Prognostic Precipitation in the Lokal Modell (LM) of the German Weather Service

Michael Baldauf[1], German Weather Service

Introduction

In the current operational version of the Lokal Modell (LM) of the German Weather Service (Doms and Schättler, 2002) the conservation equations for rain and snow

$$\rho \frac{\partial q^x}{\partial t} + \rho \mathbf{v} \cdot \nabla q^x = -\nabla \cdot \mathbf{P}^x - \nabla \cdot \mathbf{F}^x + S^x \qquad (1)$$

($x = r, s$ for rain, snow, q= mixing ratio, $\mathbf{P}$= sedimentation flux, $\mathbf{F}$= turbulent flux, S= source terms from cloud microphysics) are approximated stationary and without advection. This column equilibrium approach means that precipitation particles, arising from cloud microphysical processes, immediately fall down to the bottom in the same time step. Rain drops with a mean fall velocity of about 5 m/s which develop for example in a height of 3 km, need a falling time of 10 min. and then are drifted 6 km (by an assumed horizontal wind of 10 m/s). For snow with a mean fall velocity of about 1 m/s (and usually generated higher up) the horizontal drift is even larger. Therefore, for the LM with a grid length of currently 7 km (in the next version (LMK) a grid length of about 2.8 km is aspired) and a time step of 40 sec. the column equilibrium approach is no longer valid. This was inspected by case studies especially to the luff-lee-problem: in many models precipitation falls to much on the upwind side of mountains, whereas the measured precipitation maximum even often lies in the lee. Especially for hydrologists the solution of this luff-lee-problem is of relevance: precipitation flows in the false valleys and therefore is added to a false waters catchment area.

Semi-Lagrange-Advection

There are in principal two possibilities to handle the sedimentation term $-\partial P_z / \partial z$: either this term is discretized directly (for example implicit) or one writes the sedimentation flux as a product of an effective fall velocity and the density $P_z = v_{eff} \rho q$ and handles it in the advection scheme. In the last case one has to consider, that in LM the near to the ground layers are so thin (about 60 m), that with the currently used time step of 40 sec., particles can fall through up to three thickness layers per time step. Therefore one needs an advection scheme which remains stable up to vertical Courant numbers of about 3. Apart from this, the prognostic precipitation shall be implemented in the version LMK, in which horizontal Courant numbers up to 1.8 are aspired, for that most Eulerian advection schemes are no longer stable. For the advection of precipitation we therefore decided to use a threedimensional Semi-Lagrange (SL) scheme (e.g. Staniforth and Côté, 1991) whose stability does not depend on the Courant number.

The application of the standard SL schemes consists of two steps: 1. calculation of the backtrajectory and 2. interpolation of the fields q^r and q^s at the starting point. The implicit equation of the backtrajectory (Robert, 1981) is solved by iteration; after one iteration step one gets a truncation error of order $O(\Delta t)$, after two steps an order $O(\Delta t^2)$. Simple tests show, that an error of only $O(\Delta t)$ delivers especially nonsatisfying conservation properties; this is in agreement with Staniforth and Côté (1991), who also recommend an order $O(\Delta t^2)$. The therefore needed second iteration step requires an interpolation of the three velocity components. This interpolation is a time consuming step in the staggered Arakawa-C-grid; currently it needs more then 80 percent of the calculation time of the whole SL-scheme.

In the second interpolation step for the fields often a cubic polynomial is recommended, which shows the best relation between calculation amount and accuracy; especially the cubic spline interpolation is even ideally conserving. In contrast, for the time being we use the more simple and computer time saving trilinear (i.e. linear in all three space dimensions) interpolation. It is well known that it has bad form properties (high diffusion) and only moderate conservation properties. However, the latter is probably not significant for rain and snow which remains only a few time steps in the model area. A test with a Gaussian rain particle distribution, which is advected with a given velocity ($u = 10$ m/s and $w = -5$ m/s), yielded a mass loss of 0.05 percent per time step. After 15 time steps (according to the example above) the mass loss is less then 1 percent. Similar tests with a velocity field over mountains even yielded a small gain of mass. But this could be connected with a non divergence free velocity field; in this case the advection itself does not conserve mass.

[1]Michael.Baldauf@dwd.de; Deutscher Wetterdienst, Kaiserleistr. 42, D-63067 Offenbach

A certain diffusion of the linear interpolation is even desired, as well, and could cure the problem of an unrealistic strong small scale structure of the precipitation in irregular terrain. Another advantage of the trilinear interpolation in contrast to higher order interpolation is its positive definiteness; an essential condition for the coupling to the cloud microphysics.

