IMPLEMENTATION OF THE SUPEROBBING APPROACH TO THE RADAR DATA ASSIMILATION IN THE HARMONIE MODEL

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Abstract: This study presents two approaches adopted for the radar reflectivity data assimilation in the HARMONIE numerical weather prediction model. Both methods, the thinning and superobbing, show an improvement of precipitation prediction over the radar location area due to increased rain rates. The model simulates larger water content in the lower troposphere within the layer from 850 to 600 hPa. However, the impact varies depending on the method and internal parameters. Further improvement of the precipitation prediction is noted with tuning the superobbing parameters to fine-scale precipitation forms.

Keywords**:** radar data assimilation, thinning, superobbing, HARMONIE model

INTRODUCTION

The data assimilation process assumes adjusting model fields with available observations. An observation model, known also as an observation operator, is used for enabling the direct comparison of a model state with observations. The observation model transfers the observed quantities in terms and locations of the corresponding model variables. Remote sensing data assimilation requires additional processing of the respective measurements so as to be presented in physical values and units. The observation operator is accurate within the limits of the observation errors consisting of several components, including the representativeness one (*Lorenc, 1986; Kalnay, 2003*). This study focuses on the impact of the assimilation of heterogeneously distributed radar measurements on the numerical model simulations. This impact may arise due to the discrepancy between the continuum of atmospheric phenomena scales, as they are detected by observation networks, on the one hand, and as they are represented in the numerical weather prediction models with finite discretization, on the other hand (*Liu and Rabier, 2003; Ivanov and Palamarchuk, 2007*). The following sections successively describe the approaches of radar data processing; numerical model configurations and radar data assimilation experiments; results of the numerical experiments with various pre-processing methods and parameters; and conclusions along with further planning studies.

PROCESSING OF RADAR DATA

The data assimilation process requires a one-to-one correspondence between observed quantities and their model counterparts for further corrections in the model space. This is achieved by interpolating the model values to observation locations. An optimal solution to this issue is sought when the resolutions of both the observation network and model domain are close enough to each other.

In this way, radar measurements bring along the two opposite problems simultaneously: firstly, there is abundant information in the vicinity of a radar location; secondly, data become sparser with distance from the radar. As a result, this leads to the inhomogeneous impact from observations assimilated into the model, in both the horizontal and vertical directions. Experience with assimilating high-resolution data shows that such a data coverage may provide unsatisfactory results. In particular, tests with the Generalized Cross-Validation (GCV) method (*Desroziers and Ivanov, 2001*) using a simulated high-resolution data set at full resolution has led to a poorer analysis than a lower resolution data set that preceded it.

The larger the nonconformity between the resolution of the observations network, on the one hand, and that of the model, on the other hand, the larger the numerical impact on the result or, equivalently, the larger the representativeness error. Additionally, variational assimilation systems are based on the Best Linear Unbiased Estimating (BLUE) assumption (*Talagrand, 1997*), which implies that both observation and background errors are uncorrelated.

An easy way is to routinely perform thinning of high-resolution radar data. Simple thinning of abundant radar observations throws a significant part of data out from the process, but also affects the spectral distribution of sub-scales finer than a thinning parameter. An alternative to the thinning is the averaging of observations within a given box to create a new value located at an averaged position. This also allows to average out random observation errors (*Lorenc, 1981*). This method, called superobbing, is used for remote sensing observations, such as atmospheric motion vectors (*Berger et al., 2004*) and Doppler radar radial wind measurements (*Seko et al., 2004*). With this approach, the observation minus background (O-B) differences, or innovations, are averaged (*Salonen et al., 2007*). For each observation, its model simulated analogue is computed and an O-B innovation is calculated. These innovations are then averaged and added to the model observation closest to the center of the superobbing cell to provide the super-observation. Optimization of the superobbing processing from dense raw data is the compromise between two factors regarding the spatial averaging (*Salonen et al., 2007*).

