Assimilation of Radar Data in the LM at DWD

Stefan Klink and Klaus Stephan

Deutscher Wetterdienst, P.O.Box 100465, 63004 Offenbach a.M., Germany

1 Introduction

In the matter of mesoscale modelling at DWD a very high resolution model for short term numerical weather prediction based on the existing non-hydrostatic limited area model Lokal-Modell (LM) is under development. It is intended to run this LMK (LM Kürzestfrist) every 3 hours with a forecasting range of 18 hours. One reason for this design of the NWP model cycle is to provide input data with a high update rate for the hydrological models of flood forecasting systems with . Especially to improve the quantitative precipitation forecasting (QPF) work has to be done in the area of data analysis. In addition to the assimilation of conventional data, like surface and radiosonde measurements, high-resolution observations derived from radar networks are introduced in the nudging-type analysis of the LM. Using the Latent Heat Nudging (LHN) technique (Leuenberger and Rossa, 2003a) the thermodynamic quantities of the atmospheric model are adjusted in that way, that the modeled precipitation rates resemble the observed precipitation rates.

In the framework of the project RADVOR-OP funded by a working group of the hydrological authorities of the German federal states the use of radar data in the assimilation scheme of the LM will be made operational. Some real case studies concerning flooding events in different river catchments have been carried out. The results from these experiments show the precipitation patterns introduced due to the analysis in good agreement with those observed by radar, both in position and amplitude. The influence of the assimilation of radar derived precipitation rates lasts for several hours.

Results of a real case study and sensitivity of model predictions to model setup and settings of the assimilation scheme will be shown.

2 Theory and Implementation

Contemplating an utilization of radar reflectivities in the LM, it has to be stated, that a direct assimilation of both radar reflectivities and precipitation rates is not possible, because both quantities are no prognostic variables of the LM. Even a future prognostic treatment of precipitation in the LM would not allow a reasonable direct assimilation of precipitation rates, because there is only a small feedback from the precipitation rate to model dynamics and physics. But these two components of the model are essential for the development of precipitation. Attempts have to be done in order to assimilate radar information into the model by the use of any other variables (e.g. temperature, specific humidity or components of the wind vector). Thus a relation between precipitation rate and prognostic model variables is wanted. Concepts basing on processes, normally present in the context of precipitation, are desired. One special process connected with the formation of precipitation is the condensation of water vapour. It is directly linked to the release of latent heat. Originally, most condensation processes must be considered as the formation of cloud droplets, but this is only a preliminary stage of the precipitation forming. Nevertheless it is possible to influence the model dynamics and consequently the formation of precipitation by adjusting the model-generated latent heat release. The diabatic heating rates, which are related to phase changes of water, are tuned in that way, that the model simulates the observed precipitation rates. This is realized by adding LHN temperature increments to the 3D temperature field. This method is called “Latent Heat Nudging” (e.g. Wang and Warner, 1988). An introduction to LHN, further references to literature about this method and some aspects of the special implementation of the LHN algorithm in the LM source code can be found in Leuenberger and Rossa (2003a).

Besides the tuning of the temperature profile at a certain gridpoint, the vertical profile of specific humidity at this gridpoint can be adjusted during the LHN as well. Depending on the sign of the temperature increment, specific humidity q is increased in order to reach a value of 100% of relative humidity (positive temperature increment) or specific humidity is decreased in order to retain relative humidity (negative temperature increment).

3 Preparation of Radar Data

Input data for the assimilation is the 2D-field of the observed precipitation rate RRobs. Starting point for the provision of the LHN scheme with radar derived precipitation rates is the international composite (PI), available at DWD. The measurements of radar reflectivities gained at each individual radar site of the German radar network and at several locations in the neighbouring countries are incorporated in this product. The local reflectivity product PL of the German radar network is derived from the volume scan. The data actually used are the echos next to the ground, coded in 7 reflectivity classes. The spatial resolution of the PI, which is originally delivered in polar-stereographic projection, is $4\,km$ x $4\,km$. The product is available every 15 minutes. After a conversion of the reflectivity data into a precipitation rate by a simple Z-R-relation, an interpolation of the pixel values to the desired LM grid is performed.

