Comparison of convection and condensation schemes under non-hydrostatic Hirlam-model: A case study

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1 Introduction

Traditionally, the effects of cumulus convection and condensation are parameterized in convectively unstable areas, whereas in convectively stable regions more explicit (grid-scale) methods are used. Several studies have shown that this kind of approach is sufficient with a grid spacing larger than 50 km (e.g. Molinari and Dudek, 1992; Molinari, 1993). Weisman et al. (1997) suggested that for resolutions less than 1–4 km convection should be calculated using explicit schemes and non-hydrostatic dynamics. Molinari and Dudek (1992) recommended the use of "hybrid" methods, in which some of the parameterized cloud water is "detrained" into the grid space, at grid lengths from 20 to 50 km. In a resolution range from about 3 to 20 km it is unclear if a good solution for the convection parameterization in the numerical weather prediction (NWP) models even exists.

The grid length of the NWP models can be decreased below 10 km in a physically reasonable manner with non-hydrostatic dynamics. We made a case study for a summertime frontal system over Baltic Sea and Finland. We compared two different approaches to parameterize the convection processes using the non-hydrostatic HIRLAM (Rõõm, 2001; Männik and Rõõm, 2001) at very high resolution. The first method is the STRACO-scheme (Soft TRAnsition COndensation; Sass, 2001) which is part of the HIRLAM reference system. STRACO is based on a moisture convergence closure and may be considered a further development of the traditional Kuo-scheme (1974). The second method calculates the condensation processes using the Kain-Fritsch-scheme (KF; Kain and Fritsch, 1990) in the convective regime and the Rasch-Kristjánsson-scheme (RK; Rasch and Kristjánsson, 1998) in the stratiform regime. KFRK can be described as a "hybrid" scheme. The KF-scheme has a CAPE-based (Convective Available Potential Energy) closure. We compared the model-calculated precipitation fields with radar observations from Korppoo, Finland using a new verification method: the Radar Simulation Model (RSM; Haase and Crewell, 2000). RSM can calculate radar reflectivities from model-produced grid-scale and convective fluxes of liquid and solid precipitation.

a) b)

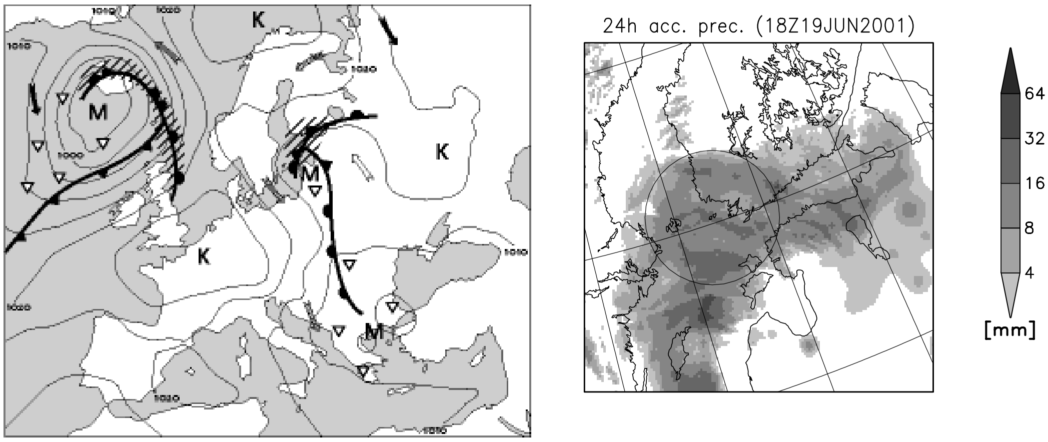

Figure 1: The synoptic condition of the frontal system case. a) The analysis chart at 12 UTC 19 June 2001. b) Accumulated precipitation. The circle represents the measurement area of the Korppoo Radar.

2 Experiments

The frontal system, from which we made the case study, propagated over Southern Finland June 19, 2001. An analysis chart and a radar-retrieval of accumulated precipitation provided by the Baltex Radar Data Centre (Michelson et al., 2000) are shown in Fig. 1. The heaviest rainfalls were observed over the Baltic Sea, north-east from Gotland. The 24 hour accumulated precipitation amount was over 32 mm in that particular region. The South-Western part of Finland, where the Korppoo radar is located, was also well covered by rainfall. This case included both convective and stratiform rain areas.

