P4.4 Three-Dimensional Radar Mosaic Integrating WSR-88Ds and Canadian Radar Network

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1 Introduction

Through the funding of the Federal Aviation Administration's Aviation Weather Research Program, a system for the creation of high-resolution national 3D radar mosaic has been developed and is running in real-time at the National Severe Storms Lab (NSSL) since June 2004 (Zhang et al. 2004). The system ingests and quality controls base level reflectivity data from over 140 WSR-88D radars in the conterminous United States (CONUS) domain, and then objectively analyzes the data onto a seamless 3-D Cartesian grid. The 3-D reflectivity mosaic grid has a horizontal resolution of ~1 km x 1 km and 31 vertical levels ranging from 500 m to 18 km above mean sea level (NSL). The mosaic is updated every 5 minutes.

Since spring of 2006, NSSL has been receiving real-time Canadian radar base level data via a connection through the National Climatic Data Center (NCDC). The data stream includes 31 Canadian radars with an average latency of about 20 minutes. The base level reflectivity data from Canadian radar along the US-Canada border are analyzed and compared to data from the neighboring WSR-88Ds, and a tool was developed for the reflectivity comparison in real-time. Preliminary 3-D mosaic results integrating both WSR-88Ds and Canadian radars from selected cases are examined and analyzed. This paper presents initial results from the real-time reflectivity comparison tool as well as the 3-D reflectivity mosaic integrating both radar systems.

The following section, section 2, will briefly introduce the Canadian radar network and scan strategies. Section 3 describes the real-time reflectivity comparison tool and shows comparison results between reflectivities from Canadian radar and WSR-88Ds for a precipitation event. Section 4 presents initial results from the experimental 3-D mosaic integrating both Canadian radar and WSR-88Ds. A summary follows in section 5.

2 Canadian Radar Network

Figure 1 shows a map of 31 radars in the Canadian radar network from which the NSSL is receiving real-time data (Lapczak et al, 1999). All the radars are C-bands except for WMN (Montreal, Quebec), which is a S-band.

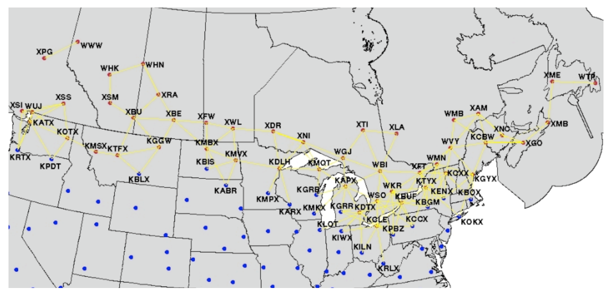

Fig. 1 A map of the Canadian radar network. Red dots with 3-letter identifiers represent the Canadian radar sites, and blue dots as well as red dots with 4-letter identifiers represent the US WSR-88Ds. Yellow lines connect radar pairs that are less than 400 km apart. The radar pairs are used for radar reflectivity comparison tool (see detail in section 2).

There are four scan strategies per radar. There is one Doppler and one conventional scan strategy for summer and another set for winter. The summer strategy starts around April 15th, and winter strategy starts around Dec. 1st each year. Elevation angles change slightly from location to location depending on the profile of the horizon – the lower the horizon, the lower the lowest angle.

The Doppler volume scan has 4 tilts (3 short and 1 long pulses) ranging from -0.5 to 3.5 degrees. In the summer, a typical Canadian radar will have short pulse tilts at 0.5, 1.5, and 3.5 degrees with a 500 m gate spacing and a maximum range of 113 km, and a long pulse tilt at 0.3 degrees with 1 km gate spacing and a maximum range of 226 km.

The conventional volume scan has 24 tilts ranging from -1 to 25 degrees. A typical Canadian radar conventional volume scan will have the following tilts (in summer): 0.3, 0.5, 0.7, 0.9, 1.1, 1.4, 1.7, 2.0, 2.4, 2.9, 3.4, 4.1, 4.8, 5.6, 6.6, 7.7, 9.0, 10.4, 12.1, 14.1, 16.3, 18.7, 21.5, and 24.6 degrees. All the conventional scan tilts have a resolution of 1° by 1 km and the maximum range is 256 km.

