Modification of EDKF parametrization in the grey zone

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- Modifications:
  1) New initialization of Mass-Flux
  1bis) Randomization of the initialization by Honnert
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- Future plans
Shallow convection

- Resolved advection – treated by the dynamics
- Subgrid advection – treated by the parametrization
Grey zone problem

- The shallow convection:
  - at low resolution (dx>~2km) is parametrized
  - at high resolution (~125m>dx) is not parametrized – it is treated by the dynamics

- What happens between?

- The model’s dynamics partly resolves the shallow convection eddies, while the parametrization is still needed → GREY ZONE

- Solution: we have to find a parametrization, which is scale-adaptive → depends on the resolution
Parametrization of turbulent flux

In AROME:

• K-theory + Mass-Flux

\[
\overline{w'\phi'} = -K \frac{\partial \phi}{\partial z} + M (\phi_u - \bar{\phi})
\]

\[
M = a_u (w_u - \bar{w})
\]

Eddy Diffusion Mass-Flux
EDMF → EDKF (Kain - Fritsch parametrization)

Note: according to an other definition:

\[
\overline{w'\phi'} = -K \frac{\partial \phi}{\partial z} + \frac{M}{\rho} (\phi_u - \bar{\phi})
\]

\[
M = a_u \rho (w_u - \bar{w})
\]

- vertical velocity
- arbitrary variable
- vertical turbulent flux
- vertical gradient of \( \phi \)
- turbulent diffusion coefficient
- mean of \( w \) and \( \phi \)
- mean of \( w \) and \( \phi \) in the updraft area
- updraft area
- density
The Mass-Flux algorithm (just sketch)

- grav. acceleration
- virt. pot. temperature
- buoyancy flux at the ground [Km/s]
- Bougeault-Lacarrère upward mixing length

**INITIALIZATION**

\[
\begin{align*}
M(z_{grd}) &= XCMF^*(\frac{g}{\theta_v} \frac{w' \theta_{v grd}^l}{L_{BL89}^{1/3}}) \\
\frac{a_u(z_{grd})}{M} &= \min\left(\frac{M}{\sqrt{w_u^2}}; 0,33\right) \\
w_u^2(z_{grd}) &= \left(\frac{M}{a_u}\right)^2
\end{align*}
\]

Note: the original equations contain density

\[
\begin{align*}
1. & \quad \frac{\partial M}{M \partial z} = (\varepsilon - \delta) \\
2. & \quad \frac{\partial \phi_u}{\partial z} = -\varepsilon(\phi_u - \bar{\phi}) \\
w_u \frac{\partial w_u}{\partial z} &= aB - b\varepsilon w_u^2
\end{align*}
\]

**Upward integration:**

1. Checks if we reached the LCL (lifting condensation level)
   a) No - \(\varepsilon, \delta\) are computed by Pergaud
   b) Yes - \(\varepsilon, \delta\) are computed by Kain and Fritsch

2. Computes: \(M, w_u, \phi_u, a_u\)
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Modification (1)

\[ M(z_{grd}) = XCMF^* \left( \frac{g}{\theta_v} w' \theta'_{v \text{ grd}} L_{BL89} \right)^{\frac{1}{3}} \]

vertical velocity scale:

\[ w_* = \left( \frac{g}{\theta_v} w' \theta'_{v \text{ grd}} z_i \right)^\frac{1}{3}, \text{ if } w' \theta'_{v \text{ grd}} \geq 0 \]

Mass-Flux values in the function of \( w_* \) according to LES data

\( M = XCMF^* w_* \)

Current value in AROME

\( XCMF = 0.065 \)

Modification (1)

We used horizontal spatial means of LES ($dx = 62.5$ m, IHOP, ARM) to get the theoretical values of the tracer concentration and vert. velocity (Honnert et al. 2011).

Structure of the surface tracer conc. $\rightarrow$ estimations of Mass-Flux values (black) by the conditional sampling method:

$$P \in CS \text{ if } w > 0; \quad w > w_{\text{mean}}; \quad c - c_{\text{mean}} > c_{\text{mean}},$$

where $c$ – tracer conc., $w$ – vert. velocity.

