A first Case Study of 3-Dimensional Turbulence with full Metrics in the Very Short Range Forecast Model LMK

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1 Introduction

At the Deutscher Wetterdienst the numerical weather forecast model LMK (LM-Kürzestfrist) is currently under development. It is based on the LM (Lokal-Modell) and will be used for very short range forecasts (up to 18 hours) and with a resolution on the meso-γ-scale (about 2.8 km). The development tasks cover the areas of data assimilation, numerics, physical parameterisations, and new verification approaches.

In Baldauf (2005a) the formulation of the turbulent fluxes and flux divergences in terrain following coordinates and for spherical base vectors was derived. The result for the scalar flux divergence is

$$\rho \frac{\partial s}{\partial t} = \underbrace{-\frac{1}{r\cos\phi}\frac{\partial H^{*1}}{\partial \lambda}}_{(a)} \underbrace{-\frac{J_\lambda}{\sqrt{G}}\frac{1}{r\cos\phi}\frac{\partial H^{*1}}{\partial \zeta}}_{(b)} \underbrace{-\frac{1}{r}\frac{\partial H^{*2}}{\partial \phi}}_{(c)} \underbrace{-\frac{J_\phi}{\sqrt{G}}\frac{1}{r}\frac{\partial H^{*2}}{\partial \zeta}}_{(d)} \underbrace{+\frac{1}{\sqrt{G}}\frac{\partial H^{*3}}{\partial \zeta}}_{(e)} \underbrace{-\frac{2}{r}H^{*3}}_{(f)} \underbrace{+\frac{\tan\phi}{r}H^{*2}}_{(g)}, \quad (1)$$

and for scalar fluxes:

$$H^{*1} = -\rho K_s \frac{1}{r\cos\phi}\left(\frac{\partial s}{\partial \lambda} + \frac{J_\lambda}{\sqrt{G}}\frac{\partial s}{\partial \zeta}\right), \quad H^{*2} = -\rho K_s \frac{1}{r}\left(\frac{\partial s}{\partial \phi} + \frac{J_\phi}{\sqrt{G}}\frac{\partial s}{\partial \zeta}\right), \quad H^{*3} = +\rho K_s \frac{1}{\sqrt{G}}\frac{\partial s}{\partial \zeta}. \quad (2)$$

(Analogous expressions for the 'vectorial' diffusion of u, v and w). The terms (a), (c) and (e) in equation (1) describe the cartesian components of the flux divergence and are already contained in the 3D-turbulence scheme of the Litfass-LM (Herzog et al., 2002), which was implemented into the LMK code (Förstner et al., 2004). The (new) metric terms (b) and (d) describe corrections due to the terrain following coordinate. The terms (f) and (g) are due to the earth curvature and can be neglected with good approximation.

2 Implementation and test of the metric terms

The horizontal cartesian terms (a) and (c) are discretised explicitely whereas the vertical cartesian term (e) is in implicit form to consider the fact that the stability criterion can be violated in the case of small vertical level distance or large diffusion coefficients. The metric terms (b) and (d) are some sort of horizontal correction due to the terrain following coordinate system and therefore the first attempt for their discretisation is also in explicit form. For the upper and lower boundaries all the centered differences were replaced by one-sided differences (for fluxes and flux divergences).

The correct discretisation of the 3D-turbulence and especially the metric terms was tested by the analytically well known isotropic diffusion of a Gaussian inital tracer distribution and with a constant diffusion coefficient. A comparison with the simulation of such a tracer cloud in the terrain-following grid, which is destorted by orography, showed the correct implementation of all the metric terms (Baldauf, 2005b).

3 A real case study

To inspect the importance of 3D-turbulence and especially the metric terms a first real case study was performed. The simulation was started at the 12. August 2004, 12 UTC and lasted 18 h. This was a strong convective situation with the development of a squall line. Three cases: (1) only 1D (vertical) turbulence, (2) 3D-diffusion without metric terms, and (3) 3D-diffusion with metric terms, were carried out. The simulations were performed with the 'standard' LMK horizontal resolution of 2.8 km and a time step of 30 sec. As in the idealized diffusion test, the explicit discretisation of the metric terms did not generate any stability problems.

