Revised Latent Heat Nudging to cope with Prognostic Precipitation

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1 Introduction

The prognostic treatment of precipitation (Gassmann 2002, Baldauf and Schulz 2004) used operationally in the LM tends to decorrelate the surface precipitation rate from the vertically integrated latent heat release and thereby violate the basic assumption of the Latent Heat Nudging (LHN) approach. This, and resulting problems have been shown by Klink and Stephan (2005), and they also suggested possible adaptations to the LHN scheme. More recent experiments have allowed to better specify preferable choices and parameters for at least some of the adaptations. Here, the specifications for the most important ones are briefly described, and results of recent experiments are shown. In the concluding remarks, the current status is summarized, and some remaining problems with LHN are outlined.

2 Major revisions to the LHN scheme

At horizontal model resolutions of 3 km or less, the prognostic treatment of precipitation allows the model to distinguish between updrafts and downdrafts inside deep convective systems. Compared to using the diagnostic precipitation scheme, it modifies both the 3-D spatial structure and the timing of the latent heating with respect to surface precipitation. Two revisions address spatial aspects and a third one an important temporal issue:

- In updraft regions at the leading edge of convective cells, very high values of latent heat release ΔT_{LHmo} occur often where precipitation rates RR_{mo} are low. Considering that

  $$\Delta T_{LHN} = (\alpha - 1) \cdot \Delta T_{LHmo} \qquad , \qquad \alpha = \frac{RR_{obs}}{RR_{mo}}$$

  high values of the scaling factor α and of the latent heat nudging temperature increments ΔT_{LHN} often occur. To mitigate this, the upper limit for α is reduced to 2 and the lower limit increased accordingly to 0.5. In addition, the linear scaling $(\alpha - 1)$ is replaced by a logarithmic scaling $\ln(\alpha)$ in order to unbias the scheme in terms of adding or taking away absolute amounts of heat energy. The effective upper and lower scaling limits are then 1.7 and 0.3 respectively. This adaptation reduces the simulated precipitation amounts during the LHN.

- In downdraft regions further upstream in convective cells, high precipitation rates occur often where latent heating is weak or even negative in most vertical layers. In order to avoid negative LHN temperature increments and cooling where the precipitation rate should be increased (and vice versa), only the vertical model layers with positive simulated latent heating are used to compute and insert the LHN increments. These layers coincide very roughly with the cloudy (saturated) layers. This modification tends to render the increments more coherent and the scheme more efficient.

- Precipitation produced by the prognostic scheme will take some time to reach the ground where it is compared to the radar-derived surface precipitation rate. Thus, the conventional LHN scheme can notice only with some temporal delay when it has already initiated precipitation aloft, and it will continue to add (or take away) heat energy for some time when it is not required any more.
  Therefore, an immediate information on the precipitation rate already initialised is required, i.e. a sort of undelayed 'reference precipitation' RR_{ref} which is used merely to replace the delayed prognostic precipitation RR_{mo} in the computation of the scaling factor α. Deploying the diagnostically calculated precipitation rate (by an additional call to the diagnostic precipitation scheme without any feedback on other model variables) is found to be prone to problems since the diagnostic and prognstic schemes are not consistent with each other. A better choice is found to be the vertically averaged precipitation flux, defined as follows:

  $$RR_{ref} = \frac{\sum_{k_{top}}^{ke} RR_{flux}^k \cdot \Delta h^k}{\sum_{k_{top}}^{ke} \Delta h^k} \quad , \qquad RR_{flux}^k = \sum_x (q_x^k \cdot \rho^k \cdot v_{sed,x}^k)$$

  where q_x is the mass fraction and $v_{sed,x}$ the sedimentation velocity of precipitate x (rain, snow, or graupel), ρ is the density of dry air, Δh the model layer thickness, k

