9A.4 MODEL PRECIPITATION SKILL EVALUATED WITH RADAR DATA

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1. INTRODUCTION

It is well known that despite rapid advances in computational power and in observational capabilities, there are still many sources of uncertainties in Numerical Weather Prediction (NWP) models. Also, characterizing these uncertainties and the subsequent errors is difficult due to the lack of a perfect set of observations to be used for verification (truth). While the weather radar does not offer a complete picture of the atmosphere, at the mesoscale, it does offer the most comprehensive set of observations, which are desirable for data assimilation. However, recent studies have shown that while assimilating radar observations in mesoscale models does improve quantitative precipitation forecasting skill (QPF), the improvement is very short-lived, the skill decreasing substantially in the first forecast hour in cases when no cycling is performed (Surcel et al, 2009; Kain et al., 2010). This model behavior could be caused by a too large disagreement between model state and observations at the initialization time. Therefore, evaluating NWP forecasts with radar observations is valuable not only for model verification purposes, but also in a data assimilation framework.

One model parameter that is highly influenced by increasing computational power is the model horizontal grid spacing. As indicated by previous research on the subject, changing the horizontal grid spacing results in completely different outcomes in terms of convective storm structure, higher resolutions providing more realistic representations (Bryan et al., 2003; Bryan and Morrison, 2011). On the other hand, model evaluation studies have shown that increasing horizontal grid spacing does not necessarily improve QPF skill. Here we will present preliminary results of investigating the effect of varying horizontal grid spacing from 3km to 1km and to 333m, both on QPF and on storm structure, by using S-band radar observations of reflectivity and Doppler velocity as verification. An additional interest is establishing a methodology of model-radar comparison to be later used for the investigation of other model errors, and for determining the relative importance of different model parameters.

2. DATA AND METHODOLOGY

2.1 *Case studies and analysis domain*

To analyze the sensitivity to horizontal grid spacing, numerical simulations were run for a long-lived convective case on 21 July 2010 over the Southern Quebec region. The analysis domain of 300x300 km^2 was centered on the McGill Radar Observatory (Ste-Anne de Bellevue, Quebec). Figure 1 shows a time sequence of reflectivity and Doppler velocity CAPPI maps at 1.5km altitude.

2.2 *Numerical simulations*

Three numerical simulations were run using the Weather Research and Forecasting – Advanced Weather Research (WRF-AWR) model version 3.2, with grid spacing of 3km, 1km and 0.33km. All three simulations had an identical setup, initialized at 00 UTC, 21 July 2010, with initial conditions obtained from the NAM (North American Model, WRF-NMM) 00 UTC analysis and boundary conditions from the NAM 00 UTC run forecasts. The physics options include Thompson microphysics (Thompson et al., 2008), RRTM (Rapid Radiative Transfer Model) for long wave radiation, the Goddard shortwave radiation scheme, the Noah Land surface scheme and the Melor-Yamada-Janjic TKE scheme.

2.3 *Verification data*

The verification data consisted of CAPPI maps of reflectivity and Doppler velocity collected with the McGill S-band radar. A short technical description of the radar can be found in Table 1.

Wavelength	10.4 cm
3-dB beamwidth	0.86°
Rotation speed	6 min^{-1}
Resolution	1km by 1°
Elevation angles	24 (0.5°-34°)
Height	75m (MSL)

Table 1. Technical description of the McGill S-band radar.

2.4 *Methodology*

The verification data were first remapped on the model grid at 1 km resolution. Rather than using radar QPE products, logarithmic reflectivity factor (henceforth referred to simply as reflectivity) and radial velocity were computed from the model output with a temporal resolution of 15 minutes. All the data were then filtered to 4 km using a Haar low-pass filter in order to allow for the fair comparison of all three simulations.

The simulated and observed 2D reflectivity maps were compared in terms of their statistical properties as represented by their power spectra (computed using the Discrete Cosine Transform – DCT) and autocorrelation functions. The model skill at different spatial scales was also assessed in terms of the Root Mean Square Error (RMSE) and Equitable Threat Score (ETS).

The vertical structure of the storm was also compared between the different simulations and the observations through the visual inspection of vertical cross sections and through Contoured Frequency by Altitude Diagrams (CFADs - Yuter and Houze, 1997).

