Mass-flux parameterization in the shallow convection gray zone

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1) Introduction

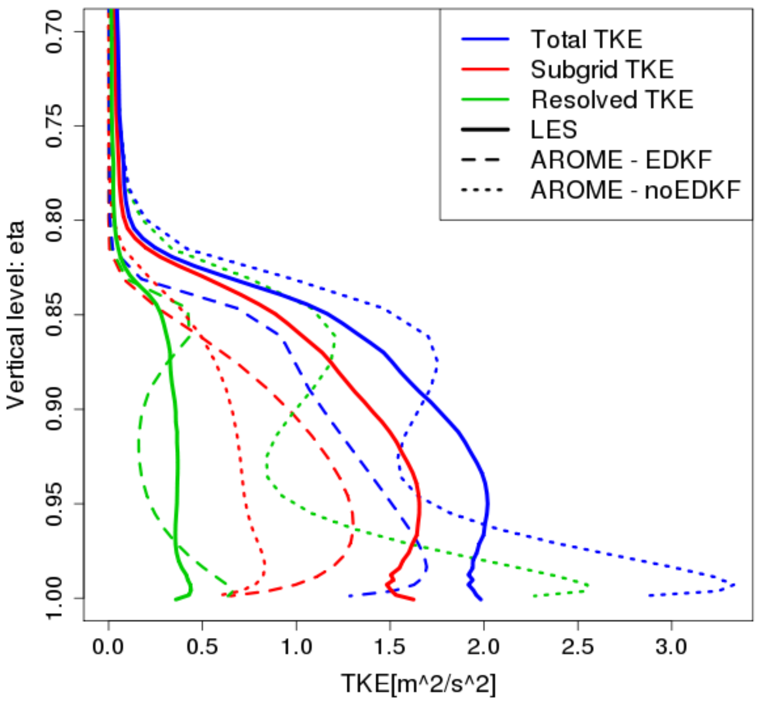
The shallow convection gray zone problem in the numerical weather simulation appears at those horizontal resolutions, where the non-local eddies in the planetary boundary layer are partly handled by the model's dynamics, however the parameterization of the vertical fluxes caused by these non-local eddies is still needed. On the first part of this stay (which took place in March 2014) we examined this problem by using idealized AROME (Application of Research to Operations at MesoscalE) runs.

On the second part (in September 2014) we were looking for a possible upgrade for the mass-flux parameterization, which is currently used in the AROME, namely the EDKF (Eddy Diffusion and mass-flux parameterization with Kain and Fritsch approach). We used MesoNH LES (large-eddy simulation) data from two ideal cases, to compute mass-flux values. The two cases were: IHOP (International H_2O Project) and ARM (Atmospheric Radiation Measurement Program). Both of them were evaluated in Honnert at al. (2011), which from we took much inspiration in our work.

These mass-flux data were then examined to see, how the parameterization of the shallow convection should work at different resolutions.

2) Gray zone problem in AROME

The research of the shallow convection gray zone problem in AROME continued after the first part of this stay. After gradually improving our idealized AROME runs, we can now show a better picture about the behaviour of the model in the PBL (planetary boundary layer).



1) The vertical cross section of the horizontally averaged subgrid (red), resolved (green) and total (blue) TKE [m^2/s^2] at the end of the simulations from AROME [dx = 1000 m] with EDKF (dashed line) and without EDKF (dotted line) and MesoNH LES [dx = 62.5 m averaged to 1000 m] (solid line) at the end of the simulation in the PBL.

In figure *1)* we can see the comparison of the TKE (turbulent kinetic energy [m^2/s^2]) values of the idealized AROME runs (with and without EDKF) and the MesoNH LES run of the IHOP case in the PBL at the end of the simulation (415 minutes for the AROME, 420 minutes for the MesoNH). The AROME cases were run at dx = 1000 m horizontal resolution and the LES at dx = 62.5 m, but the LES outputs were averaged to 1000 m horizontal resolution, so it can be used as an ideal model to compare with.