Investigations of the LHN-algorithm by means of idealized experiments have shown, that a high update rate of radar data would lead to more realistic nudging-analyses and subsequent forecasts (Leuenberger and Rossa, 2003b). Thus and because of some other reasons, which will be mentioned below, a new radar composite basing on the DX product of DWD (spatial mesh: $1\,km$ x $1°$, time resolution 5 min) will be used as proxy data for the LHN scheme. This product will be provided by the project RADOLAN as a preliminary product of the gauge adjustment procedure, the project is dedicated to. An advantage of this product, which is derived from the precipitation scan, is the additional correction of orographic attenuation and the use of a variable Z-R-relation for the calculation of precipitation rates from echo intensities.

4 Case Study

For a selected event LM-runs on the operational domain (mesh size $7\,km$, 325 x 325 gridpoints, 35 vertical levels) and runs on an experimental domain (mesh size $2.8\,km$, 361 x 441 gridpoints, 40 vertical levels) have been carried out. Results of horizontal fields are presented on a limited evaluation domain (see fig. 1). In general the convective parameterization scheme has been switched off, in order to give the model the chance to directly simulate convection. The provisioning of the LM with boundary data is done by the GME. After 6 hours of data assimilation (nudging and latent heat nudging, including humidity adjustment during the LHN) from 6-12 UTC a free forecast lasting from 12-18 UTC has been carried out.

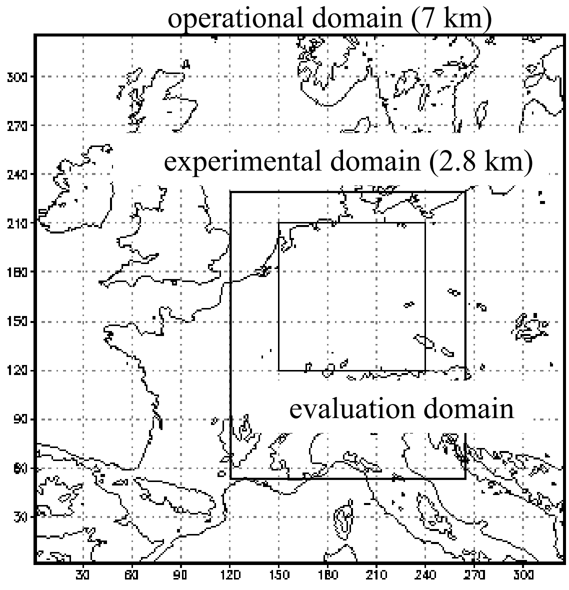

Figure 1: Domains of interest

4.1 Overview of the Meteorological Situation

At the 28th of August 2002 Germany was influenced by only small synoptic-scale pressure gradients. In the warm, moist and unstable air mass a development of showers and thunderstorms took place in the afternoon in the area of a quasi-stationary front, which lay over Germany (see fig. 2). It was reported that heavy precipitation occured locally (e.g. 70 mm between 15.15 and 16.30 UTC in Herborn, Hesse and 85.5 mm within 4 hours in Wissen, NRW).