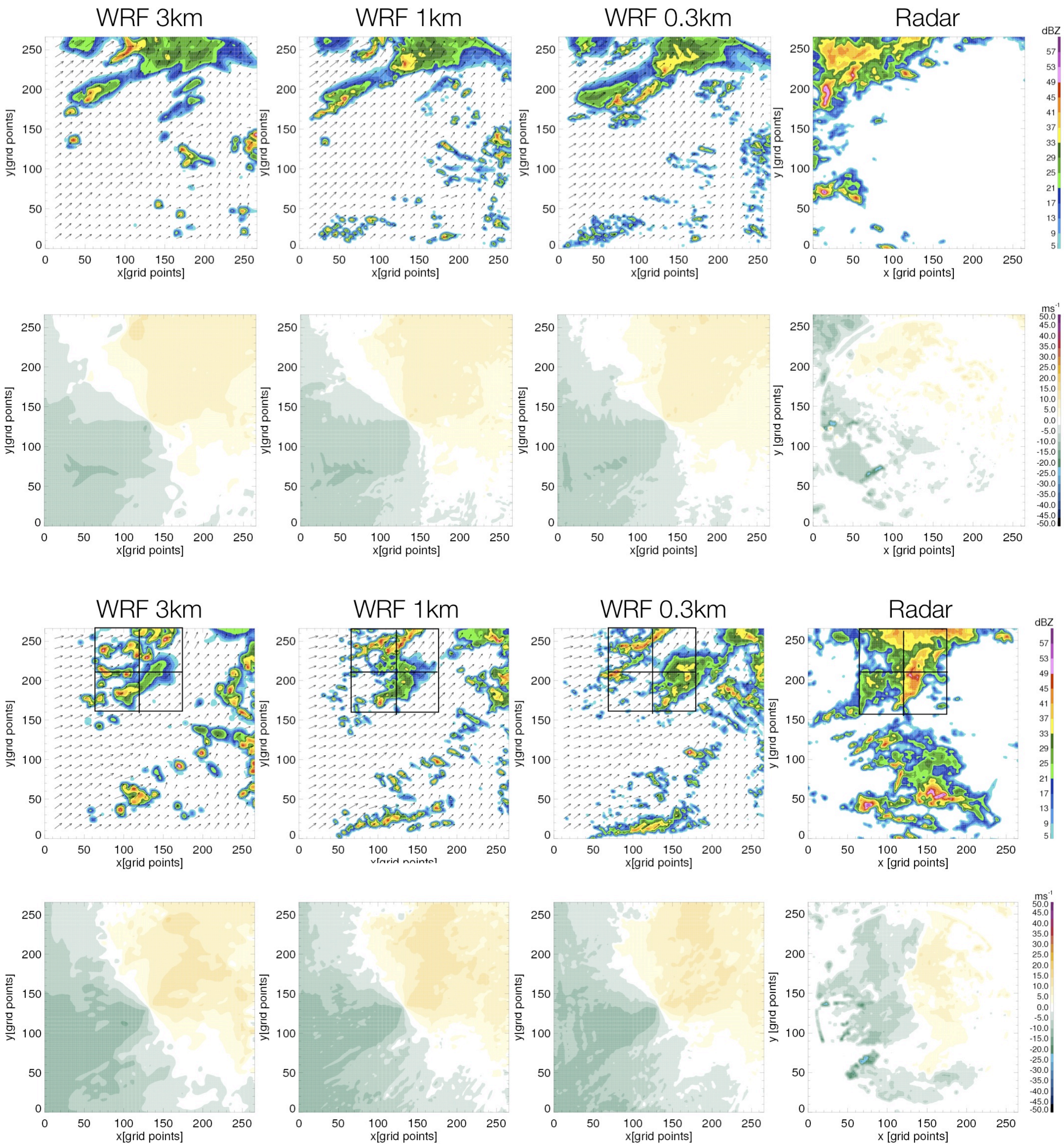

Fig. 1. Time sequence of reflectivity (upper) and radial velocity (lower) for models and radar at 1615 UTC and at 1815 UTC on 21 July 2011. The black rectangles and the lines represent the subdomains analyzed in section 4 and the lines through which the cross-sections of fig. 6 were drawn.

3. EVALUATION OF 2D FIELDS

Figure 1 shows a time sequence of simulated and observed reflectivity and radial velocity maps at 1.5km height. Several things are evident from these figures. First, while the precipitation forecasts definitely suffer of displacement errors, given the limited dimension of the domain, we could say that the model does a fairly good job at forecasting convective activity for this case, especially in the northern part. There are some major misses in the southern part of the domain, and it seems that the simulated storms are much weaker than observed. Vertical cross section could reveal if this is the case at all vertical levels. In terms of radial velocity, the forecasts seem to slightly overestimate wind speeds, and while there is good agreement in radial wind direction at 16 UTC, it deteriorates later on.

