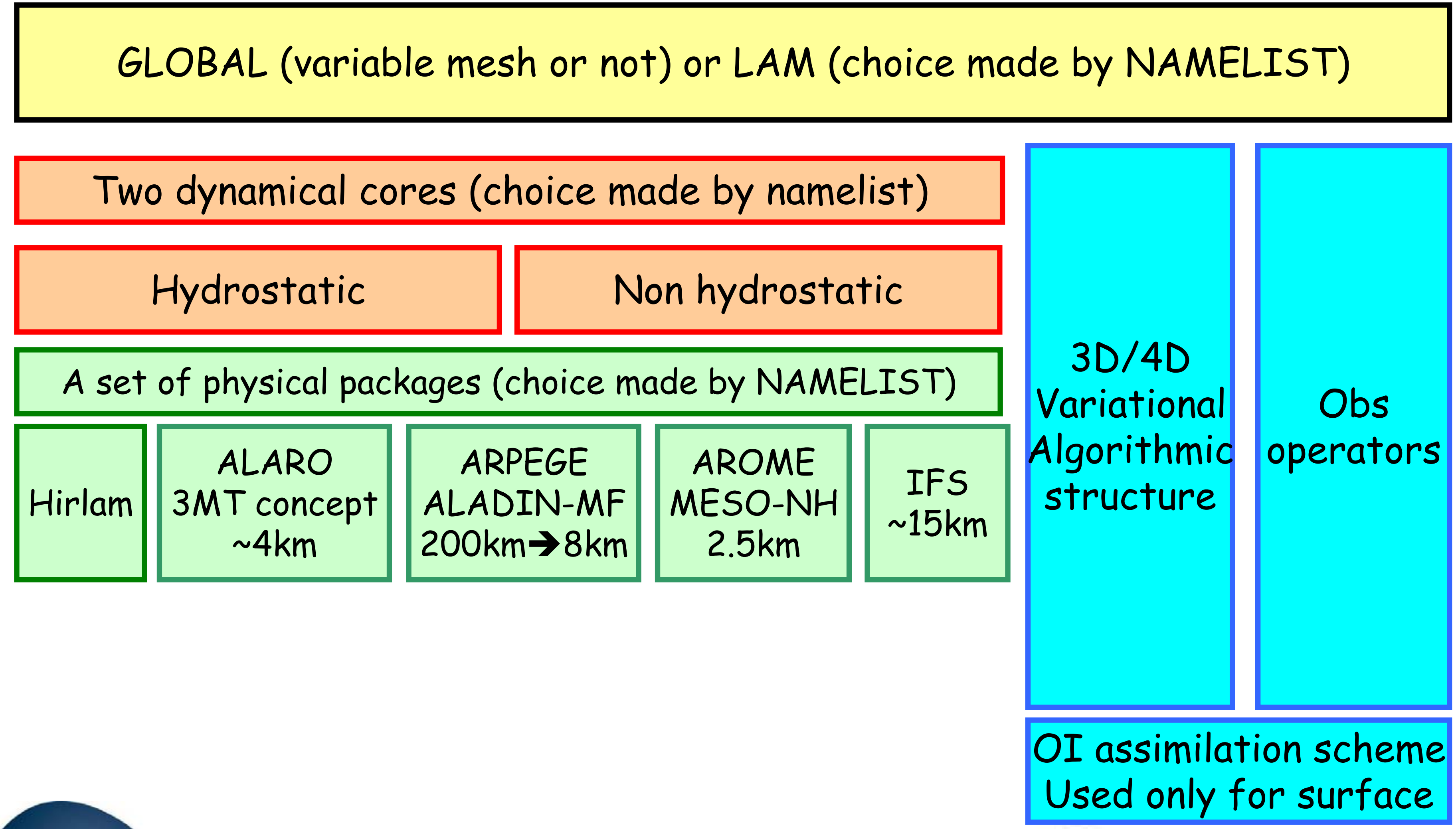
Physical parameterization team

- François Bouyssel ➔ team leader
- Eric Bazile
- Yves Bouteloup
- Jean-Marcel Piriou (deep convection)
- Yann Seity (AROME)

Talk's overview

- Current operational situation (KFB)
- Evolution strategy (EDKF, convergence with AROME)
  - o Presentation of the scheme
  - o Stability problem in ARPEGE
  - o Other problems
- Conclusion and prospects

ARPEGE/ALADIN/AROME/IFS/HARMONIE
A unified sofware



GLOBAL (variable mesh or not) or LAM (choice made by NAMELIST)

Two dynamical cores (choice made by namelist)

Hydrostatic

Non hydrostatic

A set of physical packages (choice made by NAMELIST)

Hirlam

ALARO
3MT concept
~4km

ARPEGE
ALADIN-MF
200km→8km

AROME
MESO-NH
2.5km

IFS
~15km

3D/4D
Variational
Algorithmic
structure

Obs
operators

OI assimilation scheme
Used only for surface

ARPEGE/ALADIN-MF operational configurations

- ARPEGE is a global spectral model with a variable mesh

- T798 *C*=2.4 (**Δt** = 600s) ➔ 10 km over France and around 60 km at the antipode, few hundred kilometers east New-Zealand

- 70 vertical levels ➔ Close to ECMWF vertical resolution in the troposphere

- 4DVAR multi-incremental data assimilation, with two outer loops T107 *C*=1 (**Δt** = 1800s) and T323 *C*=1 (**Δt** = 1350s) using a 6 hours window

- ALADIN-MF is an hydrostatic LAM with the same physics it runs over France, Indien Ocean, West Indies, French Polynesia, New-Caledonia and some secret parts of the world (army queries !)

- 3DVAR data assimilation

- Presently 8km, 70 levels, **Δt** = 480s

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Toujours un temps d'avance

AROME operational configuration

- AROME is a non-hydrostatic LAM
- Physical parametrizations come from Méso-Nh
- It runs over France (coupling model is ARPEGE)
- 3DVAR data assimilation
- Presently 2.5km, 60 levels (more levels than ARPEGE in the PBL)
- Δt = 60s

Operationnal «NWP» Boundary layer physics at Météo-France

All NWP models (AROME, ARPEGE and ALADIN-MF) use « EDMF » concept

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + \frac{M_u}{\rho}\left(\phi_u - \overline{\phi}\right) \quad \text{with} \quad K = cL_{BL89}\sqrt{TKE}$$

and

$$L_{BL89} = \left[\frac{\left(l_{up}\right)^{-\frac{2}{3}} + \left(l_{down}\right)^{-\frac{2}{3}}}{2}\right]^{-\frac{3}{2}}$$

Where l_{up} and l_{down} are computed using dry buoyancy following Bougeault and lacarrère (1989)

ARPEGE and ALADIN-MF

- ➢ Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000)
- ➢ Shallow convection mass flux scheme « KFB » (Bechtold et al 2001)