In this study, the focus is on the general impact from radar data assimilation in the HARMONIE model, at first; secondly, on the comparison of the results obtained with the use of different procedures for radar data pre-processing, such as thinning and superobbing. The viewpoint is that the representativeness error can be decreased through optimization of pre-processing due to the better representation of the atmospheric flow scales in the model. The impact of the model errors is beyond the scope of this endeavour.

HARMONIE MODEL CONFIGURATION

Numerical experiments with the HARMONIE model using radar data from the BaltRad experiment have been carried out in an effort to investigate the impact of the above approaches on the assimilation process. Implementation of both methods proved to be a computationally inexpensive methodology.

The non-hydrostatic convection-permitting HARMONIE model developed by the HIRLAM consortium (*Bengtsson et al., 2017*) is explored in this study. The forecast model and analysis system are used at the default horizontal resolution of 2.5 km. The dynamical core is based on a two-time level semi-implicit Semi-Lagrangian discretization of the fully elastic equations, using a hybrid coordinate in the vertical (*Seity et al., 2011*). The default upper air data assimilation is the 3DVAR scheme. Background error statistics have been calculated using the NMC method (after National Meteorological Center, now, National Centres for Environmental Prediction). An analytical balance condition is applied. The observation data types presently assimilated by default are conventional observations (TEMP, SYNOP, AIREP, PILOT, SATOB, SHIP, DRIBU). Additionally, it is possible to assimilate MODIS atmospheric motion vectors, SEVIRI cloud-cleared radiances, wind profilers and sea winds scatterometer data. Observation screening involves logical and representivity checks, background quality checks, black-or-white listing, multi-level and station level checks, redundancy checks and moving platform checks. Initial and boundary conditions are taken from the IFS (ECMWF) model. All variables are externally prescribed by the nesting model. A relaxation zone of 10 grid points is adopted. Boundary relaxation is performed after the horizontal diffusion. At the upper boundary, a condition of zero vertical velocity is imposed.

RADAR DATA ASSIMILATION EXPERIMENTS

Radar reflectivity data from the BaltRad project (2009-2014) covering the Finnish domain were used in this study. Initially, during the project, the World's most advanced international weather radar network has been developed (http://git.baltrad.eu/) for the Baltic Sea Region. The cooperation continues in the form of an extension-stage project and is operating in real-time, with high-quality data and with demonstrated value to forecasters and decision-makers. The Finnish domain was choosen due to several reasons. First, the major part of the domain is covered by radar measurements. Second, the smooth orography and relatively homogeneous surface significantly decrease potential external impact from sharp gradients of the complex orography and surface contrasts.

The experimental design has been implemented as follows. Radar reflectivity data from the BaltRad field experiment were assimilated in the mesoscale operational HARMONIE-40h1.1 model. A heavy precipitation event over Finland during 14-15 August 2010 was considered. Three numerical runs have been performed with the same model configuration except the data assimilation procedure. The control run (CNTR) included for assimilation all the available SYNOP, TEMP and AIREP observations over the domain. In two radar data assimilation runs the "prepopera" script developed by Mats Dahlbom (DMI) was explored in the thinning (RAD-th) and superobbing (RAD-so) versions. Six radars over south Finland (Anjalankoski, Ikaalinen, Korpo, Kuopio, Vantaa, Vimpeli) were taken into account in the experiments.

