# Latent Heat Nudging and Prognostic Precipitation

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## 1 Introduction

Within the framework of the development of LMK (LM Kürzestfrist), which is a meso-$\gamma$-scale version of the operational nonhydrostatic limited area model LM, it is intended to use remote sensing data for the continuous data assimilation stream of LMK (Doms and Förstner, 2004). As the main focus of LMK is on the prediction of severe weather, which often forms in context with deep moist convection (such as super- and multi-cell thunderstorms, squall-lines, mesoscale convective complexes and mesocyclones), we expect a beneficial impact on the assimilation cycle of LMK from radar measurements of these meso-$\gamma$-scale structures. Thus, in addition to the assimilation of conventional data, like surface and radiosonde measurements, as a first step 2D radar reflectivities derived from the German radar network will be introduced in the nudging-type analysis of LMK. Using the Latent Heat Nudging (LHN) technique (Leuenberger and Rossa, 2003) the thermodynamic quantities of the atmospheric model are adjusted in that way, that the modelled precipitation rates resemble the observed precipitation rates. Due to complaints from forecast meteorologists as well as from hydrological authorities on a non-realistic distribution of precipitation in mountainous terrain, given by the operational forecasts of LM, a reconsideration of the numerical treatment of precipitation quantities within LM took place. These investigations on the topic of "Prognostic Precipitation" have been carried out by Gassmann (2003) and Baldauf and Schulz (2004). Resulting from this, since April 2004, the advection of hydrometeors is taken into account in the operational LM. Because the Latent Heat Nudging algorithm is highly sensitive on the 3D thermodynamical field of cloud and precipitation physics, the LHN has to be tested under these new circumstances of a changed treatment of grid scale precipitation, which will also be used in the LMK version. Results from preliminary experiments with a purely diagnostic precipitation scheme have shown that precipitation patterns can be assimilated, using the LHN algorithm, in good agreement with those observed by radar, both in position and amplitude (Klink and Stephan, 2004 and Leuenberger and Rossa, 2003) but later experiments using the "prognostic precipitation" revealed some problems with the LHN. However, some recent tests show, that several adaptations to the conventional LHN scheme are necessary in order to reestablish the good performance of LHN during the assimilation run and to get a positive impact on the free forecasts.

## 2 Interaction of Prognostic Precipitation and Latent Heat Nudging

In order to test the performance of the LHN algorithm under the conditions and constraints of a prognostic treatment of precipitation (Gassmann, 2003 and Baldauf and Schulz, 2004) a case study has been conducted for a convective event in summer 2004. During the morning hours of the 9th June 2004 a convergence line reached the northerly parts of Germany. Hamburg has been hit by a severe thunderstorm, which was part of this squall line approaching the land from the North Sea. This is outlined by fig. 1, which shows the current precipitation rate measured by the German radar network at 6 UTC (fig. 1a) and 8 UTC (fig. 1b).

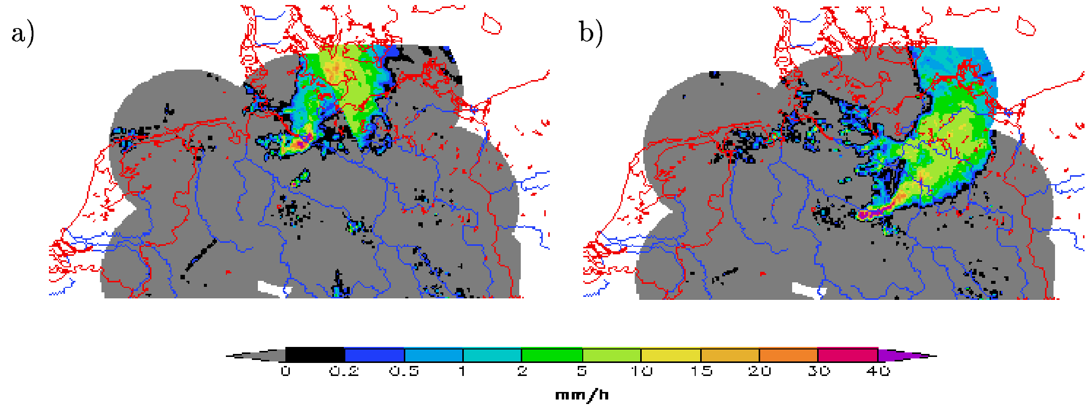


Figure 1: Current precipitation rate in mm/h (derived from radar) on 9th June 2004 at 6 UTC (a) and 8 UTC (b).

