Eddy-Diffusivity Mass Flux parameterization in AROME and ARPEGE

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Talk's overview

- The ARPEGE/IFS/AROME/HARMONY… world
- Current operational situation (ARPEGE and AROME)
- EDMF concept
- Evolution strategy (seamless approach, convergence with AROME)
- Stability problem and implicit solution
- References

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 = 514s) ➔ 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 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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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 (Hourdin et al 2002, Soares et al 2004, Siebesma et al 2007)

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

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)

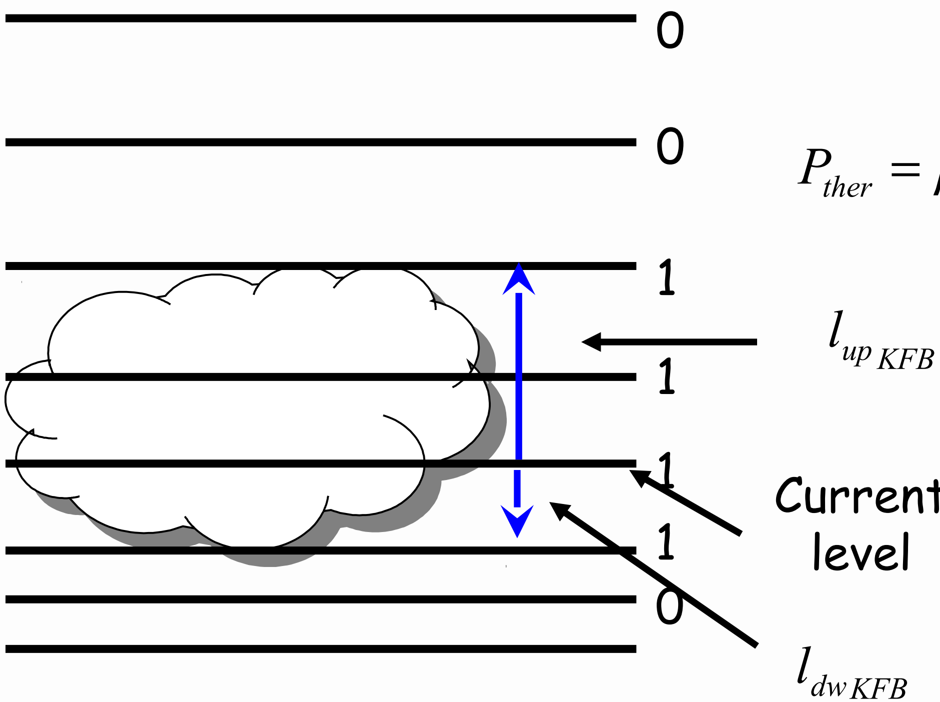
ARPEGE and ALADIN-MF	Equations should be the same ⟷	AROME
➢ Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000) ➢ Shallow convection mass flux scheme « KFB » (Bechtold et al 2001)		➢ Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000) ➢ Shallow convection and dry 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

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



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

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

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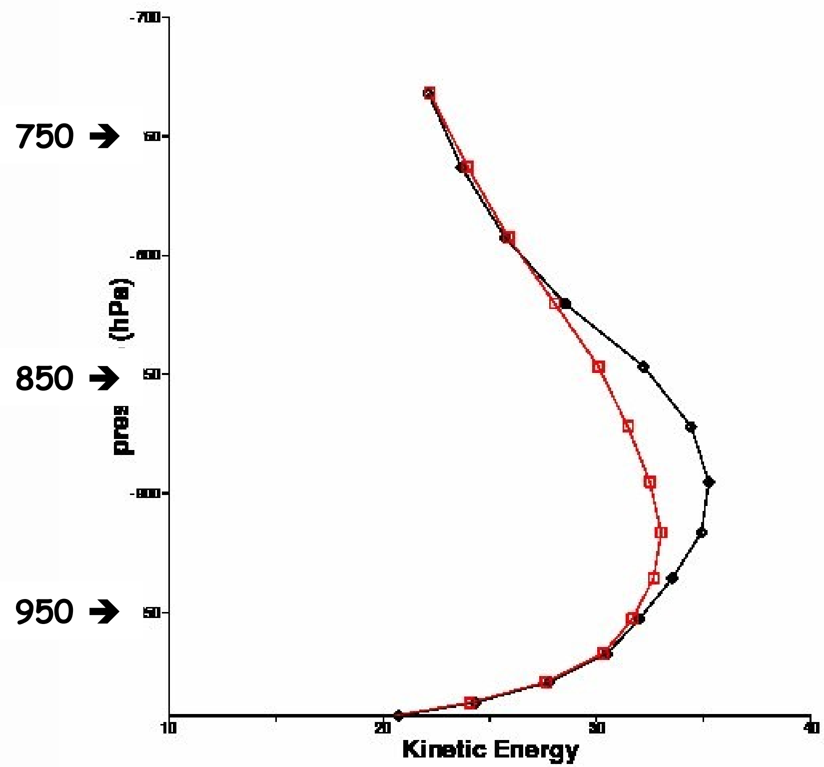
It was found a large beneficial impact on wind in the tropics (20S ➔ 20N)