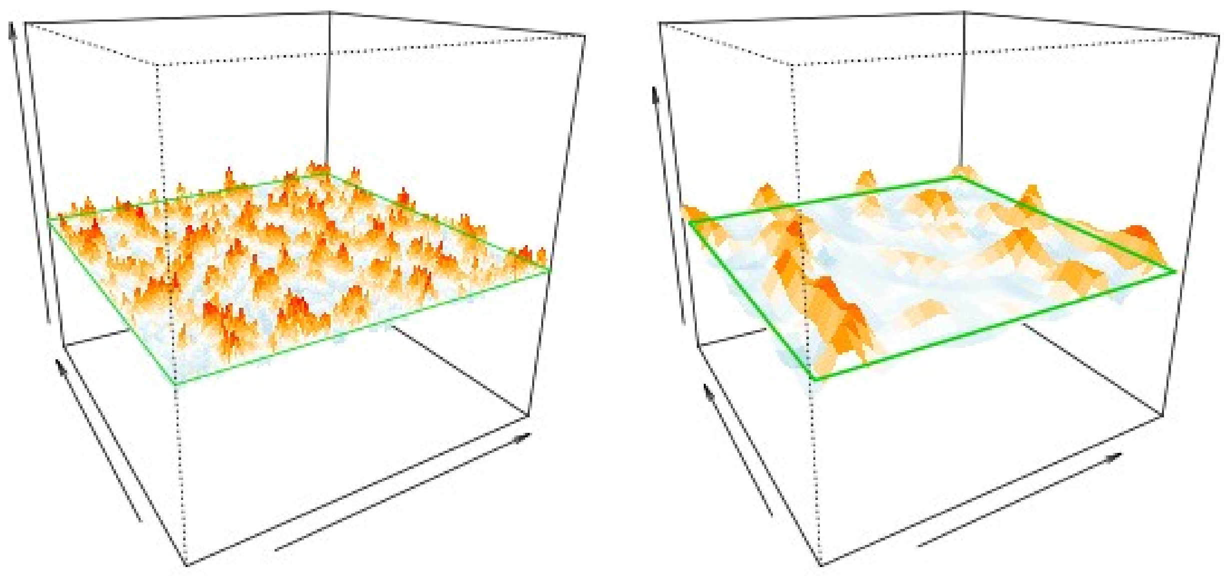
In the case of the LES the total TKE is the sum of the subgrid and the resolved TKE from the 62.5 m run, where the subgrid TKE comes from the parameterization and the resolved TKE is computed by the equation

$$TKE_{res}=\frac{1}{2}[(u-\langle u\rangle)^2+(v-\langle v\rangle)^2+(w-\langle w\rangle)^2] \quad ,$$

where u,v are the horizontal wind components [m/s], w is the vertical velocity [m/s] and the $\langle\ \rangle$ symbol means the average in space for the given vertical level. This total TKE at 62.5 m horizontal resolution is used as a reference total TKE for the averaged case (seen in figure *1)*). For the averaged case the resolved TKE is computed from its averaged velocity field (the same way as in the case of the LES) and the subgrid TKE is the difference between the total and resolved TKE.

In the case of the AROME runs the subgrid TKE comes from the parameterization, the resolved TKE is computed the same way as in the case of the LES and the total TKE is the sum of them.

In the comparison of the TKE values we can see that the AROME runs did not simulate perfectly the PBL, neither with nor without the EDKF. However, we can say that with the EDKF the model predicted a better ratio between the resolved and subgrid TKE.



2) The structure of the vertical velocity field in the PBL at the end of the simulation of IHOP case. Left: from MesoNH LES [dx = 62.5 m]. Right: AROME [dx = 500 m, without EDKF].

