Subgrid mixing in Arome and links with the cloud representation and the microphysics

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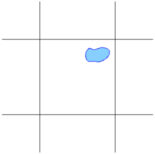
What is the question ?

- What about mixing in a model with a 2.5 km resolution ?
- What about cloud and precipitations in a model with a 2.5 km resolution ?

A few « obvious » comments (1)

- The pronostic variables are mean variables.
- There is a difference between mean and resolved : the mean may contain information from the unresolved scales (for exemple cloud, or mean effect of unresolved mixing)



$\overline{q}_c \neq 0$ but ${q_c}^{resolved} = 0$

- The subgrid of a 100 km resolution model is necessarily different from the subgrid of a 1 km resolution model.

A few « obvious » comments (2)

- The mean wind is not sufficient to describe all the mean evolution due to mixing in the grid box : we need a parametrisation of the mean effects of the subgrid mixing processes
- The mean water variables are not enough to describe correctly the mean water cycle : we need a subgrid representation of cloud + maybe a subgrid microphysics
- At mesoscale, the dynamics and the parametrised water cycle are very much interconnected.

Mean « mixing »

Numerical/conceptual scale separations

$$\boxed{\mathbf{u} = \overline{\mathbf{u}} + \mathbf{u}'}$$

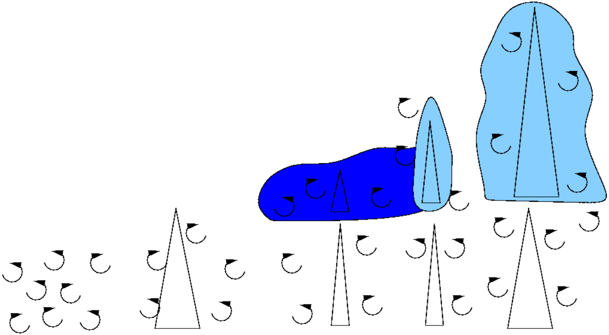
Caracteristic scales

$\frac{\partial\overline{\psi}}{\partial t} \simeq \overline{\mathbf{u}}\frac{\partial\overline{\psi}}{\partial x} \rightarrow 1/\tau \simeq U/L$

for $L = 5$ km, $\tau \simeq 10$ min

- $\overline{\mathbf{u}}$ is the mean wind in the grid box. It is representative of the flow at a scale of a few km : it may be far from geostrophic, but it does not « feel » the quickest or smallest details of the real flow.
- The mixing of the mean quantity $\overline{\psi}$ by the mean wind = horizontal and vertical advections of $\overline{\psi}$ by the mean wind.
- At 2.5 km, mean vertical advections contain a large part of the dynamics of deep convection (but not all ?).
- In Arome, the horizontal advection and the numerical diffusion are the only processes which are able to produce exchanges between horizontally adjacent grid boxes. The physics is still a « column » physics.

Subgrid mixings



$$\boxed{\overline{\rho}\frac{\partial\overline{\psi}}{\partial t}_{\,subgrid} = -\underbrace{\frac{\partial\overline{\rho w'\psi'}}{\partial z}}_{transport} + \underbrace{\overline{S'}}_{e.g.\;microphysics}}$$

The RHS terms have to be parametrised.

Diffusive turbulent mixing (1)

- Classical theory on turbulent fluxes propose solutions to solve numericaly the isotropic and homogeneous mixing by unorganized eddies (Eddy Diffusivity mixing).
- By analogy with molecular mixing, turbulent mixing coefficients are used to parametrised the diffusive fluxes :

$$\overline{\rho w'\psi'} = -K_\psi \frac{\partial \overline{\psi}}{\partial z}$$

Diffusive turbulent mixing (2)

- In Arome, $K_\psi = C_\psi l_{mix}\sqrt{\overline{e}}$.
- The mean turbulent kinetic energy $\overline{e}$ is a pronostic variable :

$$\begin{aligned}\frac{\partial \overline{e}}{\partial t} &= -\frac{1}{\rho}\frac{\partial}{\partial z}(\rho\overline{e}\,\overline{w}) - \overline{u_i' w'}\frac{\partial \overline{u_i}}{\partial z} + \frac{g}{\theta_{v\,ref}}\overline{w'\theta_v'} \\ &\quad + \frac{1}{\rho}\frac{\partial}{\partial z}(C_{2m}\rho L \overline{e}^{\frac{1}{2}}\frac{\partial \overline{e}}{\partial z}) - C_\epsilon \frac{\overline{e}^{\frac{3}{2}}}{L}\end{aligned}$$