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 (seamless approach)
- Global model is a great testbed for parametrizations
- But, global models are very sensitive clockworks
- KFB is numerically stable at large time step ➔ T107 **Δt = 1800s**
- With EDKF we uncountered numerical stability problems
- The solution was a common implicit solver for Eddy-Difusivity and Mass Flux part

Implicit treatment of the Mass Flux equation (1)

$$\begin{cases} F_\psi = \rho\overline{w'\psi'} = M\left(\psi_u - \overline{\psi}\right) \\ \left(\dfrac{\partial\psi}{\partial t}\right)_{MF} = \dfrac{1}{\rho}\dfrac{\partial}{\partial z}F_\psi \end{cases}$$

Second equation is solved implicitly

$$F_\psi = \left(1 - z_i\right)F_\psi^- + z_i F_\psi^+$$

$$F_\psi^+ = F_\psi^- + \delta F_\psi = F_\psi^- + \frac{\partial F_\psi}{\partial\psi}\delta\psi = F_\psi^- - M\left(\tilde{\psi}^+ - \tilde{\psi}^-\right)$$

Then :

$$\left(\frac{\partial\psi}{\partial t}\right)_{MF} = \frac{1}{\rho}\frac{\partial}{\partial z}\left(F_\psi^- - \underbrace{z_i M\left(\tilde{\psi}^+ - \tilde{\psi}^-\right)}_{\text{Implicit correction}}\right)$$

Implicit correction

J+1 .... $\psi(j+1)$

J+1 ———————— F_ψ M $\tilde{\psi}$

J .... $\psi(j)$

J ———————— F_ψ M $\tilde{\psi}(j) = 0.5\psi(j) + 0.5\psi(j-1)$

J-1 .... $\psi(j-1)$

Implicit treatment of the Mass Flux equation (2)

We obtain :

$$\psi^{+}(j)-\psi^{-}(j)=\frac{\Delta t}{\rho\Delta z}\Big[F_{\psi}^{-}(j+1)-F_{\psi}^{-}(j)$$
$$-z_i M(j+1)\big(0.5\psi^{+}(j+1)+0.5\psi^{+}(j)-0.5\psi^{-}(j+1)-0.5\psi^{-}(j)\big)$$
$$+z_i M(j)\big(0.5\psi^{+}(j)+0.5\psi^{+}(j-1)-0.5\psi^{-}(j)-0.5\psi^{-}(j-1)\big)\Big]$$

Grouping '+' terms in the left hand side of the equation we obtain the following tridiagonal system :

$$\psi^{+}(j+1)\left[0.5\frac{\Delta t}{\rho\Delta z}z_i M(j+1)\right]$$
$$+\psi^{+}(j)\left[1+0.5\frac{\Delta t}{\rho\Delta z}z_i M(j+1)-0.5\frac{\Delta t}{\rho\Delta z}z_i M(j)\right]$$
$$-\psi^{+}(j-1)\left[0.5\frac{\Delta t}{\rho\Delta z}z_i M(j)\right] = \psi^{-}(j)+\frac{\Delta t}{\rho\Delta z}\left(F_{\psi}^{-}(j+1)-F_{\psi}^{-}(j)\right)$$
$$+0.5\frac{\Delta t}{\rho\Delta z}z_i M(j+1)\big(\psi^{-}(j+1)+\psi^{-}(j)\big)$$
$$-0.5\frac{\Delta t}{\rho\Delta z}z_i M(j)\big(\psi^{-}(j)+\psi^{-}(j-1)\big)$$