Equations should be the same

⟷

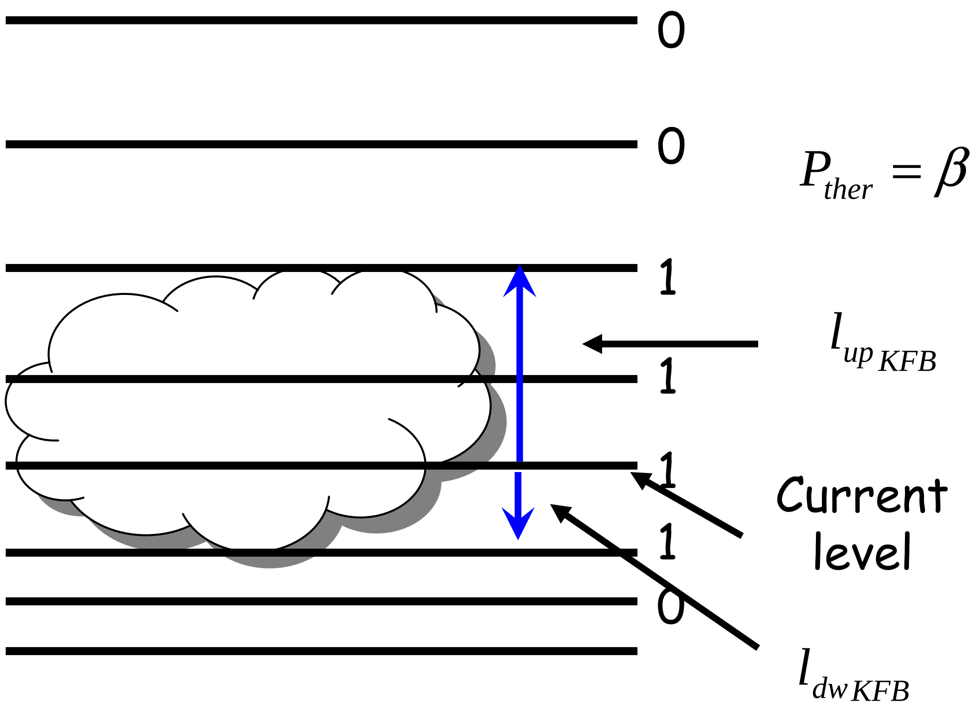
AROME

- ➢ Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000)
- ➢ Shallow convection and dry thermal mass flux scheme « EDKF » (Pergaud et al 2009)

Connection between TKE and Shallow convection

- ➢ With KFB, during our first evaluation tests in ARPEGE, we found too much low level clouds and too much wind in the PBL in the tropical area

- ➢ A thermal production term is then computed by KFB and Bougeault Lacarrère (1989) mixing lengths are increased in the shallow clouds



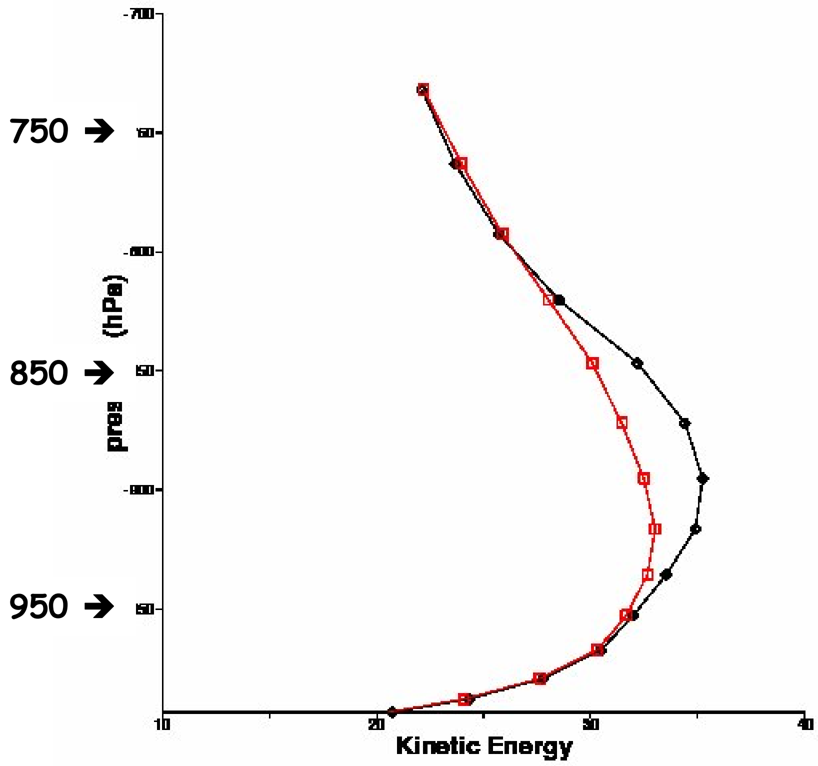
$$P_{ther} = \beta\left(E_\theta \overline{w'\theta_l'} + E_q \overline{w'q_t'}\right) \boxed{+ \beta\left(\overline{w'\theta_l'}\right)_{KFB}}$$

$$\boxed{l_{up\_cvpp} = Max(l_{up\,bl89}, l_{up\,KFB})}$$

$$\boxed{l_{dw\_cvpp} = Max(l_{dw\,bl89}, l_{dw\,KFB})}$$

It was found a large beneficial impact on wind in the tropics (20S ➔ 20N)

Zonal mean over the tropical area of the Kinetic energy (J/kg) with (red) and without (black) the thermal production term coming from shallow convection and the modification of the mixing length inside the cloud.



The reasons of a test of EDKF in ARPEGE

- No dry thermal in KFB
- No mixing of wind in KFB
- Convergence strategy between NWP models physics
- Global model is a great testbed for parametrizations
- But, global models are very sensitive clockworks
- KFB is numerically stable at large time step ➔ T107 Δ**t = 1800s**

EDKF scheme equations

Mass flux equation ➔ $$\frac{1}{M_u}\frac{\partial M_u}{\partial z} = (\varepsilon - \delta)$$

Updraft vertical speed equation ➔ $$w_u \frac{\partial w_u}{\partial z} = aB_u - b\varepsilon w_u^2$$

$$a_u = \frac{M_u}{\rho w_u}$$ then $CF = C_{cf} a_u$

$$(a = 1 \quad b = 1 \quad C_{cf} = 2.5)$$

Entrainment and detrainment rate in the dry thermal ➔

$$\begin{cases} \varepsilon_{dry} = Max\left[0, C_\varepsilon \frac{B_u}{w_u^2}\right] & (C_\varepsilon = 0.55) \\ \delta_{dry} = Max\left[\frac{1}{L_{up} - z}, C_\delta \frac{B_u}{w_u^2}\right] & (C_\delta = -10) \end{cases}$$

Closure ➔ $$M_u(z_{grd}) = C_{M_0\rho}\left(\frac{g}{\theta_{vref}}\overline{w'\theta'_{vs}}L_{up}\right)^{1/3} \qquad (C_{M_0\rho} = 0.065)$$

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In the cloud ➔ Kain and Fritsch (1990) approach

- It is supposed that the cloud is surrounded by a transition (mixing) region

- Subparcel mass mixture in the transition region is estimated by a probability density function f(x) where x is the fraction of environmental air in mixed subparcel (1-x is the fraction of updraft air)

- Entrainment and detrainment rate are then given by :

$$\varepsilon_{cloud} = \delta M_t \int_0^{x_c} x f(x) dx$$

and

$$\delta_{cloud} = \delta M_t \int_{x_c}^{1} (1-x) f(x) dx$$

Where x_c is the neutrally buoyant mixture and δM_t the total rate at which mass enters in the transition region

$$\delta M_t = M(-0.03 \delta P / R)$$

R is the updraft radius and M the mass flux

Kain and Fritsch (1990) approach in KFB and EDKF

- The two schemes use this approach with an updraft radius R=50m but :

- In KFB f(x) is gaussian while in EDKF f(x) is a flat distribution

- Both cases were discussed in Kain and Fritsch : « It appears that the general form of the mass flux profile is primarily dictated by the environmental thermodynamic profile. »

- I tested flat distribution in KFB ➔ impacts are low

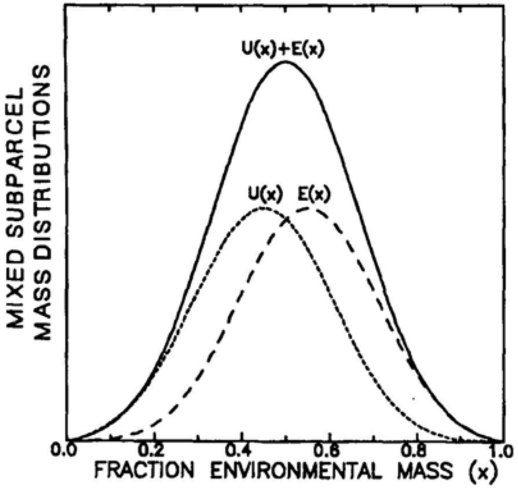


FIG. 2. Hypothetical distribution of environmental mass, $E(x)$; updraft mass, $U(x)$; and total mass, $E(x) + U(x)$, in mixed updraft subparcels as a function of the fraction of environmental air in individual mixed subparcels. The total mass distribution is based on the Gaussian distribution function.