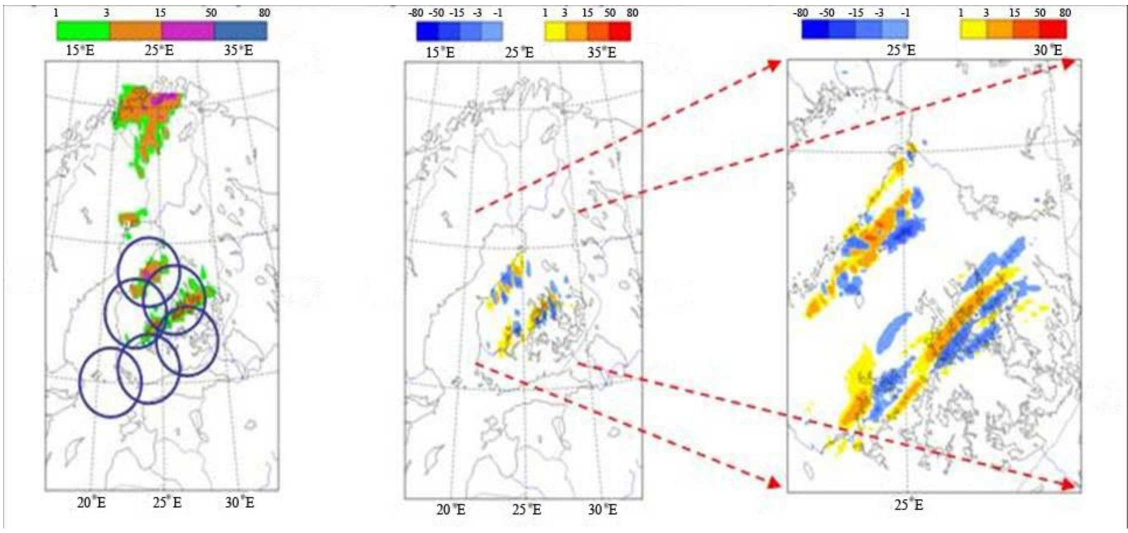

Figure 1. (a) Precipitation over the model domain and radar locations (blue circles); (b) difference in rain rates between the control and radar assimilation runs; (c) scaled domain from fig.1a for the heavy rain area. Color scale bars for reflectivity in dBz are shown at the top of each figure.

APPLICATION AND RESULTS

Results of the numerical experiments have revealed a significant impact of radar reflectivity data assimilated in the model on prediction of a heavy precipitation event. Moreover, it has been shown that this impact varies depending on pre-processing procedures and their corresponding parameters. Figure 1a shows the domain with radar locations along with the precipitation rate over it from a posteriori analysis. Two areas of heavy precipitation are observed over the north part of the domain and over its central part, covered by the radar responsibility zone. Assimilating radar reflectivity influences the model output only over the latter area. The difference between the control and assimilation runs is shown in Figure 1b and Figure 1c at a scaling vision. Although the impact occurs in a heterogeneous intermittent form with the opposite signs, the rain rate has increased up to 10 mm/12 hours in total over the selected part (Table 1). The vertical distribution of precipitable water in the atmosphere has also been increased in the simulations (not shown). The main changes have occurred within the layer between 850 and 600 hPa and achieved values up to 5-7 mm/hour. The series of numerical experiments with various thinning and superobbing parameters have shown similar impacts in general mapping, however, there were visible differences in the fine-scale cells. Their sizes, configuration and signs were dependent on the thinning values and superobbing meshes (not shown).

Thus, radar data assimilation improves the prediction of heavy precipitation within the available data area by increasing the rain rate. However, the impact is numerically sensitive to the radar pre-processing approaches and their internal parameters.

Table 1. Difference in rain rate and corrsponding area covered with precipitation between the control and radar assimilation runs

Rain rate, mm / 12 h	-50 – -40	-40 – -30	-30 – -20	-20 – -10	-10 – 0	0 – 10	10 – 20	20 – 30	30 – 40	40 – 50
Area, km^2	7	15	19	110	6093	36588	191	21	5	0

CONCLUSIONS AND RECOMMENDATIONS

The data assimilation system in HARMONIE has been further developed by involving radar reflectivity measurements. The focus was on optimizing pre-processing procedures. The thinning and superobbing approaches with different internal parameters were explored. Results have shown that radar data allow for a better simulation of precipitation due to the correction of water content in the low troposphere and as a result increasing the rain rate at the surface. However, the impact is sensitive to the choice of a pre-processing approach and its internal parameters. Thus, in pursuing the compatibility between the model resolution, radar observation density and dominating precipitation patterns, further tuning of optimal parameters for a superobbing mesh size will be performed for particular regions and atmospheric flow regimes.

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