Physical initialization to incorporate radar precipitation data into a numerical weather prediction model (lokal model)

JP1.15 PHYSICAL INITIALIZATION TO INCORPORATE RADAR PRECIPITATION DATA INTO A NUMERICAL WEATHER PREDICTION MODEL (Lokal Model)

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August 18, 2005

1 Introduction

Numerical prediction of precipitation strongly depends on the accurate representation of the initial state of the atmosphere and the parameterization and microphysical representation of precipitation in the model. Typically NWP model runs are initialized in a so-called dry state leaving the state variables for condensed water at zero. Usually several hours of simulated weather evolution will pass until the hydrological cycle is established (spin-up time). Assimilation of rain data reduces the spin-up time significantly and makes nowcasting with numerical NWP models possible.
In NWP, assimilation is used to combine past and present observations with the dynamical constraints of a forecast model in order to generate a complete three-dimensional description of the atmosphere, which can be used as starting point for a forecast. There are basically two categories of techniques: physical and variational approaches.
The variational procedure consider a system as a whole, combines model and observations in a statistically optimal sense and does not deal explicitly with the individual components of the system.
The physical approaches adjusts some or several model state variables responsible for the considered process during the procedure based on physical reasoning.
In this work we are using a physical approach called PI (Physical Initialization). The PI procedure developed by *Krishnamurti* et al. (1991) assimilates 'observed' measures of rain rates into a Numerical Weather Prediction (NWP) model. The first mention of PI was from *Krishnamurti* et al. (1984), and it provided the information to the model every assimilation timestep. The method focuses on consistent model physics, which can generate the observed precipitation data. This is achieved through a number of reverse physical algorithms within the assimilation mode, which include a reverse similarity algorithm, a reverse cumulus parameterization and the algorithm which restructures the vertical distribution of humidity. In *Krishnamurti* et al. (1991) and *Krishnamurti and Bedi* (1996) the moisture and wind fields are modified during the pre-forecast nudging phase by assimilating both satellite-derived rain rates and outgoing radiation. Another physical approach of assimilation is the latent heat nudging, where increments of moisture and temperature are added throughout the pre-forecast period (see *Jones and Macpherson* (1997) and *Manobianco* et al. (1994)).

2 Model and Data

2.1 Model description: Lokal Model (LM)

The LM (Lokal Model, see *Doms and Schättler* (1999)) used in this work is the one used at present at the DWD (Deutscher Wetterdienst) for the regional operational forecasts. It is a non-hydrostatic model usually run with a horizontal resolution of 7 km for the operational forecasts. The boundary conditions come from a global model, the so-called GME, wich has a grid resolution of 60 km.
In this work the LM (versions 3.9 and 3.15) is run with 2.8 km horizontal resolution for an area of $560km \times 350km$ in the northern part of Germany with the lower left point at lon=$6,016^0$ and lat=51.363^0. This resolution will soon become

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operational at DWD, especially for short-range precipitation forecasts. The initial and the boundary fields for the LM forecast are then provided by the analysed fields for the LM at 7 km resolution and 35 vertical terrain-following sigma coordinate levels.
The prognostic model variables, which are calculated on an Arakawa-C-grid, are the wind vector, temperature, pressure, specific water vapor and cloud water content. The integration timestep is 25 seconds. The model includes a grid-scale cloud and precipitation scheme as well as a parameterization of moist convection (Tiedtke mass flux scheme). For this study the convection parameterization is switched off, because we assumed that convection will be resolved by the high model resolution. In this work snow and other frozen particles are not considered.

2.2 Data

We use as input for the PI the DWD national radar composite (DX-data) and nowcasting products for satellite data from the Satellite Application Facility to support Nowcasting and Very Short Range Forecasting applications (SAFNWC).