Implicit treatment of the Eddy-Difusivity equation

Eddy Difusivity equation, $$\left(\frac{\partial \psi}{\partial t}\right)_{eddy} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left(k\frac{\partial \psi}{\partial z}\right)$$

is discretized as follows :

$$\psi^{+}(j)-\psi^{-}(j) = -\frac{\Delta t}{\rho \Delta z(j)}\left[\frac{k(j+1)}{\Delta z(j+1)}\left(\psi^{+}(j+1)-\psi^{+}(j)\right)-\frac{k(j)}{\Delta z(j)}\left(\psi^{+}(j)-\psi^{+}(j-1)\right)\right]$$

This yields to the simple tridiagonal system :

$$\psi^{+}(j+1)\left[\frac{\Delta t}{\rho \Delta z(j)}\frac{k(j+1)}{\Delta z(j+1)}\right]$$
$$+\psi^{+}(j)\left[1-\frac{\Delta t}{\rho \Delta z(j)}\left(\frac{k(j+1)}{\Delta z(j+1)}+\frac{k(j)}{\Delta z(j)}\right)\right]$$
$$+\psi^{+}(j-1)\left[\frac{\Delta t}{\rho \Delta z(j)}\frac{k(j)}{\Delta z(j)}\right] = \psi^{-}(j)$$

J+1 .... $\psi(j+1)$

J+1 ———————— $\frac{\partial \psi}{\partial z}(j+1)$

J .... $\psi(j)$

J ———————— $\frac{\partial \psi}{\partial z}(j)$

Common implicite resolution of the EDMF equation

Discretization of the full EDMF equation :

$$\left(\frac{\partial \psi}{\partial t}\right)_{edmf} = \frac{1}{\rho}\frac{\partial}{\partial z}\left(-k\frac{\partial \psi}{\partial z} + M\left(\psi_u - \overline{\psi}\right)\right)$$

Yields to the following tridiagonal system :

$$\psi^{+}(j+1)\left[\frac{\Delta t}{\rho\Delta z(j)}\left(\frac{k(j+1)}{\Delta z(j+1)} + 0.5M(j+1)\right)\right]$$

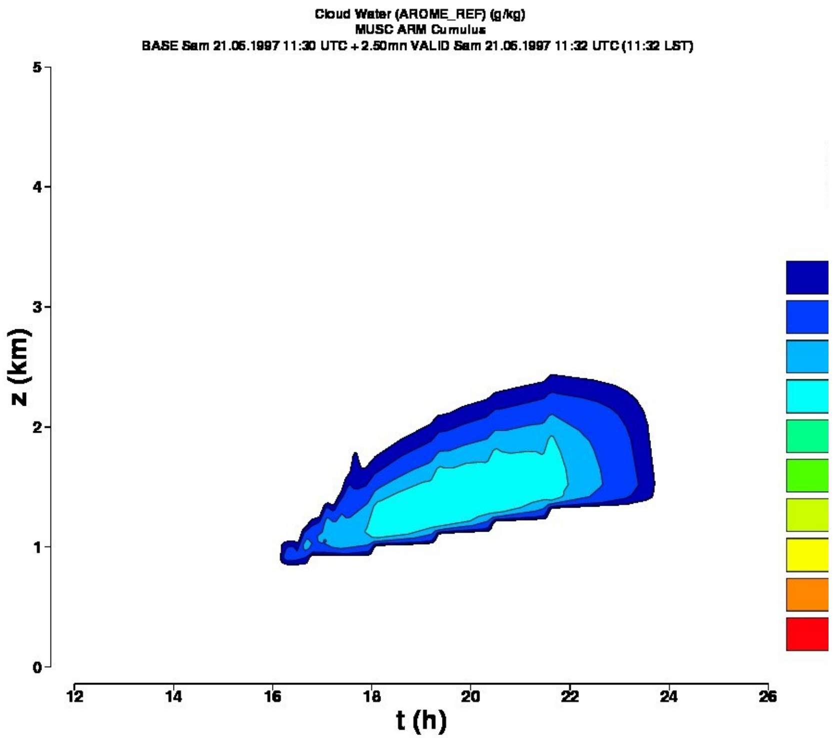
$$+\psi^{+}(j)\left[1-\frac{\Delta t}{\rho\Delta z(j)}\left(\frac{k(j+1)}{\Delta z(j+1)} + \frac{k(j)}{\Delta z(j)} + 0.5M(j+1) - 0.5M(j)\right)\right]$$