- A parcel of air having the initial kinetic energy of its level, can travel upwards (l_{up}) and downwards (l_{down}) before being stopped by buoyancy effects :

$$\begin{aligned}\int_z^{z+l_{up}} \frac{g}{\theta_{v\,ref}}(\theta(z)-\theta(z'))dz' &= -e(z) \\ \int_{z-l_{down}}^{z} \frac{g}{\theta_{v\,ref}}(\theta(z')-\theta(z))dz' &= -e(z)\ and\ l_{down} \leq z\end{aligned}$$

$$\frac{1}{l_{mix}^{2/3}} = \frac{1}{2}\left[\frac{1}{l_{up}^{2/3}} + \frac{1}{l_{down}^{2/3}}\right]$$

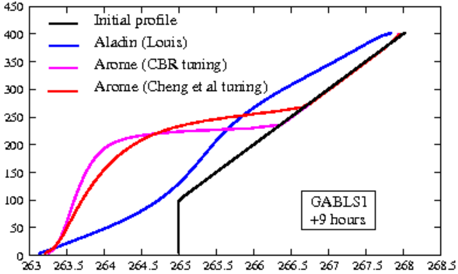
Diffusive turbulent mixing (3)

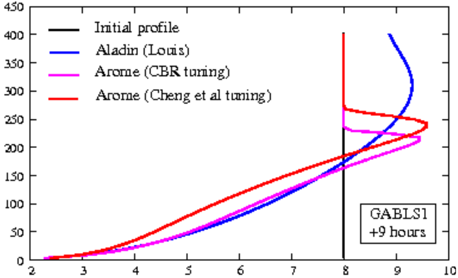
- The vertical ED mixing is written for conservative variables (if the variable is not conservative, a source terme $\overline{S'_\psi}$ has to be added in the evolution of $\overline{\psi}$) :

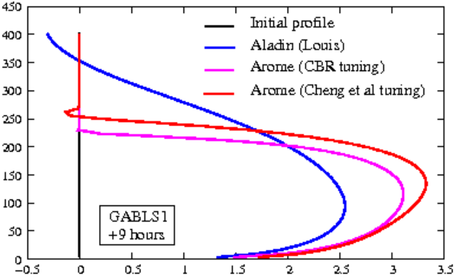
$$\overline{\rho}\frac{\partial\overline{\psi}}{\partial t}_{ED} = \frac{\partial K_\psi \frac{\partial\overline{\psi}}{\partial z}}{\partial z} + \overline{S'}$$

- In Arome, the ED mixing is computed for variables which are conservative with respect to pressure change (vertical motion) and latent heat release : the « liquid » potential temperature θ_l and the corresponding « potential » waper vapor content $q_t = q_v + q_c + q_i$.

Turbulent mixing in stable layer : GABLS1 case







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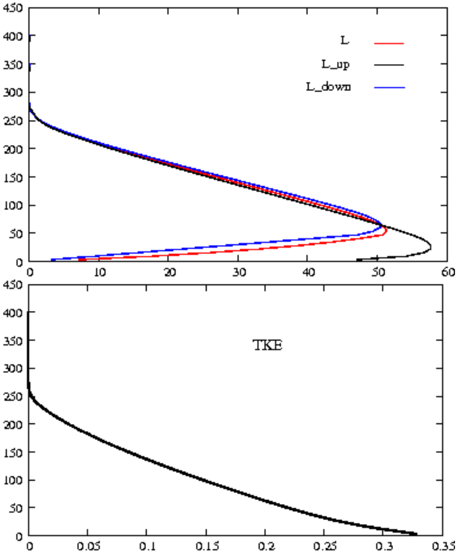
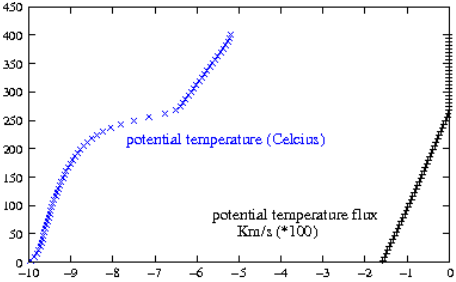
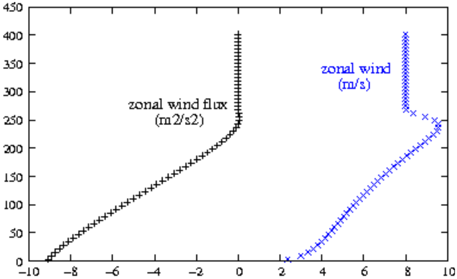
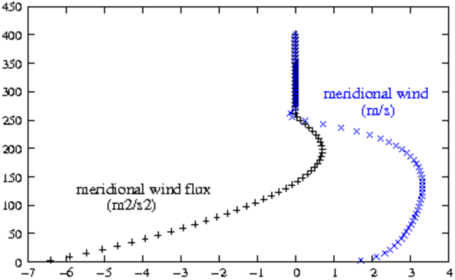


