Reflectivity retrieval in a networked radar environment: Demonstration from the CASA IP1 radar network

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***Abstract*—A network-based reflectivity retrieval technique has been developed within the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA). The concept of a networked-radar system is simultaneous observations of the same precipitation event by multiple radars operating at the attenuating frequency such as X-band and scanning in a low elevation plane. This paper presents the preliminary demonstration of the network-based retrieval using data from the first Integration Project (IP1) radar network in Oklahoma.**

Electromagnetic waves backscattered from a common volume in a networked radar system are attenuated differently along the different paths. The CASA networked-retrieval method is based on a set of governing integral equations describing the backscatter and propagation of common volume with constraints of total path attenuation. The method has been implemented in a multiprocessor environment, which operate simultaneously and collaboratively to meet the real time requirement of CASA. The performance of the implemented retrieval algorithm such as computation requirement will be presented. Comparison of the CASA networked retrieval is made against the conventional attenuation correction based on the principle of coupling the specific attenuation, differential propagation phase and reflectivity. The preliminary results show good agreement with conventional differential phase base attenuation correction.

I. Introduction

The usefulness of radar to a specific application is heavily dependent on the accuracy and resolution of coverage. A fundamental physical limit imposed by transmission from a single radar is the problem of changing resolution as a function of range. In addition, the lowest coverage altitude gets higher with range due to earth curvature [1]. A networked radar environment concept has been proposed [2], [3]. The concept of the networked radar system is simultaneous observations of the same precipitation event by multiple radars in different locations. The networked radar system is capable of high spatial coverage and temporal resolution.

The Engineering Research Center for CASA was recently founded to create the underlying scientific and engineering basis for a new paradigm of Distributed Collaborative Adaptive Sensing (DCAS) radars applied to hazardous localized weather detection, tracking, and predicting. DCAS is a new approach to radar sensing of the atmosphere being investigated to overcome the coverage limitations inherent in long-range radar networks [4]. A testbed for the first Integration Project (IP1) was deployed in Oklahoma. The IP1 network is composed of a network of four sensing nodes located over a grid off as 13.2, -13.8, 15.5, -15.5 km at x-axis direction and 22.7, 5.2, -1.6, -22.7 at y-axis direction from the center of the network (Chickasha(KSAO), Cyril(KCYR), Rush Springs(KRSP) and Lawton(KLWE)), respectively. Fig. 1 shows the locations of the IP1 experiment site. The CASA IP1 radars are X-band pulsed Doppler systems with magnetron transmitters and dual-channel receivers.

A network-based reflectivity retrieval technique has been developed for a networked radar environment within CASA. The solutions of reflectivity and specific attenuation along each beam can be obtained by the combined back scatter and forward scatter equations of the precipitation medium with total path attenuation constraints. The algorithm has been tested by data from CASA IP1 testbed. The results of evaluation are compared against against the conventional attenuation correction [5], [6]. The computation requirement for the network-based retrieval algorithm will also be presented.

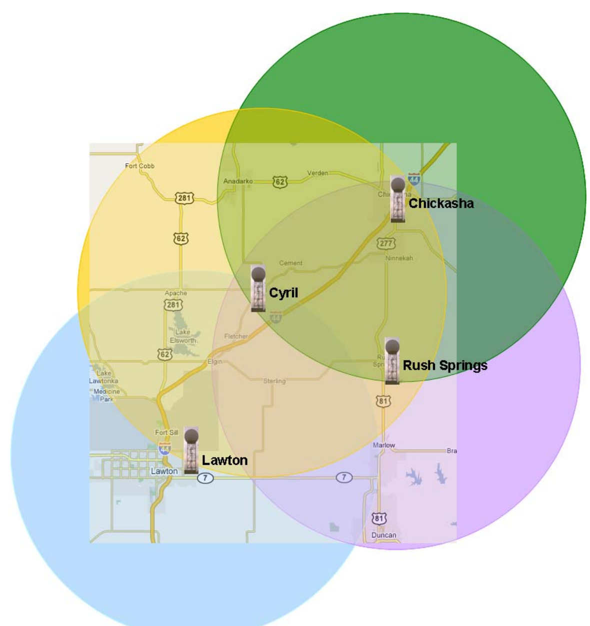

Fig. 1. Configuration of IP1 testbed.

