IMPACT OF HORIZONTAL MODEL RESOLUTION ON CLOUD PARAMETERS FORECASTED BY A NON-HYDROSTATIC MESOSCALE MODEL

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1. INTRODUCTION

The scale of macroscopic cloud processes like stratus clouds or deep convection is in the order of a few kilometers. If the horizontal grid spacing of operational mesoscale weather prediction models is refined to these scales, it is expect that these phenomena can at least partly be resolved explicitly resulting in improved forecasts of cloud related quantities by avoiding uncertainties which are inherent to any parameterization.
To investigate the effect of horizontal refinement on prediction of cloud parameters we have performed integrations using the operational non-hydrostatic mesoscale model Lokal-Modell (LM) of the German weather service with grid spacings of 7km down to 1km. Since high resolution simulations require high computational costs, we were restricted to concentrate on case studies. In the following, the results of six case studies during observation periods of the Cloud Liquid Water Network (CLIWA-NET) project (Crewell, 2002) will be presented.

2. MODEL DESCRIPTION AND EXPERIMENTAL DESIGN

The LM is a fully compressible non-hydrostatic model which is currently operated with a horizontal resolution of 7km. The time integration is implicit in the vertical direction and split-explicit in horizontal directions following the concept of Klemp and Wilhemson (1978).

The model has a generalized terrain-following vertical coordinate, which divides the model atmosphere into 35 layers from the earth's surface up to 20hPa height. The vertical resolution is highest close to the surface with less than 50m vertical grid spacing and increases with altitude. Prognostic model variables are the wind vector, temperature, pressure perturbation, specific humidity, and cloud water of grid scale clouds. Precipitative fluxes of rain and snow become diagnostic quantities by assuming steady state conditions within each atmospheric column.

Grid-scale condensation is parameterized according to the concept of saturation adjustment: Water vapour exceeding saturation is converted into cloud water instantaneously and if a grid point becomes unsaturated, cloud water will be evaporated as long as cloud water is available or until saturation is reached.

The physical parameterization package is completed by a mass flux convection scheme (Tiedtke, 1989), a level-2.5 turbulence parameterization, a delta-2-stream radiation transfer scheme, and a 2-layer soil model. Initial and boundary values are provided by operational nudging LM-analysis of DWD. A detailed model description is given by Doms and Schaettler (1999).

In order to identify effects of horizontal refinements simulations with horizontal grid spacings of 7, 2.8 and 1.1km were performed. To maintain the same numerical accuracy the Courant number was kept constant resulting in decreasing time steps of 60, 25 and 10s respectively. It is essential to use the same model boundaries at all resolution because otherwise effects due to different boundary conditions might have the same magnitude as refinement effects. The target area of the CLIWA-NET campaigns differed and consequently two different model domains, POTSDAM and CABAUW which are centered over the respective measuring site were necessary (see Figure 1). Both domains cover an area of 440x440km^2 with very moderate orographic structures. The CABAUW domain is more maritime influenced since it comprises a significant part of open sea and costal regions.

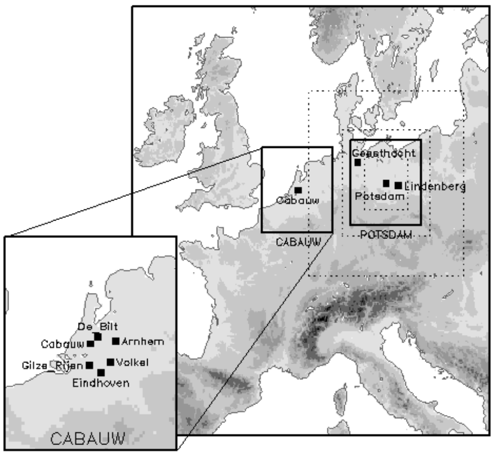

Figure1: Model domains „CABAUW“ and „POTSDAM“ with corresponding measuring stations.