Turbulent mixing in stable layer : GABLS1 case

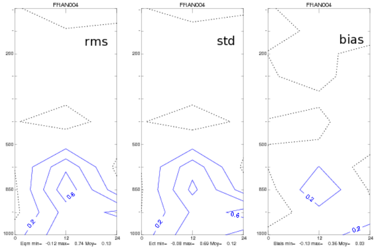




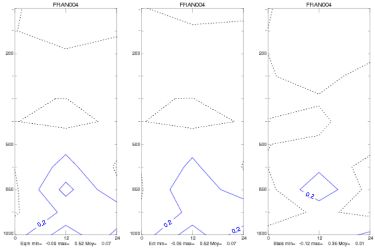


Tuning of the Arome ED TKE scheme

Winter score : (Arome-Aladin) for 1-10/11/2007



CBR tuning



Cheng et al tuning

Convective updraft mixing

- The isotropic and homogeneous mixing is not the only type of subgrid mixing which is not solved with a 2.5 km model.
- A complementary mixing is made by subgrid vertical plumes (dry or possibly cloudy).
- A classical method to parametrised the effect of these plumes is the mass flux approach :

$$\overline{\rho}\frac{\partial\overline{\psi}}{\partial t}_{MF} = -\frac{\partial M_u(\psi_u - \overline{\psi})}{\partial z} + \overline{S'_\psi}$$

where $_u$ stands for updraft characteritics, $M_u = \rho a_u w_u$ with w_u the vertical velocity of the updraft in the plume and $a_u = s_u/\overline{s}$ is the fraction covered by the updraft in the grid box.

The mass flux scheme(s) in Arome

- Specialized for (dry plumes) and shallow cumuli
- The mass flux is more representative of a PDF of convectively buoyant mass than a single updraft
- The mass flux is changing from one level to the next one because of entrainment and detrainment, but the thermodynamic characteristics of the updraft are changing only because of the entrainment (dilution with environmental air).

$$\Delta M_u = \epsilon_u - \delta_u$$

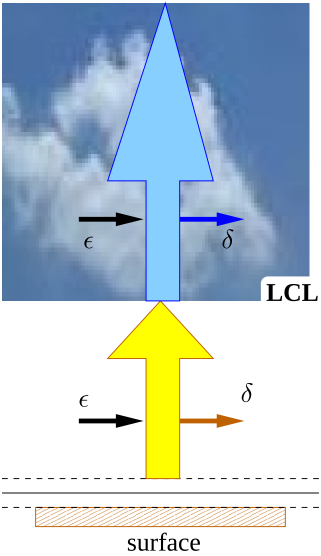
$$M_u \Delta \psi_u = \epsilon_u (\overline{\psi} - \psi_u)$$

- $\overline{w'\theta'_v}_{MF}$ is used for the thermal production of the TKE.

Mass flux schemes in test in Arome

- Prototype : Shallow convection scheme originally developped for Méso-NH (cloudy updraft only) : KFB (Bechtold et al, 2000)
- e-suite : (ED)KF (Pergaud et al, 2008, from EDMF (Soares et al, 2004)), a single updraft from the surface to the top of the dry or cloudy layer to be mixed with an original formulation for the entrainment/detrainment in the dry layer and a KF formulation in the cloudy layer.
- « DUAL » scheme from KNMI in a research branch.

One « flavour » of the MF mixing in Arome : (ED)KF (1)



In the cloudy layer (if it exists)

KF formalism (1990) with buoyancy sorting considerations for ϵ and δ.

In the dry layer

Formulations for ϵ and δ are still in test.

Updraft trigger

The characteritics of the updraft at the base are computed from the surface fluxes and the tke near the surface.

