Improvements of the operational latent heat nudging scheme used in COSMO-DE at DWD

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1 Introduction

Since April 2007 the convection permitting model COSMO-DE (Baldauf et al., 2007) runs operationally. Its main purposes is the prediction of severe weather events related to deep moist convection and to interactions of the flow with small scale topography. To satisfy this goal the initial conditions include small scale precipitation information obtained from radar measurements beside the large scale structures obtained from conventional data. The radar measurements are assimilated by applying the latent heat nudging (LHN) approach. Herein an assumed relation between precipitation formation and latent heat release is used to change the model dynamics in such a way that the model will respond by producing a rain rate close to the observed one. At every model grid point the model is compared to the radar measurement. If the two are different, the vertical profile of modelled latent heat release at that grid point is scaled according to the ratio between observed and modelled precipitation rate. The original LHN technique proposed by Jones and Macpherson (1997) had to be adapted for COSMO-DE because the latter uses a prognostic precipitation scheme (Klink et al., 2006; Stephan et al., 2008). The adapted LHN scheme applied in COSMO-DE deploys a reference precipitation rate for comparison with the observed precipitation rate. This mitigates the spatial and temporal decorrelation of precipitation and latent heat release, caused by treating precipitation as prognostic variable. This improves the performance of LHN unless the used reference is globally biased to the surface precipitation.

Recent changes within the microphysical parameterisation of COSMO model, which improved the quality of the precipitation forcast of COSMO-DE (and of the coarser-resolution COSMO-EU), resulted in a bias between reference and modelled surface precipitation. The changes modified the formation of precipitation and included a reduction of evaporation and a more comprehensive parameterisation of the snow formation. This had an impact on LHN, and the model overestimated the surface precipitation during assimilation significantly. Furthermore it confirmed, that the LHN is strongly dependent on the microphysics. Especially the formulation of the grid point search algorithm within the LHN was found to be very sensitive to the changes in the microphysics. Therefore, two modifications of the operational LHN scheme will be discussed in the following:

- revised definition of the reference precipitation to correct its bias against surface precipitation,
- improvement of the LHN-internal grid point search algorithm.

2 Improvement of the LHN scheme

2.1 Correction of the bias between reference and surface precipitation

Since COSMO-DE treats precipitation as a prognostic variable the original LHN scheme had to be adapted so as to cope with the drifting of precipitation (Stephan et al. 2008). A major challenge was to reduce the decorrelation of the latent heat release and surface precipitation. This is mainly caused by the temporal delay of the precipitation reaching the ground relative to the time of condensation and precipitation formation. One adaptation of the LHN scheme has been to introduce a reference precipitation, which should be closer in time to the process of precipitation formation. It is compared with the observed precipitation and defined as

$$R_{Ref} = \frac{1}{z(k_{top}) - z(k_0)} \int_{k_0}^{k_{top}} \left[\sum_i \{\rho(z) q_i(z) \nu_i\} \right] dk \quad (1)$$

where q_i is the mass fraction and v_i the sedimentation velocity of precipitate i (rain, snow, or graupel). The fluxes of the different precipitation constituents are integrated vertically starting from a certain layer k_{top} down to the ground (k_0). Herein k_{top} is a free parameter, which is not predetermined by a physical constraint. It determines the number of layers which are considered for the average. Therefore the amount of the reference precipitation depends on the parameter k_{top}. k_{top} was defined as the uppermost layer in which the precipitation flux exceeds 0.1 mm/h. This seemed plausible because this value is used as a general threshold within LHN, below which no LHN is performed in order to introduce precipitation. With this definition of k_{top} and for the former parameter setting of the microphysics the resulting reference was nearly unbiased to the surface precipitation. However, the changes within the microphysics and especially the reduction of evaporation of the precipitation beneath clouds have caused a significant bias. The surface precipitation is enhanced, whereas the reference precipitation is nearly unchanged.

