16B.6 APPLICABILITY OF GRID-SIZE-DEPENDENT CONVECTION PARAMETERIZATION TO MESO-γ-SCALE HIRLAM.

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1. INTRODUCTION

The representation of convective phenomena is very difficult in meso-γ-scale (2–20 km) models. The rapid development of computing power has enabled operational limited area NWP models to use a grid spacing of about 10 km. Weisman et al. (1997) proposed that organized convective structures could be resolved explicitly with a smaller grid spacing than 4 km. The grid spacing range of 5–20 km is especially difficult for convection schemes to handle. Within that range, some parameterization is still needed, because the explicit simulation of convection produces slowly evolving and overshooting precipitation events.

Jung and Arakawa (2004) showed that the convection parameterization is highly dependent on the model resolution (in both time and space) in the range of meso-γ scales. Traditionally, convection parameterizations are "tuned" for a fixed grid spacing. Therefore, the behaviour of non-resolution-dependent convection schemes may be undesirable, when these schemes are applied for different scales. Jung and Arakawa (2004) also suggested that the future parameterizations should include the grid-size dependences.

It is argued that the future NWP models operating in meso-γ scales should include precipitating hydrometeors as prognostic variables (e.g. Tao et al., 2003). However, explicit treatment of convection (2–3 km scale) with sophisticated microphysical parameterization is still computationally extremely expensive. Consequently, the transition from scales used in current operational models (about 10–20 km) to kilometer scale will take some years. Weather services that lack high computing power would especially benefit if a computationally more efficient "intermediate" solution could be found.

The objective of this study is to evaluate the applicability of the existing convection and condensation scheme of the High Resolution Limited Area Model (HIRLAM) in meso-γ-scale convective conditions. Here, we concentrate on comparing the performance of the grid-size-dependent and "traditional" convection parameterizations. A case study of a single cold air outbreak event over Southern Finland is conducted.

2. DESCRIPTION OF THE MODEL

HIRLAM is a complete NWP system including an anelastic nonhydrostatic dynamics with an extensive set of physical parameterizations and data assimilation. A more detailed description of the whole HIRLAM system is given in Undén et al. (2002). The present study is based on HIRLAM version 6.1.0 including nonhydrostatic dynamics (Männik et al., 2003) and the following physical parameterization schemes.

The turbulence scheme is based on prognostic turbulent kinetic energy (TKE) and a diagnostic length scale. This TKE-l scheme is adapted from the planetary boundary layer model by Cuxart et al. (2000). Soil and surface processes are modelled using the ISBA (Interaction Soil Biosphere Atmosphere) scheme (Noilhan and Planton, 1989). The fast radiation code is based on the work of Savijärvi (1990).

STRACO scheme (Soft TRansition COndensation; Sass, 2002) parameterizes both convective and stratiform condensation, clouds and precipitation. It also allows a gradual transition between both regimes. The convection scheme is based on moisture convergence closure and it includes cloud water as a prognostic variable, following the work by Sundqvist et al. (1989). The diagnostic precipitation release depends on the amount of cloud water.

STRACO was originally developed for use on

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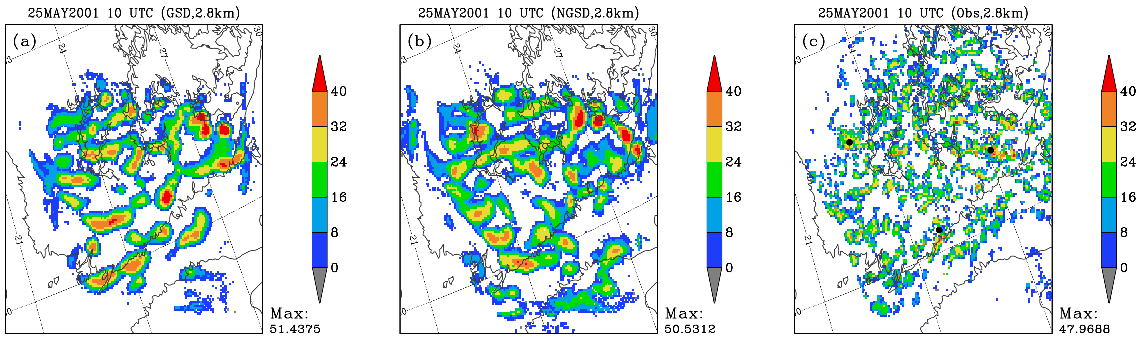