As for the comparison between the different resolution runs, it appears visually that skill increases as grid spacing decreases, both in terms of the structure of the precipitation field and in terms of positional errors. Also, the differences between the three forecasts increase with lead-time.

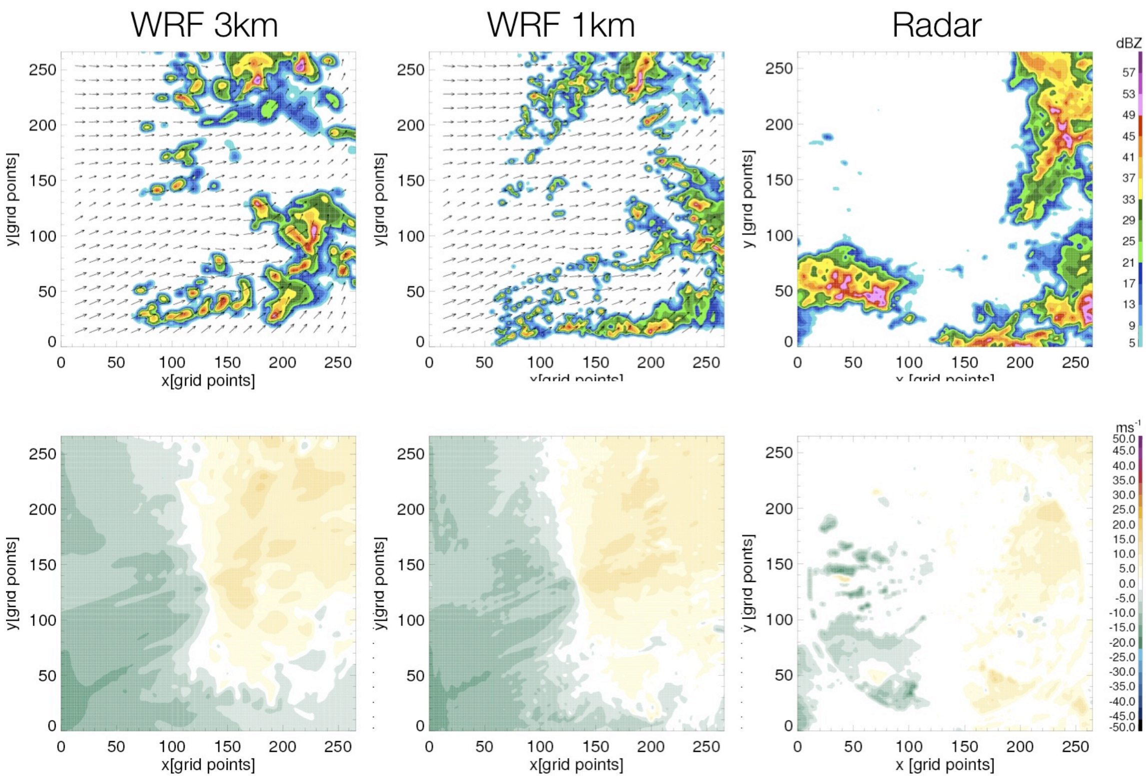

Fig. 1 (cont'd). Reflectivity and radial velocity for WRF3km, WRF1km and radar for 21 July 2010, 2015UTC.

To quantify the differences between forecasts and observations, fig. 2 shows the power spectra and the spectral differences (the difference between the model and radar amplitudes at each scale normalized by the amplitude of the radar at that scale) averaged for all forecasts between 1515 UTC and 1815 UTC. The power spectra graph shows that WRF3km underestimates the power at scales smaller than about 15 km, while WRF0.3km and WRF1km overestimate the power at those scales.

On the other hand, the normalized spectral differences are always about 0.5, even for scales larger than 15 km, which means that all model setups either underestimate amplitudes by 0.5, or they overestimate them by 1.5. For scales between 15km and 50km, WRF0.3km gives the best representation.