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The Doppler volume scan data contains 4 variables including total reflectivity, ground clutter corrected reflectivity, radial velocity, and spectrum width. The conventional scan, however, contains only reflectivity field that is not corrected for any ground clutter.

3 Reflectivity Comparisons Between Canadian Radar and WSR-88Ds

3.1 Radar Reflectivity Comparison Tool

The Radar Reflectivity Comparison Tool (RRCT) finds “matching” reflectivity bins from two adjacent radars based on the following criteria:

1. the bins must be in a 20km (range) x 120km (azimuth) x 20km (height above surface) zone along the equidistant line between the two specific radar sites (Fig.2);
2. centers of the two bins are less than 0.75km apart in any direction;
3. both reflectivities are above 10 dBZ;
4. the difference between observational times of the two bins is less than 6 min.

Once all the matching pairs are determined, reflectivities from all the bins for each radar are summed on the linear scale (in unit of mm6/m3). The difference in the logs of the total power between the radars is then called the dBz difference for that volume scan. So this approach is basically looking at a volume integral difference of total power reflected from a large rectangular slab midway between the radars. The procedure is run every five minutes and if precipitation is present, the software records one dBz difference per radar pair.

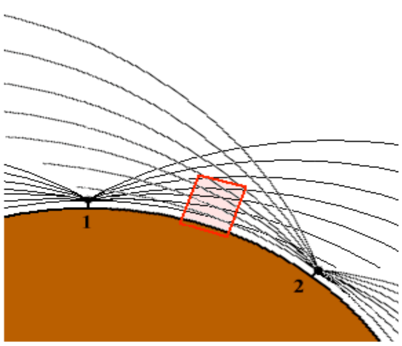

Fig. 2 An illustration shows the 3-D zone (pink shaded area) for computing reflectivity differences between a pair of adjacent radars in the RRCT.

An experimental real-time RRCT is developed to compute and to display reflectivity differences between any radar pairs that are less than 400 km apart in the Canadian and the WSR-88D networks. These radar pairs include the adjacent Canadian and WSR-88D radars along the US-Canada border (Fig.1). Figure 3 shows an example web-based display of the experimental RRCT for a region along the northeast US – southeast Canada border. Each circle represents a radar site, either Canadian or US WSR-88D. The color of the circle indicates net reflectivity difference between the radar and all its neighbors and the difference is averaged in the predefined regions (Fig.2) and over various time intervals (e.g., 30 days for Fig.3). The arrows between radar pairs indicate the difference between a single radar pair, where the color shows the magnitude and the direction points to the radar with higher reflectivities. Detailed time series of the reflectivity difference between any radar pairs over user-defined time intervals can be obtained from the RRCT as well (Fig.4).

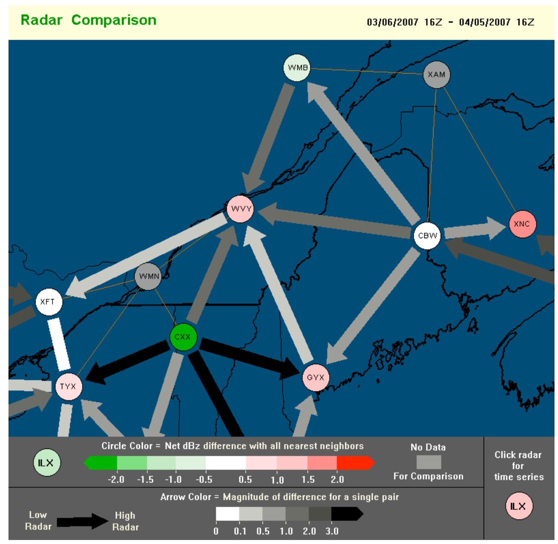

Fig. 3 A regional view of reflectivity comparison results between the Canadian and the US WSR-88D radar networks for a 30-day time period from 16:00UTC Mar. 6 to 16:00UTC Apr. 5, 2007.