The model experiments were based on HIRLAM version 5.0.0. The calculation area was 156×156 grid-points with a 0.05 degree (about 5.5 km) resolution covering Southern Finland, the Baltic countries, and most of the Baltic Sea. We used 40 vertical levels whereas the reference HIRLAM has 31 levels. All experiments used a turbulence scheme, which has a prognostic equation for the turbulent kinetic energy (Cuxart et al., 2000). Four different model runs were made: 1) non-hydrostatic dynamics with STRACO-scheme (NHS), 2) non-hydrostatic dynamics with KFRK-scheme (NHK), 3) hydrostatic dynamics with STRACO-scheme (HHS) and 4) hydrostatic dynamics with KFRK-scheme (HHK). Each experiment consists of a 27 hour forecast starting from an operational Finnish HIRLAM-analysis of 22 km resolution valid at 18 UTC 18 June 2001. Operational analyses were also used as lateral boundary conditions.

3 Results

The time series of the radar reflectivity areas are shown in Fig. 2. Both model experiments generally overestimate the intensity of the rain (reflectivity is exponetially proportional

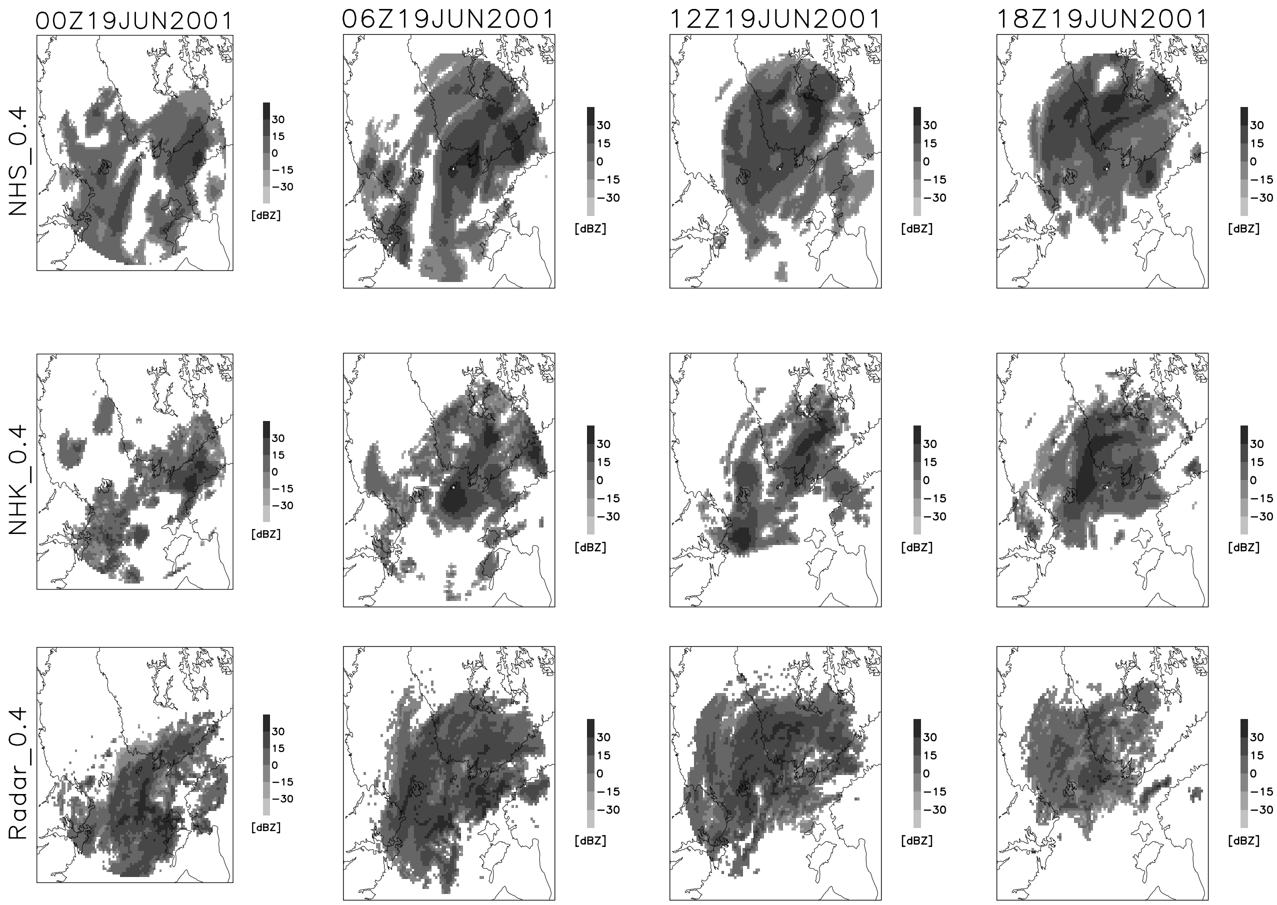

Figure 2: Radar-simulated precipitation areas around Korppoo radar. First row: NHS-experiment. Second row: NHK-experiment. Third row: radar observations. The elevation angle is 0.4 ° in all pictures. The start time of the forecast is 18Z18JUN2001.