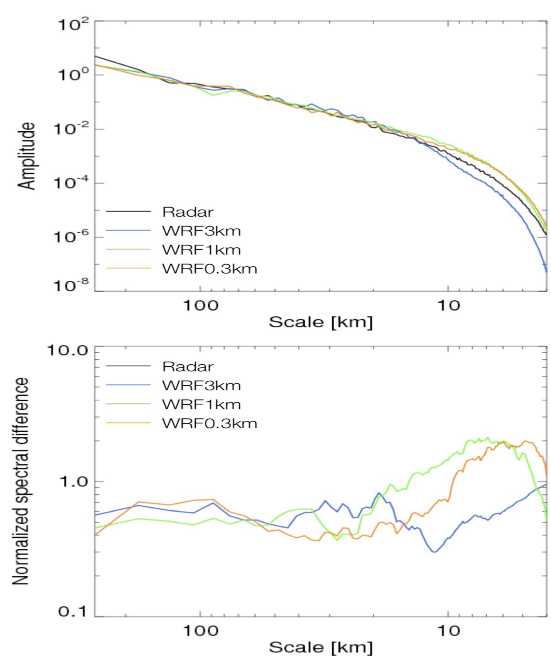

Fig. 2. Average power spectra and normalized spectral difference between models and radar. See legend for details.

Fig. 1 showed that observed convective cells are larger and better defined than in the simulations, with WRF0.3km giving most realistic results. We can quantify this aspect by computing the autocorrelation functions for the observed and simulated reflectivity fields. Fig. 3 shows the autocorrelation functions corresponding to the reflectivity fields in Fig. 1. Indeed, the decorrelation distance is always larger for the observed systems, with WRF0.3km being closest to observations. It seems that WRF1km has the shortest decorrelation distance. The fact that observed precipitation fields decorrelate less fast that simulated fields is corroborating the findings of Surcel et al. (2009) who showed that the diurnal cycle of simulated precipitation shows more variability than the diurnal cycle of observed rainfall during spring 2008.

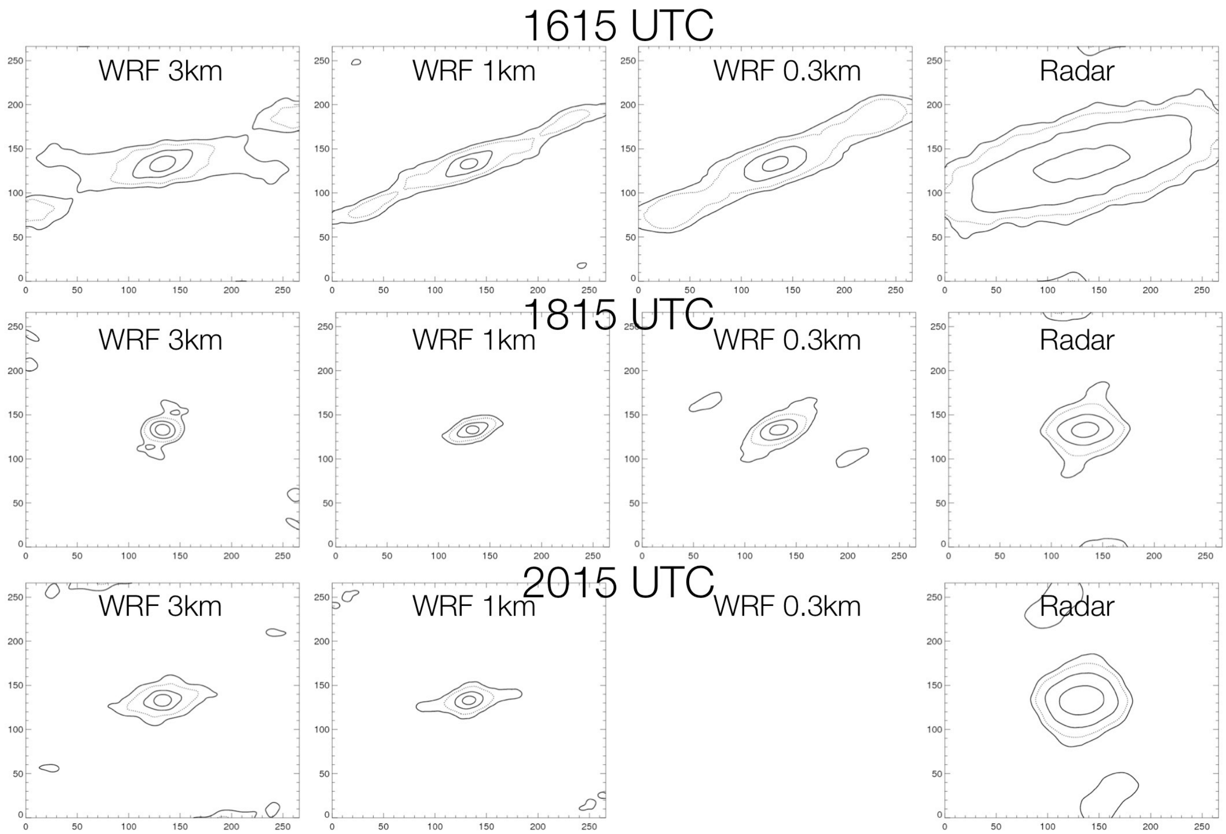

Fig. 3. Autocorrelation functions for models and radar corresponding to the reflectivity sequence in Fig. 1. Solid contours are 0.7, 0.5 and 0.3. Dotted contour represents 1/e.