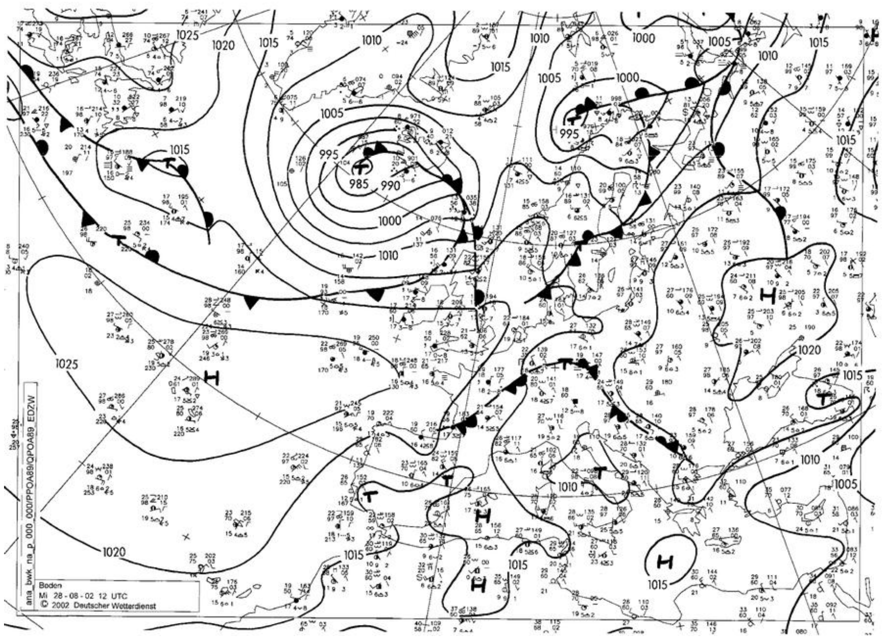

Figure 2: Meteorological situation at the 28th of August 2002

4.2 Influence of the LHN on the nudging-analysis depending on the mesh size of the LM

In this paragraph three nudging-analyses, one without LHN and two with different mesh sizes (7 km, 35 vertical levels and 2.8 km, 40 vertical levels respectively) are compared with radar derived precipitation rates. The 2.8 km run was started at 21 UTC one day before by interpolating the analysis of the 7 km run to the finer mesh. Afterwards 9 hours of conventional nudging were carried out in both suites independently. This is the reason for the distinct differences between the 7 km and 2.8 km run in the first hour (6-7 UTC) of nudging and LHN (see fig. 4a). The simulation on the finer grid contains in this case not so much erroneous precipitation as the corresponding run on the 7 km grid. Thus the LHN algorithm has not to remove much misplaced precipitation from the run but mainly has to insert observed precipitation at points where the model does not simulate precipitation so far. In the first hour of LHN this works much better on the finer grid than on the operational one. Throughout the next two hours the assimilation of observed precipitation rates turns out well in both LHN runs. In contrast with these LHN suites the control run shows a more extended area of precipitation, which is shifted moreover to the southeast. After that the convection weakens over a wide range (except Bavarian forest, compare with Radar 10-11 UTC). But the convergence line remains in the Radar as well as in the LHN assimilation runs. During the last hour of assimilation from 11 to 12 UTC a revival of the convection can be observed in the Radar and in the LHN runs respectively but not in the control run. The assimilation of small convection cells e.g. in the Thuringian forest naturally works better in the 2.8 km run than in the 7 km run. All in all, the LHN experiments show precipitation patterns which fit much better to the corresponding radar derived observations than the control experiments without LHN (see fig. 4e). The hit rate for hourly precipitation sums (threshold 0.1 mm) reaches at the end of the assimilation period values, which are on an average 30 % higher than those of the control experiments (see fig. 3).

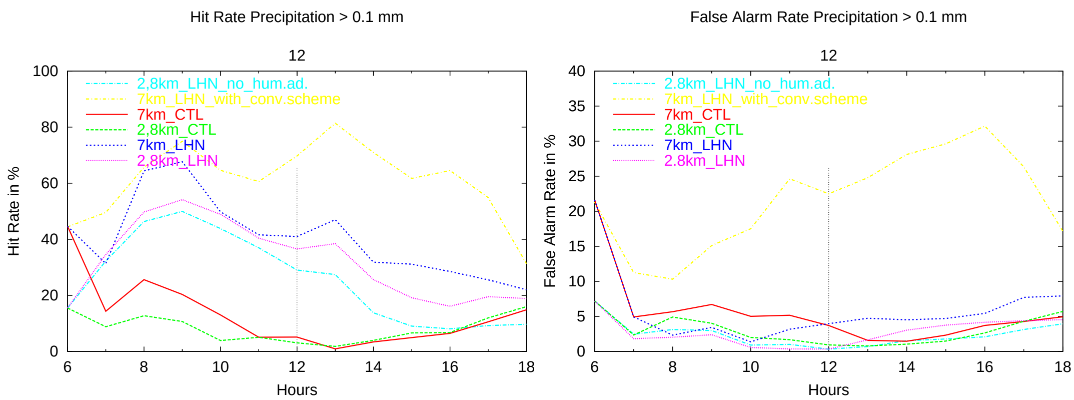

Figure 3: Hit rate (left) and false alarm rate (right) in hourly precipitation sums for different runs