For this case different assimilation runs testing the LHN in connection with diagnostic and prognostic precipitation have been carried out. Figure 2 displays hourly accumulated precipitation heights for the hour from 8 to 9 UTC for the radar measurements (b), the control run (i.e. Nudging without LHN) (a), a LHN run with diagnostic precipitation (c) and a LHN run with prognostic precipitation (d). When comparing fig. 2b and 2c we can see, that the LHN run with the conventional diagnostic precipitation scheme almost perfectly meets the patterns given by the radar measurements. In contrast to this, the run with LHN and prognostic treatment of precipitation (fig. 2d) shows a distinct overestimation of the mean precipitation amount. Furthermore the local maxima and minima, visual in the radar data (fig. 2b), are not in the correct position for this LHN run (fig. 2d). The results from other experiments sustained the impression, that there is a typical overestimation of precipitation and a misplacement of local extremes when using LHN in combination with prognostic precipitation.

When searching for reasons for this bad performance of LHN under the conditions of a prognostic precipitation scheme we have reconsidered the general outline of the LHN algorithm and the basic assumption one acts on, when using this assimilation method for radar data. The basic assumption for LHN is the proportionality between vertically integrated latent heat release and surface precipitation rate in one single column (Leuenberger and Rossa, 2003). This is based on the observation that relatively little moisture is stored in clouds. The proportionality itself allows to scale the modelled latent heating rate with the ratio of observed to modelled precipitation rate. But this relation is just valid for large scales and long time periods, where we can assume, that cloud and precipitation producing (mainly condensation) and cloud dissipating (precipitation) processes are balanced, which means that no net storage of cloud liquid water and precipitation quantities takes place inside one column. A horizontal grid length of roughly 3 km in combination with an appropriate time step and an additional prognostic treatment of precipitation can be understood as a step towards cloud resolving models. This means, that the model itself is able to distinguish between updrafts and downdrafts inside convective systems. Because the main part of positive latent heat release (due to condensation) occurs in updrafts and strong precipitation rates are often connected with downdrafts, we can expect, that on cloud resolving scales areas with positive latent heating and patterns with strong precipitation rates will be located at different horizontal positions. Figure 3b exemplifies the changed thermal structures in convection cells, when advection of precipitation is taken into account, while fig. 3a shows the well known strong correlation of latent heat release and precipitation rate for a simulation