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II. Network-based reflectivity retrieval

The network-based reflectivity retrieval is established on simultaneous observations of the same event by multiple radars in different locations. In the absence of attenuation, the reflectivity in a common volume for each radar should be the same. However, the observed reflectivities in a common volume are different because of the difference of the integrated attenuation along the paths from each radar. Specific attenuation distribution can be solved by the integral equation for reflectivity with total path attenuation constraint, in a manner similar to that used with a differential phase constraint [5], [7]. A solution of specific attenuation can be expressed as

$$\begin{aligned}
&\hat{\alpha}_h(r) = \frac{[Z_h'(r)]^b(10^{0.1b\Delta Z(r_m)}-1)}{I(r_0;r_m)+(10^{0.1b\Delta Z(r_m)}-1)I(r;r_m)};\\
&\Delta Z(r_m) = 10log_{10}(Z_h(r_m)) - 10log_{10}(Z_h'(r_m)); \qquad (1)\\
&I(r_0;r_m) = 0.46b\int_{r_0}^{r_m}[Z_h'(s)]^b ds
\end{aligned}$$

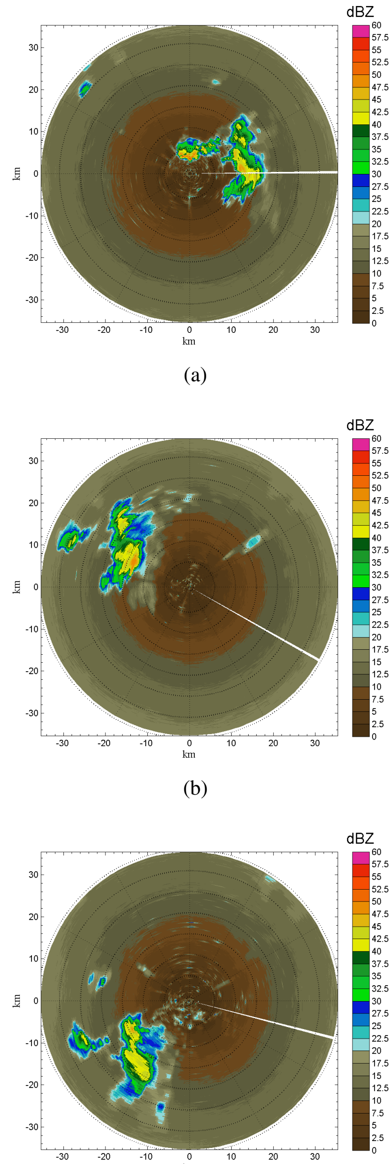
where $\Delta Z(r_m)$ is the difference between intrinsic reflectivity $(Z_h(r_m))$ and observed reflectivity $(Z_h'(r_m))$ at range r_m, namely two-way cumulative attenuation, and parameter b corresponds to the $\alpha - Z$ relation. If we figure out the intrinsic reflectivity at range r_m, we can solve for the specific attenuation distribution and reflectivity along path r_0 to r_m. The intrinsic reflectivity at the common volume (r_m) can be obtained by making an initial estimate of reflectivity and iteratively solving for it, based on constraints to match the multiple radar observations.

III. Demonstration of the networked-based retrieval using data from IP1 radar network

The network-based retrieval was tested using data from the CASA IP1 radar network (http://www.casa.umass.edu/research/testbeds.html). For brevity, two cases are demonstrated here.

The first test data (Case I) were collected from KCYR, KRSP and KSAO radars on August 15, 2006. This event was a isolated severe thunderstorm with embedded convection. Fig. 2 shows the observed reflectivity from three radars, while Fig. 3 shows the retrieved reflectivity. Comparison of the CASA networked retrieval is made against the conventional attenuation correction based on the principle of coupling the specific attenuation, differential propagation phase and reflectivity [8]. Fig. 4 shows the comparison between network-based retrieval system and conventional rain-profiling algorithm based on differential propagation phase. From the results of Fig. 4 we can see that the network-based algorithm agrees well with conventional differential phase base attenuation correction.

Second (Case II) is a case of severe thunderstorm that developed across IP1 site in the evening of April 10 from approximately 22-02 UTC. Severe hail and winds were observed within the test bed. Fig. 5 shows observed reflectivity from four radars. Fig. 6 shows the composite of retrieved reflectivities for four radars. From the results of Fig. 6, we can see the network-based algorithm works reasonably.



(a)

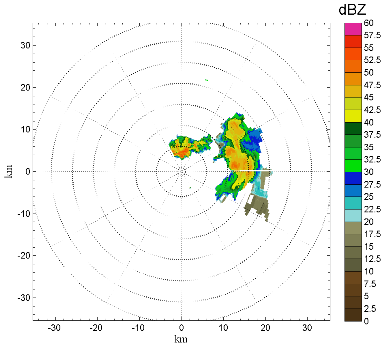
(b)

(c)

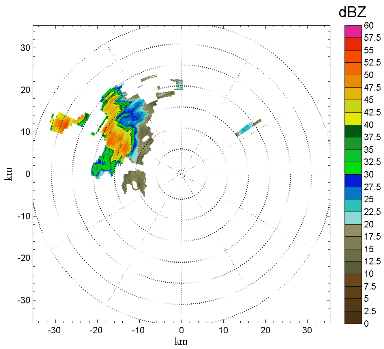
Fig. 2. Observed reflectivity from (a) KCYR, (b) KRSP and (c) KSAO