We can also notice in figure *1)* two maximums in the resolved TKE of the AROME which represents the resolved large eddies in the PBL. At the top end the bottom of the eddy the variance of the horizontal wind components are bigger than in the middle, while for the vertical velocity it is conversely. Because the horizontal wind components add the bigger part at the computation of the resolved TKE, the resolved eddies can be detected in its profile. However in the LES resolved TKE profile these maximums can't be seen. That is because the LES resolves the eddies in the PBL in a wide range including the smaller ones, which maximums smooth the resolved TKE profile. The coarse mesh of the AROME does not allow to simulate these small eddies as it shows in figure *2)*, where we can compare the vertical velocity structure of the IHOP case in the PBL at the end of the simulation from the LES (dx = 62.5 m) and from the AROME (dx = 500 m, without EDKF).

In the future we plan to study not only the TKE but the vertical fluxes of temperature and humidity too, which are more important in the weather prediction.

3) The EDKF parameterization

The EDKF parameterization is meant to handle the vertical fluxes caused by the shallow convection. It assumes that in the grid-box is a thermal, whose effect in the vertical turbulent flux equation for the arbitrary variable ϕ is described by the second term on the right side (Siebesma et al. 2007):

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

where $\overline{w'\phi'}$ is the vertical turbulent flux [m/s] of the variable ϕ, K is the turbulent diffusion coefficient [m^2/s], $\frac{\partial\overline{\phi}}{\partial z}$ is the vertical gradient of $\overline{\phi}$, the over-line means the spatial average in the grid-box and the *u* index the variables in the updraft zone. The *M* is the mass-flux value [m/s] and it is defined by the equation

$$M \equiv a_u(w_u - \overline{w}) \quad ,$$

where a_u is the updraft fraction area.

The EDKF parameterizations algorithm follows Pergaud et al. (2009) work. It begins with the initialization of the *M*, w_u, a_u, and ϕ_u variables at the surface and then integrates them upward until the *M* or the w_u disappears. For the upward integration of the mass-flux, the conservative ϕ_u variable and the updraft vertical velocity are used these equations:

$$\frac{1}{M}\frac{\partial M}{\partial z} = (\epsilon - \delta) \quad ,$$

$$\frac{\partial \phi_u}{\partial z} = -\epsilon(\phi_u - \overline{\phi}) \quad \text{and}$$

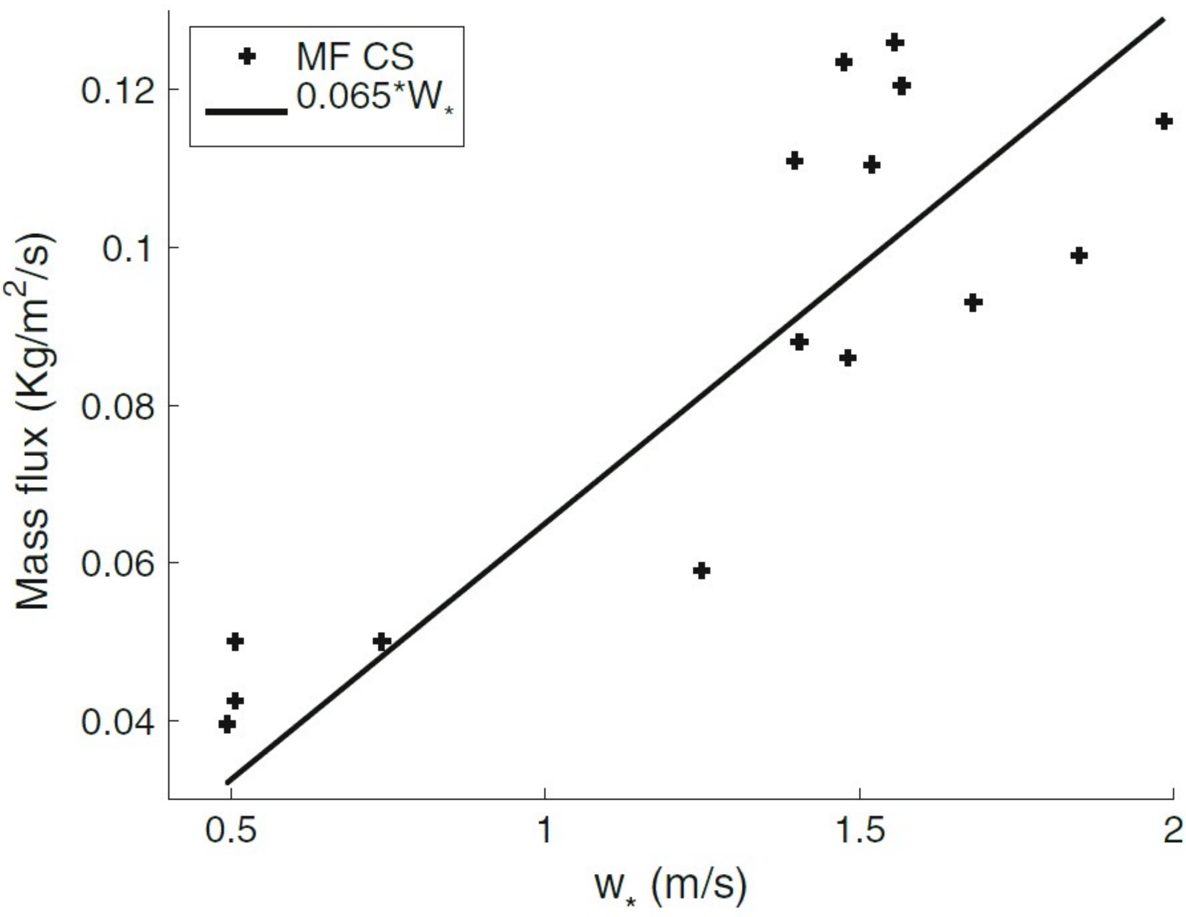
$$w_u\frac{\partial w_u}{\partial z} = B_u - \epsilon w_u^2 - P$$