One « flavour » of the MF mixing in Arome : (ED)KF (2)

Cloud top

The cloud top is given by a classical w_u-equation

$$\Delta((w^u)^2) = \frac{2g}{1+\gamma}\left[\frac{\theta_v^{um} - \overline{\theta}_v^m}{\overline{\theta}_v^m}\right]\Delta z - 2\frac{E^u}{M^u}(w^u)^2$$

Updraft fraction/Cloud fraction

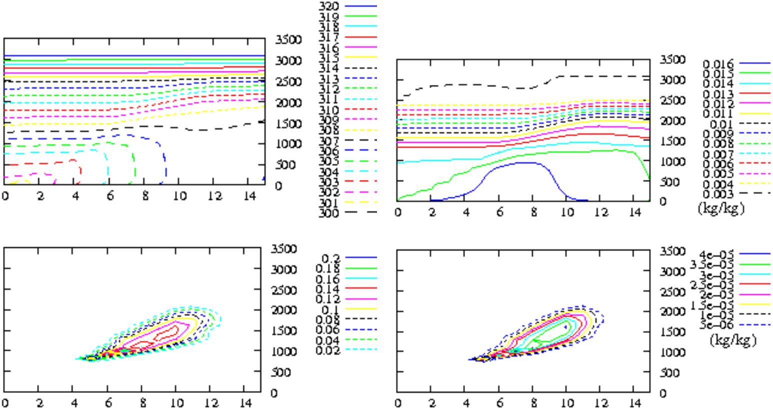
In EDKF, the mass flux M_u and the vertical velocity w_u of the updraft are computed separatly. The updraft fraction, and then, the cumulus cloud fraction may be deduced from

$$a_u = M_u/w_u$$

(In EDKF, there is no need to prescribe a priori the updraft fraction.)

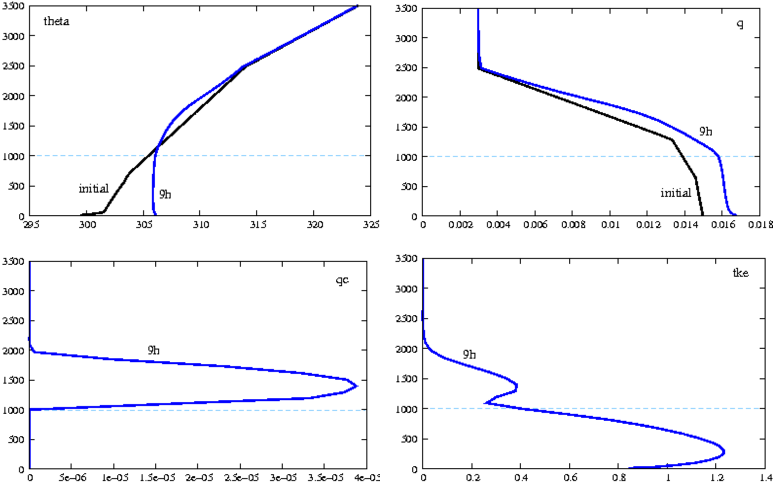
The MF mixing in a cumulus layer : Eurocs/Arm/Cu

The mean profil evolution



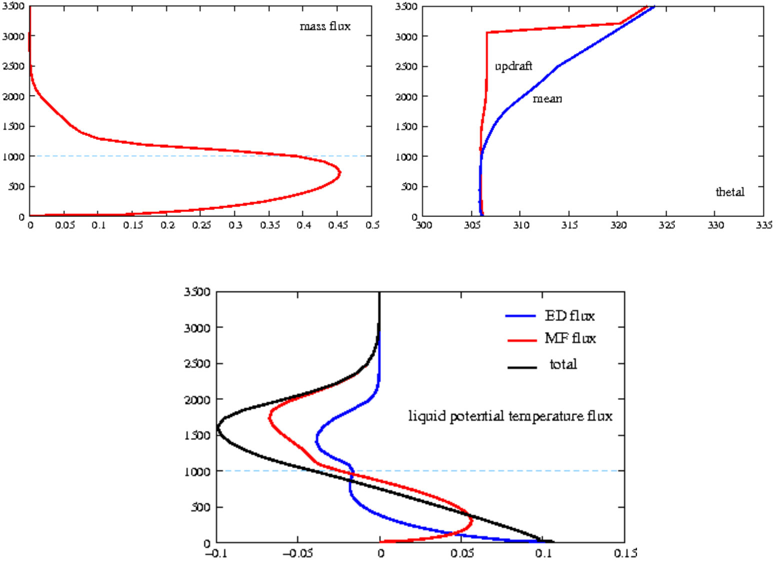
The MF mixing in a cumulus layer : Eurocs/Arm/Cu