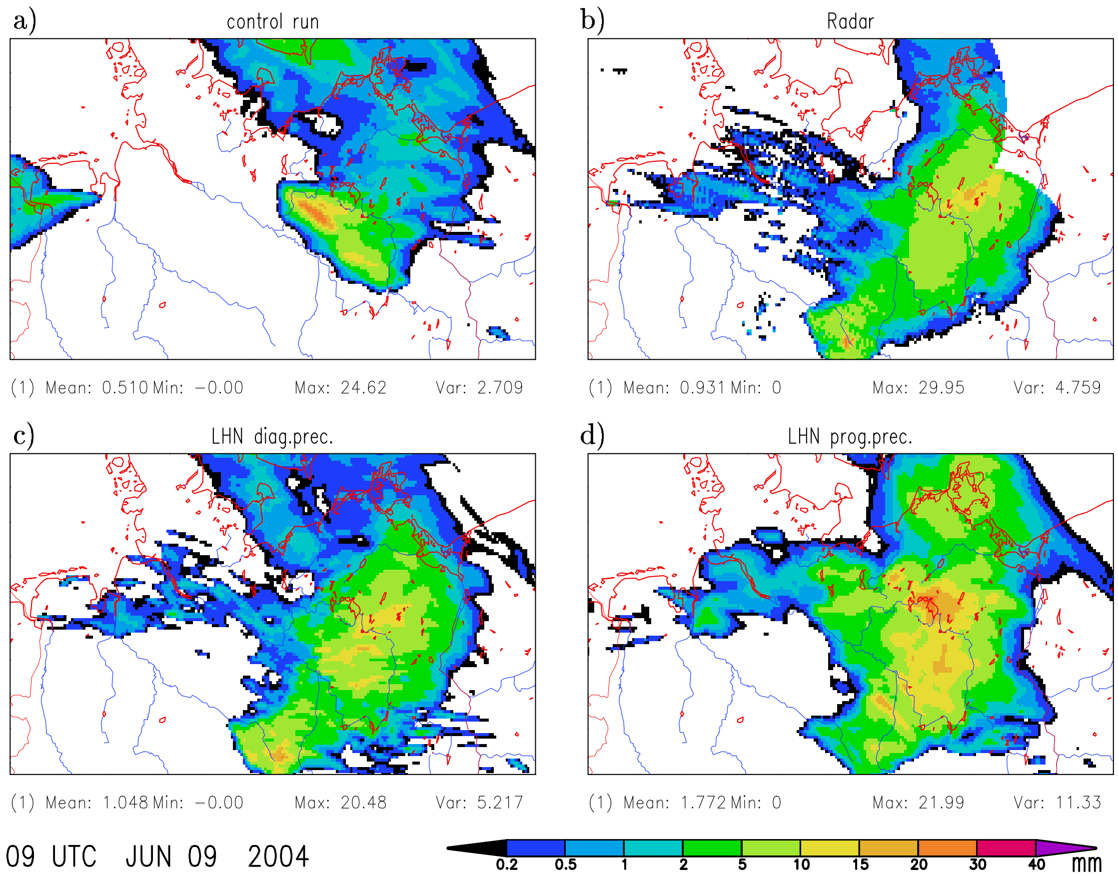


Figure 2: Hourly accumulated precipitation heights in mm on 9th June 2004 8-9 UTC: control run (a), radar observation (b), LHN run with diagnostic precipitation (c) and LHN with prognostic precipitation (d).

with diagnostic treatment of gridscale precipitation. Recognizing a northwesterly flow in this case, one finds that the area of positive latent heat release, which marks the region of cloud and precipitation formation, is a little bit ahead of the surface precipitation area (see fig. 3b). Due to this displacement the problem arises, that LHN temperature increments will probably be inserted in the wrong locations. The fact, that the correlation between the vertically integrated rate of latent heat release and the surface precipitation rate is significantly smaller for the simulation with prognostic precipitation compared to the diagnostic run is shown by Fig. 4. Thus, we have to state, that the use of prognostic precipitation at least weakens the validity of the basic assumption of the LHN algorithm. Furthermore it takes some time for the precipitation to reach the ground when advection is considered. For this reason no immediate response of the model to temperature increments of the LHN algorithm is possible. The scheme does not notice, if precipitation has already been activated by the LHN. On account of this new situation the LHN scheme, implemented in the LM, had to be revised. Which adaptations are possible and useful, will be described in the following section.