Modification (1)

We suppose:
\[ M_{\text{resolved}}(62.5m) = M_{\text{total}} \]
\[ M_{\text{subgrid}}(dx) = M_{\text{total}} - M_{\text{resolved}}(dx) \]

Fitted function:
\[ f(x) = 0.065 \times \tanh(x \times b) \]
(idea of \tanh() \rightarrow Boutle at al. 2014)

\[ \downarrow \]
We implemented it into the code:

\[ M(z_{\text{grd}}) = 0.065 \times \tanh\left(\frac{\sqrt{dx \times dy}}{h} \times 1.86 \times \left(\frac{g}{\theta_v' \theta'_{\text{grd}} L_{BL89}}\right)^{\frac{1}{3}}\right) \]

\( M_{\text{subgrid}}/w* \) ratio at the surface as a function of \( dx/PBL \) height

To study the effect of the modification we used idealized AROME simulations - case IHOP

- Examined parameters:
  - **TKE** – turbulent kinetic energy \([m^2/s^2]\)
    - subgrid TKE \(\rightarrow\) from the history files
    - resolved TKE \(\rightarrow\) computed with:
      \[
      TKE_{res} = \frac{1}{2} [(u−<u>)^2 + (v−<v>)^2 + (w−<w>)^2]
      \]
    - total TKE = subgrid TKE + resolved TKE
  
  - **WTHV** – subgrid buoyancy flux \([Km/s]\) (vertical turbulent flux of virtual potential temperature) \(\rightarrow\) from the history files

- (model levels heights: level 60 \(\rightarrow\) ~ 10 m
  level 45 \(\rightarrow\) ~ 1116 m
  level 30 \(\rightarrow\) ~ 4004 m)
Modification (1)

Reference idealized AROME simulations:

The mean total, subgrid and resolved TKE [m²/s²]
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Reference idealized AROME simulations:

The mean subgrid buoyancy flux [Km/s]

- with EDKF
- without EDKF

- $dx = 2000m$
- $dx = 1500m$
- $dx = 1000m$
- $dx = 500m$
Modification (1)

**Differences from the reference:**

\[ h = \text{PBL height} \]

\[ h = L_{BL89} \]

Delta mean subgrid and resolved TKE \([\text{m}^2/\text{s}^2]\)
Modification (1)

Differences from the reference:

\[ h = \text{PBL height} \]

\[ h = L_{BL89} \]

Delta mean subgrid buoyancy flux [Km/s]
Modification (1bis)

Randomization of the initialization of Mass-Flux:
idea by Rachel Honnret

- The goal is to get more realistic structure of thermal-spacing
  - The dispersion of mass-fluxes in the grey zone are not independent on the resolution
  - We used Mass-Flux values in the middle of the boundary layer, when they are well developed, to estimate this relationship
  - We fitted a log-normal function on these dispersions
  - The initialized mass-fluxes are randomly perturbated in the range of this fitted function → factor RAND

\[
M(z_{\text{grad}}) = 0.065 \times \tanh\left(\frac{\sqrt{dx \times dy}}{h} \times 1.86 \times \left(\frac{g}{\theta_v} \frac{w' \theta'}{v_{\text{grad}} L_{\text{BIL89}}^3} \right)^{\frac{1}{3}} \times \text{RAND}\left(\frac{\sqrt{dx \times dy}}{h}\right)\right)
\]
Modification (1bis)

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Randomization of the initialization of Mass-Flux:

Here $M_u$ values were computed for every single point in the averaged LES fields with theoretically ideal values

Middle of the BL

$M_{\text{subgrid}}/w^*$ as a function of the $dx/(h+hc)$ – 5%, 95% quantiles, Dispersion of the $M_{\text{subgrid}}/w^*$ as a function of the $dx/(h+hc)$, The green line is the fitted log-normal function.