Mean profils at 9h



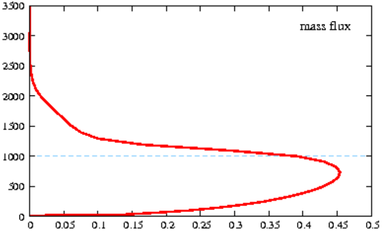
The MF mixing in a cumulus layer : Eurocs/Arm/Cu

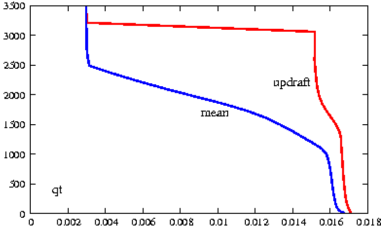
Updraft caracteristics and fluxes

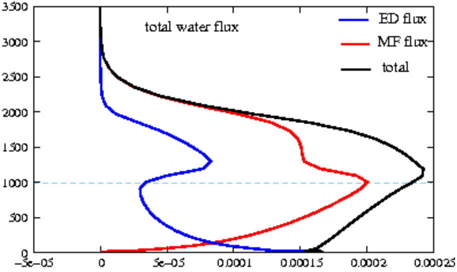


The MF mixing in a cumulus layer : Eurocs/Arm/Cu

Updraft caracteristics and fluxes







From conservative variables to « cloudy variables »

The ED and MF parametrisations are based on the mixing of conservative variables (no explicit computation of $\overline{S}'$ in the complex implicit resolution of the subgrid mixing). However, several processes need at some stage the mean temperature, the mean cloud contents and the cloud cover (all buoyancy terms, radiation ...)
You are then faced with the difficulty of describing in a grid box such a threshold process as the thermodynamic equilibrium between the 3 water phases.

The mean cloudy variables in Arome

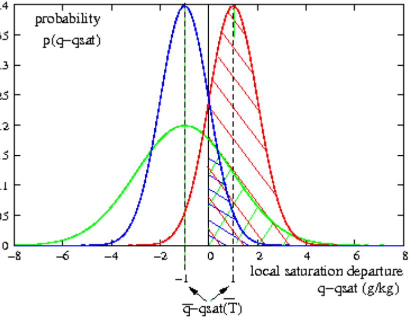
- The mean cloudy variables $\overline{T}$, $\overline{q}_v$, $\overline{q}_c$ and $\overline{q}_i$ in Arome are the **pronostic** variables. There is no « diagnostic » cloud contents for the radiation scheme for exemple.
- There is only one cloud fraction N in agreement with the total cloud contents.
- The main source of cloud in Arome is the mean vertical advection. But other processes may be at the origin of clouds : radiative cooling, ED mixing and of course subgrid cloudy plumes.

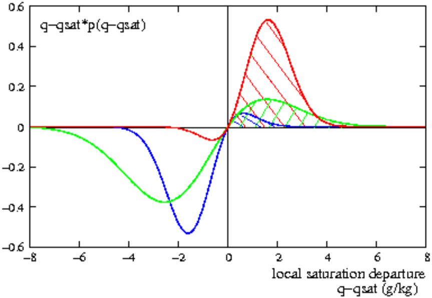
The mean cloudy variables in Arome

The current approach is that the adjustment to saturation is instantaneous (time scale much shorter than the time step) so the computation of the cloudy state at each time step is diagnostic (the real pronostic variables are the conservative variables). The cloudy state is then a pseudo-pronostic state (it is known from one time step to the other, but it is overwritten at each time step depending on the evolution of the conservative variables).