where ϵ and δ are respectively the entrainment and detrainment [1/m], B_u is the buoyancy [m/s^2] and *P* represents the pressure term [m/s^2].

Our proposal of the modification of the EDKF algorithm applies to the initialization of the mass-flux value at the surface $M(z_{grd})$. The currently used equation for this is

$$M(z_{grd}) = C_M \left(\frac{g}{\overline{\theta_{vref}}} \overline{w'\theta'_{vs}} L_{up} \right)^{1/3}$$

where g is the gravity acceleration [m/s^2], $\overline{\theta_{vref}}$ is the mean virtual temperature [K], $\overline{w'\theta'_{vs}}$ is the surface buoyancy flux [Km/s] and L_{up} is the Bougeault and Lacarrère upward mixing length [m] (Note: in the original equation the right side is multiplied by the density, because in Pergaud et al. (2009) work the mass-flux is defined with the ρ [kg/m^3] density: $M \equiv \rho a_u w_u$ and the mean vertical velocity is neglected). The C_M coefficient value is 0.065 and it was estimated from LES results using the conditional sampling method. Pergaud et al. (2009) examined the mass-flux values at the surface as the function of the w_* vertical velocity scale (figure *3)*) and from this relation the C_M value was obtained.



3) Pergaud et al. (2009): The mass-flux values in the surface layer obtained by conditional sampling from LES results as the function of the vertical velocity scale.

The goal of this work is to propose an other value for the C_M coefficient, which would not be independent from the horizontal resolution of the model. In this way, the EDKF could work better in the shallow convection gray zone.

4) The conditional sampling

We used the conditional sampling (CS) based on the one, described by Couvreux et al. (2009), to receive the mass-flux values at the surface from the IHOP and ARM cases simulated by the MesoNH. In this method we checked every grid-point in the LES models mesh and by using a condition, we chose which belongs to a thermal, i.e. has a mass-flux value, and which is part of the environment. The condition we used is