$\text{median, boxplot}$ – where $h$ is the PBL height, $h_c$ is the cloud layer height, when the thermals are well developed.
Modification (1bis)

Differences from the modification (1):

\[ h = \text{PBL height} \]

\[ h = L_{BL89} \]

Delta mean subgrid and resolved TKE \([\text{m}^2/\text{s}^2]\)

note: the scale Delta TKE of modification (1) was from \(-0.2\) to \(0.2\) \([\text{m}^2/\text{s}^2]\)
Modification (1bis)

Differences from the modification (1):

$h = \text{PBL height}$

Delta mean subgrid buoyancy flux [Km/s]

Note: the scale Delta wthv of modification (1) was from $-0.02$ to $0.02$ [m$^2$/s$^2$]
Structure of the vertical velocity (blue - downdraft, orange - updraft) fields at the 47. model level of the simulations with EDKF-modification (1), $dx=500 \text{ m}$ and $h = L_{BL89}$. 
Modification (2)

Decrease subgrid turbulent fluxes by Boutle at al. (2014)

- In Boutle at al. (2014) a simple solution was suggested to decrease the subgrid turbulent fluxes - based on the work of Honnert at al. (2011)
- The subgrid turbulent fluxes are multiplied by the coefficient $Z_{PLAV}$ which depends on the normalized resolution:

$$Z_{PLAV} = \frac{X^2 + 0.19 \times X^{2/3}}{X^2 + 0.15 \times X^{2/3} + 0.33}$$

$$X = \frac{\sqrt{dx \times dy}}{L_{BL89}}$$
Modification (2)

Differences from the reference:

- subgrid TKE
- resolved TKE
- $dx = 2000m$
- $dx = 1500m$
- $dx = 1000m$
- $dx = 500m$

$\Delta TKE \, [m^2/s^2]$

$\Delta \text{wthv} \, [K*m/s]$
Modification (3)

New set of equations for the Mass-Flux paramertization by Rachel Honnert

\[ w' \theta'_{MF} = M(\theta_{lu} - \bar{\theta}) \frac{1}{1-\alpha} \]

\[ w' r'_{MF} = M(r_{lu} - \bar{r}) \frac{1}{1-\alpha} \]

\[ \alpha = \frac{M}{w_u - w} \]

\[ \frac{1}{M} \frac{\partial M}{\partial z} = \varepsilon - \delta \]

\[ \frac{1}{2} \frac{\partial (w_u - \bar{w})^2}{\partial z} = -\varepsilon (w_u - \bar{w})^2 \frac{1}{1-\alpha} - (w_u - \bar{w}) \frac{\partial \bar{w}}{\partial z} + B_u - B - (P_u - P) - \frac{1}{\alpha} \frac{\partial \alpha w'^2 \bar{u}}{\partial z} \]

\[ B = g \times \frac{\theta_{vu} - \bar{\theta}_v}{\bar{\theta}_v} \]

\[ \theta_{vu} = f(\theta_{lu}, r_{lu}) \]

\[ \frac{\partial \theta_{lu}}{\partial z} = -\varepsilon (\theta_{lu} - \bar{\theta}_l) \frac{1}{1-\alpha} \]

\[ \frac{\partial r_{lu}}{\partial z} = -\varepsilon (r_{lu} - \bar{r}_l) \frac{1}{1-\alpha} \]

- The new mass-flux equations do not neglect the resolved vertical velocity and the subgrid thermal fraction

\( \bar{\theta}_l \) is the liquid potential temperature, \( r_t \) is the total water content, \( \theta_v \) is the virtual potential temperature, \( \alpha \) is the thermal area, the overline means the spatial average (with \( u \) it means over the thermal area), \( \varepsilon \) is the entrainment, \( \delta \) is the detrainment, \( B_u \) is the buoyancy and \( P_u \) is the pressure
Modification (3)

Differences from the reference:

- subgrid TKE
- resolved TKE
- $dx = 2000\text{m}$
- $dx = 1500\text{m}$
- $dx = 1000\text{m}$
- $dx = 500\text{m}$

Delta TKE [m$^2$/s$^2$]

Delta wthv [K*m/s]
Modification (3)

Differences from the reference WITHOUT EDKF:

- subgrid TKE
- resolved TKE

EDKF-noEDKF

Delta TKE [m²/s²]

Delta wthv [K*m/s]

dx = 2000m
dx = 1500m
dx = 1000m
dx = 500m
Future plans

- Make idealized AROME simulations with ARM case too

- Try modification (1) with an other coefficient value and examine the effect

- Validate modification (1) via LES MesoNH simulations – case IHOP and ARM

- Validate modification (1) via real cases
Thank you for your attention!

References:


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