Coupling with cloud microphysics and real test cases

The dynamic core of the current operational LM consists of a 3-timelevel-scheme with time splitting by Klemp und Wilhelmson (1978). In the frame of this dynamic core the coupling between advection and cloud physics is done with a Marchuk-splitting, this means that in one time step the SL-advection from timelevel t^{n-1} to t^{n+1} (with velocities at t^n) is calculated and then with the updated values the cloud physics scheme is carried out. The latter is formulated implicitly, as mentioned above, but can be solved quasi-explicitly, because the sedimentation velocity is always directed downwards and therefore the system of equations has diagonal form.

The figures below show the whole precipitation (rain + snow) during a 24 h period for 20.02.2002+6-30 h over Southwest-Germany. The left figure shows a simulation with the operational LM, the right the same situation with the new prognostic precipitation scheme. The spatial precipitation distribution in the new scheme is much more similar to the observations (middle figure) than the current LM: the maxima are reduced (the operational LM overestimated them up to 150 %, the new version only by 20 %), the maxima are shifted to the lee side and therefore the unrealistic dry regions in the lee do not arize. The measured precipitation distribution had a mean value of about 16 kg/m^2, the operational LM-version yielded 30 % too much, the new version about 10 % too much. The calculation amount for the new version is about 20 % higher than the operational version, which seems acceptable for two new prognostic variables (q_r and q_s).

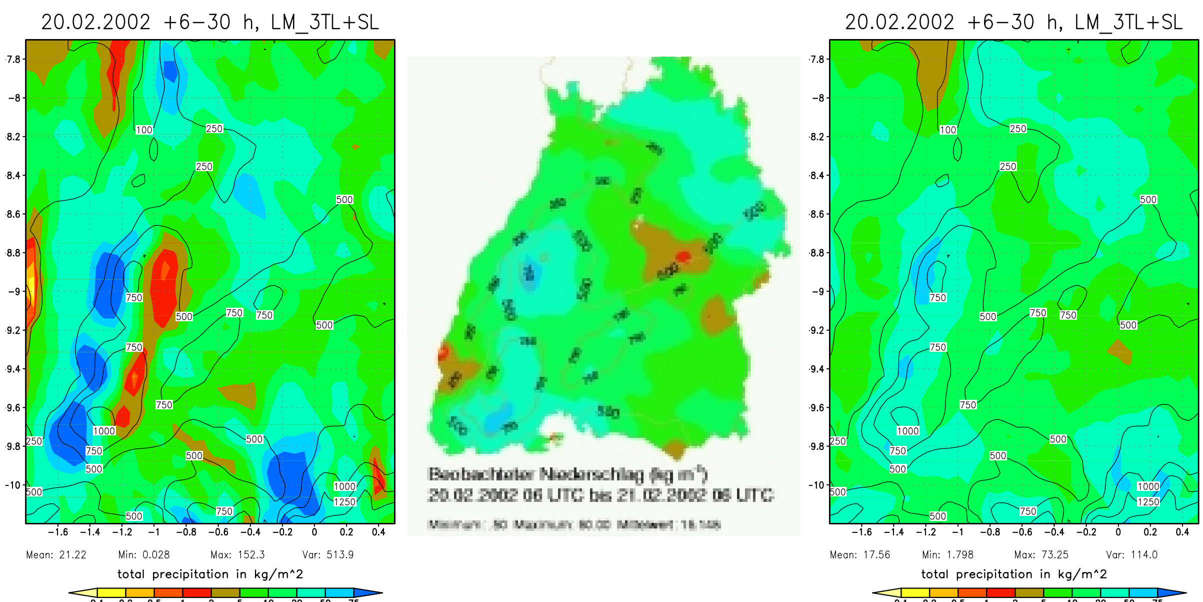

Figure 1: Simulation of the day 20.02.2002+6-30 h with the current operational LM without (left) and with (right) prognostic precipitation; observations (middle).

References

Staniforth, A. and Côté, J. (1991): Semi-Lagrangian Integration Schemes for Atmospheric Models - A Review, Mon. Wea. Rev., 119, 2206-2223.

Robert, A. (1981): A stable numerical integration scheme for the primitive meteorological equations, Atmos. Ocean, 19, 35-46.

Klemp, J. B. and Wilhelmson, R. B. (1978): The simulation of three-dimensional convective storm dynamics, J. Atmos. Sci., 35, 1070-1096

Doms, G. and Schättler, U. (2002): A description of the Nonhydrostatic Regional Model LM, http://cosmo-model.cscs.ch/cosmoPublic/