to rain intensity). The total area of the rain region produced by NHS is similar to the observed, whereas NHK produces a much smaller area, especially at the early stages of the forecast.

The frequency distributions of the radar reflectivity within 200 km radius around the Korppoo radar are shown in Fig. 3. The NHS experiment overestimates the amount of lower rain intensity (below 10 dBZ) whereas the results of NHK are much closer to the observations. However, the amount of reflectivities between 20 and 40 dBZ is evidently underestimated in both non-hydrostatic experiments. What causes this underestimation is not yet clear. One partial explanation could be that the experiments were arranged badly. All the experiments begin with the rain area already in the calculation area. The model tends to underestimate precipitation in the early stages of the forecast (see Fig. 2 first column). However, all the model experiments produce very strong echoes (over 40 dBZ), which are not observed at all. In Fig. 3, the bars between reflectivities −40 and −30 dBZ describe the amount of rain-free grid points. The NHK-experiment clearly

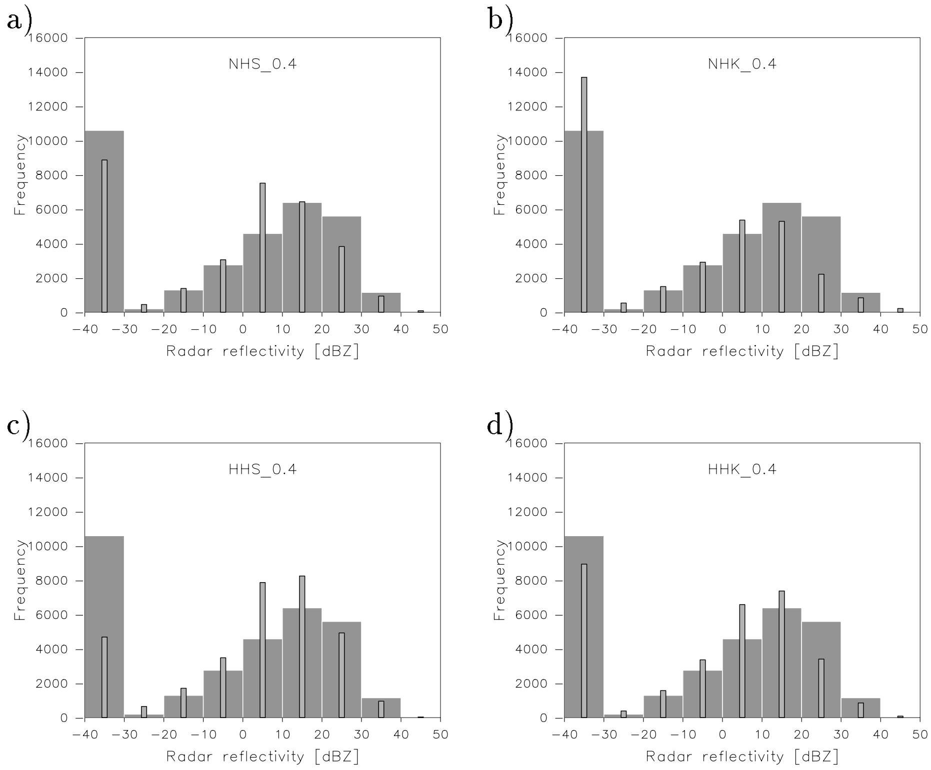

Figure 3: Frequency distribution of the radar reflectivity over 24 hour forecast period. Thin bars describe the experiment values and thick bars describe the observations. a) NHS b) NHK c) HHS d) HHK

overestimates the echoless area, which is underestimated by the other experiments.