At the beginning of the free forecast the convective cells are strongly intensifying in both LHN runs. The simulated intensities of precipitation reach maxima, which are clearly above the corresponding observations (see fig. 5a, 12-13 UTC). At the same time the convective cells remain strongly limited in their horizontal extension. The control run shows at this stage a further weakening of precipitaton in contrast with the radar measurements. Throughout the third hour of free forecast the LM runs basing on LHN-assimilations still have more forecast skill than the control run. This is especially true for the total amount of precipitation in the evaluation domain. But inaccuracies already occur in the correct position and intensity of single convection cells. An interesting aspect is the occurence of small convective cells over the mountain ranges of Swabian and Franconian Alb between 16 and 18 UTC. Besides the radar only the 2.8 km run shows these structures. Altogether the precipitation patterns of all three LM simulations resemble to each other more than to the radar observation in the sixth hour (17-18 UTC) of free forecast (see fig. 5e). This is also caused by the fact, that within this hour the convergence line, which has been introduced in the LHN-runs some hours earlier, is been developed even in the control experiment.

4.3 Sensitivity of LHN concerning humidity adjustment

Two LM runs have been carried out on the experimental domain (mesh size 2.8 km), one run with humidity adjustment during the LHN, the other one without. After three hours of nudging and simultaneous LHN both runs already show a good correspondence between their precipitation patterns and the distribution given by the radar observations (see fig. 6a). While the position of the precipitation maxima is assimilated quite well, there are problems in areas with low precipitation rates. Especially the assimilation run without humidity adjustment still depicts wide areas with weak precipitation between 8 and 9 UTC, which already have been misplaced in the analysis at 6 UTC (compare to fig. 4a) and could not be dried up completely throughout the following three hours. After another three hours of assimilation, i.e. within the last hour of nudging and LHN, the position of the convergence line over western Germany is reproduced well by both assimilation runs (see fig. 6b). At a first glance the two assimilation runs do not seem to differ much. But when zooming in the area of Thuringian forest and in the mountains of “Erz- and Fichtelgebirge” (see fig. 6c), it can be seen, that the assimilation of the newly developing thunderstorms works better in the case of additional humidity adjustment. After three hours of free forecast, again the run with humidity adjustment during the LHN shows more realistic precipitation patterns than the corresponding run without humidity adjustment (see fig. 6d). This is especially true when concerning the intensity but lesser in case of the position of the maxima of the predicted precipitation fields. Both simulations have in common, that the horizontal extension of precipitation patterns is much smaller than in the corresponding radar observations. The total amount of precipitation (integrated over the evaluation domain) is too small in the forecasts compared to the radar observation.

5 Summary and Outlook

Incorporating the LHN-algorithm in the nudging-type analysis scheme of the LM makes it possible to assimilate the radar-derived precipitation rates during the assimilation runs very well. Experiments have shown that the explicit simulation of convection leads to more realistic results than model runs with parameterized convection. Using a finer grid within the simulation shows a potential for further improvements of the quantitativ precipitation forecast. An additional humidity adjustment during the LHN results in a more exact analysis of the atmospheric state and in more realistic free forecasts.

References

Leuenberger, D. and A.M. Rossa, 2003a: Assimilation of Radar Information in aLMo. COSMO Newsletter, No. 3, 164-172 (available at www.cosmo-model.org).

Leuenberger, D. and A.M. Rossa, 2003b: Assimilation of Radar Information in aLMo. Oral presentation, 5th General COSMO-Meeting, Sep. 2003, Langen (Germany)

Wang W. and T.T. Warner, 1988: Use of Four-Dimensional Data Assimilation by Newtonian Relaxation and Latent-Heat Forcing to Improve a Mesoscale-Model Pricipitation Forecast: A Case Study. *Monthly Weather Review*, **116**, 2593-2613.