Figure 1: Composite radar reflectivity (dBZ) fields after a 10 hour simulation valid at 10 UTC 25 May 2001. (a) GSD, (b) NGSD and (c) radar observation. The horizontal grid spacing of each field is 2.8 km. The maximum dBZ-value within the area is given next to the figure. The locations of the radars are marked with dots in figure (c).

meso-β scales. However, improved applicability for meso-γ scales is sought by introducing a simple grid-size-dependent entrainment function in the triggering mechanism for convection scheme

$$\epsilon_e = \left(1.3 \times 10^{-4}\ \mathrm{m}^{-1} + \frac{7.5 \times 10^{-4}\ \mathrm{m}^{-1}}{\mathrm{Ri}_*}\right) \times \left(\frac{z}{500\ \mathrm{m} + z}\right)\left(\frac{10\ \mathrm{km}}{D}\right), \quad (1)$$

where z is height [m], D is a grid size [km] and Ri_* is a Richardson number. The purpose of this function is to make the convective entities more shallow by mixing the cloudy air with cooler ambient air in the triggering phase. Consequently, the convection parameterization switches gradually off as the grid size decreases.

Another grid-size-dependent function is introduced in the moistening parameter (β) formulation of the convection scheme. Originally, the β-parameter is a function of the vertically integrated relative humidity $\langle RH \rangle$ (within the convective cloud),

$$\beta = (1 - \langle RH \rangle)^2 , \quad (2)$$

which is similar to that originally described by Anthes (1977). An tentative approach,

$$\beta = \frac{1}{(1 + \frac{D}{3\ \mathrm{km}})}, \quad (3)$$

ensures that most of the moisture input is directed to increase the prognostic cloud condensate amount instead of the specific humidity when the grid size is larger than 3 km. The purpose of β is not to switch off parameterized convection. This decision is made during the triggering phase (Eq. 1).

3. EXPERIMENTAL SETUP

The convective event occurred over Southern Finland on 25 May 2001. During that day a cold air flow aloft over a diurnally heated surface created favourable conditions for convective instability to build up. At 9 LT (=UTC+3 h) the first convective precipitation cells were observed. At 13 LT almost the whole of Southern Finland was covered with small-scale and shallow cells with little mesoscale organization (see Fig. 1c). These kinds of convective conditions are common in Finland during May and early June.

Three different type of model experiments are carried out (GSD, NGSD and GSD2). GSD utilizes the grid-size-dependent entrainment profile (Eq. 1) together with the original moistening parameter (Eq. 2), whereas in NGSD the third term in Eq. 1 equals 1 (i.e. no grid-size dependency). GSD2 utilizes both Eq. 1 and Eq. 3. All three experiments are conducted with 11, 5.6 and 2.8 km horizontal grid spacings.

The integration domain for the coarse grid experiments covers almost the whole of Scandinavia, whereas the domain with the most dense grid includes only Southern Finland and the Gulf of Finland (see Fig. 1). For all the experiments, analyses from the operational HIRLAM runs of the Finnish Meteorological Institute