The average profiles of different variables calculated over the regions of the Southern Finland, Baltic Sea and Estonia are shown in Fig. 4. The majority of the rain areas were located in that particular region. Overall, the KFRK-scheme predicts more rain than the STRACO-scheme does. The behaviour of the cloud water profiles is just the opposite (Fig. 4b). The STRACO-scheme produces considerably more cloud water than KFRK does. The difference is largest at about 3000 m above the ground and at the lowest model levels, especially over water (not shown).

The hydrostatic model experiments (Figs. 3cd and 4a) give a bit more rain than do the non-hydrostatic experiments. Although the frequency distribution of the radar reflectivity of HHK appears to coincide relatively well with observations, the rain areas develop slower in the hydrostatic model than in the non-hydrostatic during the first 6 hours of the forecast (not shown).

The average profiles of the vertical velocity ω and of the variance of ω are shown in Fig. 4 c and d, respectively. As expected, the hydrostatic model produces larger vertical velocities than does the non-hydrostatic one. The main difference between STRACO and KFRK is that in STRACO the velocity maxima are situated higher than in KFRK.

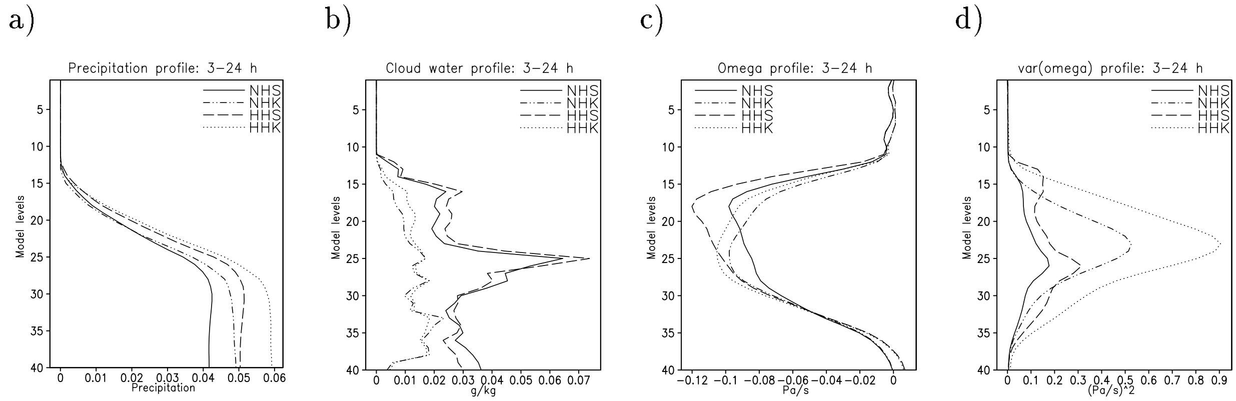

Figure 4: Average profiles of a) precipitation, b) cloud water, c) vertical velocity and d) the variance of the vertical velocity over Southern Finland, Baltic Sea and Estonia.

The difference is more noticeable in the variances of the vertical velocity: the variance is considerably larger with KFRK than STRACO. This may indicate that the model generates stronger upward and downward motions with KFRK than with STRACO.

It should be emphasized that the averaged profiles presented in Fig. 4 are very sensitive to the averaging area. The region, which covered Southern Finland, Baltic Sea and Estonia, was chosen because it contained the most of the rain areas produced by the model.

4 Conclusions

The goal of this case study was to evaluate the performance of the different convection and condensation schemes in a high resolution non-hydrostatic mesoscale NWP model. Four different experiments were established to simulate a summertime frontal system over the Baltic Sea region. Model-produced precipitation fields were compared with radar observations using RSM. The differences between the non-hydrostatic and the hydrostatic model were also studied.

NHK predicted the occurrence of reflectivity values below 10 dBZ reasonably well whereas NHS clearly overestimated it. Both schemes underestimated the amount of cases between 20 and 40 dBZ. What causes this underestimation is yet unknown. The results of the NHS experiment contained much more cloud water than did NHK. Hydrostatic model predicts more precipitation than does the non-hydrostatic model. However, it must be remembered that the average profiles depend very much on the area. The hydrostatic model developes larger rain regions than does the non-hydrostatic model, but their development is a bit slower.

A limitation of this "pilot study" is that it was made using one warm season case only. The study should be extended to include both warm and cold season. The resolution dependence of the condensation and convection schemes should be studied. It would also be interesting to compare the results with radar network observations instead of a single radar.

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