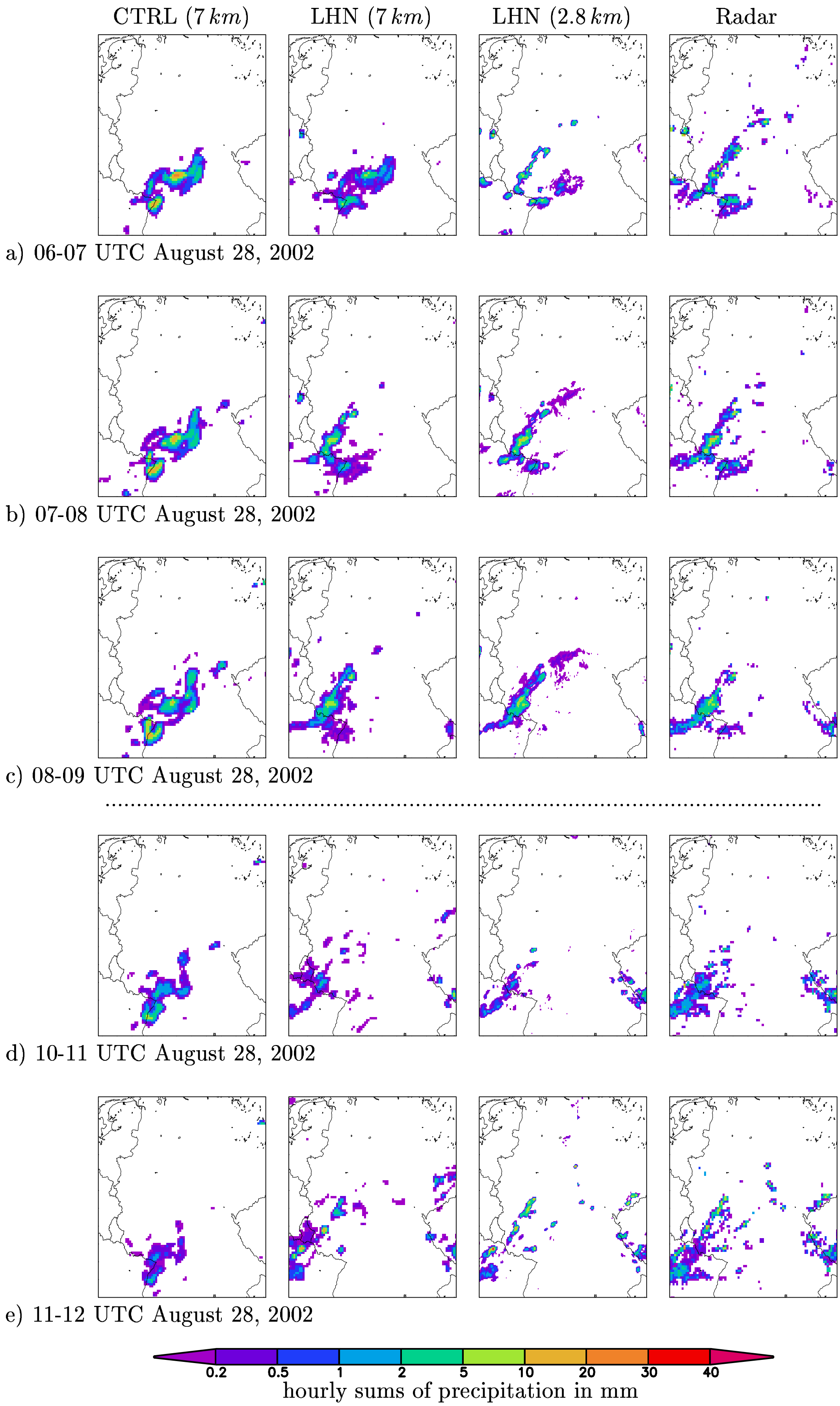

Figure 4: Influence of the LHN on the nudging-analysis depending on the mesh size of the LM, assimilation (1st column: CTRL (7 km), 2nd column: LHN (7 km), 3rd column: LHN (2.8 km), 4th column: Radar)