$$+\psi^{+}(j-1)\left[\frac{\Delta t}{\rho\Delta z(j)}\left(\frac{k(j)}{\Delta z(j)} + 0.5M(j)\right)\right] = \psi^{-}(j) + \frac{\Delta t}{\rho\Delta z(j)}\left(F_{\psi}^{-}(j+1) - F_{\psi}^{-}(j)\right)$$

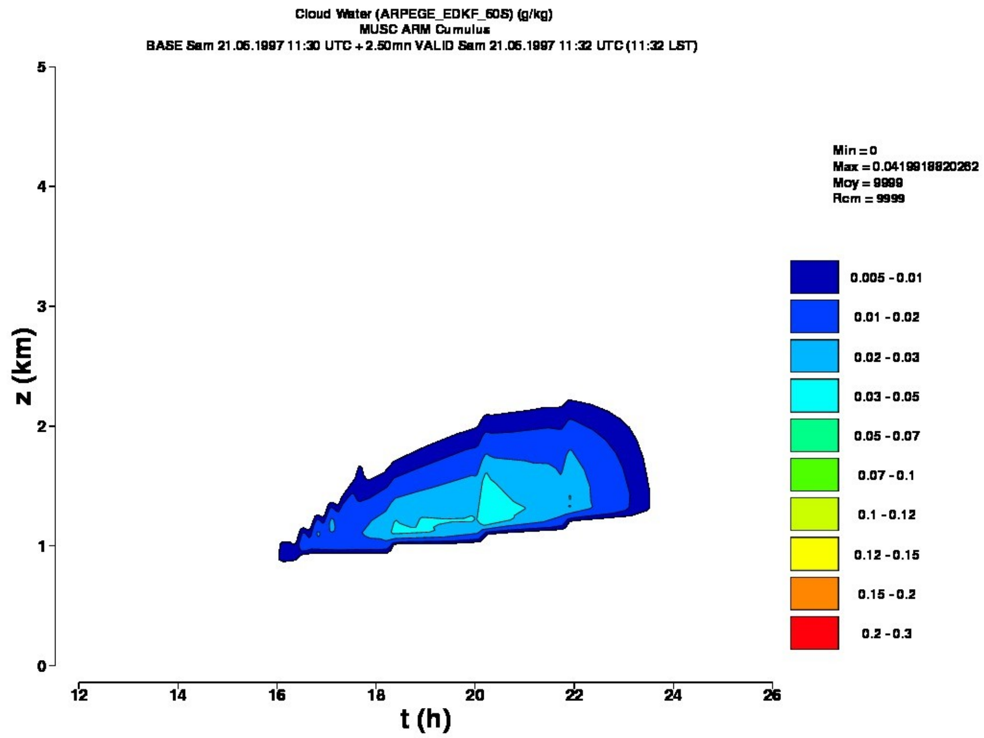
$$+0.5\frac{\Delta t}{\rho\Delta z(j)}M(j+1)\left(\psi^{-}(j+1) + \psi^{-}(j)\right)$$

$$-0.5\frac{\Delta t}{\rho\Delta z(j)}M(j)\left(\psi^{-}(j) + \psi^{-}(j-1)\right)$$

Test in 1D model using the Arm Cumulus case (1)