Figure 2 and 6 from Kain and Fritsch (1990)

🡐Gaussian distribution (KFB)

Flat distribution (EDKF) ➔

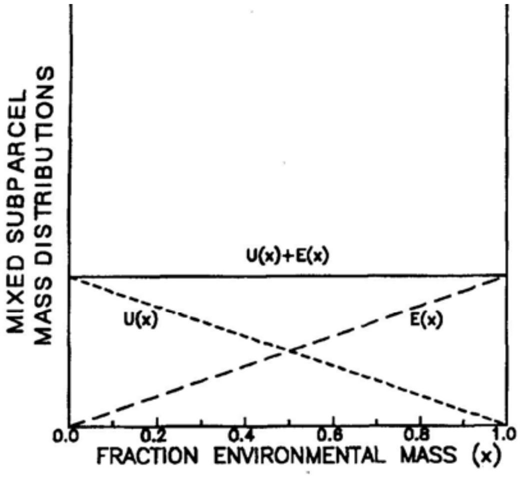
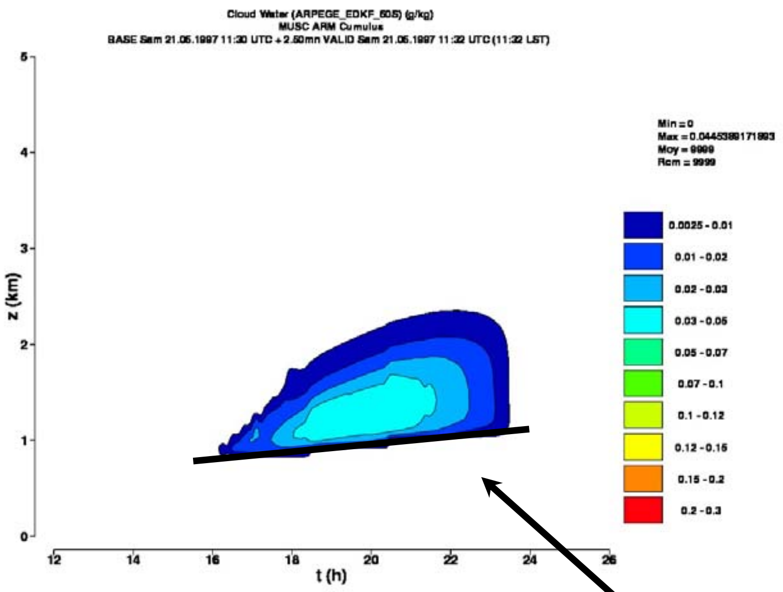
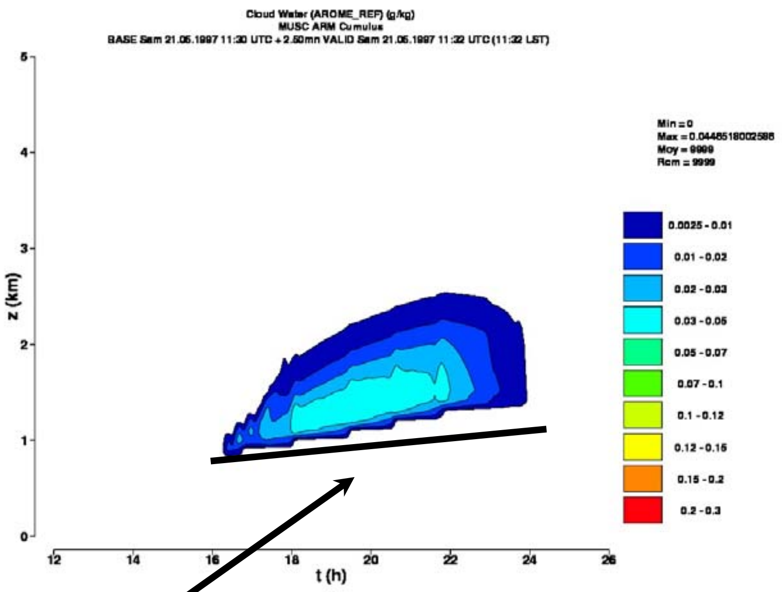


FIG. 6. Hypothetical distributions of environmental mass, $E(x)$; updraft mass, $U(x)$; and total mass, $E(x) + U(x)$, in mixed updraft subparcels as a function of the fraction of environmental air in individual mixed subparcels. The total mass distribution is based on a simple flat distribution function.

First test in ARPEGE ➔ 1D ARM shallow cumulus case

Cloud water content (g/kg)





ARPEGE **Δt = 60s**

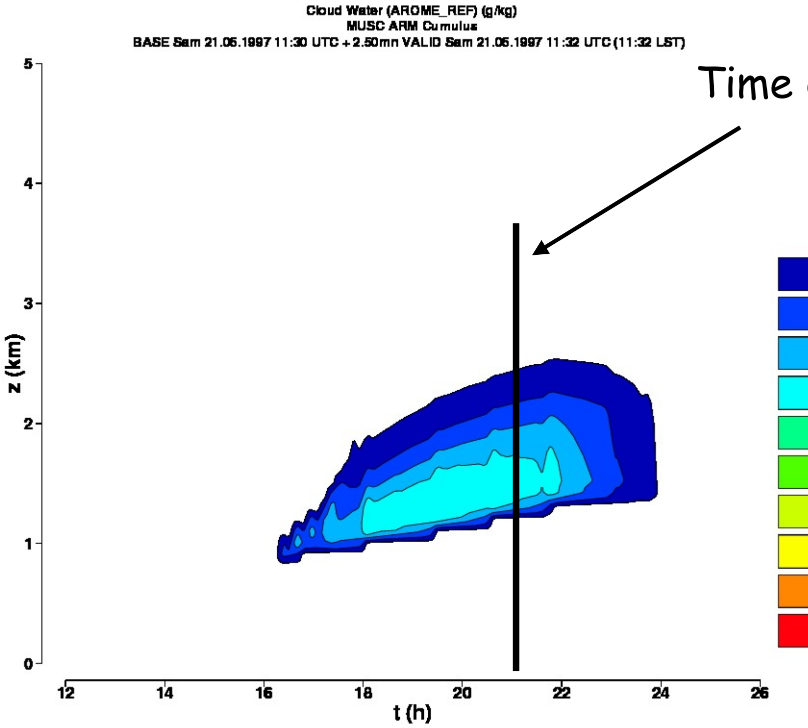
AROME **Δt = 60s**

AROME cloud base is higher

Why ? ➔ {
- Microphysics ?
- Turbulence ?