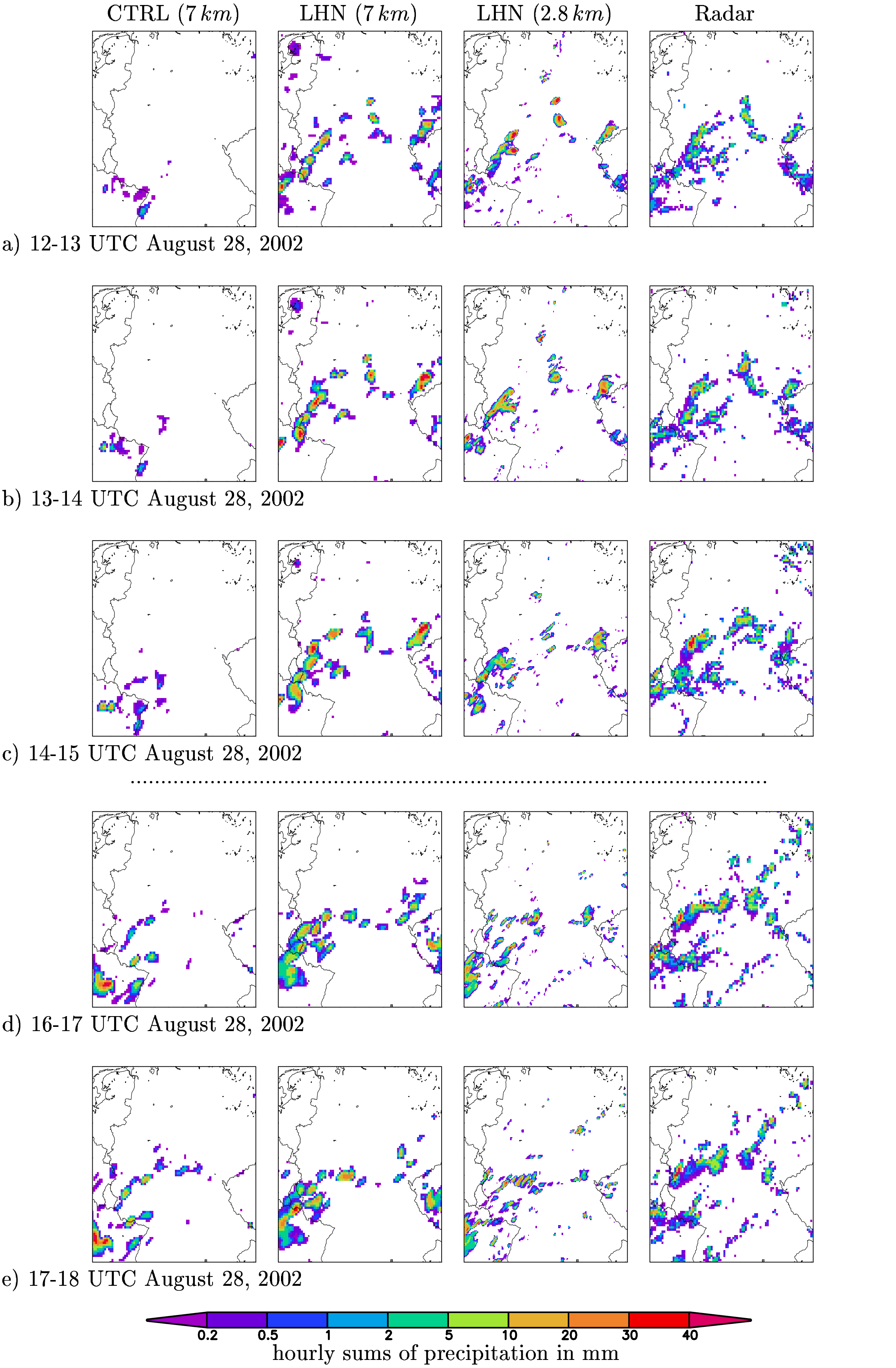

Figure 5: Influence of the LHN on the nudging-analysis depending on the mesh size of the LM, free forecast (1st column: CTRL (7 km), 2nd column: LHN (7 km), 3rd column: LHN (2.8 km), 4th column: Radar)