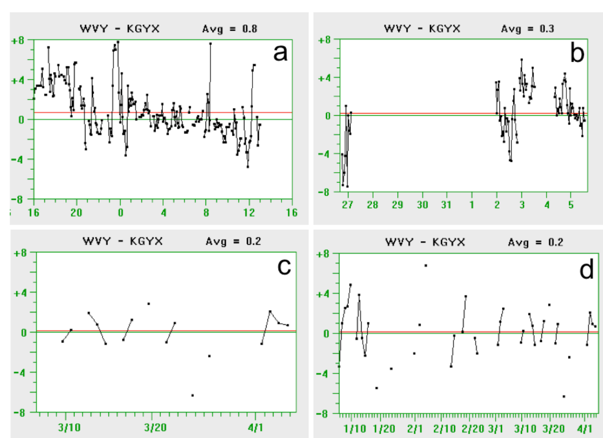

Fig. 4 Time series of reflectivity differences between WVY (Villery, Quebec) and KGYX (Portland. ME) over a 24-h period from 16Z on 4 April to 16Z 5 April 2007 (a), a 10-day period from 26 March to 5 April 2007 (b), a 30-day period from 6 March to 5 April 2007 (c) and a 90-day period from 6 Jan. to 5 April 2007 (d).

3.2 Reflectivity Comparison Results

The spatially and temporally averaged reflectivity difference can provide important information about calibration discrepancies between two radars of the same type (e.g., WSR-88Ds, Gourley et al., 2003). Differences between two different radar types (e.g., a C-band and a S-band) may contain additional information such as the attenuation in observations of C-band radars (e.g., the Canadian network) with respect to S-band radars (e.g., WSR-88Ds) for radar pairs where both radars are free of blockage in the RRCT computational region. Figure 5 shows a precipitation system that passed through the Great Lakes area on 25 August 2007. Reflectivities between two WSR-88D radars, KAPX (Gaylord, MI) and KGRR (Grand Rapids, MI) and between KAPX and a Canadian radar, WBI (Sudbury, Ontario), are analyzed using the RRCT.

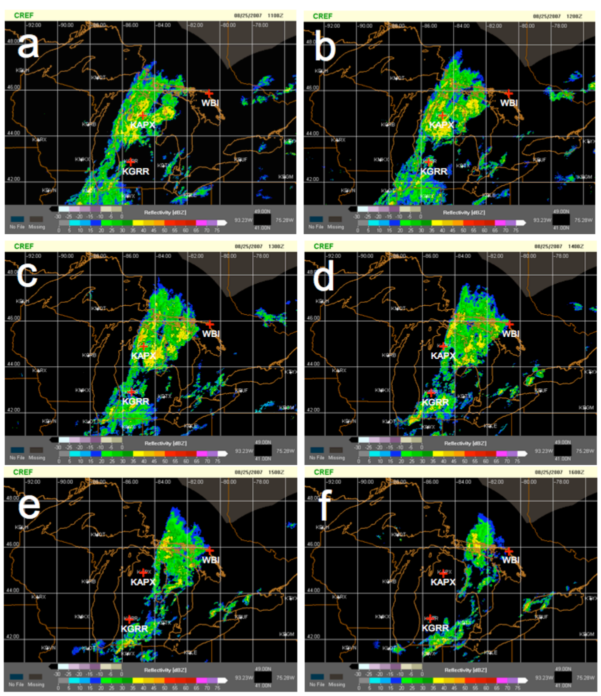

Fig. 5 Composite reflectivities in the great lakes area valid at 11 (a), 12 (b), 13 (c), 14 (d), 15 (e), and 16Z (f) on 25 August 2007. The three radars discussed in the paper are indicated by red "+" symbols.