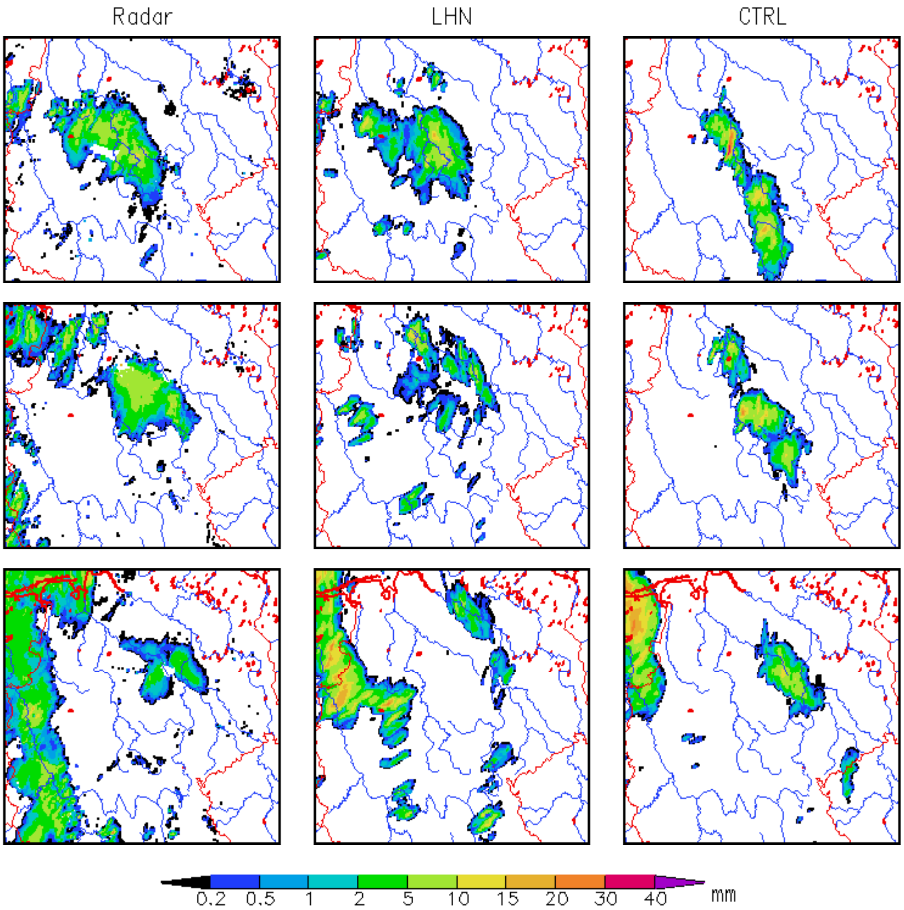

Figure 1: Hourly precipitation over northern and central Germany for LMK forecasts starting at 17 July 2004, 15 UTC. Left column: radar-derived surface precipitation; middle: LMK free forecast from the assimilation cycle with LHN; right: control LMK forecast without LHN. Upper row: 0-h forecast valid for 15 UTC; middle: 2-h forecast for 17 UTC; lower row: 4-h forecast for 19 UTC.

the model level index, ke the index of the lowest model level, and k_{top} the uppermost layer in the grid point column with $|RR^k_{flux}| > 0.01\,\mathrm{mm/h}$.
This type of reference precipitation is compatible with the prognostic model precipitation since both quantities are produced by the same scheme. Note, however, that the averaged flux is a mixture of undelayed and 'fully delayed' information and therefore does only mitigate rather than eliminate the temporal delay problem.

3 Results for an 11-day case study

The above mentioned revisions have been tested for an 11-day convective summer period from 7 to 18 July 2004. An assimilation cycle and 3 daily forecast runs from 00, 12, and 18 UTC have been carried out with the LMK configurations for the general model setup (with Bott advection for humidity and condensate). Note that during the first 3 hours of the forecast runs, the assimilation including LHN was still switched on (unintendedly) so that the free forecasts started in fact at 03, 15, and 21 UTC. In addition to the major revisions, several minor modifications have been implemented in the LHN scheme (e.g. at the grid point search), and the LHN configuration in the experiments also included the following features:

- use of radar observations from the so-called precipitation scan every 5 minutes, and application of a blacklist to reject suspicious radar pixels (e.g. near wind power plants)
- limitation of LHN to grid points with $RR_{obs} > 0.1\,\mathrm{mm/h}$ or $RR_{mo} > 0.1\,\mathrm{mm/h}$

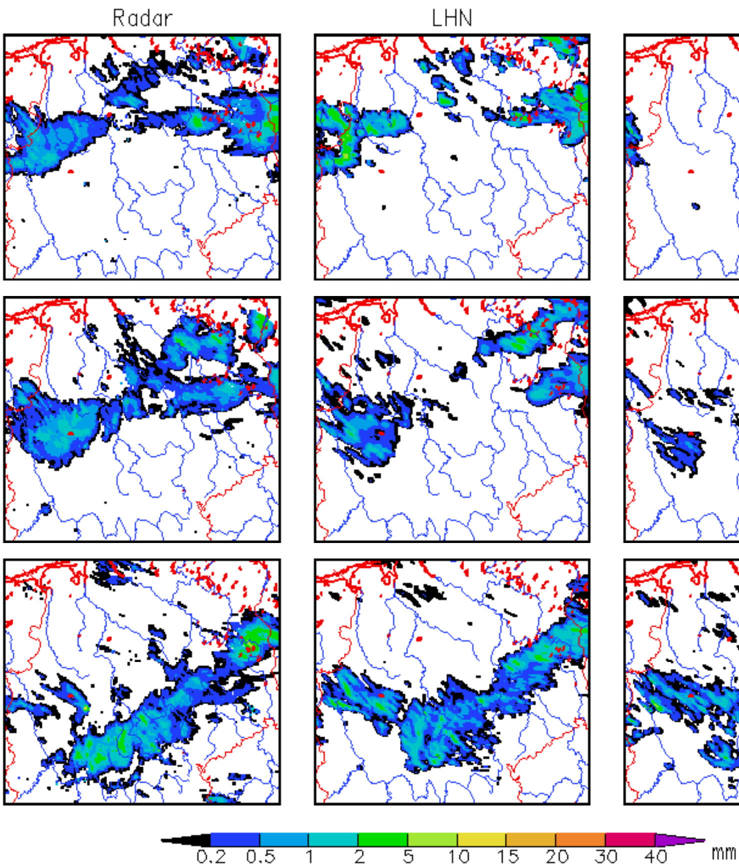

Figure 2: As Fig. 1, but for LMK forecasts starting at 12 July 2004, 3 UTC. Upper row: 0-h forecast valid for 3 UTC; middle row: 2-h forecast for 5 UTC; lower row: 7-h forecast for 10 UTC.