One opportunity to reduce the bias is changing the definition of k_{top}. The new definition sets k_{top} at the uppermost layer in which the precipitation flux exceeds a certain ratio α of the maximum of the precipitation flux within the column. Then, α determines the height of the column used for the vertical average. A value 0.4 for α has been evaluated to be optimal with respect to both the mentioned bias as well as the overall performance of LHN. Figure 1 illustrates the correction of the bias. It shows that the surface precipitation in the operational analysis was much higher than the reference precipitation, especially for higher precipitation amounts. The new definition of the reference precipitation reduced this positive bias to the extent that, in fact, a slight overestimation of the reference precipitation against the surface precipitation occurs. As a result when using the new reference precipitation for

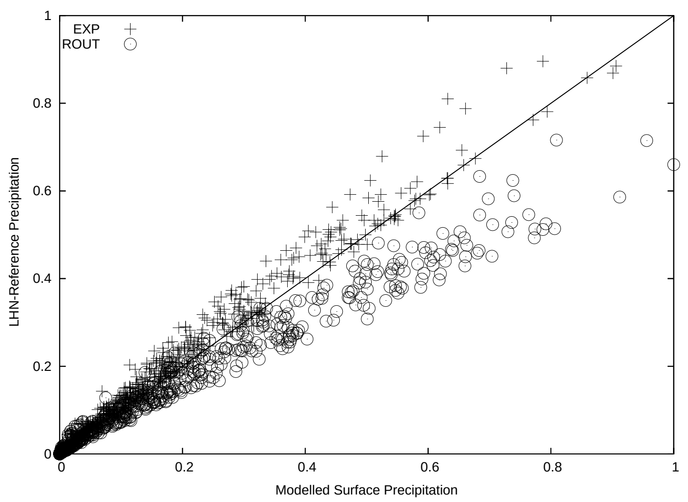

Figure 1: Scatter plot of reference precipitation against surface precipitation for spatially averaged hourly precipitation in August 2007. The circles indicate the values obtained from the operational analyses and the plus signs the values for the experimental analyses with the revised definition for the reference precipitation.

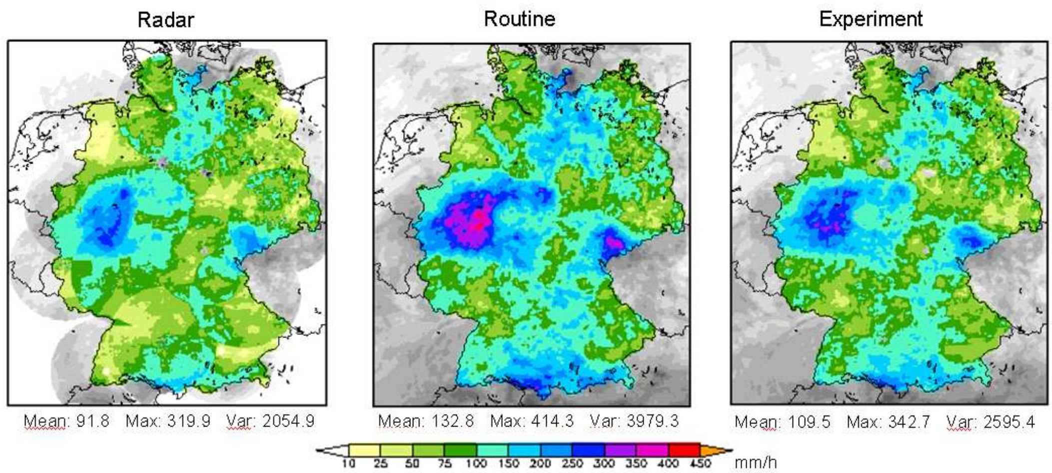

Figure 2: Monthly precipitation of August 2007: radar observastion (left), operational analysis (middle), experimental analysis with the revised definition of the reference precipitation (right)

the assimilation of August 2007 the overestimation of surface precipitation against radar observations was reduced (see Figure 2). The impact on the free forecast is slightly positive.

2.2 Improvement of the LHN-internal grid point search algorithm

While the above mentioned modification is important in general, the second modification concerns cases in which the model produces far too little precipitation compared to the observation. Then the latent heating profile at this grid point is not likely representative for conditions as indicated by the observed precipitation.