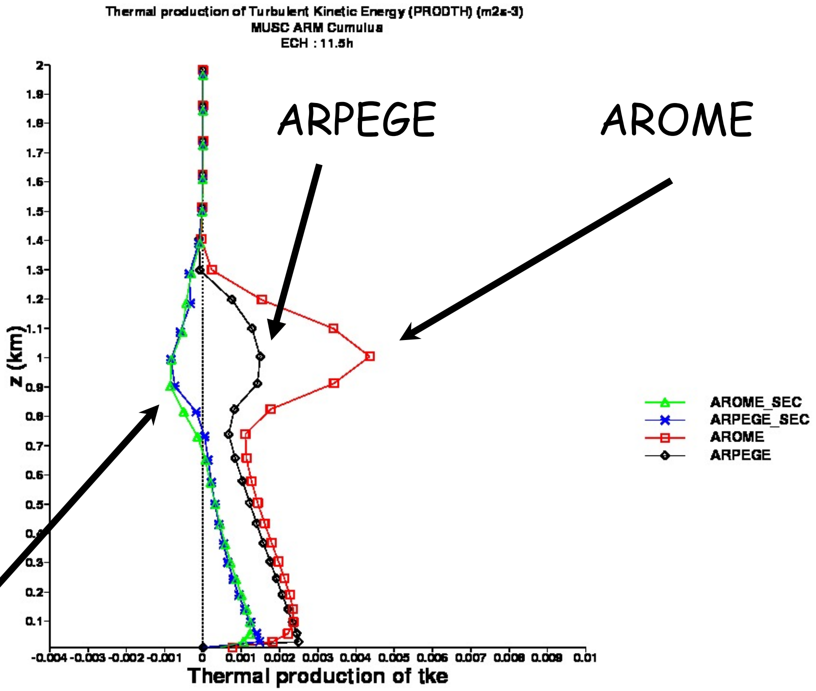
To understand the problem, the simulation is re-started for one time step from an AROME simulation

AROME oper Δt = 60s



Time of restart

TKE thermal production



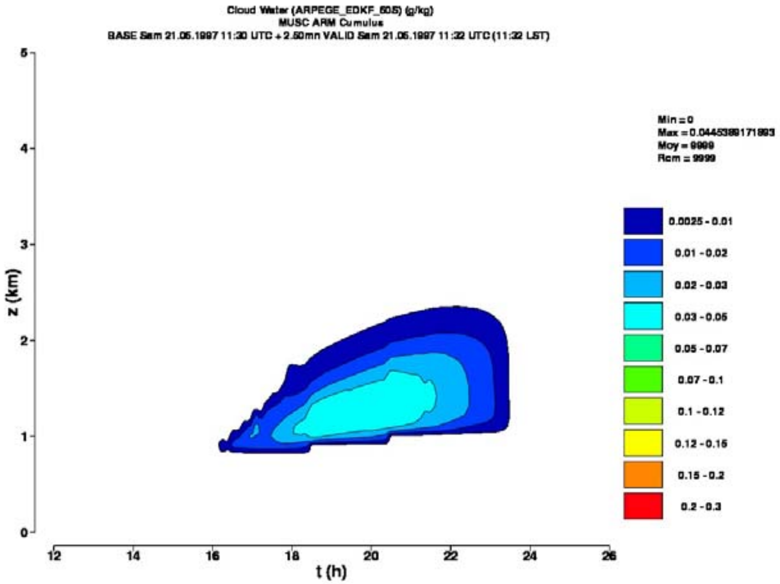
ARPEGE

AROME

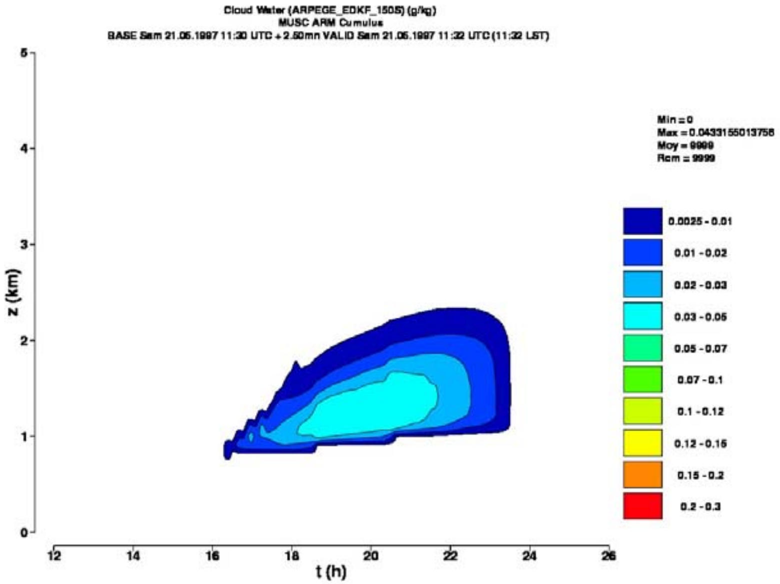
Dry (qv=ql=0) thermal production

Equations should be the same,
so it will be necessary to have a look at this issue