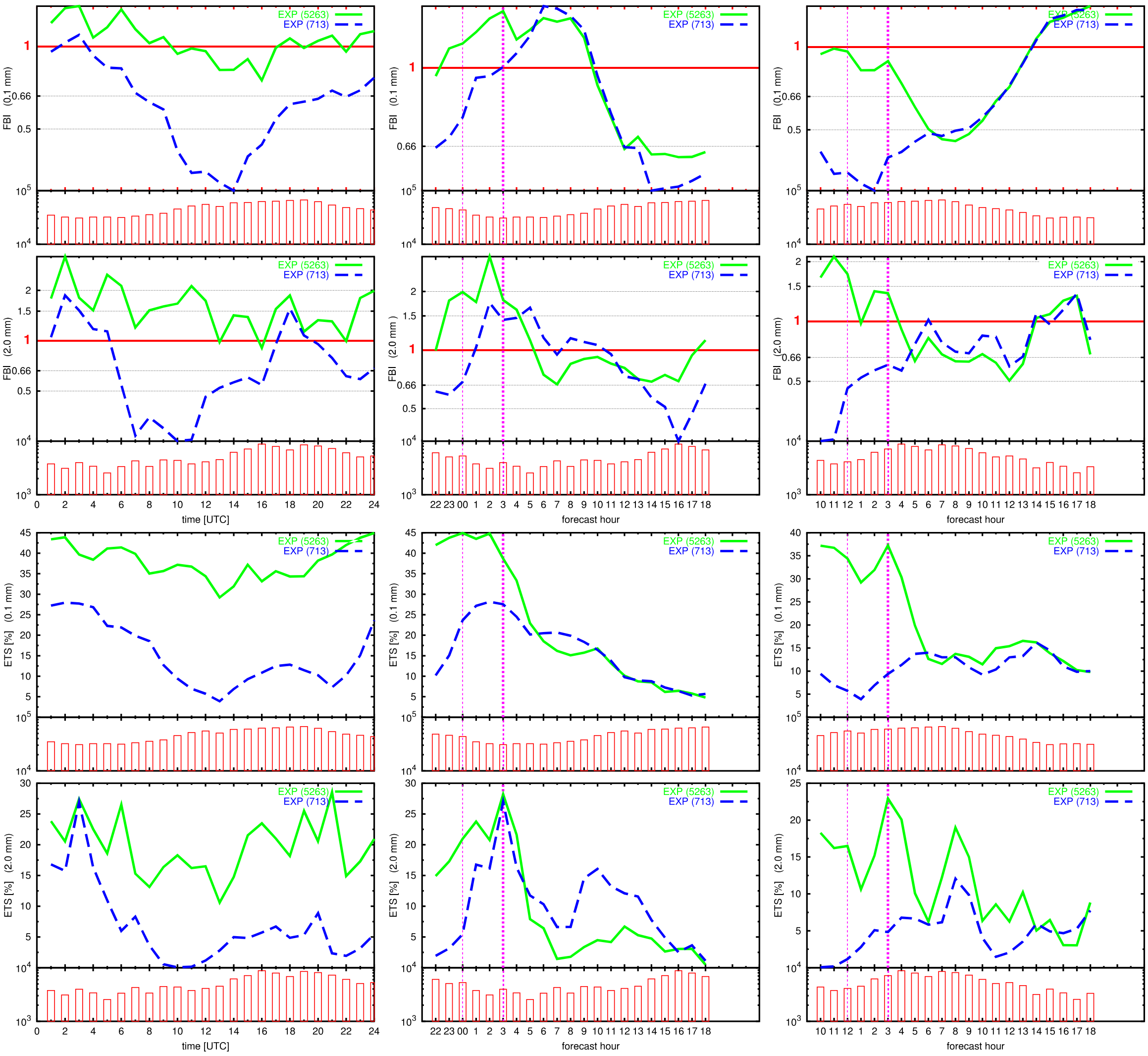

Figure 3: Scores of hourly precipitation (LMK versus radar) as a function of time for a 10-day period from 8 to 17 July 2004. Upper two rows of panels: Frequency Bias (FBI) for a threshold of 0.1 mm and 2.0 mm , respectively; lower two rows: Equitable Threat Score (ETS) for 0.1 mm and 2.0 mm . Left column of panels: assimilation cycle as a function of daytime; middle panels: 0-UTC forecast runs as a function of forecast time (free forecasts starting only at 3 UTC, indicated by the thick pink vertical lines); right panels: 12-UTC forecast runs (free forecasts from 15 UTC). Within each panel: green solid line: LHN experiment; blue dotted line: control experiment without LHN; red columns in lower part: total number of grid points with observed precipitation larger than threshold.

- search for nearby profiles of latent heat release, if both RR_{mo} and the latent heating are 'too small'; use of an idealised 'climatological' profile in case of unsuccessful search
- adjustment of specific humidity (by preserving relative humidity, and by nudging towards saturation at cloud-free model grid points with observed precipitation)

The LHN experiment is evaluated in comparison to a control experiment without LHN. Plots of surface precipitation fields (see e.g. Figs. 1, 2) reveal that during the assimilation, LHN greatly improves the match to the observed rain patterns. In the forecasts however, the improvement is usually reduced very rapidly. In Figure 1, the squall line tends to break up erroneously within two hours and then rearrange in an elongated broken north-south band, so that it is even degraded compared to the 4-hour control forecast. On the other hand, a