In such a case, a 'suitable' nearby grid point is searched (within a search radius of 10 grid points). The scaled heating profile from that grid point is then defined to be the profile of LHN temperature increments at the target grid point. (If no point is found, a climatological profile will be scaled and used.) The suitable nearby grid point had to satisfy two criteria. Firstly, it should be representative of the real conditions at the target grid point. The only direct indication of these conditions comes from the radar observation. Therefore, it was required that the reference precipitation at the selected grid point had to be close to the observed value at the target point. With the prognostic treating of precipitation in the model this however does not imply that the latent heat release is large enough to allow for reasonable LHN increments. Near-zero latent heating occurs for instance at precipitating grid points at the upstream edge of precipitation cells where cloud formation is almost finished. Therefore, a second criterion was defined which required that the vertical integral of modelled latent heat release had to be larger at the suitable nearby grid point than at the target grid point.

The above-mentioned changes of the microphysics have significantly increased the variability of the local ratio between precipitation rate and latent heating. In some cases, the latent heating could become very large at grid points which met both criteria and were selected by the grid point search algorithm. The resulting excessively large LHN increments then caused strong gravity waves related to small-scale, mostly positive strong pressure anomalies and excessive precipitation. This is illustrated in Figure 3 for a frontal case. To avoid that, the second criterion has been revised as follows. At a suitable grid point, the ratio between the

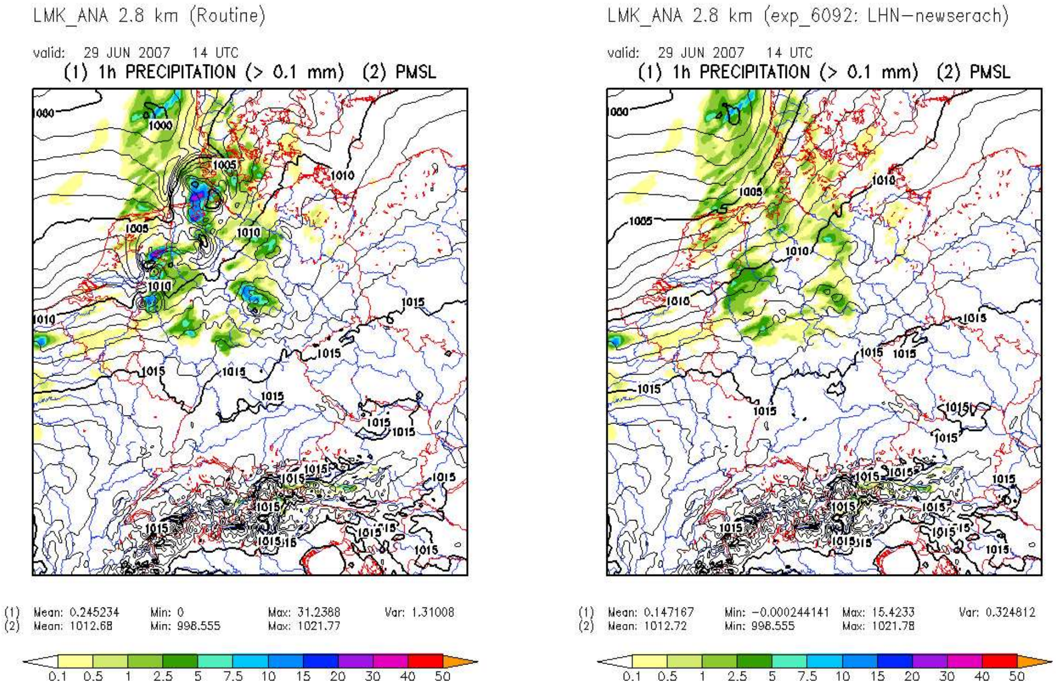

Figure 3: Analysis of surface pressure (contours) and hourly precipitation (colors) for 29. June 2007 14 UTC obtained from COSMO-DE assimilation. Left: operational analysis, Right: experimental analysis with the revised grid point search

precipitation rate and the integral of latent heat release must not exceed ± 50% of the ratio of the model's climate (as obtained from long-term averaging). The result of this improvement is shown in the right panel of Figure 3 for the considered case. The pressure anomaly vanishes and the precipitation pattern responds quite well to the observations. The modification also improves the 24-hour precipitation sum as shown in Figure 4.

The positive impact of both modifications found during the assimilation cycle disappears quickly in the free forecast. This is revealed by a verification against radar observations.