German national radar composite

The radar composite data is a two dimensional product with a spatial resolution of 1 km and a temporal resolution of 5 min. The conversion from reflectivity to rain rate is performed by DWD (Fig. 1) using the following Z-R relation (*Schreiber* (1997)) :

$$RR_{OBS} = (\frac{Z_{OBS}}{256})^{\frac{1}{1.42}} \qquad (1)$$

and given as precipitation flux (RR_{OBS} in kg/m^{2}s).
The composite is produced from the sixteen radars of the DWD radars network (see Fig. 1) basically by using the strongest signal in the overlapping areas. Thus the composite contains the portrayal of the ground-proximate radar reflectivity distribution over Germany.

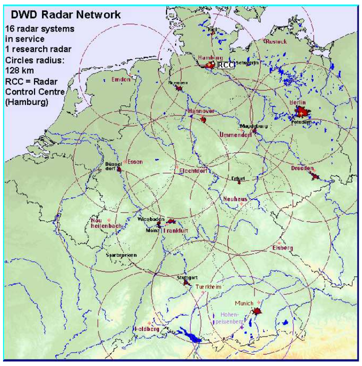

Figure 1: *DWD radar network. The circles maround each radar site have a radius of 128km.*

SAFNWC

The SAFNWC is hosted by the Spanish Meteorological Institute (INM), and the satellite data we use are already processed data from DWD using the SAFNWC algorithms. The objective of SAFNWC is to develop operational software to produce a total of 12 different daily products, thought to be valuable for nowcasting applications, using data from the current NOAA and the EUMETSAT MSG and EPS satellites. The data has full resolution at satellite nadir (3km × 3km for MSG at the equator), and is interpolated to the LM grid. From the many parameters, we currently use only Cloud Top Temperature/Height (CTTH) and the Cloud Mask (CMa).

3 PI

Our PI scheme (derived originally from *Haase* et al. (2000)) modifies the values of vertical wind (w in m/s), specific water vapor (q_v in kg/kg), and cloud water content (q_c in kg/kg).
The cloud top height (z_{ct} in m) for the runs without the use of satellite data is temporally and spatially constant (at about 6500 m). In our work we began to use the satellite data in order to determine the cloud top height.
The cloud base height is approximated by the Convective Condensation Level (CCL) derived from NWP model output in the grid areas where the precipitation analyzed from the radar data is greater then $0,1mm$. This approach agrees with the intention of PI to initialize deep convection; the maximum CCL is, however, limited to a height of 3000m AGL.
¿From the values of cloud top and cloud bottom we compute the vertical wind inside the cloud using the rain rate from the radar data.

The expression for the vertical wind inside a cloud at model level k is:

$$\widehat{w}_k = (\rho^*_{v,k})^{-1}\{\rho^*_{v,k-1}\widehat{w}_{k-1} - (z_{k-1} - z_k)\frac{R(z_{cb})}{z_{ct} - z_{cb}}$$
$$[1 - \frac{\pi}{2}(1 + \frac{1}{c})sin(\frac{\pi}{2}\frac{z_{k-1/2} - z_{cb}}{z_{ct} - z_{cb}})]\}$$

with

$$c = \frac{R}{\rho^*_v \widehat{w}}\ |_{z=z_{cb}} \qquad [0,1] \qquad (2)$$

The only tuning parameter is c; it is a measure for the conversion efficiency of saturated water vapor into rain water at cloud base (currently it is set to a value of 0,9).
Beneath the cloud the vertical wind is estimated using a linear interpolation from the vertical wind at the cloud base to the value of 0 at the earth surface.
The specific water vapor (q_v) inside the cloud is set to the saturated specific water vapor (q^*_v); beneath the cloud the saturated specific water vapor at the cloud bottom is taken; above the cloud top we fix the water vapour maximum to $RH = 85\%$. This threshold avoids saturation above the cloud.
The cloud water content inside the clouds is calculated using (*Karstens* et al. (1994)):