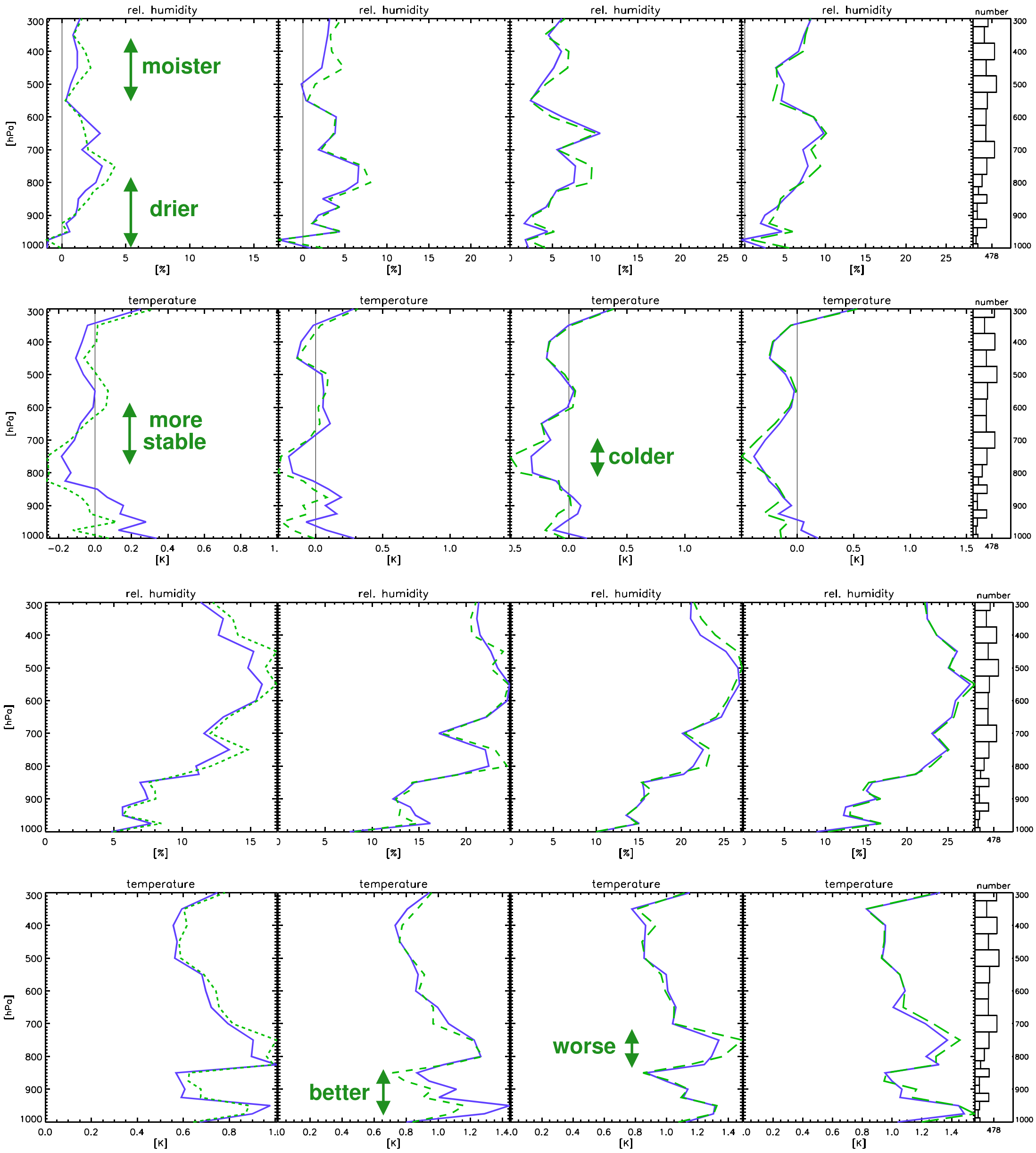

Figure 4: Upper-air verification against German radiosondes for an 11-day period from 8 to 18 July 2004. Panel rows from top down: bias for relative humidity, bias for temperature, rmse for relative humidity, rmse for temperature. Panel columns from left to right: 0-h, 3-h, 9-h, resp. 15-h free forecasts. Green dashed lines: LHN experiment; blue solid lines: control experiment without LHN.

better indication is given of the rain in southwestern Germany. Figure 2 shows a favourable case, where a significant benefit from LHN prevails for 7 hours in the forecast.