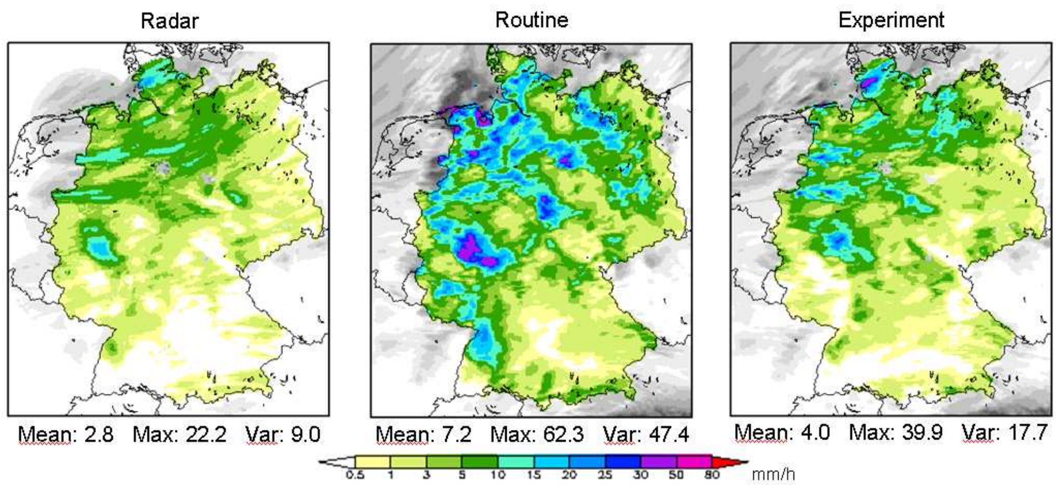

Figure 4: 24h precipitation of 29. June 2007: radar observastion (right), operational analysis (middle), experimental analysis with revised grid point search (left)

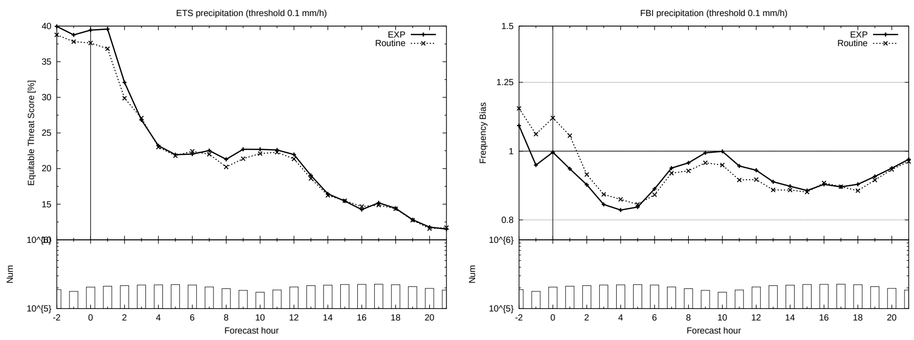

Figure 5: Verification of modelled hourly precipitation greater than 0.1 mm/h against radar observations for 34 forecasts in August 2006 for the last two hours of assimilation and the consegutive forecast (21 hours), left: ETS and right: FBI. The dashed line depicts the scores for the operational setup and the solid line for the experimental setup with revised grid point search and definition of the reference precipitation. The bars at the botton indicate the number of radar observations.

Figure 5 shows equitable threat scores (ETS) and frequency biases (FBI) for the last hours of assimilation and 34 consecutive forecasts over 21 hours. The modifications improve the ETS and FBI during the assimilation, but the positive effect almost vanishes after about three hours of free forecast.

3 Conclusions

The improved grid point search and definition of the reference precipitation in the latent heat nudging provide a better match of the initial state of COSMO-DE to the precipitation patterns derived by radar observations. Both improvements reduce the overestimation of surface precipitation during the assimilation. Especially the overestimation of higher precipitation amounts (greater than 5 mm/h) could be greatly reduced. However, the positive impact during the assimilation reduces very rapidly in the free forecast.

It can be assumed that the better agreement of the precipitation patterns in the analysis with real measurements should gradually improve the distribution of modelled soil moisture. As soil moisture is a sensitive parameter for the simulation of moisture fluxes into the atmosphere, an improvement of the free forecast might occur after a longer period than inverstigated in the present study.

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