$$q_{c,ad}(z) = \int_{z_{cb}}^{z} \rho_{air}(z')\frac{c_p}{L}(\Gamma_d - \Gamma_s)dz' \qquad (3)$$

where ρ_{air} is the density of air, c_p is the specific heat at constant pressure, L the latent heat of vaporization, Γ_d the dry adiabatic and Γ_s is the pseudoadiabatic lapse rate. The LM version used so far contains no ice scheme. The reduction of the liquid water content due to entrainment of unsaturated air, precipitation formation and freezing is considered by modifing $q_{c,ad}$ as follows:

$$q_c(z) = q_{c,ad}(z)[1.239 - 0.145 \ln z - z_{cb}] \qquad (4)$$

These changes are only applied where the analysed precipitation (calculated using the radar data) are greater then $0,1$ mm/h. (see also tab. 1)

height	$R_{ana} > R_{th}$	$R_{ana} \leq R_{th}$
$z > z_{ct}$	$w = 0$ RH=min(RH, 85%) $q_c = 0$	w not modified RH=min(RH, 85%) $q_c = 0$
$z_{ct} \geq z \geq z_{cb}$	$w = \widehat{w}(z)$ $q_v = q^*_v$ q_c equation 4	w not modified RH=min(RH, 85%) $q_c = 0$
$z < z_{cb}$	$w = linear$ $q_v = q^*_v(z_{cb})$ $q_c = 0$	w not modified RH=min(RH, 85%) $q_c = 0$

Table 1: *LM variables modified by PI scheme*

4 Results

We have performed several forecasts for August 13, 2004: a control run, a run with PI without using the satellite data for the cloud top, a run with PI using the satellite data and one with LHN. All runs were initialized at 10 UTC).
The assimilation window is three hours after which another three hours of free LM run are performed (for the control run there are six hours of LM run).
The meteorological event is characterised by strong convection in northern Germany, which started in the morning of August 13 in the east part of our forecast area; it then propagates to the west with several convective cells scattered over the area.
We have compared all the runs with the radar data using the following skill scores.

Hit rate:

$$HR = 100\frac{d}{b + d} \qquad (5)$$

False Alarm Rate rate:

$$FAR = 100\frac{c}{c + d} \qquad (6)$$

where the values for a,b,c,and d are derived from the contingency table (see tab. 2)

	$R_{rad} \leq R_{th}$	$R_{rad} > R_{th}$
$R_{LM} \leq R_{th}$	a	b
$R_{LM} > R_{th}$	c	d

Table 2: *Contingency table for precipitation verification, R_{rad} radar precipitation, R_{LM} model precipitation, R_{th} threshold for precipitation rates 0.1mm/h*

4.1 Control run

In this simulation we have used the version 3.15 of LM. The control run clearly shows the spin-up effect; there is a much less precipitation in first three hours of the forecast, expecially in the southwestern part of the area, where the radar has detected precipitation and the model is dry. The convective cells detected from the radar are not represented at all in the control run.

4.2 PI

In this simulation we have used the version 3.9 of LM. During the assimilation window (from 10 UTC to 13 UTC), the agreement between the precipitation in the model and in the radar is very good (see the skill scores in fig. 2 and 3), but in the time after the assimilation window the model creates for about an hour several strong convective cells. These influence the quantitative precipitation forecasts by inserting exaggerated precipitation also in areas where the radar detects less precipitation or is even dry.

The use of the satellite data for the cloud top has reduced this problem but did not solve it fully. We plan also to initialize non-precipitative clouds in the future, which might lead to more balanced forecast runs.

4.3 LHN

In this simulation we have used version 3.15 of LM. Also the run with LHN the precipitation fields exhibit several exaggerated convective cells after the assimilation window. For LHN precipitation covers larger areas leading to a better better hit rate and worse false alarm rate (compared with the run with PI), see pictures 2 and 3.