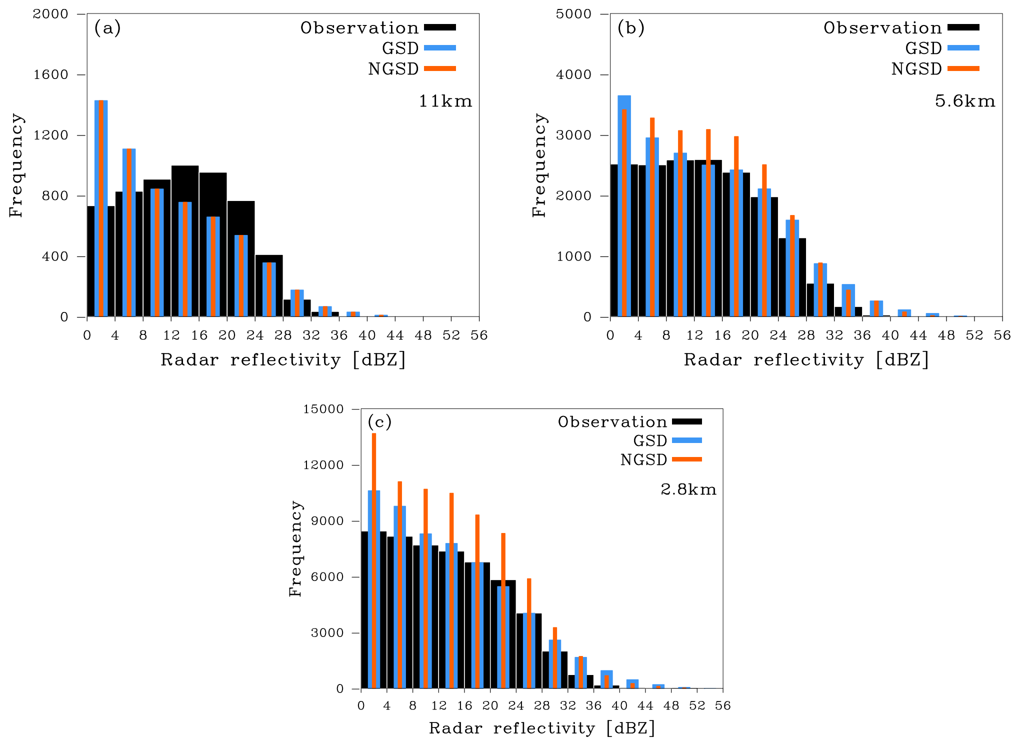

Figure 2: Frequency distributions of radar reflectivity (dBZ) produced by 21 hour simulations (GSD and NGSD) starting at 00 UTC 25 May 2001. Horizontal grid spacings are (a) 11, (b) 5.6 and (c) 2.8 km. Black bars represent dBZ-observations. The radar antenna elevation is 0.4°. In this case reflectivity values below 0 dBZ are not meteorologically important and are therefore omited.

(22 km grid spacing) are used as boundaries.

The results of the different model configurations are mainly validated using radar reflectivity data from the Finnish radar network. Modelled radar reflectivites are produced by using the Radar Simulation Model (RSM, Haase and Fortelius, 2001). The RSM is a software package that simulates radar measurements corresponding to the output of a NWP model. It computes the local reflectivity at each grid point of the model, and generates a simulated measurement by taking into account the beam propagation and attenuation within the simulated atmosphere. The purpose of RSM is to make it possible to use radar measurements for forecast verification directly, without having to solve the difficult problem of linking the observed reflectivity to precipitation at the ground.

4. RESULTS

Fig. 1 shows the radar reflectivity fields from the experiments with the highest model resolution (2.8 km) after 10 hours of simulation. Both GSD and NGSD tries to form cellular structures similar to the observed ones. However, it is clearly seen that even a 2.8 km grid spacing is not fine enough to describe such small-scale features. The total area of precipitation is well represented by both experiments except near the northern boundary of the integration area.

The radar reflectivity distributions of GSD and NGSD experiments are compared in Fig. 2. All configurations tend to overestimate the areas of both very strong (>32 dBZ) and very weak (<8 dBZ) reflectivity. Although the overestimation of weak echoes is in most of the cases noticeable, we focus on the strong echoes, because of their larger practical importance.

GSD produces the reflectivity distributions, which are closer the observed values, whereas

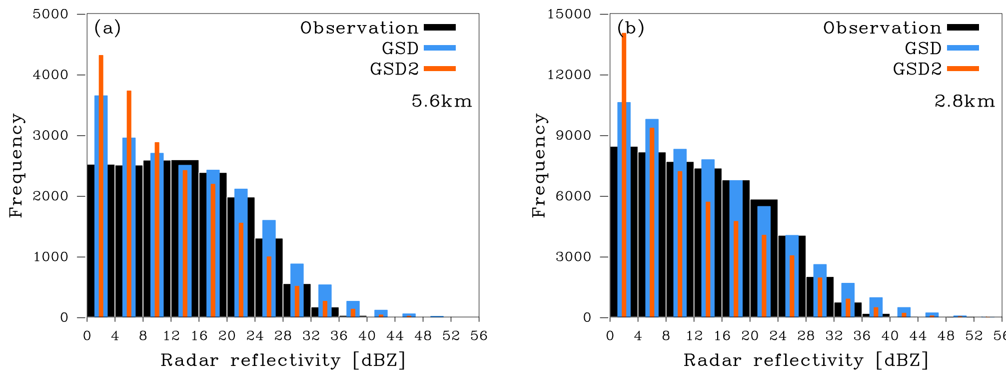

Figure 3: Same as in Fig. 2, but the distributions are from GSD and GSD2. Grid spacings are (a) 5.6 and (b) 2.8 km.

NGSD increasingly overestimates the amount of moderate reflectivities as the grid spacing reduces. Evidently, without any dependency on model resolution the convection scheme is too active. However, the grid-size-dependent triggering mechanism does not have an effect on strong reflectivities. Both GSD and NGSD overestimate the areas of strong echoes.

Fig. 3 shows the reflectivity distributions of GSD and GSD2. By introducing the grid-size-dependent moistening parameter in GSD2, the amount of both moderate and strong (>16 dBZ) reflectivities is further reduced. Especially with a 5.6 km grid-size, the strong part of the frequency distribution is closer to observed one.