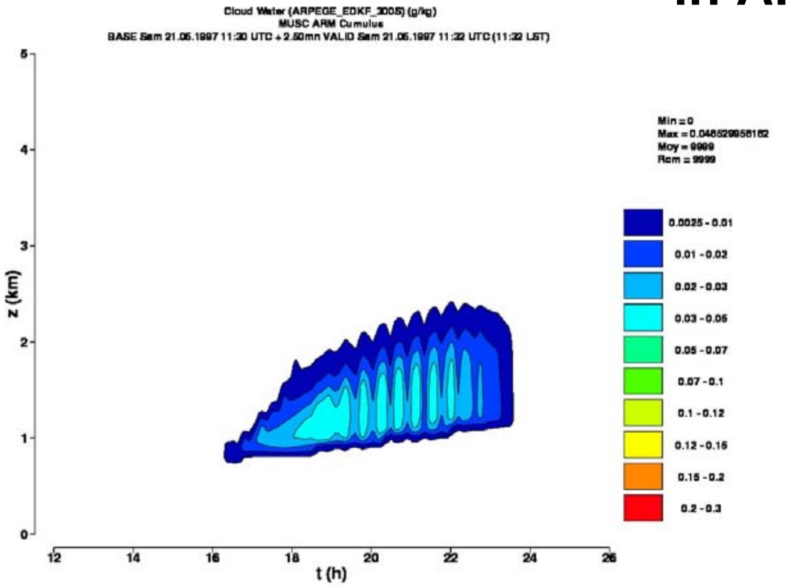
Sensitivity to time step in ARPEGE SCM



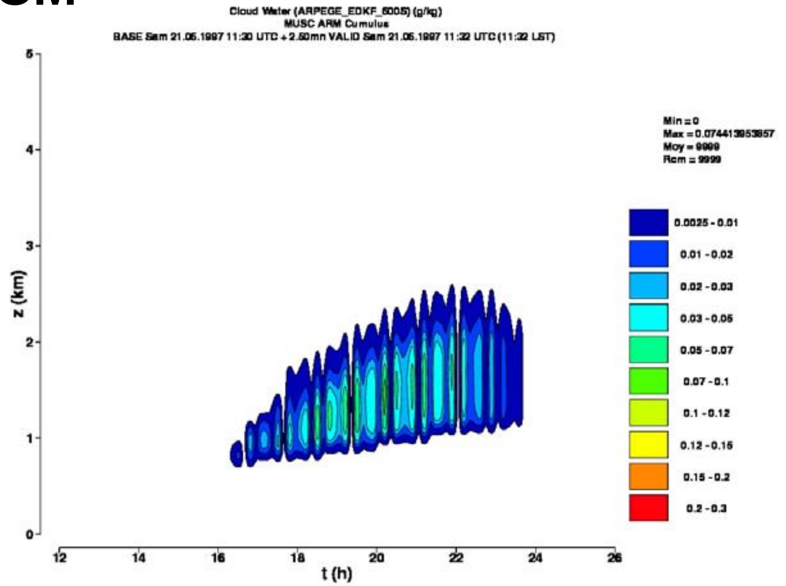
Δt = 60s



Δt = 150s



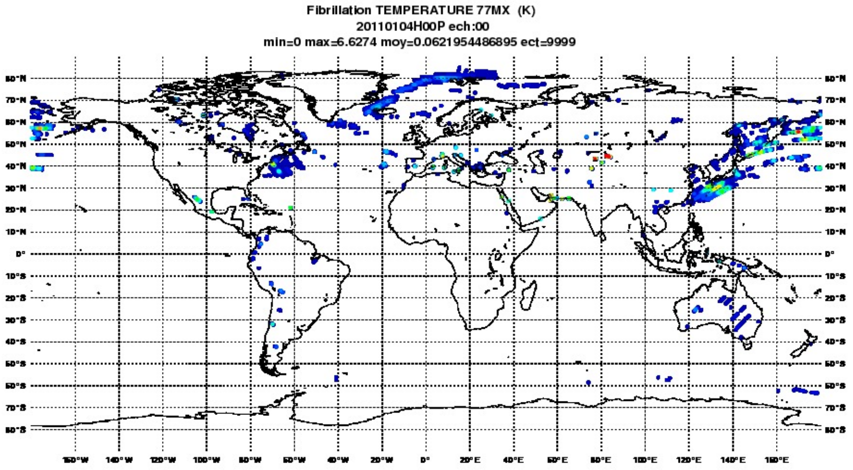
Δt = 300s



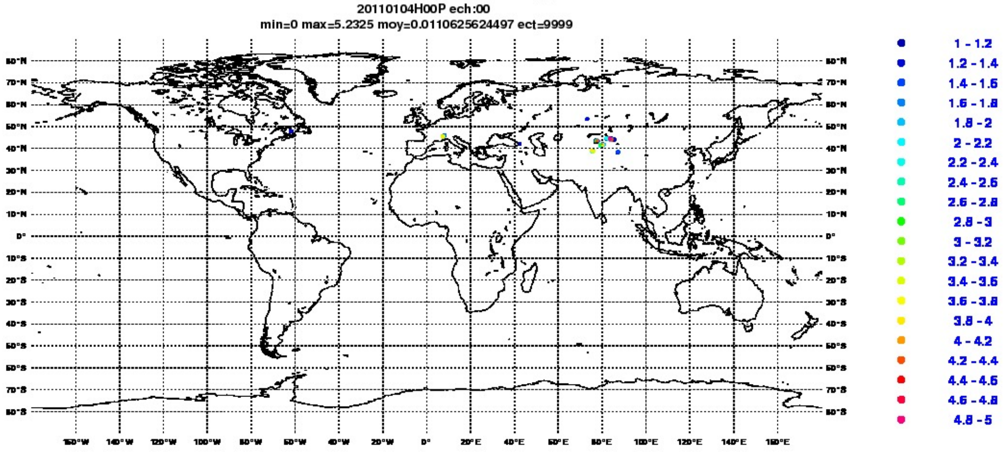
Δt = 600s

Stability problem in ARPEGE 3D
ARPEGE T798 C=2.4 (Δt = 300s) temperature at lower level

ARPEGE + EDKF t=1



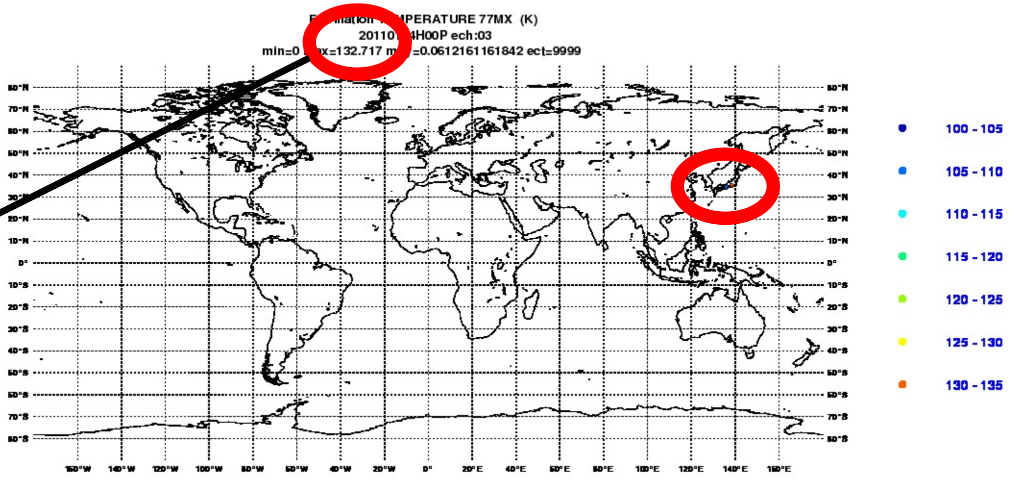
ARPEGE Oper t=1



$$\boxed{T_{t-1}+T_{t+1}-2T_t}$$

Is plotted

132 K !



ARPEGE + EDKF t=36

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Stabilization technics (Valéry Masson)

For a conservative variable Φ we need to resolve :

$$\left(\frac{\partial \phi}{\partial t}\right)_{MF} = \frac{\partial}{\partial z}\left(\overline{w'\phi'}\right)_{MF} = \frac{\partial}{\partial z}\frac{M}{\rho}\left(\phi_{up}-\overline{\phi}\right)$$

The classical way is to use an implicit formulation which leads to a tridiag.
To further stabilize the system at large time step a time spliting technics is also introduced.

A small time step is defined : $\Delta t = n\delta t$

Then a loop is iterated : $\delta\phi_{MF}^{i+1} = \delta t\,\frac{\partial}{\partial z}\frac{M^{i}}{\rho}\left(\phi_{up}^{i}-\phi^{i}\right)\left(+\,\delta\phi_{turb}\right)$

Updraft can be updated

ED tendency can be added

Of course implicit formulation is used at each small time step
But … it's not enough … and the model still blow up

Statistical formulation

By analogy with the sedimentation flux in a microphysics scheme : $F_r = \rho q_r V_t$

It is possible to apply the statistical formulation as it was introduced in Geleyn et al (2009) and described in Bouteloup et al (2011) in the framework of ARPEGE and AROME. A « mass flux » courant number and two proportions are introduced :

$$C_{MF} = \frac{\Delta t}{\Delta z}\frac{M_u}{\rho} \qquad P_1 = Min(1, C_{MF}) \qquad P_2 = Max\left(0, 1 - \frac{1}{C_{MF}}\right)$$