Figure 6 shows the time series of reflectivity differences between the two radar pairs over a 5-hour period from 11 to 16Z on 25 August 2007. The reflectivity difference between the two WSR-88Ds was very small over the entire period, with an average of 0.2 dBZ (Fig.6b). The difference between KAPX and WBI was relatively small during the first hour (11-12Z, Fig.6a). As the echoes moved towards WBI (Figs.5b-5e), the difference increased significantly, and the 5-hour mean reached 4.1 dBZ (Fig.6a). The negative bias in WBI reflectivities may due to the attenuation of the 5-cm radar wave by the precipitation along the radar beam path. As the echoes moving towards WBI, the precipitation in the path between the radar and the RRCT computation region (i.e., equidistant region between KAPX and WBI) increased (Fig.5). As a result the attenuation to the WBI reflectivities increased and reflectivity differences between the two radars became larger.

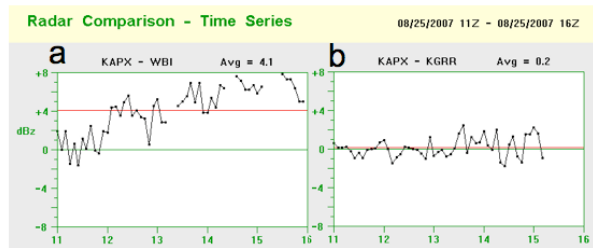

Fig. 6 Time series of reflectivity differences between KAPX and WBI (a) and between KAPX and KGRR (b) over a time period from 11 to 16Z on 25 August 2007.

These radar reflectivity comparison results are still preliminary. More cases need to be analyzed to obtain robust and quantitative statistics for the attenuation effects on 5-cm radars. In addition, the current RRCT does not have constraints on beam blockages, which could cause some incorrect biases in the results. The beam blockages will be addressed in the next version of the RRCT.

4 3-D mosaicing of WSR-88D and Canadian radar reflectivity data

The conventional volume scan (CONVOL) data has been used in the initial 3-D mosaic that integrates Canadian radar data and WSR-88D data. The Doppler volume scan (DOPVOL) data are not used due to the limited spatial coverage of the data (i.e., only four tilts, and the maximum range only goes to 113 km for the three upper tilts). Figure 7 shows RHI and PPI images of reflectivity from a conventional and a Doppler volume scans around the same time from XDR (Dryden, Ontario) radar. The CONVOL data (Figs. 7b and 7d) have a much better coverage both in horizontal and in vertical than the DOPVOL data (Figs. 7a and 7c). Ring shaped artificial echoes in the DOPVOL reflectivity (Fig. 7c) were due to a second-trip echo recovery procedure in the DOPVOL data process. This artifact poses another challenge in addition to the coverage limitation for using DOPVOL data in the 3-D mosaic. A challenge with CONVOL reflectivity data is the ground clutter near the radar site (see Fig. 7d). Initial efforts of quality controlling (QC) the CONVOL data and removing the ground clutter are ongoing. An existing QC algorithm developed for the WSR-88Ds will be tested on CONVOL reflectivity data and its performance assessed.