Fig. 4 presents 12-hour accumulated areal precipitation as a function of grid size. Figs. 4b and c show how the total precipitation is composed of the stratiform and convective parts. Both GSD and NGSD overestimate the average precipitation amount. However, in GSD the amount of convective precipitation is decreased compared to NGSD as the grid spacing is reduced. This effect starts to be significant with a smaller grid spacing than 3 km. GSD2 produces average precipitation amounts that are close to the observed value provided by the Baltex Radar Data Centre (Koistinen and Michelson, 2002). The rainfall seems to be very sensitive to the choice of the β-parameter, especially with small grid size.

5. CONCLUSIONS

Model simulations of a single cold air outbreak event with convective precipitation over Southern Finland (25 May 2001) have been conducted in order to investigate the applicability of the HIRLAM's grid-size-dependent convection scheme on the meso-γ scales. Such conditions are common in Finland during spring and early summer. Model results are mainly validated against radar reflectivity data.

The best results are obtained with a fully grid-size-dependent convection scheme (GSD2) and with a 5.6 km grid spacing. This combination produces a reflectivity distribution that resembles the observed distribution surprisingly well. A slight overestimation of the strong reflectivity value amount is present, but it is not as severe as in GSD and NGSD. Nevertheless, none of the convection schemes employed for a 2.8 km grid size are able to produce satisfactory results due to overestimation of strong reflectivities.

The grid-size-dependent triggering mechanism (Eq. 1) for convection parameterization is evidently beneficial for models operating with a dense grid. This approach reduces the overestimation of the average precipitation by deactivating the convective heating and condensation as the grid spacing decreases. However, this approach reduces only the amount of moderate reflectivities, leaving the strong reflectivities nearly untouched.

A limitation of the present study is that the simulations are conducted for a single case

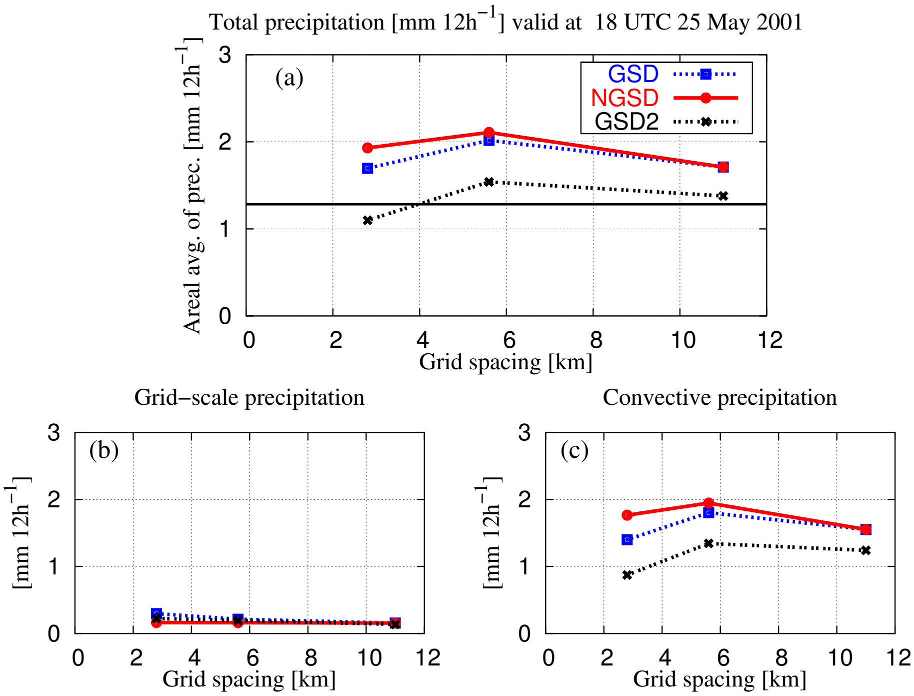

Figure 4: Areally-averaged 12-hour accumulated precipitation (mm) as a function of the grid spacing. (a) Total precipitation, (b) grid-scale precipitation and (c) convective precipitation. Areal averages are defined over the area shown in Fig. 1. The solid horizontal line in graph (a) represents an areally-averaged radar retrieval of accumulated precipitation provided by the Baltex Radar Data Centre.

only. Although the convective conditions studied here are typical of those in Finland, future studies should be extended to a larger variety of atmospheric phenomena. The results seem to be very sensitive to the formulation of the β-parameter, depending on the atmospheric conditions. More interest should be directed in particular into severe thunderstorm activity with extreme precipitation.

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