A two timelevel integration scheme for the nonhydrostatic Lokal-Modell (LM) of DWD

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The current three timelevel integration scheme for the LM has several disadvantages and should be improved or even replaced by an other scheme. The main drawbacks are its low order of approximation for advection, its need for a relatively large number of small time steps for the fast waves integration, its need of the Asselin time filter and its incompatibility to any positive definite advection scheme desired for the moisture variables.

Split-explicit time integration schemes split slow and fast terms of the equations and treat the fast sound and gravity wave terms with a shorter timestep than the others. During this short time step integration, the advective or slow tendency remains a constant. Besides the three time level scheme of Klemp and Wilhelmson (1978)[1] which is used in the operational LM a two timelevel scheme was presented by Wicker and Skamarock (1998)[2]. But this scheme has the disadvantage that it only works in connection with a Runge-Kutta scheme of second order in time and its stability properties are not excellent.

A new scheme works only a bit different than that of Wicker and Skamarock (1998). First, it integrates only the fast wave terms until the center of the time step and one gets result values ϕ^*. Second, from this ϕ^*-values advective tendencies are computed. These might be calculated with any stable two timelevel advection scheme. In a short notation they read as

$$\left(\frac{\partial \phi}{\partial t}\right)_{ADV} = \frac{\phi^{n+1} - \phi^n}{\Delta t} = F(\phi^*).$$

Here $F(\phi^*)$ denotes the advective tendency calculation. In the third step, short time steps are calculated from the beginning of the large time step till its end by retaining the advective tendencies constant. A sketch of this scheme is given in figure 1. The stability analysis of this scheme with different advection algorithms (Runge-Kutta scheme of second order in time, Lax-Wendroff scheme, semi-implicit scheme) shows eigenvalues smaller than one almost everywhere. That means the scheme is stable and reliable.

In the framework of the LM the new scheme needs only 6 short time steps in our configuration (instead of 7 in the current scheme). The Runge-Kutta scheme of second order in time with third order spacial upstream differences is chosen for advection in the horizontal direction. The vertical advection has to be a Runge-Kutta scheme of second order, too. Thereby, centered differences work well and the integration is stable as can be shown by a stability analysis. Third order upstream horizontal differences should also be taken into account for the metric terms appearing in the calculation of the contravariant vertical velocity $\dot{\zeta}$ and of the lower boundary condition for w which is free-slip. Moisture variables are treated with a positive definite van-Leer advection scheme. No horizontal diffusion is added because a slight diffusion effect is present in the advection scheme anyway.

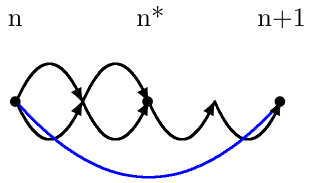
First, ideal 2-dimensional test runs with a dry atmosphere flow over a bell shaped mountain with small scale terrain variations were performed.[3] If the flow field is not exactly balanced, this test fails and a very distorted wave pattern appears, especially in the upper air region. In our simulations, this test performs very well and the result for the w-field (figure 2) is comparable to the analytic solution.

Results of realisic simulations suggest that the scheme is working, but the predicted field of precipitation is noisier in mountainous regions than that of the current scheme (see figure 3). This behaviour is not astonishing, because some of the diffusive and damping mechanisms are no longer present now. May be that other effects as the horizontal transport of precipitation become necessary. Other predicted fields look similar for both runs and stability and performance seem to be satisfactory. There is still work to be done, above all more experiments on realistic cases. All together the two timelevel scheme is promising.

[1] Klemp, J. B. and Wilhelmson, R. B., 1978: The Simulation of Three-Dimensional Convective Storm Dynamics. J. Atmos. Sci., 35, 1070-1096.

[2] Wicker, L. J. and Skamarock, W. C., 1998: A Time-Splitting Scheme for the Elastic Equations Incorporating Second-Order Runge-Kutta Time Differencing. Mon. Wea. Rev., 126, 1992-1999.

[3] as done in Schär, C. et al., 2001: A new terrain-following vertical coordinate formulation for atmospheric prediction models. Submitted to Mon. Wea. Rev.