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Table 1: Fractional deviation of mean quantities (averaged over model domain and 24h) simulated at different resolutions relative to 7km run. Mean values of all six cases in bold letters, smallest (biggest) deviation indicated above (below). Convection scheme is always switched off.

	Integr. water vapour	Liquid water path	Precipi-tation	Total cloud cover	Grid scale cloud cover	Net surface radiation	Sensible heat flux	Latent heat flux
2.8 km	1,00	1,10	1,26	0,98	0,96	0,95	0,92	0,97
	1,01	**1,33**	**1,93**	**1,04**	**1,05**	**1,00**	**0,99**	**1,00**
	1,02	1,74	4,26	1,10	1,16	1,05	1,08	1,02
1.1 km	1,00	1,03	1,36	0,96	0,89	0,94	0,88	0,96
	1,01	**1,54**	**2,25**	**1,01**	**1,02**	**0,99**	**0,97**	**0,99**
	1,02	2,38	5,49	1,07	1,24	1,09	1,07	1,02

3. RESULTS

3.1 Spatial and temporal averaged quantities

A perfect model will add small scale features without changing the coarse scale structure, if grid spacing is reduced. Consequently area averaged quantities are expected to be insensitivity to changes in resolution. Table 1 summarizes the deviation of averaged quantities observed by simulation without convection parameterization with reference to the 7km run. The integrated water vapour content (IWV), which is one of the key variables defining the probability of cloud formation, obeys this rule very well, since this quantity is mostly determined by large scale advection. In contrast, liquid water path (LWP) and precipitation have significant trends; these quantities increase as grid spacing is reduced. Surprisingly, parameterized as well as resolved cloud cover seems to be consistent in terms of mean values. As a consequence hardly any deviations in the net surface radiation occur, because cloud cover is the most relevant parameter modifying radiative fluxes. Since not only the energy input but also the boundary layer stability remains unchanged, the surface energy budget is not affected by the refinement.

The increase in cloud water can be mostly attributed to the lack of a subgrid condensation scheme. Due to humidity fluctuations saturated areas connected with positive cloud water content may occur within a box, which is on average unsaturated. Since cloud water content is a positive definite quantity, this type of sampling error will result in a systematic underestimation of cloud water content at coarse scales. Derived from the three case studies at the “Cabauw” area, an increase of cloud water content due to resolved water vapour fluctuations in the order of 25% at the 2.8km scale and of 80% at the 1.1km can be expected. Since more cloud water will directly increase precipitation, the observed trend is even stronger here.

It is expected that simulations at 1km horizontal scale can resolve at least deep convection and that therefore a parameterization of convection becomes superfluous or less important. Therefore it is of great interest to compare simulations with and without parameterized convection. As far as mean quantities are considered, IWV, cloud cover and net surface radiation show no sensitivity, small differences occur in sensible and heat flux and significant discrepancies can be observed with respect to LWP and precipitation, as depicted by figure 2. The Tiedtke convection scheme implemented into LM assumes stationarity neglecting all storage terms. Over saturation is directly converted into rain without producing cloud water. Consequently LWP values of simulations with parameterized convection are dramatically reduced. The results concerning precipitation give no clear picture.