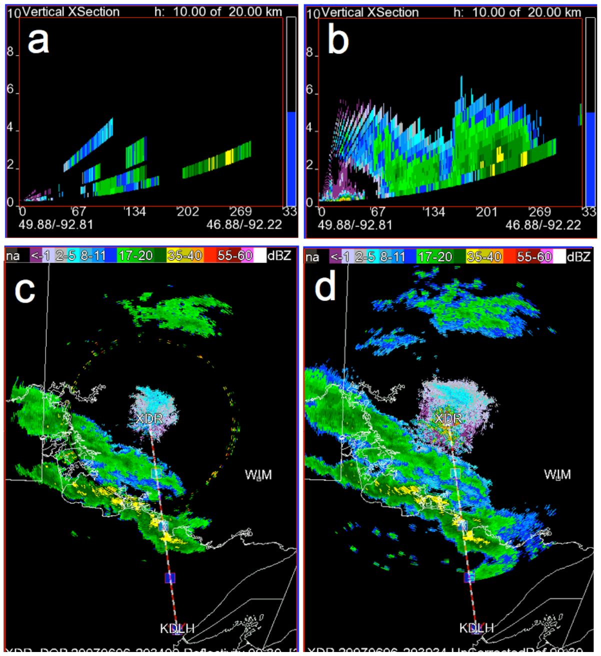

Fig. 7 Example reflectivity images from XDR observations on 6 June 2007: a) RHI from DOPVOL scan at 2034UTC; b) RHI from CONVOL scan at 2039UTC; c) 0.30 degree PPI from DOPVOL scan at 2034UTC; and d) 0.30 degree PPI from CONVOL scan at 2039UTC. The red-white lines in c) and d) indicate where the RHI images in a) and b) were taken, respectively.

Figure 8 shows RHI images from KDLH and from XDR along the same line. The reflectivity distributions observed by the two radars are comparable. However, the Canadian radar data has a much higher vertical resolution because of its smaller beam width (~0.65 degree vs. ~0.95 degree for the WSR-88D) and a finer elevation resolution (see section 2.1). Therefore the inclusion of Canadian radar data can provide higher resolution storm structure in the 3-D mosaic across the US-Canada boundary. This fine resolution storm structure can be potentially useful for various aviation applications and products including convective weather monitoring and prediction, icing hazard warnings, as well as data assimilation in numerical weather prediction models.

Each volume scan of reflectivity data from Canadian radars is transformed onto the 3-D single radar Cartesian grid using the same procedure for WSR-88Ds (Zhang et al., 2006). The single radar Cartesian grid from Canadian radars and WSR-88Ds are then combined into a regional 3-D mosaic.

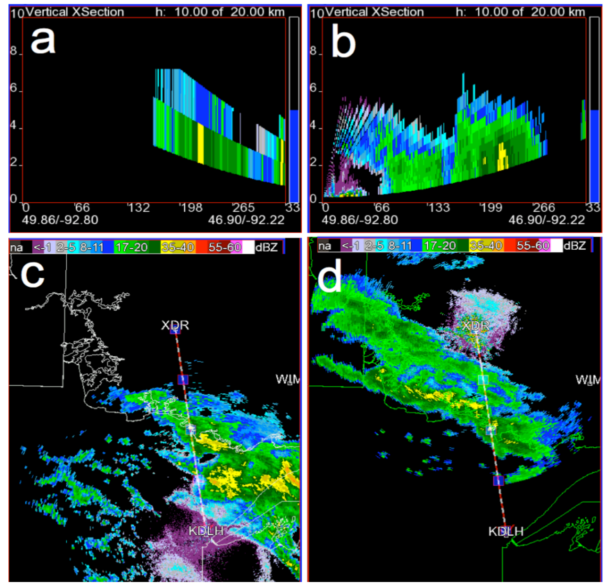

Fig. 8 Example reflectivity images from XDR and from KDLH observations on 6 June 2007: a) RHI from KDLH at 2047UTC; b) RHI from XDR at 2049UTC; c) 0.50 degree PPI from KDLH at 2047UTC; and d) 0.50 degree PPI from XDR at 2049UTC. The red-white lines in c) and d) indicate where the RHI images in a) and b) were taken, respectively.

Figure 9 shows a series of horizontal cross sections of reflectivity from the 3-D mosaic with and without Canadian radar data. Images in the left column of Fig. 9 are the horizontal cross sections from the 3-D mosaic using KDLH and KMVX (Mayville, ND) only, and images in the right column are the 3-D mosaic including three Canadian radars: XWL (Woodlands, Manitoba), XDR, and XNI (Superior West, Ontario). The Canadian radar provided better coverage of the precipitation system at all altitudes (Fig.9). The extra coverage in the lower levels (Figs. 9b and 9d) is even more pronounced because of the lower bottom scans from the Canadian radars. The additional coverage at lower atmosphere could potential improve quantitative precipitation estimation in the Great Lake region because of several Canadian radars in the vicinity. The upper level images (Figs. 9f and 9h) show seamless mosaicing between WSR-88D and Canadian radars. The seamless 3-D reflectivity grid across the US and Canada border can be beneficial for convective and winter weather monitoring and prediction as well as for icing condition analyses.