## 3 Possible Adaptations to the conventional LHN scheme

As mentioned above there are two major challenges when treating the precipitation prognostically. First of all, it is strongly related to the temporal and spatial characteristics of

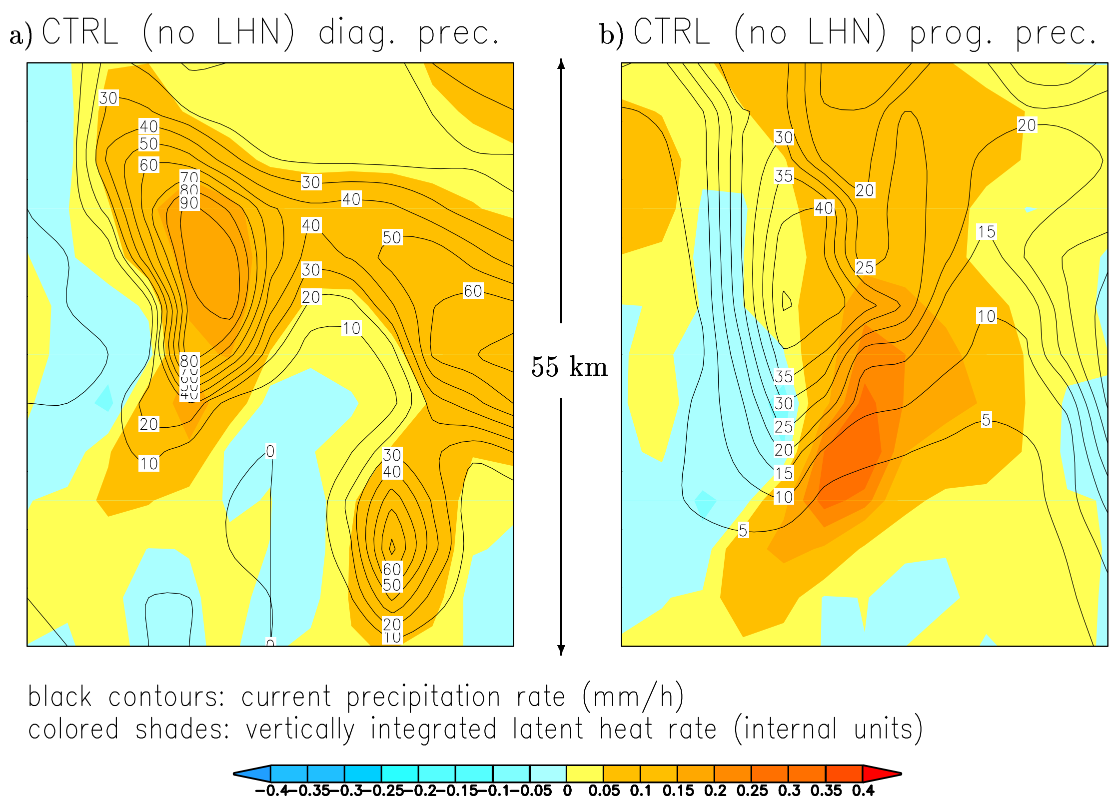


Figure 3: Horizontal fields of vertically integrated latent heat rate (shaded colours) and current precipitation rate at the ground (black contours) for a run with diagnostic precipitation (a) and prognostic precipitation (b).

the prognostic precipitation itself. One can show that the temporal effect of drifting of precipitation particles is much more important for the LHN-approach than the spatial displacement. However, one suggestion is, to spatially smooth the fields of observed as well as modelled surface precipitation rate and the 3D field of latent heat release, in order to get a better correlation of precipitation and latent heating. Of course, this would lead to a loss of information on the grid scale. The temporal delay leads to a lack of feedback between the temperature increment and the forced precipitation. To tackle this problem an immediate information, of how much precipitation the temperature increment has initialised already, is necessary within each time step. This information is used as a reference in the comparison of modelled with the observed precipitation rates to measure the essential scaling factor. Remember, the LHN increment is calculated with respect to the ratio of observed to modelled precipitation rate. This ratio minus 1 gives the essential scaling factor:

$$\begin{aligned} \Delta T_{LHN}(z) &= \alpha \cdot \Delta T_{LatentHeatRelease}(z) \qquad \text{with} \\ \alpha &= \left( \frac{RR_{Obs}}{RR_{Mod}} - 1 \right) \end{aligned}$$