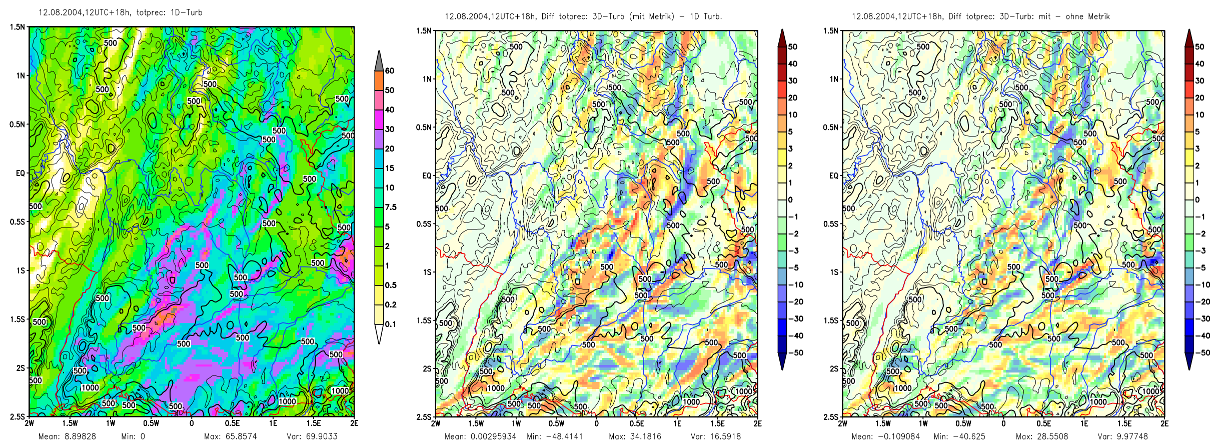

Figure 1: Left: Total precipitation sum over 18h for the 12.08.2004, 12 UTC run with the currently used 1D turbulence. Differences of the 18h precipitation sum between 3D-turb. with metric terms and 1D-turb. (middle), and between 3D-turb. with and without metric terms (right).

Figure 1 (left) shows the precipitation sum after 18 h simulation time over Southern Germany. This area was chosen, because during the simulation time the precipitation event travelled completely over this area and lied outside of it at the end of the simulation. Therefore in the following difference plots, we can be sure, that the differences do not alter because of new precipitation events. Figure 1 (middle) shows a difference plot between case 3 (complete 3D-turbulence) and case 1 (only vertical turbulence). The differences can reach maximum and minimum values nearly at the same order as the precipitation sum itself. But the mean value shows, that the 3D-turbulence has almost no influence to the total amount of precipitation. This seems to be reasonable, as turbulence occurs mostly in the boundary layer, whereas the most part of precipitation is generated above. But the transport of precipitation (especially with the prognostic precipitation scheme, which is unconditionally necessary at this resolution) is heavily influenced by the boundary layer flow. The 18h-precipitation sum is a marker of all these integrated flow changes due to 3D-turbulence. These effects can lead to shifts of the precipitation areas up to 20-30 km, which is a non-neglectable effect e.g. for hydrological applications. Of course further work has to be done to inspect if this influence can be seen also in other weather situations.

The effect of the metric terms themselves is shown in Figure 1 (right), the difference between case 3 (with metric terms) and case 2 (without metric terms). The maxima and minima are slightly smaller, but obviously they cannot be neglected in comparison to case 2 (this was already theoretically derived in Baldauf, 2005a). The mean value of the difference 'case 1 - case 3' is even smaller as in the difference 'case 2 - case 3'. If one accepts the statement, that 3D-turbulence does not alter the total amount of precipitation, then the metric terms obviously have a positive impact on the conservation of total precipitation amount, too.

References

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