5 SUMMARY

Real-time base level data from Canadian radar network and from the US WSR-88D network are analyzed and 3-D mosaic grid is created using reflectivity observations from both systems. Since the Canadian radars are C-bands and WSR-88Ds are S-bands, reflectivities from the two networks may have different characteristics. A reflectivity comparison tool is developed to compute reflectivity differences between co-located radar bins from any Canadian-US radar pairs that are adjacent to each other. A case study showed that the comparison tool could potentially be used to study attenuations in Canadian radar reflectivity observations. Canadian radar data (conventional scans) has a higher vertical resolution and better coverage at the lower altitudes than the WSR-88Ds. Initial 3-D reflectivity mosaic study integrating Canadian radar and WSR-88Ds along the US-Canada border indicated that the mosaic grids provided better depictions of the 3-D structure of precipitation systems than using WSR-88Ds only. The expanded 3-D mosaic grid provides a data base that could potentially improve radar quantitative precipitation estimation and numerical weather predictions of convective and winter weather along the US-Canada border area.

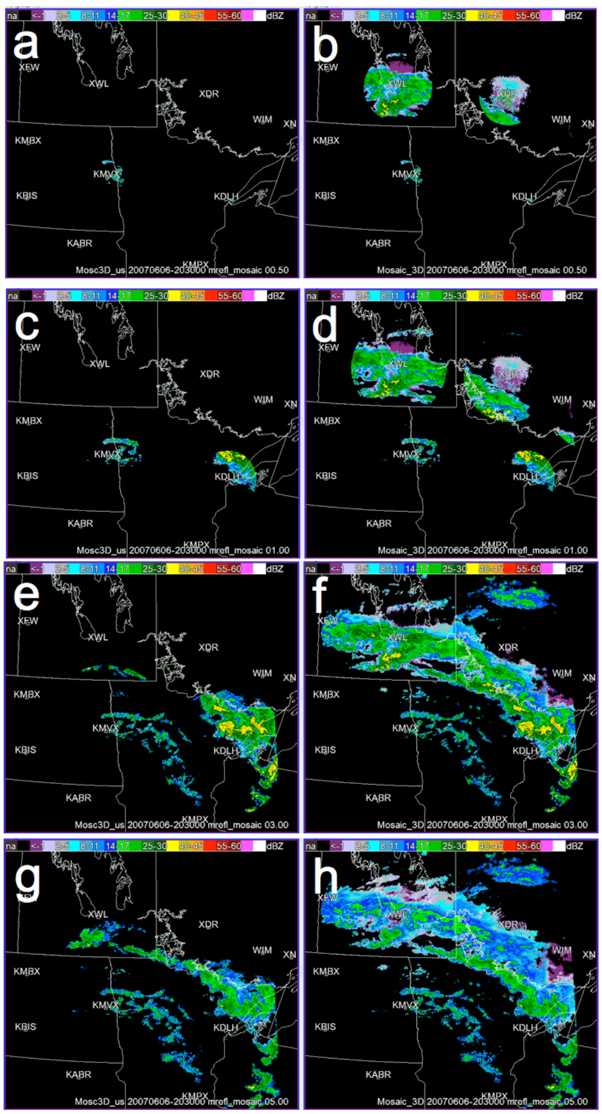

Fig. 9 Horizontal cross sections at 0.5 (row 1), 1.0 (row 2), 3.0 (row 3), and 5.0 (row 4) km above mean sea level from the 3-D mosaic grid with KDLH and KMVX only (left column) and from the 3-D mosaic grid with KDLH, LMVX, XWL, XDR, and XNI (right column).

Future work will focus on automated quality controls of the Canada radar conventional scan reflectivity data. Comparisons between the two radar systems will continue with more cases to further assess the differences between 5-cm and 10-cm radars and to provide guidance for a robust and consistent 3-D mosaic of Canadian and US radar data.

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