Such a reference could be the diagnostically calculated precipitation rate. For this purpose an additional call of the former cloud microphysics scheme (`HYDCI`) is enforced. This additional calculation must not have any further effect on the simulation. No feedback on other model variables has to be performed. It just diagnoses the amount of precipitation what would fall out at once within each separate vertical column. This precipitation rate can not be compared with the precipitation rate of the former diagnostic treatment. It is quite different

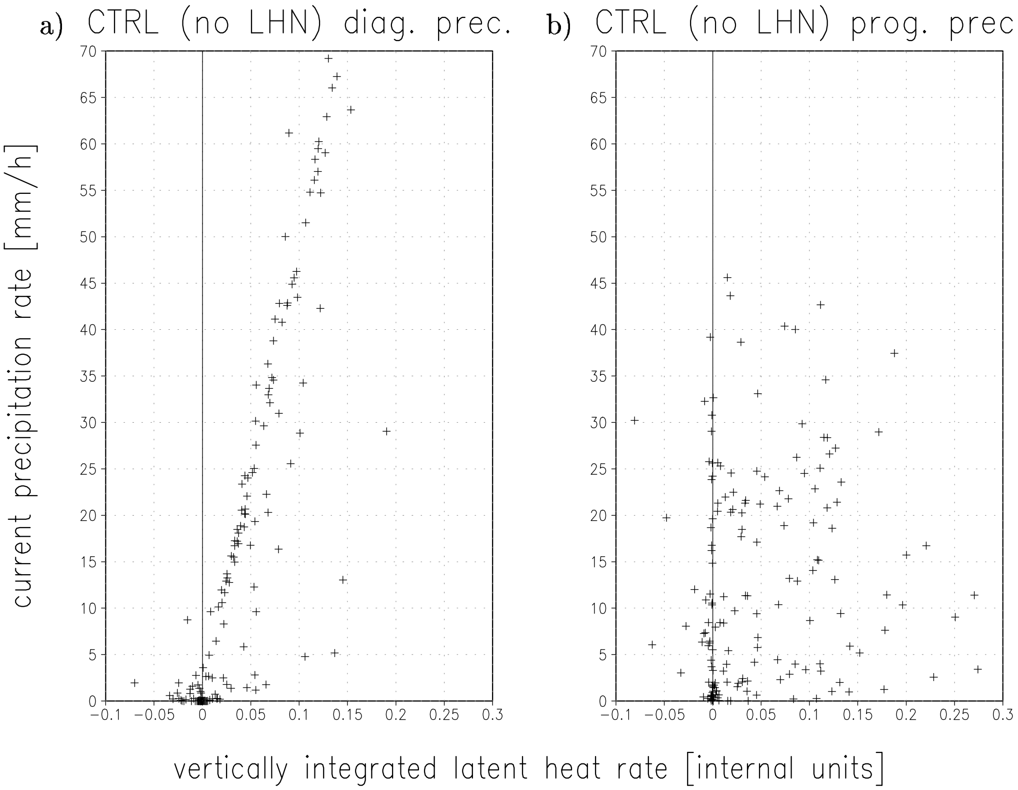


Figure 4: Scatter plots of vertically integrated latent heat rate and current precipitation rate at the ground for a run with diagnostic precipitation (a) and prognostic precipitation (b).

to both the former diagnostic and the newer prognostic precipitation rate. It still gives an important hint of the efficiency of the LHN so far. Unfortunately this precipitation rate is hardly to interpret. It does not match the actual rate and therefore has to be calibrated. A more sophisticated solution might be the application of the vertical integrated precipitation flux as a reference.