4. EVALUATION OF 3D STORM STRUCTURE

As in Yuter and Houze (1997), we will represent the probability distribution of reflectivity values as function of height using CFADs. Fig. 4 illustrates the CFADs for simulated and observed reflectivity. The different colors represent the percentage of the total number of reflectivity values above a given threshold (in this case 5 dBZ) which falls in a given reflectivity bin. The bin size selected for this diagram is 2 dBZ. For example, at a height of 4 km, about 12% of all reflectivity values are between 26 and 28 dBZ.

It can be seen in this figure that there is a larger percentage of high radar reflectivities at levels higher than 4 km than in the simulations, and that reflectivity values tend to increase with decreasing height. The shape of the distribution is very different between model and observations, while all three simulations are similar to each other independent of horizontal resolution. It remains to be seen if this is caused by a localized system, by the microphysics scheme or if it is due to the computation of simulated reflectivity.

Fig. 5 also depicts CFADs this time computed for the 1815 UTC maps but on a smaller domain highlighted by a rectangle in fig. 1. Here the differences between models and radars are even larger, the radar showing a narrow distribution of reflectivity values, with a peak at about 3km height, probably due to the radar brightband. The model distributions are wider and the 3 km peak is less clear.

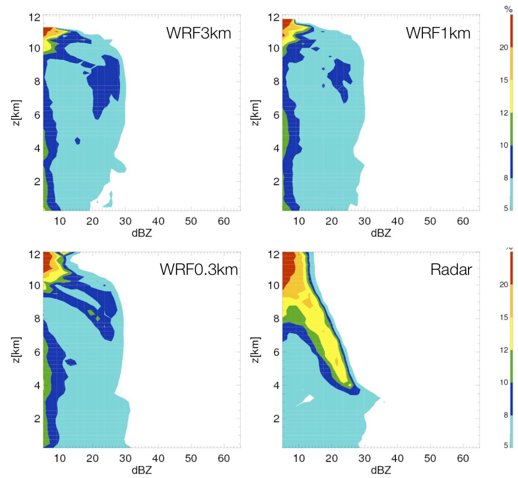

Fig. 4. Contoured frequency by altitude diagrams (CFAD) of reflectivity values for models and radar computed over the entire domain for the reflectivity map of 21 July 2010, 1815 UTC. See text for details.

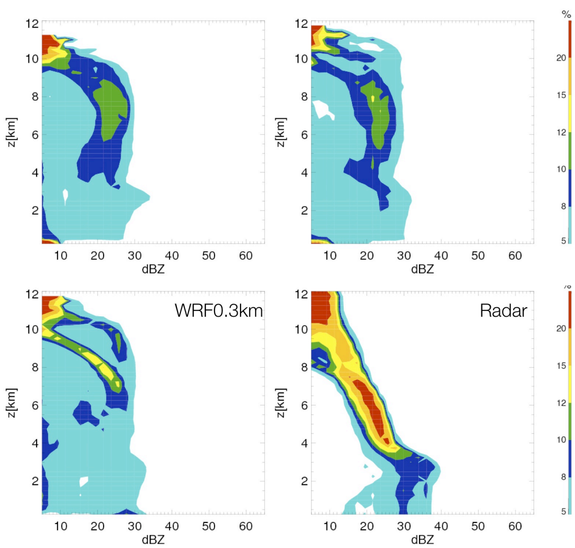

Fig. 5. CFADs of reflectivity values for models and radar computed over the subdomain indicated in fig. 1.

5. CONCLUSIONS

This paper presents a preliminary comparison of three sets of forecasts produced with WRF-AWR V3.2 with horizontal grid spacing of 3km, 1km and 0.3km. The results so far show a slightly better representation of the 2D structure of precipitation fields by WRF0.3km. In terms of the vertical storm structure, CFADs show large differences in the vertical distribution of reflectivity between models and radar. Future work will focus on addressing these differences and on using the radial velocity information for model verification. Furthermore, as a main source of errors in NWP models are the initial conditions, it would be interesting to investigate the importance of horizontal grid spacing for radar data assimilating models.

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