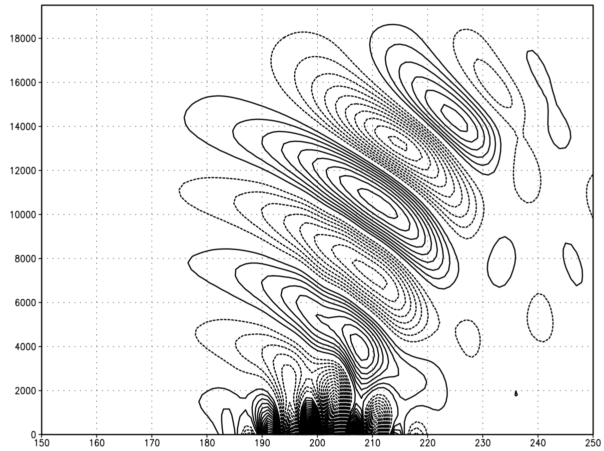


Figure 1: Sketch of the new two timelevel scheme, the line indicates the advection tendency computed of n*, the arrows mark the fast waves computation. ⇑

Figure 2: The w-field for the idealized flow over a hilly orography, the contour interval is 0.05 m/s. ⟹

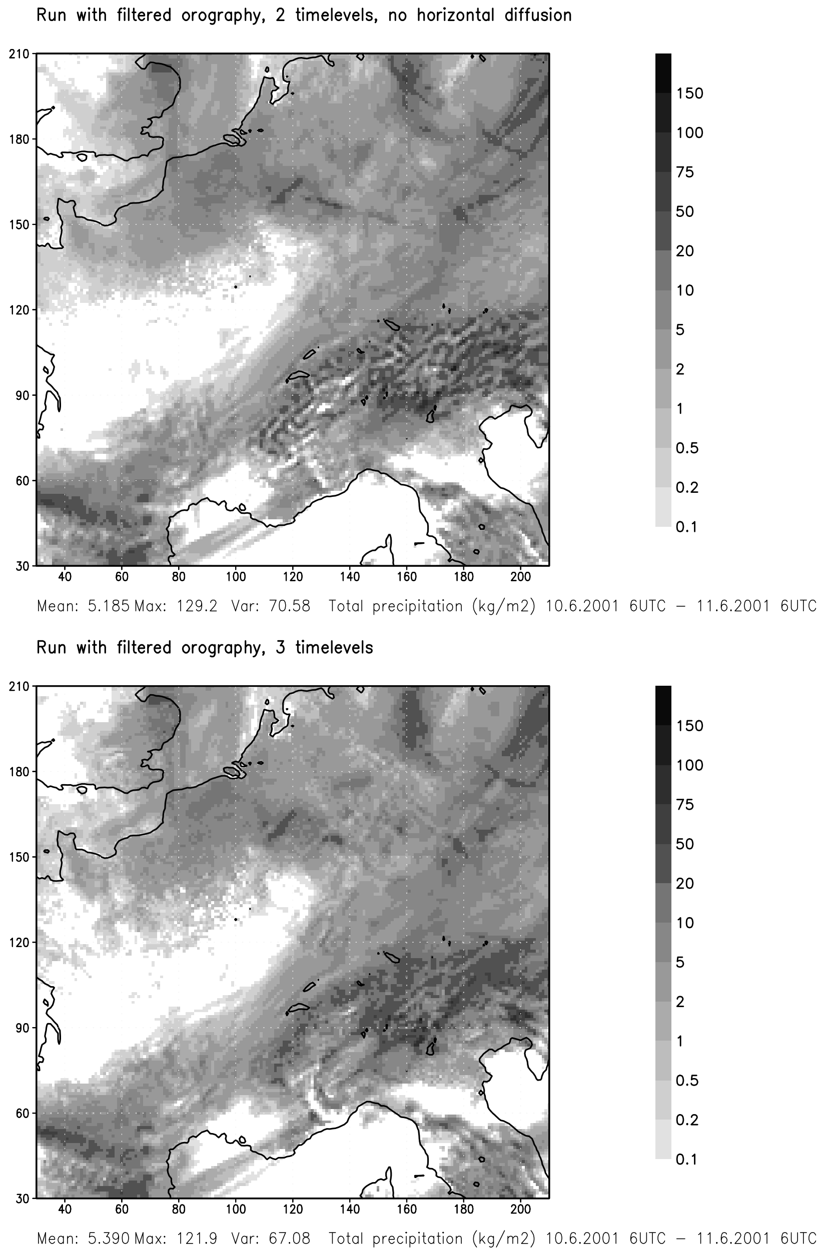


Figure 3: Precipitation pattern for an arbitrary test run wherein the forecasting area includes the Alps. Above: with the two timelevel scheme, below: with the three timelevel scheme