The second challenge is to be found as the change of the spatial structure of latent heat release within the model. In contrast to a diagnostic treatment of precipitation, latent heat release is now layered more horizontally than vertically. Very high values of latent heat release will be found in the updraft regions at the leading edge of a convective cell. No precipitation will reach the ground, there. Further upstream the release of latent heat becomes weaker and the precipitation rate arises. In terms of correlation of precipitation rate and latent heat release it means that within the same vertical column there is a weak correlation at an early state of a convective cell, a higher positive correlation in the middle of its lifetime and a weak negative correlation at the end of the lifetime. This feature strongly influences the effects of LHN. To consider these influences, the original LHN routine has to be checked, if it is still consistent. Especially all the control parameters have to be recalibrated in order to take into account the higher amounts of latent heat release. One essential effect will be discussed here in more detail. Performing prognostic precipitation will get vertical columns with a certain precipitation rate at the ground but no appreciable latent heat release above it. This will take place mainly in upstream regions of a convective cell, where the cell is almost dissipated. At these locations the model generally produces negative values of latent heat release due to evaporation of precipitation. In the case, that too much precipitation is modelled at these grid points (i.e. $\alpha < 0$), the resulting temperature increment will be positive. This of course will increase the precipitation rate instead. Therefore it is necessary to assure that increments will only be inserted at the right vertical layers. At grid points, where the precipitation rate of the model has to be increased, only positive temperature increments are added and negative increments at grid points where the model produces higher amounts than the observations. There is now implemented a check of the sign of the increment and the scaling factor within each model layer, which decides, if the increment will be used or not.

Figure 5 shows the hourly sum of precipitation for different LHN configurations (panels c to h) in comparison with the radar observation (panel a) and a simulation without LHN at all (panel b) for the 8th July 2004 9 UTC after 6 hours of assimilation. For panel c we just used the LHN configuration maintained in all the runs with diagnostic precipitation. This means, using

- an additional moisture adjustment,
- vertical filtering of the increments,
- grid point search for grid points without appreciable precipitation and
- LHN parameters as follows:
  - upper limit of the ratio is set to 3.0 (i.e. $\alpha <= 2$),
  - lower limit of the ratio 0.3 (i.e. $\alpha >= -0.7$) and
  - nudging coefficient equal 1.0.