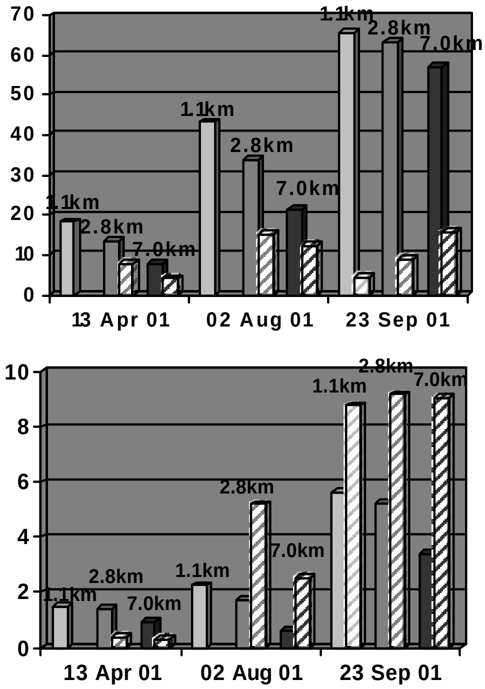

Figure 2: Daily mean values averaged over model domain for all “Cabauw” cases. Solid bars as result of runs without parameterized convection, dashed ones including the Tiedtke convection scheme. Top: LWP [g/m^2], Bottom: Amount of rain [mm]

Nevertheless, relying more on the stronger precipitating cases one might assume, that explicitly resolved convection produces less rain but the differences become smaller as the resolution is increased. The remaining gap may be traced back to the lack of subgrid scale condensation at scales smaller than 1km.

3.2 Vertical profiles and fluxes

The most important effect of convection modifying the atmospheric development on longer time ranges is the stabilization due to vertical transport. This transport differs between resolved and parameterized convection. Humidity deviations in the order of 10% appear and differences of potential temperature with the magnitude of 1K can be observed. It is worthwhile to note, that simulations at different resolutions with explicit convection are in much closer agreement than compared to the simulation with parameterized convection.

As already indicated by the analysis of averaged values, less water vapour is converted into rain by simulations without parameterized convection and consequently less latent heat is released in the free atmosphere. This is the main reason, why explicit convection is less efficient in transporting energy from the boundary layer to the free atmosphere.

3.3 Cloud structure

Concerning cloud structures, the size of resolved convective cells seems to shrink systematically as the grid spacing was reduced. The development of an objective cell detection algorithm, which uses certain LWP thresholds to identify pixels in the surrounding of local LWP maxima as part of a convective cell (see Figure 3 as an example), allows quantifying this effect. Normalized cell size distributions plotted in Figure 4 clearly indicate that the size of cells remains nearly constant in number of grid points but not in physicals units. One reason is that the turbulence scheme is based on the boundary layer approximation, which assumes no horizontal exchange. This approximation is well justified as long as the horizontal grid spacing is large compared to the boundary layer height. The lack of horizontal exchange allows the development of

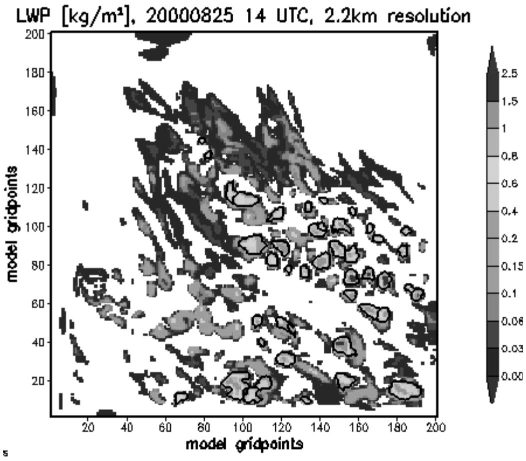

Figure 3: Example of LWP field at one time step. Detected cells are encircled by thick black lines.

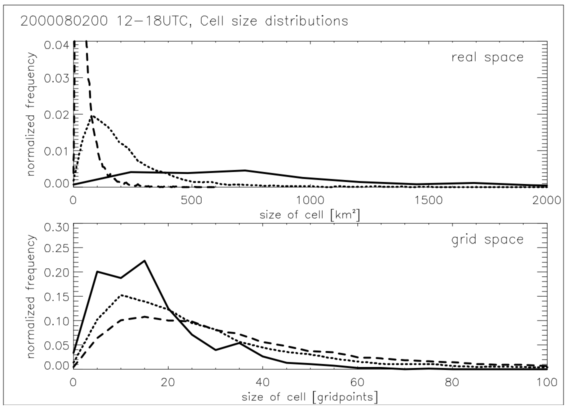

Figure 4: Normalized cell size distribution in physical units (top) and in number of grid points (bottom).7km (solid), 2.8km (dashed), 1.1km (dotted). Convection scheme always switched off.