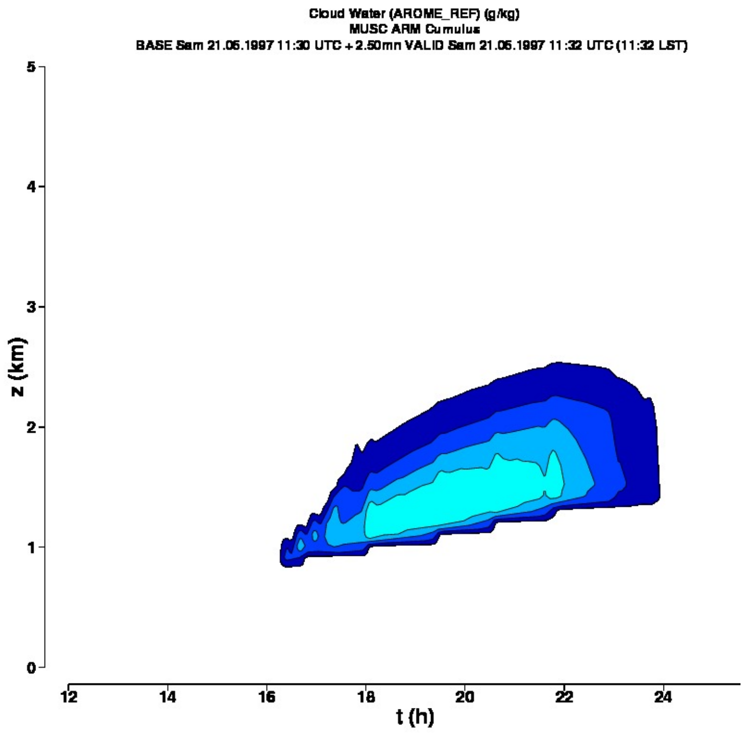
The flux of a variable Φ is computed from bottom to top using the following equation

$$F_\phi^{j+1} = \rho\left(\overline{w'\phi'}\right)_{MF}^{j+1} = P_1 \frac{\rho \Delta z}{\Delta t}\left(\phi_{up} - \overline{\phi}\right)^j + P_2 F_\phi^j$$

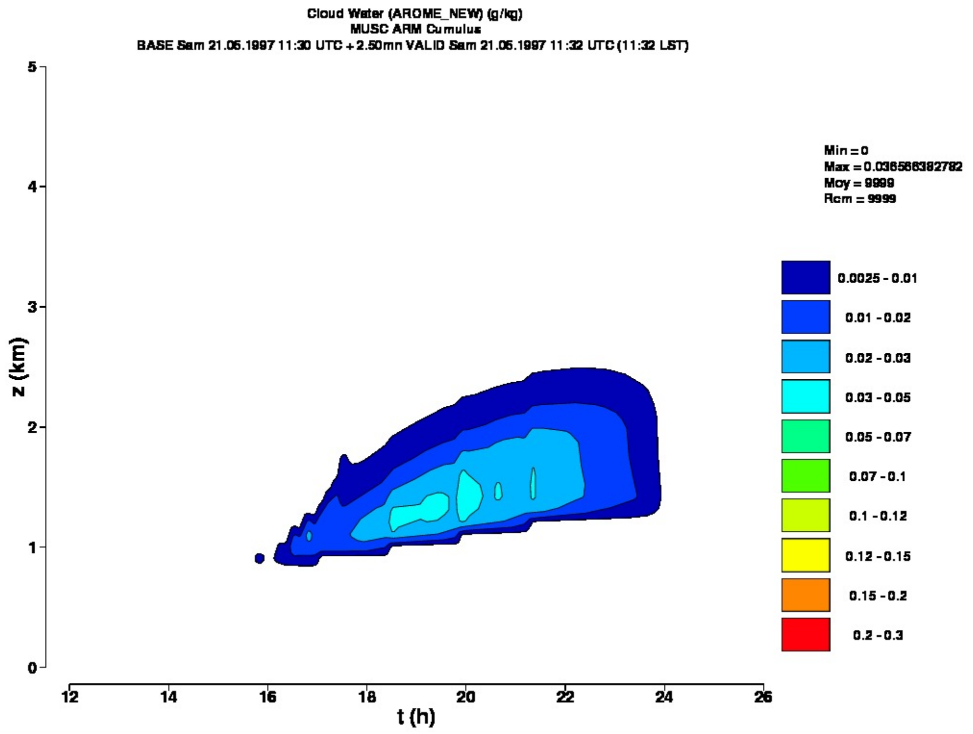
And the tendency is computed by : $\Delta \phi_{MF} = \frac{\Delta t}{\rho \Delta z}\left(F_\phi^j - F_\phi^{j+1}\right)$