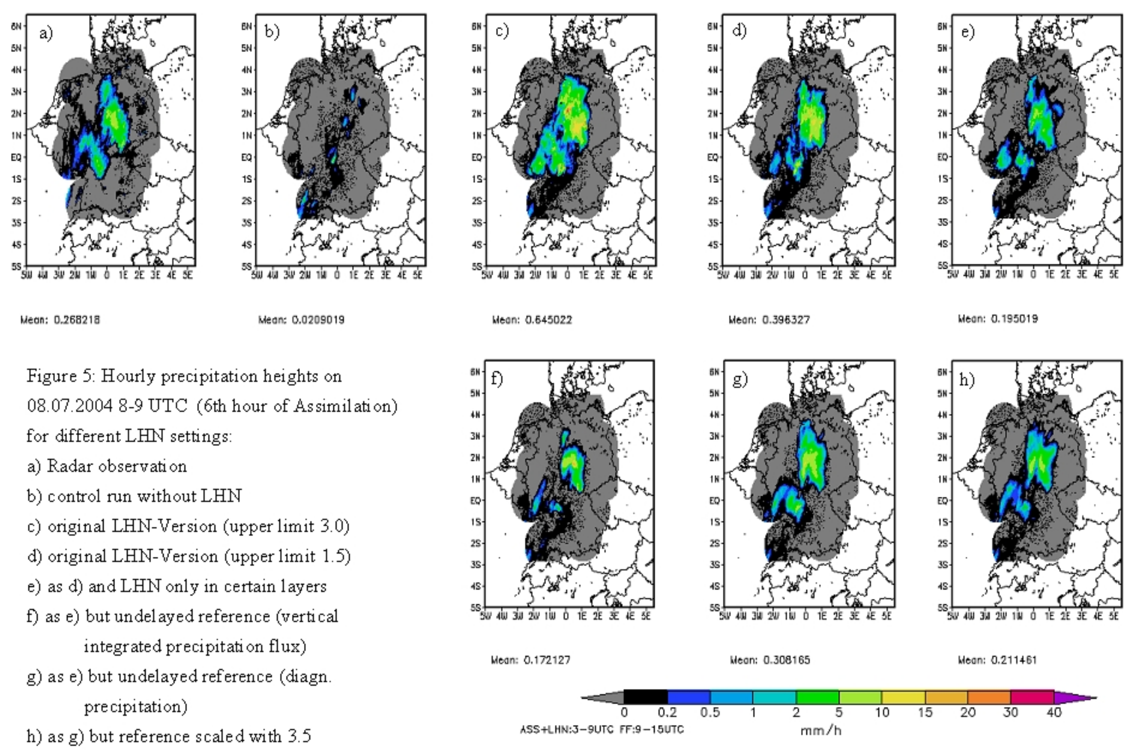


Figure 5: Hourly precipitation heights on 8th July 2004 8-9 UTC (6th hour of assimilation run) for different LHN configurations.

Again, we get a strong overestimation of precipitation due to the LHN. In the simulation for panel d we just changed the upper limit of the ratio to 1.5 (i.e. $\alpha <= 0.5$). Only this little change has a distinct effect on the forecast. The overestimation is not as strong as before and the locations of the patterns fit better, as well. In the next step of development we only apply the LHN increments in certain vertical layers as mentioned above. The results look quite good, even though the precipitation is underestimated now. So far, all the LHN simulations used the delayed prognostic precipitation as reference. Using an undelayed reference yields some additional benefits, especially in position and structure of the precipitation patterns. As a matter of fact, the application of an undelayed precipitation reference within the LHN approach is still under development.

## 4 Case Study with LHN and an undelayed reference precipitation

In order to test the previously mentioned adaptations to the LHN algorithm and to assess the effectiveness of LHN under the new circumstances, we carried out an assimilation run covering 5 days and also started 00, 12 and 18 UTC forecasts at each of these days. The period starting on the 7th July 2004 mainly covers convective precipitation events. For the simulations we used LM version 3.13 and we chose LMK configurations for the general model setup. Some additional LHN features are:

- use of an undelayed precipitation (diagnostic precipitation),
- spatial averaging (20 gridpoints) of latent heating and precipitation fields,
- LHN-coefficient: 0.5,
- applying temperature increments only in certain layers (more or less only in clouds).

For the purpose of comparison a control experiment without LHN was made. Figure 6 shows mean Equitable Threat Scores (ETS) and mean Frequency Biases (FBI) for hourly accumulated precipitation heights for a threshold of 0.1 mm for the assimilation run and the free forecasts starting at 18 UTC. The use of the LHN algorithm leads to continuously improved analysis states during the assimilation. This is shown by the higher values of ETS in fig. 6a. This positive impact of radar data is visible in the free forecasts for up to 7 hours (fig. 6b) on average. However, there is also a weak but persistent increase in the FBI present, which most of the time during assimilation tends towards the desired value of 1.0 (see fig. 6c). Unwanted are the greater values of FBI after the 8th hour of the 18 UTC forecasts (fig. 6d). But these values as well as the values in the night time hours of the assimilation run can probably be explained by a too low number of precipitation events during the hours from 0 until 6 UTC.

## 5 Summary and Outlook

Applying the Latent Heat Nudging approach in combination with a prognostic treatment of precipitation, we had to realise a bad performance of the LHN scheme. A distinct overestimation of surface precipitation took place. The features of the so called "prognostic precipitation" weaken the validity of the basic assumption of the LHN-approach. Several investigations were caried out. In the end two features could be identified to be the main reasons for the bad interaction of LHN and prognostic precipitation. First, precipitation needs a certain time to reach the ground and second, the change of spatial distribution of latent heat release in the model. After adapting the scheme, the model is again able to simulate the precipitation patterns in good agreement with radar observations. Over all we can state, that after tackling the challenges due to prognostic precipitation, the skill scores of