Cloud liquid water AROME 60s



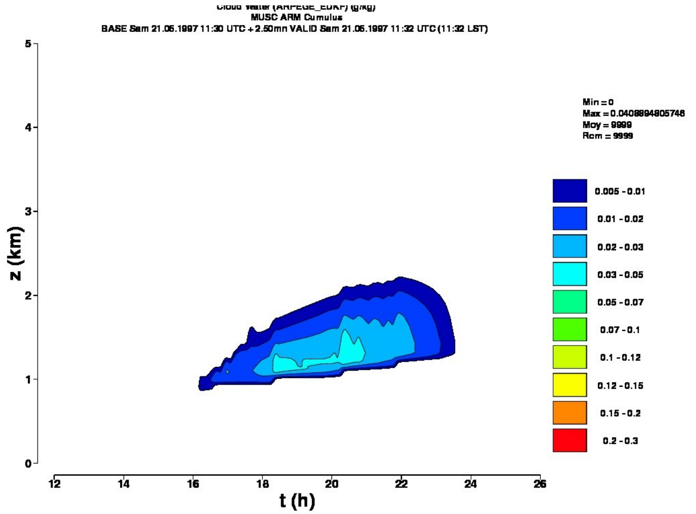
Cloud liquid water ARPEGE 60s

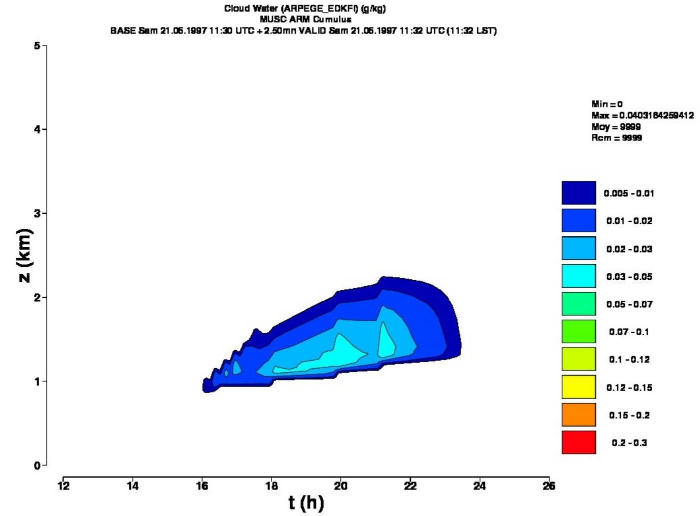
Test in 1D model using the Arm Cumulus case (2)

ARPEGE split implicit treatment

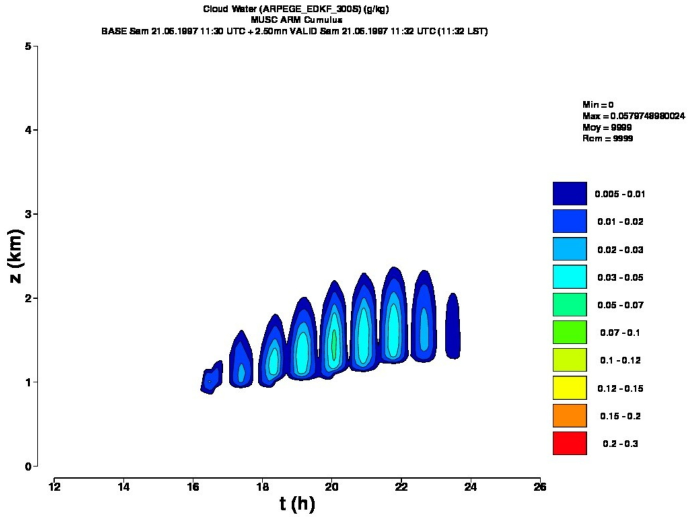
ARPEGE common implicit solution

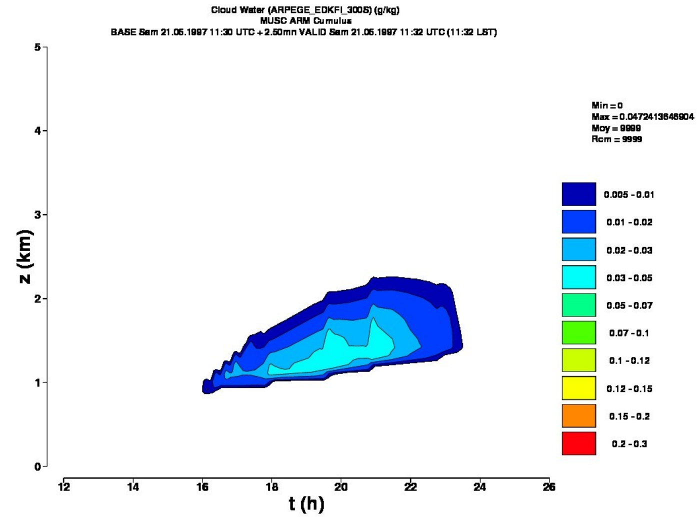
150s





300s





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