Impact of new formulation in AROME 1D

Implicit formulation

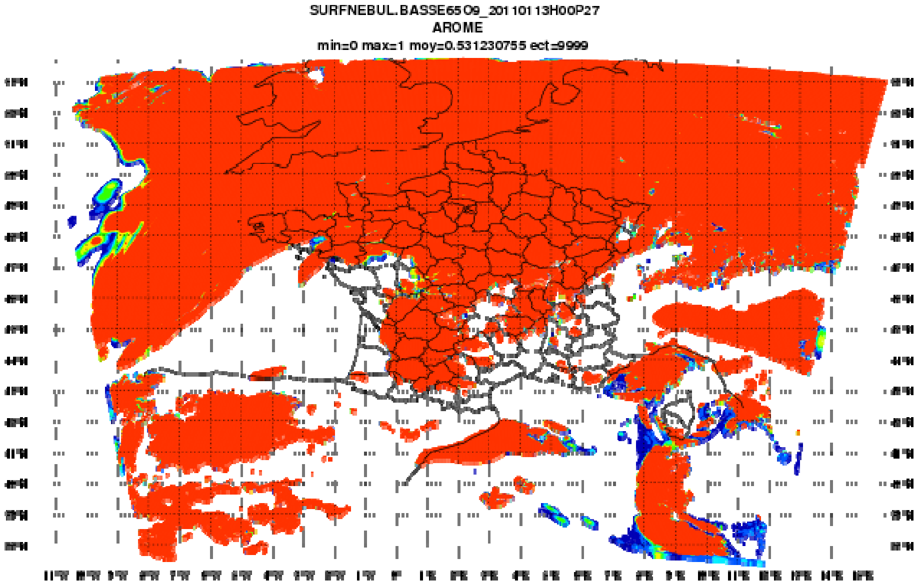


Statistical formulation

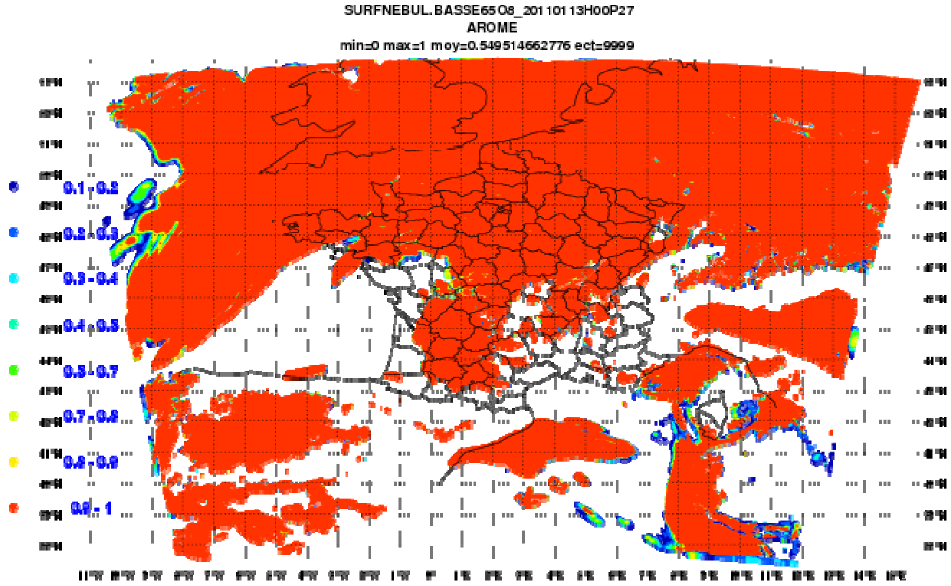


Impact of new formulation in AROME 3D

27 hours forecast, low level cloudiness



Implicit formulation



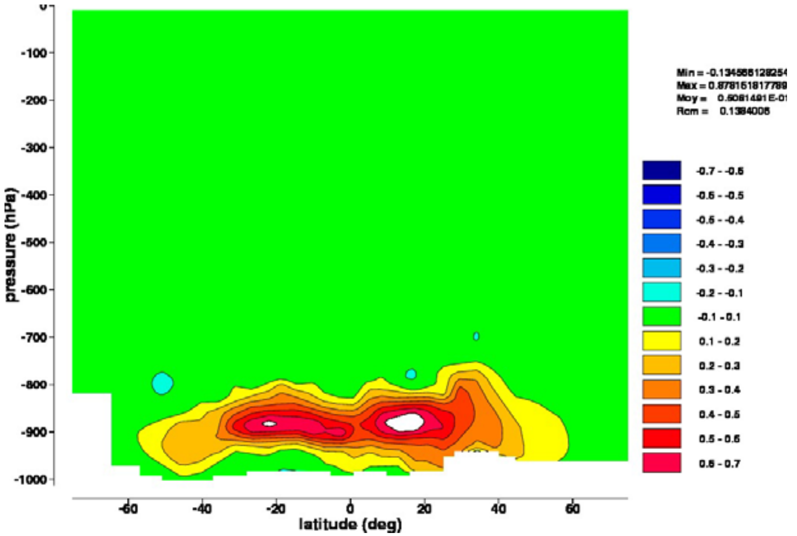
Statistical formulation

Zonal mean impact of EDKF in ARPEGE (Δt = 600s)

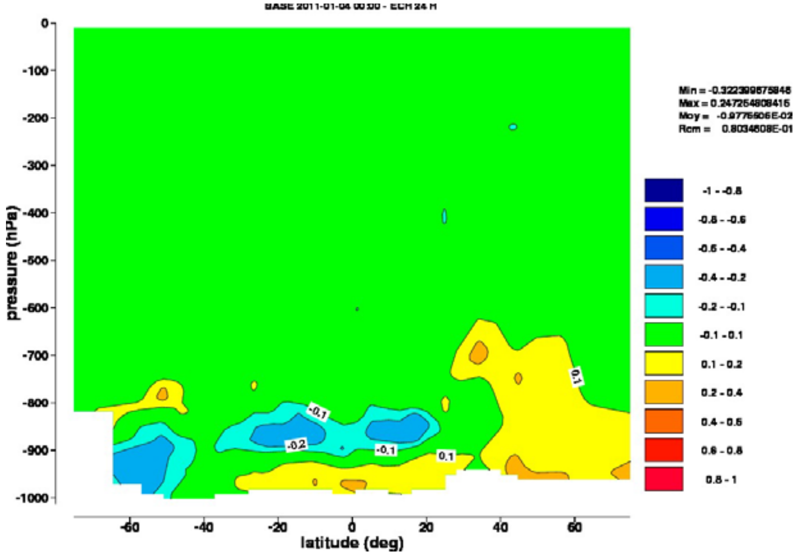
Too much water vapor around 850hpa

➔ too much cloud ➔ impact on temperature

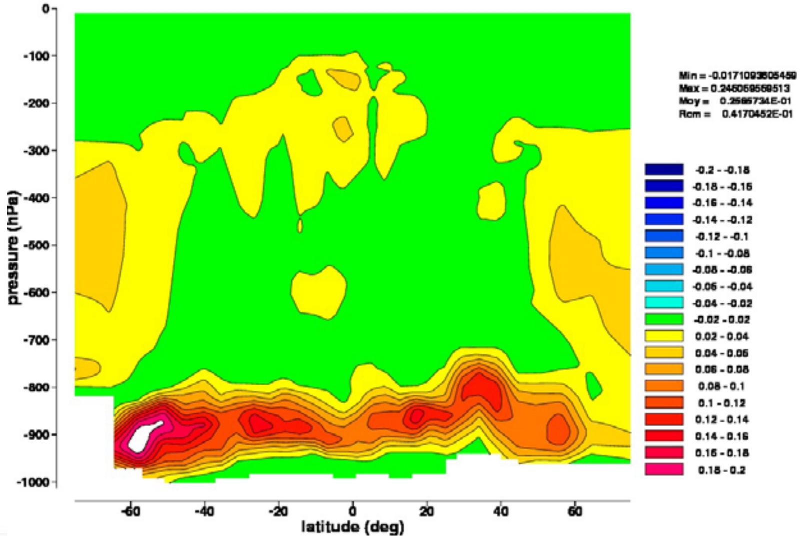
Water vapor zonal mean tendency g/kg/day