locally confined convective updrafts at the pixel scale. The only type of horizontal diffusion implemented into the LM is a computational mixing to numerically stabilize the leap-frog integration scheme. A sensitivity study varying the strength of computational mixing proved the dependence between cell size distribution and horizontal diffusion

3.4 Comparison with ground based observations

Figure 5 shows time series with high temporal resolution measured as well as simulated at the CLIWA-NET station Potsdam. In order to compensate the different spatial scales of model and observation, the measurements are filtered with the advective time scale corresponding to each resolution. It is obvious, that simulations with higher horizontal resolution do not predict cloud conditions at a certain time and space more accurately, but the statistical representation of cloud conditions are improved, e.g. as far as intermittence is concerned.

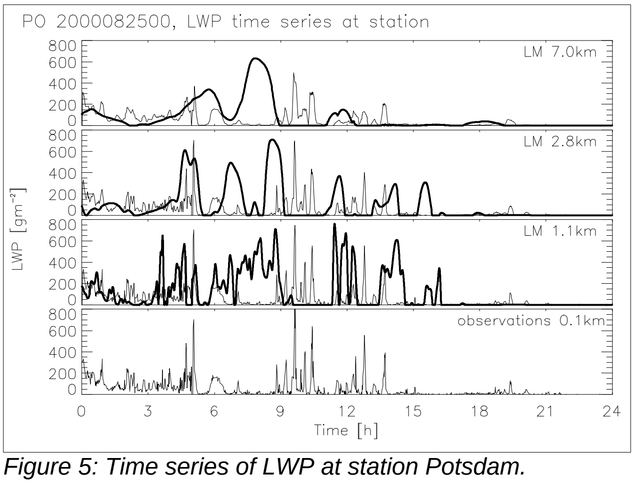

Figure 5: Time series of LWP at station Potsdam. Microwave radiometer measurements (black lines) are filtered with the advective timescale to be representative for each model resolution.

4. CONCLUSIONS

Undergoing a horizontal refinement the nonhydrostatic, mesoscale model LM is consistent in terms of mean IWV, mean cloud cover and averaged surface fluxes. The systematic trends in LWP and rain rate, which occur in simulations without convection scheme, are mainly caused by neglecting subgrid scale variability of water vapour and cloud water. This is an indication that sub-grid scale condensation schemes are required even at horizontal scales of a few kilometers. A comparison between simulations with parameterized and with explicit convection revealed differences concerning the vertical stratification and vertical transport. One important reason is the less efficient conversion of water vapour into rain if the convection scheme is switched off. It is observed that the size convective cells shrinks as the grid spacing is reduced and that no real convergence can be detected at scales larger than 1km. This effect can partly be counteracted by introducing a physical motivated horizontal diffusion. A comparison of time series with high temporal resolution at CLIWA-NET stations showed that the benefit of high resolution modelling can not be expected to be a more accurate deterministic forecast of cloud conditions at a particular time and place but to provide a better characterization of the statistical properties of cloud conditions.

References:

Crewell, S., M. Drusch, E. van Meijgaard and A. van Lammeren, 2002: Cloud observations and Modeling within the European BALTEX Cloud Liquid Water Network, Boreal Environment Research, 7, 235-245

Doms, G. and U. Schaettler, 1999: The Nonhydrostatic Limited-Area Model LM (Lokal-Modell) of DWD, Part 1: Scientific Documentation, (available from http://www.cosmo-model.org)

Tiedtke, M., 1989: A comprehensive mass flux scheme for cumulus parameterization in large-scale models, Mon. Wea. Rev., 117: 1779-1799