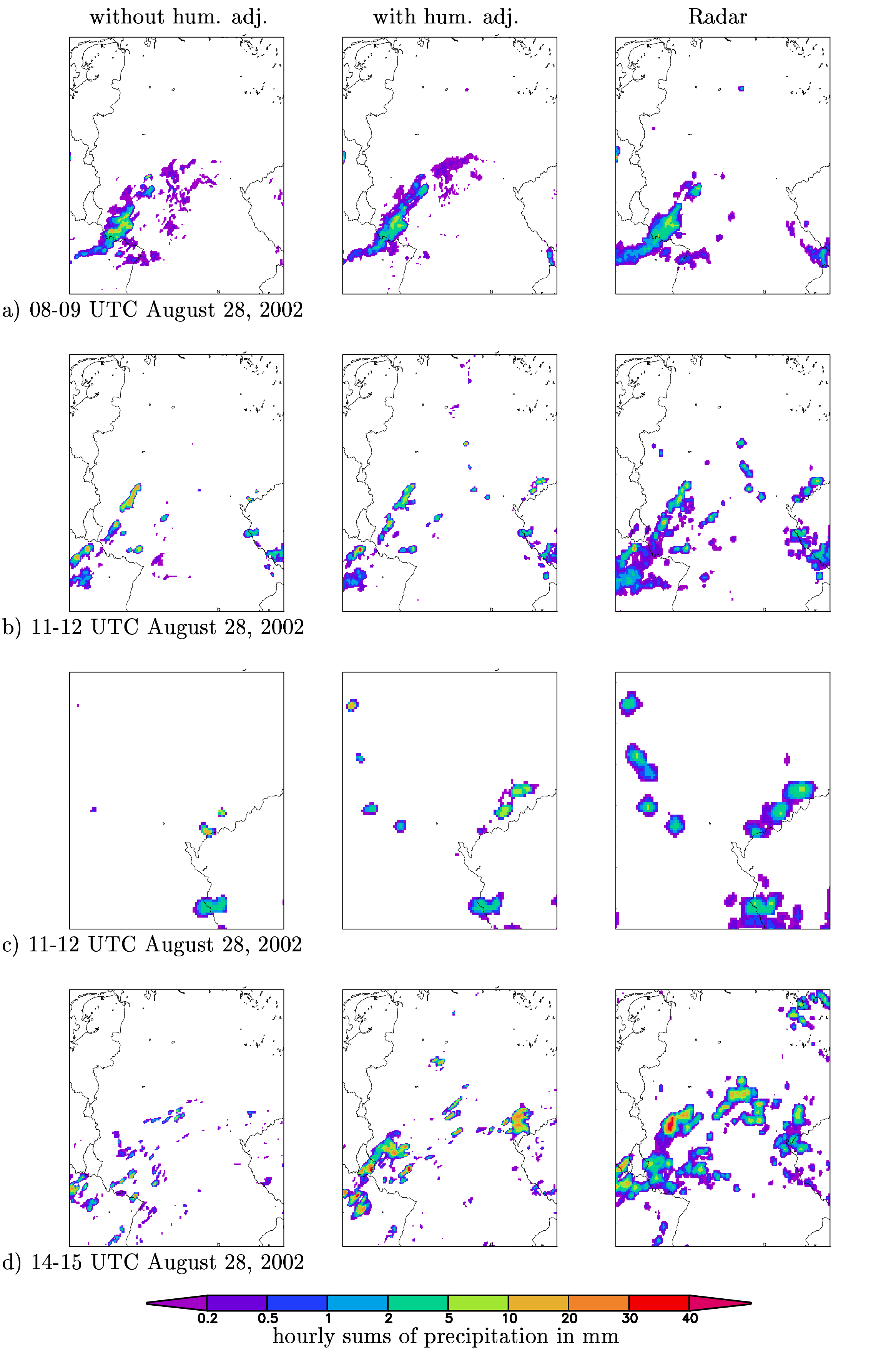

Figure 6: Sensitivity of LHN concerning humidity adjustment, (1st column: without humidity adjustment, 2nd column: with humidity adjustment, 3rd column: Radar)