Temperature zonal mean tendency

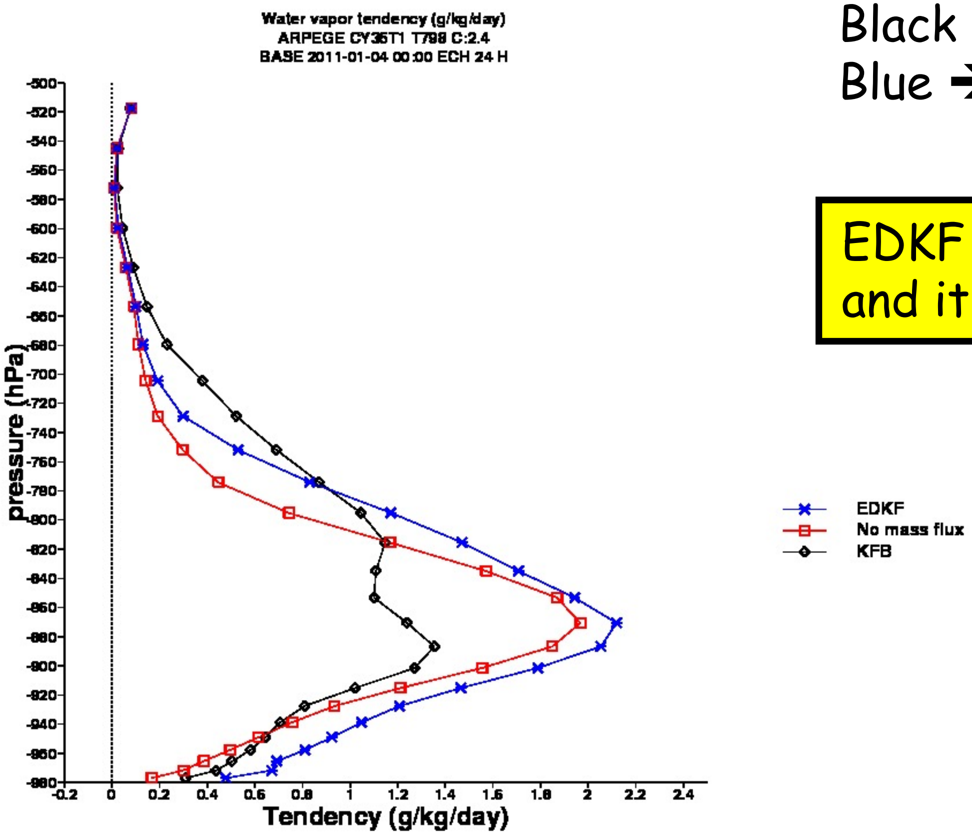


Cloudiness zonal mean tendency



Global mean impact of EDKF in ARPEGE

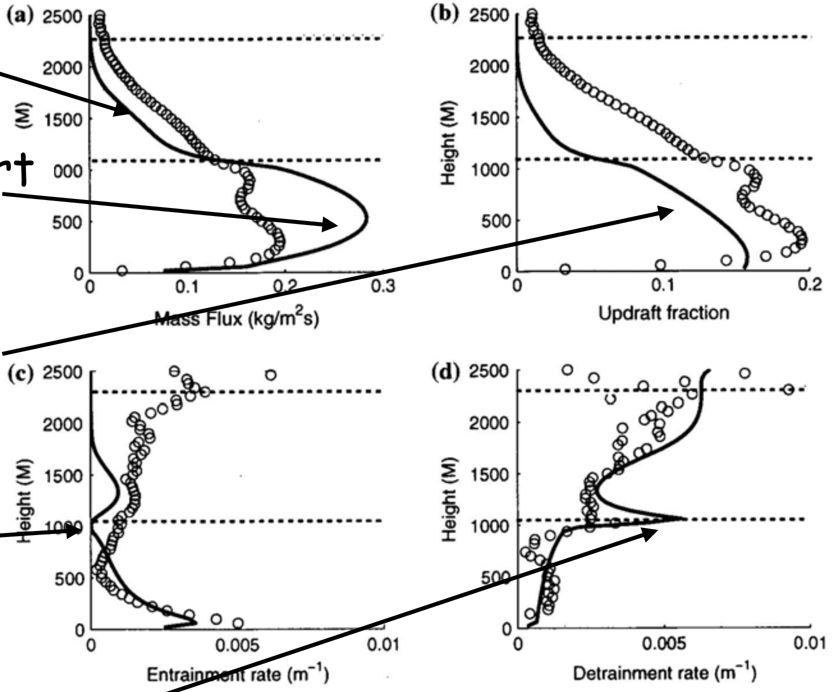
Water vapor global mean tendency due to ED and shallow MF



Red ➔ No shallow convection
Black ➔ KFB (operational model)
Blue ➔ EDKF

EDKF is too active in the boundary layer and it does not rise high enough

Come back in SCM model : ARM cumulus, EDKF against LES (Pergaud et al 2009)



Mass flux is too low in the cloud

Mass flux is too strong in the dry part

Updraft fraction is too low, may be because vertical speed is too high

Entrainment is 0 at cloud base

Detrainment is too strong at cloud base

.9 ARM case: Mass flux (a), updraft fraction (b), entrainment ε (c) and detrainment δ (d) profiles after 8 h imulation. *Solid line* represents 1D results and *circles* are LES values obtained by conditional sampling. *dashed lines* represent the cloud base and top

Figure 9 of Pergaud et al (2009)

Behaviour consistent with ARPEGE simulations

Return to EDKF equations ➔ first minor modifications

Updraft vertical speed equation ➔ $w_u \frac{\partial w_u}{\partial z} = aB_u - b\varepsilon w_u^2$

But, when $B_u > 0, \quad \varepsilon_{dry} = C_\varepsilon \frac{B_u}{w_u^2} \Rightarrow w_u \frac{\partial w_u}{\partial z} = (a - bC_\varepsilon)B_u$

There is no dependence to vertical speed ➔ too high speed.
A new term is added to this equation :

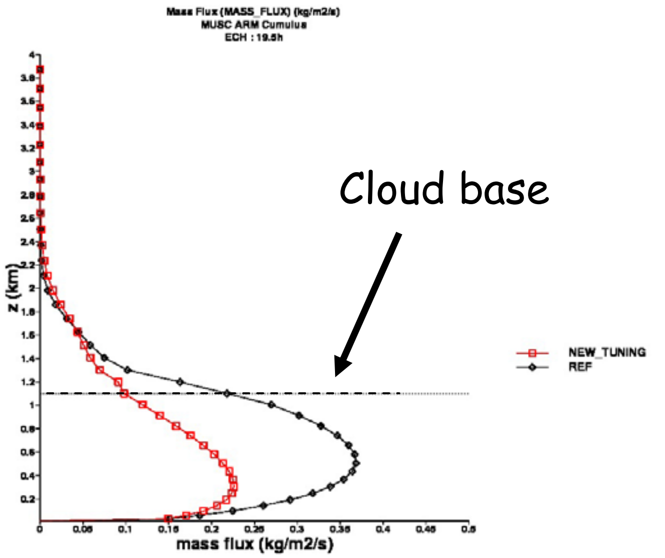
$$w_u \frac{\partial w_u}{\partial z} = (a - bC_\varepsilon)B_u \boxed{-\delta_0 w_u^2} \qquad \text{with} \qquad \delta_0 = 0.005$$

Then some coefficients are adjusted ➔

$$\begin{cases} C_\varepsilon : (0.55 \Rightarrow 0.4) \\ C_\delta : (-10 \Rightarrow -6) \\ a : (1 \Rightarrow 1.2) \end{cases}$$

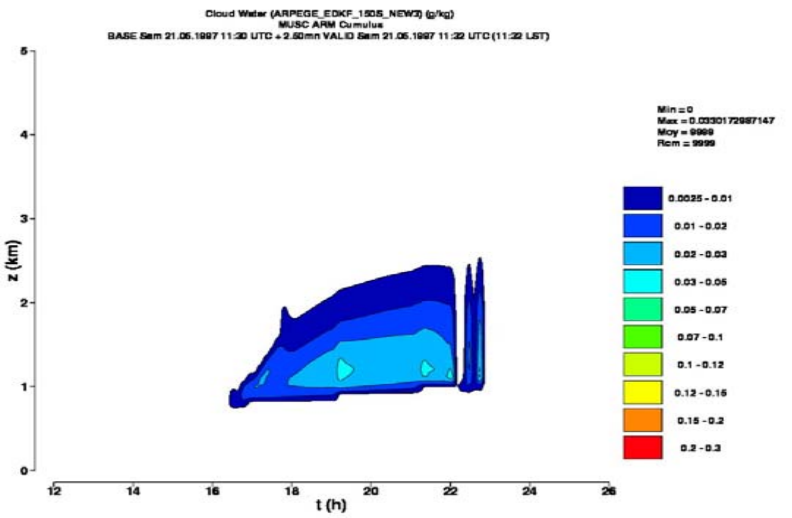
But no change of entrainment and
detrainment in the cloud … (next step ?)

First results with these modifications



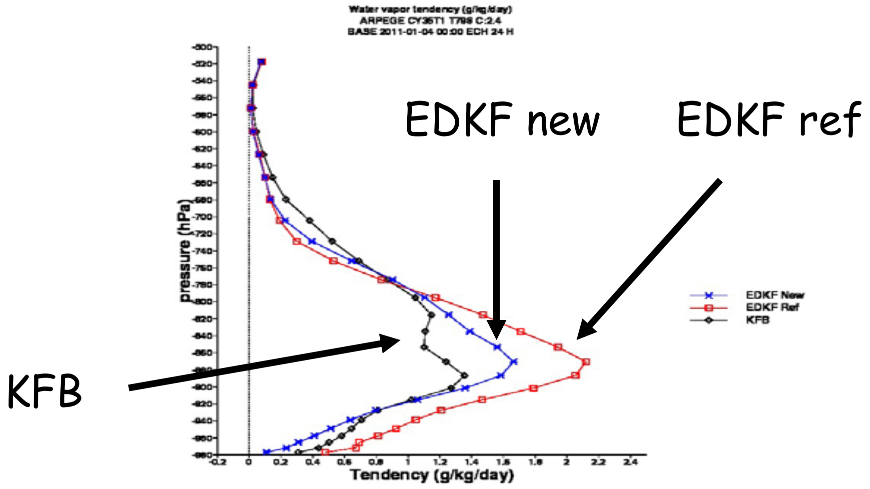
Cloud base

Reduction (improvement ?) of the mass flux …



… but degradation of the cloud …

… and improvement in ARPEGE 3D ➔



EDKF new

EDKF ref

KFB

Conclusion and prospects

- EDKF can run in ARPEGE with operational time step

- EDKF seems to work well in AROME but in ARPEGE current settings are not appropriate

- Simple adjustments give better results

- Attention shoul be paid to the transition zone between dry and cloudy part of the scheme (entrainment and detrainment formulation)

- Work must be done to understand the differences between the two prognostic TKE schemes

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Thank you
for your attention !