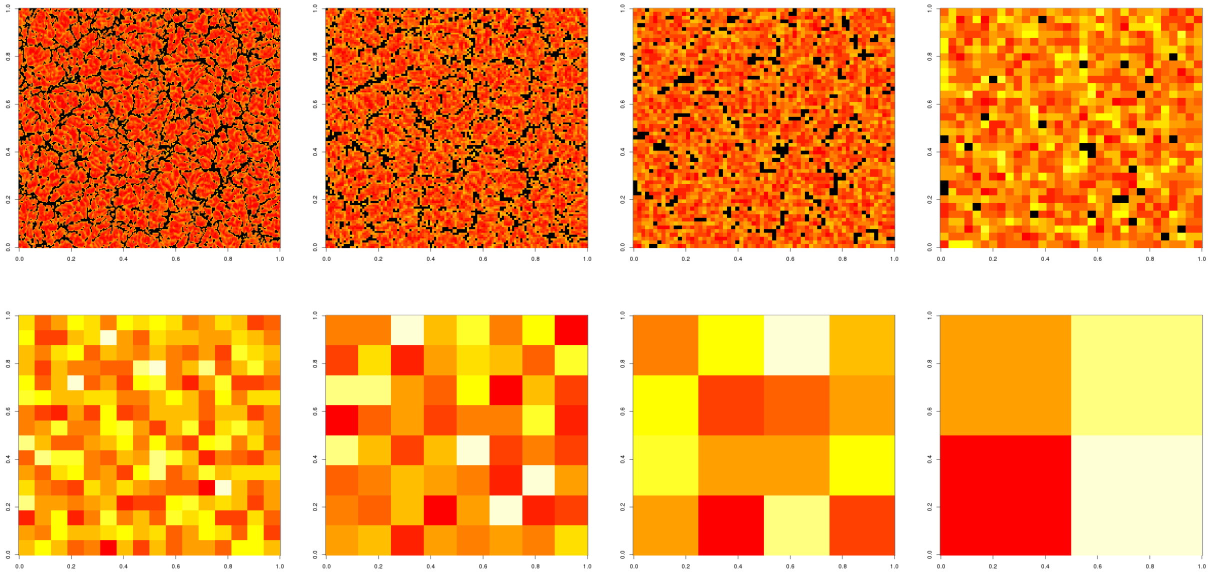
$$Gridpoint \in CS\; sv - \langle sv \rangle > m \times \sigma_{sv} \wedge w > 0 \wedge w > \langle w \rangle \quad ,$$

where *sv* is the tracers concentration, σ_{sv} is the standard deviation of the tracers concentration and *m* is a scaling parameter, which we set in every case *m* = 1. The tracer has a constant surface flux and it disappears with a radioactive decay. The mass-flux value was determined by the equation

$$M_{LES} = \frac{N_{CS}}{N} \sum_{i \in CS} \left(w_i - \langle w \rangle \right) \quad ,$$

where N_{CS}/N, playing the role of the updraft fraction area, is the ratio of grid-point-numbers of the conditional sampling and number of all grid-points of the LES mesh. The horizontal grid-size of the LES was 62.5 m and we assume that at this resolution all non-local eddies are resolved, so the M_{LES} can be considered as the reference mass-flux value. Then we prepared from the LES fields the averaged fields with 125, 250, 500, 1000, 2000, 4000, 8000 m resolutions, just as in Honnert et al. (2011), and using the same conditional sampling, we computed the resolved mass-flux values (figure *4)*):

$$M_{resolved}(dx) = \frac{N_{CS}(dx)}{N(\Delta x)} \sum_{i \in CS} \left(w_i(dx) - \langle w \rangle \right) \quad .$$