Figure 3 shows statistical scores for the whole period. The frequency bias (FBI) indicates that during the assimilation, precipitation is greatly underestimated at daytime without LHN, and it is increased significantly by LHN. While the areal extent (low threshold) is matched very well with LHN, rain amounts are overestimated (by about 50 % for the 2-mm threshold), but less strongly than in previous experiments that used the old LHN scheme. Moreover, the equitable threat scores (ETS) confirm that LHN greatly improves the location of the precipitation patterns. In the forecasts, however, the benefit from LHN decreases rapidly within 2–3 hours. After this, the impact on ETS is neutral for the 18-UTC forecast runs (not shown), remains slightly positive for the 12-UTC runs, and becomes even moderately negative for the 0-UTC runs. Whether this result given by the ETS reflects a real degradation or is an effect of the double penalty problem inherent to the ETS still needs to be evaluated.

The upper-air verification against radiosonde data (Figure 4) indicates that LHN modifies the vertical stratification in the troposphere significantly. In the analyses, it cools and, in terms of absolute humidity, dries the lower troposphere (below 750 hPa resp. 850 hPa) and heats and moistens the upper troposphere (above 600 hPa). As a result, the stability is increased considerably between 750 hPa and 600 hPa . This may be due to an enhanced triggering of convection (reflected by the higher precipitation rates), which acts to reduce atmospheric instability. In terms of rms error, the fit of the analyses to the assimilated temperature and humidity radiosonde observations is decreased. However, the overall impact on the forecasts is very close to neutral (for temperature, humidity, and wind).

4 Concluding Remarks

Several adaptions to the LHN algorithm have been developed to mitigate the problems of LHN related to the prognostic treatment of precipitation. Most importantly, a vertically averaged precipitation flux is used as a 'reference precipitation' instead of the real model precipitation for comparison to the observed precipitation. The revised LHN scheme has been tested for an 11-day convective summer period. During the assimilation, the simulated rain patterns agree well with radar observations, and the overestimation of precipitation is reduced significantly compared to previous LHN versions. In the forecasts, the impact on precipitation decreases rapidly, similarly to past experiments using a diagnostic treatment of precipitation. With respect to other forecast parameters, the overall impact is nearly neutral, e.g. in terms of rmse against radiosonde observations.

Thus, the problems related to prognostic precipitation appear to be mitigated to a satisfactory degree. However, the scheme needs still to be tested for stratiform precipitation, and at least two important shortcomings remain. Firstly, this is the rapid decrease of benefit in the forecasts, and secondly, there are indications that the LHN forcing is too strong:

- The surface pressure fields indicate that strong gravity waves are induced during the assimilation. While local pressure disturbances of $2-3$ hPa can be realistic for convective systems, they sometimes exceed 5 hPa in LHN simulations. The fact that these perturbations do also occur before precipitation is triggered by LHN indicates that they are not primarily linked to the problems related to prognostic precipitation.
- In comparison to surface observations, the convective outflow appears to be too strong (Leuenberger, personal communication).
- LHN tends to stabilise the mid troposphere too much.
- LHN leads to significant cooling and drying of the planetary boundary layer (PBL). This is likely to contribute to the rapid decrease of impact in the precipitation forecasts.

Hence, there is still a need to improve and better balance the scheme. One line of thought is to modify the vertical distribution of LHN increments and add (or take away) more energy and humidity at lower levels and less further above. Unless this is found to require larger LHN increments altogether, it may reduce the effects on the stratification and possibly even extend slightly the period of positive impact on predicted precipitation as a result of increased PBL humidity and decreased stability. To pave the way for developing modifications or new methods with significantly longer forecast impact, a better understanding is needed of how the model itself produces convection, which conditions (such as low-level moisture convergence) it needs, and consequently what kind of observational information and forcing it should be given at which scale.

References

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