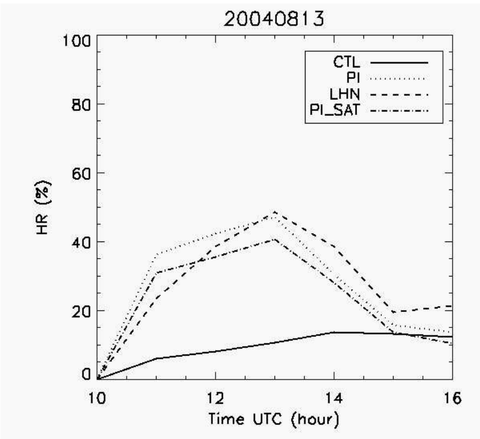

Figure 2: *Hit rate for the three runs*

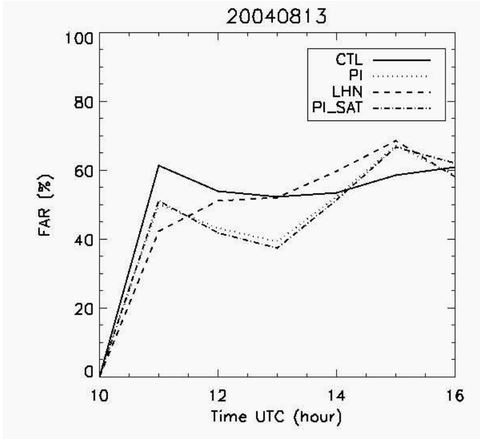

Figure 3: *False Alarm Rate for the three runs*

5 Summary and conclusions

The present study used a Physical Initialisation method (PI) in order to incorporate radar derived precipitation and satellite cloud data into the LM. The use of PI leads to a very good agreement between the precipitation field in the radar data and the one obtained using LM with PI during the assimilation window. During this time the life cycle of the convection events and his quantitative precipitation are well represented. Our results show also that during the free run the precipitation forecasts are better than during the control run. We have, however, problems due the presence of exaggerated strong convective cells, which we currently analyse in more detail. Improvements of this assimilation method might come from using the SAFNWC products for cloud type and the assimilation also of non precipitating clouds.

References

Doms, G. and U. Schättler, *The nonhydrostatic limited-area model LM (Lokal-Modell) of DWD. Part I: scientific documentation*, German Weather Service (DWD), Research Department, P.O. 100465, D-63004 Offenbach, 1999.

Haase, G., S. Crewell, C. Simmer, and W. Wergen, Assimilation of radar data in mesoscale models: Physical initialization and latent heat nudging, *Physics and Chemestry of the Earth*, 25, 1237–1242, 2000.

Jones, C. and B. Macpherson, A latent heat nuging scheme for the assimilation of precipitation data into an operational mesoscale model, *Meteorological Applied*, 4, 269–277, 1997.

Karstens, U. C., C. Simmer, and E. Ruprecht, Remote sensing of cloud liquid water, *Meteorology and Atmospheric Physics*, 54, 157–171, 1994.

Krishnamurti, T. N. and H. Bedi, A brief review of physical initialization, *Meteorology and Atmospheric Physics*, 60, 137–142, 1996.

Krishnamurti, T. N., K. Ingles, S. Cocke, and T. Kitade, Details of low latitude medium range numerical weather prediction using a global spectral model, part ii: effects of orography and physical initialization, *Journal of the Meteorological Society of Japan*, 62, 613–649, 1984.

Krishnamurti, T. N., J. Xue, H. Bedi, K. Ingles, and D. Oosterhof, Physical initialization for numerical weather prediction over the tropics, *Tellus*, 43, 53–81, 1991.

Manobianco, J., S. Koch, V. Karyampudi, and A. Negri, The impact of assimilating satellite-derived precipitation rates on numerical simulations of the ERICA IOP 4 cyclone, *Monthly Weather Review*, 122, 341–365, 1994.

Schreiber, K. J., Der Radarverbund, *DWD, Technical Infrastructure Department*, 1997.