The uniform cloud scheme

In Méso-NH, the original statistical cloud scheme was strongly linked with the turbulent scheme.





$$\sigma^2 = \frac{\left(\overline{r'^2_{np}} + J^2\overline{\theta'^2_l} - 2J\overline{r'_{np}\theta'_l}\right)}{(2(1+M))^2}$$

$$Q_1 = [\bar{r}_t - r_{sat}(\overline{T})]/\sigma$$

$Q_1 > 0$ and $\sigma \simeq 0$	$N \rightarrow 1$	$\bar{r}_c \rightarrow \bar{r}_t - r_{sat}(\overline{T})$
$Q_1 > 0$ and $\sigma >> 0$	$N \rightarrow 0.5$	$\bar{r}_c$ small
$Q_1 < 0$ and $\sigma \simeq 0$	$N \rightarrow 0$	$\bar{r}_c = 0$
$Q_1 < 0$ and $\sigma >> 0$	$N \rightarrow 0.5$	$\bar{r}_c$ small

The uniform cloud scheme

A « pure » statistical scheme

A generalization of the original cloud scheme is proposed by Lenderink et Siebesma (2000) for shallow convection and by Chaboureau and Bechtold (1995) for shallow and deep convection.

$$\sigma = \sqrt{(\sigma_{turb}^2 + \sigma_{conv}^2)}$$

A combined scheme

$$\sigma = \sigma_{turb} \implies N_{stat}$$

$$a_u = M_u / w_u \implies N_{conv}$$

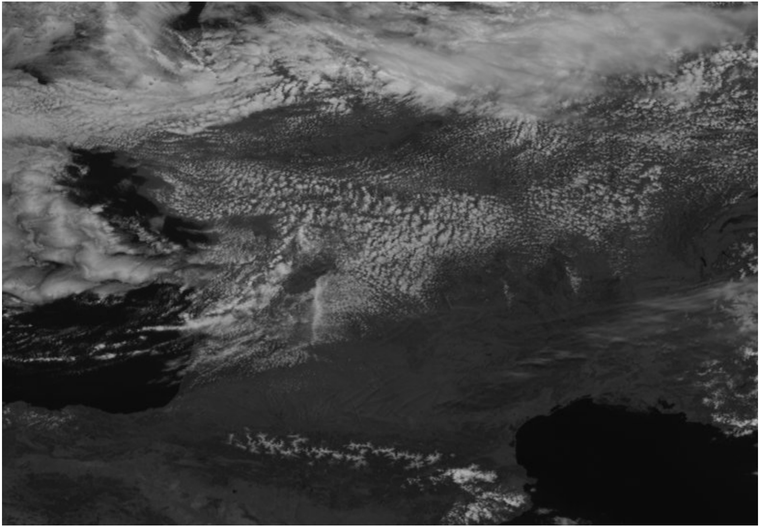
$$N_{tot} = max(1, N_{stat} + N_{conv})$$

What is currently done in Arome

- The current prototype is still running with the KFB/shallow convection scheme + a cloud scheme linked with the turbulence only.
- The e-suite is running with the mass flux scheme EDKF (Pergaud et al, 2007) and a combined cloud scheme.
- We are starting tests with a new formulation of the updraft (Pergaud et al, 2008) (less agressive in the subcloud layer in Sc situation).