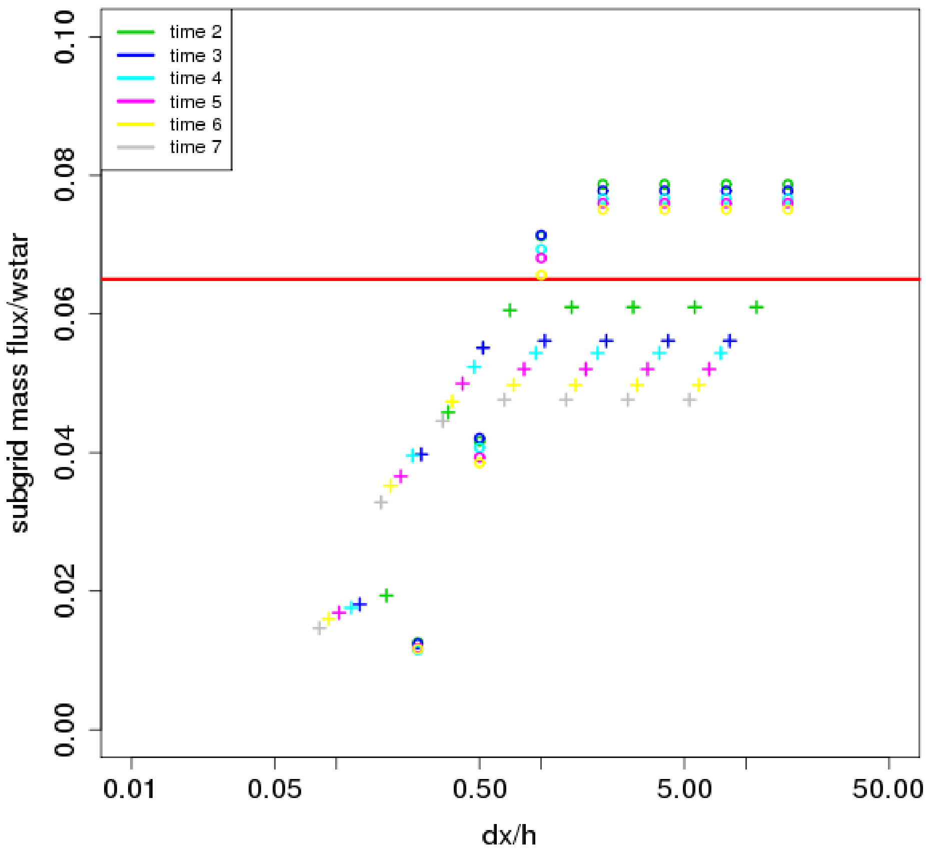


4)The structure of the tracer's concentration in the surface layer and the mass-flux fields (black) obtained by conditional sampling in the LES (62.5 m) and averaged fields (125, 250, 500, 1000, 2000, 4000, 8000 m) in IHOP case at the end of the simulation.

The subgrid part of the mass-flux was obtained as the difference between the reference mass-flux and the resolved mass-flux at various resolutions:

$$M_{subgrid}(dx) = M_{LES} - M_{resolved}(dx) \quad .$$

This way we got the part of the initial mass-flux at the surface, which should be parametrized. We plotted the ratio of these subgrid mass-flux and the vertical velocity as a function of the ratio of the horizontal grid-size and the boundary-layer height (*dx/h*) in figure *5)*.



5) The ratio of subgrid mass-flux and the vertical velocity as a function of the ratio of the horizontal grid-size and the boundary-layer height from the ARM (○) and IHOP (+) case at different times. The red line shows the currently used C_M = 0.065 value.

4) Summary and future plans

In our work we examined how the initial mass-flux at the surface depends on the horizontal resolution. We used the conditional sampling method to receive mass-flux from LES results. As in figure *5)* can be seen, the currently used C_M = 0.065 value is not appropriate for the resolutions in the gray zone.

The assumption, that at 62.5 m grid-size all non-local eddies are resolved have to be verified. For this reason we want to check it by comparing the $M_{LES}(62.5\ m)$ with the resolved mass-flux from an LES at 31.25 m resolution. It would be also good to try more idealized cases and more types of conditional sampling method to examine the initial mass-flux values at high resolution.

In the future we plan to parametrize the relation between the C_M coefficient and the resolution and insert it in the AROME, then this new method must be tested and validated. We also have to rethink every assumption made at EDKF parameterization, because some of them may not be valid at the high resolutions in the gray zone.

5) Acknowledgment

I want to thank for all the help I got in Toulouse at CNRM, especially to Rachel Honnert, who leaded my work there.

6) References

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