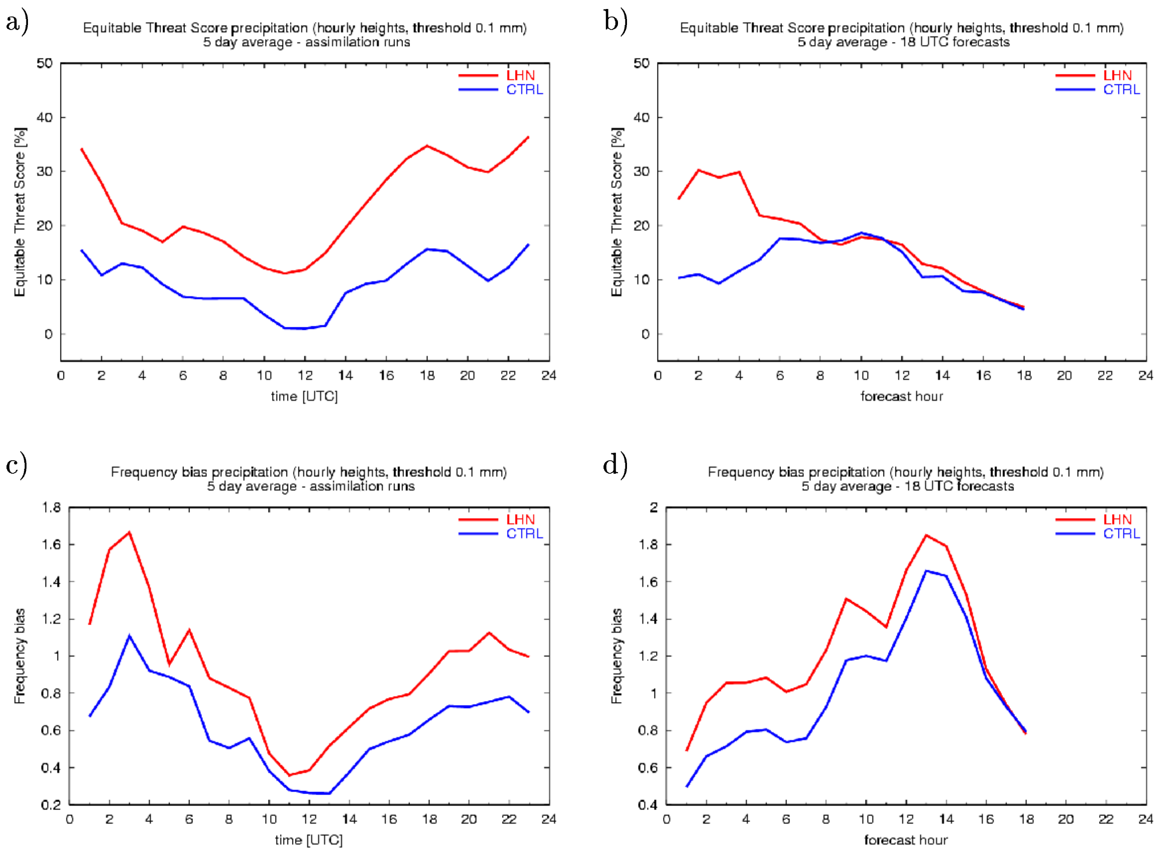


Figure 6: Mean Equitable Threat Scores and Mean Frequency Biases for hourly precipitation heights (threshold 0.1 mm) for assimilation runs (a) and (c) and for 18 UTC forecasts (b) and (d). The Mean scores were obtained by averaging over a 5 day period.

simulations with LHN are better than for simulations with the former diagnostic treatment of precipitation. With respect to a short simulation period in summer 2004, we can observe a benefit of LHN up to several hours within the free forecast. Further adaptations of the LHN scheme are possible and should allow to tune the results, as for instance spatial smoothing of precipitation fields and fields of latent heat release. In addition, simulations over longer periods in summer and winter are necessary, to decide on the operational use of the LHN approach.

## References

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