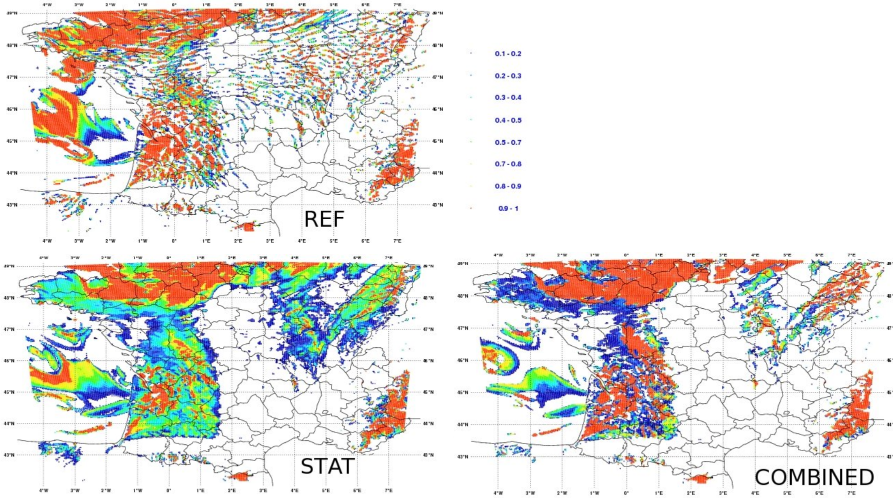
A Shallow convective day : 30/04/2006

HRV



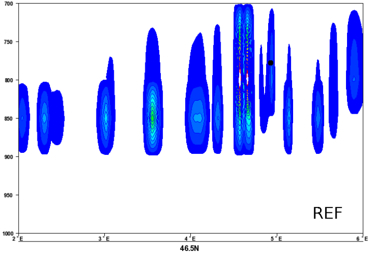
A Shallow convective day : 30/04/2006

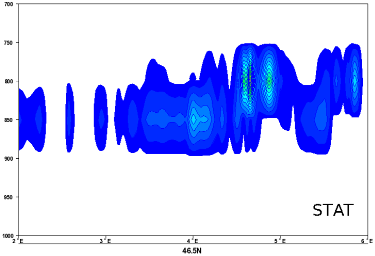
Low level cloud fraction

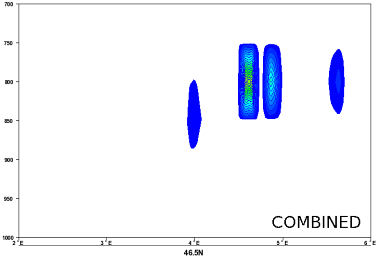


A Shallow convective day : 30/04/2006

Cloud representation

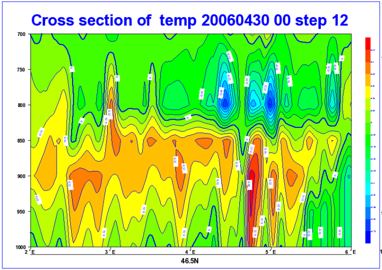


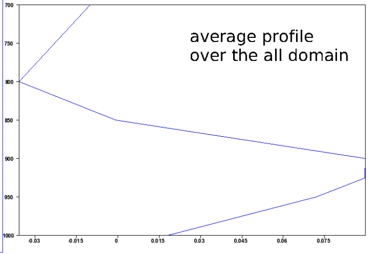




A Shallow convective day : 30/04/2006

Potential temperature — Differences between EDKF and KFB

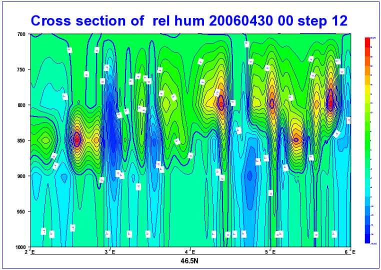


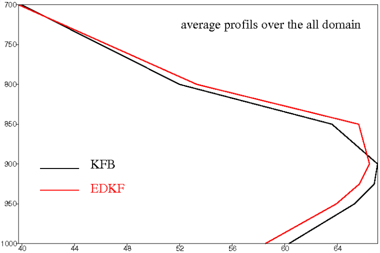


EDKF produces significantly more mixing than KFB

A Shallow convective day : 30/04/2006

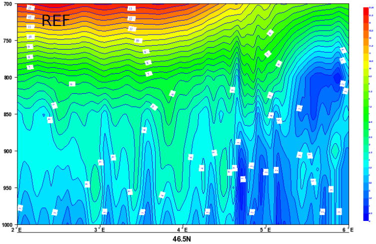
Humidity profiles — Differences between EDKF and KFB

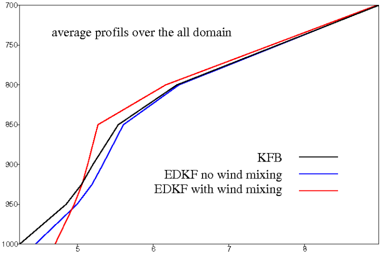


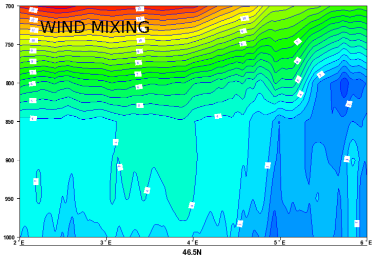


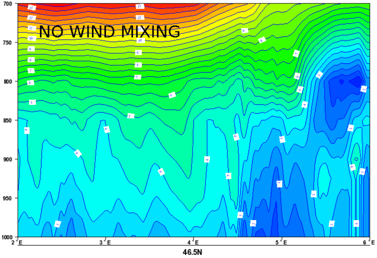
A Shallow convective day : 30/04/2006

Low level wind









A uniform microphysics of the precipitation

ICE3 in Arome

- We have now finished with ICE3 Part1 : instantaneous processes : the subgrid cloud scheme
- After the coffee break : ICE3 Part2 : finite time processes : the precipitations schemes