IV. Computation performance

The algorithm had been implemented using GCC with POSIX thread library. In addition to the standard GCC library, a numerical library is used which provides mathematical routines such as matrix operations, and basic statistical functions. The program was tested on a processing node which is a 3.06 GHz Xeon Dual Processor machine with 2GB RAM running Linux 2.6.18. We assume that NetCDF files from the radars (KCYR, KSAO, and KRSP) are delivered to the processing node using a file transfer program. In each iteration, the program reads three NetCDF files from local directories of the processing node, processes the radar data in the files, and writes the result to a NetCDF file. To determine the execution time of the program we measure the duration from



(a)



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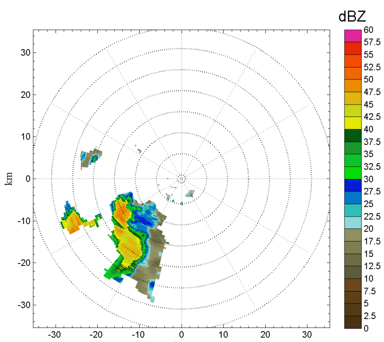

(c)

Fig. 3. Retrieved reflectivity from (a) KCYR, (b) KRSP and (c) KSAO

reading the NetCDF files to writing the results. Fig. 7 shows the distributions of execution time for two data sets taken at August 15 2006 and April 10 2007. Each data set consists of 63 NetCDF files. As seen in the figure, the maximum of the execution time is 20seconds, and in the majority of the cases, the program completes the processing within 4 7seconds.

V. Summary

The network-based retrieval algorithm was tested using preliminary data from CASA IP1 radar network in Oklahoma. The results of network-based retrieval algorithm show good agreement with that of the conventional rain-profiling algorithm based on differential propagation phase. For real time implementation, the network-based algorithm also studied for computation time. The processing time were within real time

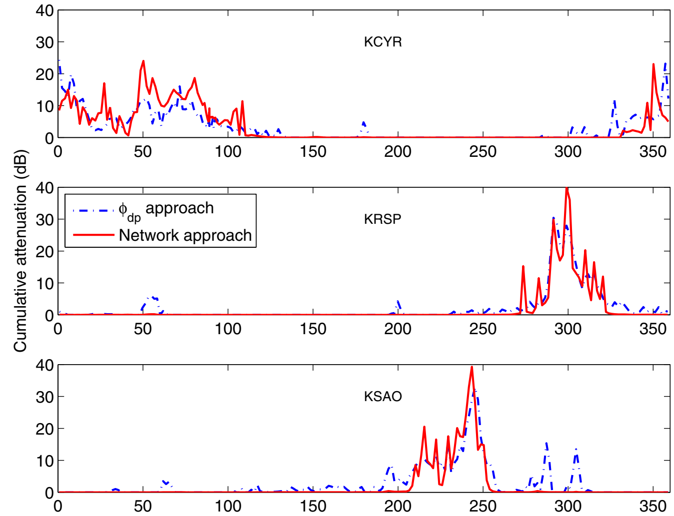

Fig. 4. Comparison of retrieved cumulative attenuation between network-based algorithm and conventional rain-profiling algorithm for radar KCYR, KRSP KSAP from top panel

requirement for CASA. The fundamental test for the network-based retrieval algorithm has been accomplished.

Acknowledgment

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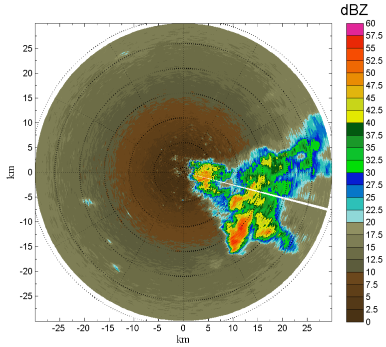
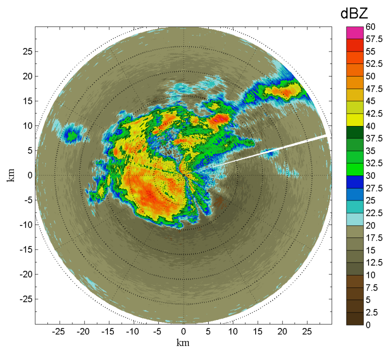


(a)



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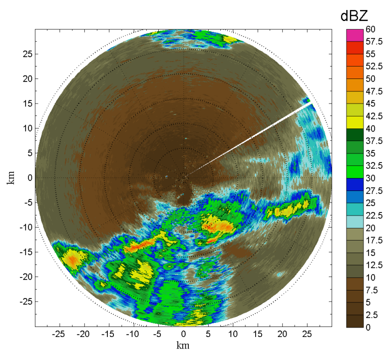

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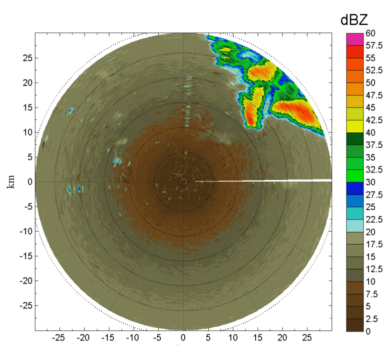

(d)

Fig. 5. Observed reflectivity from (a) KCYR, (b) KRSP, (c) KSAO, (d) KLWE

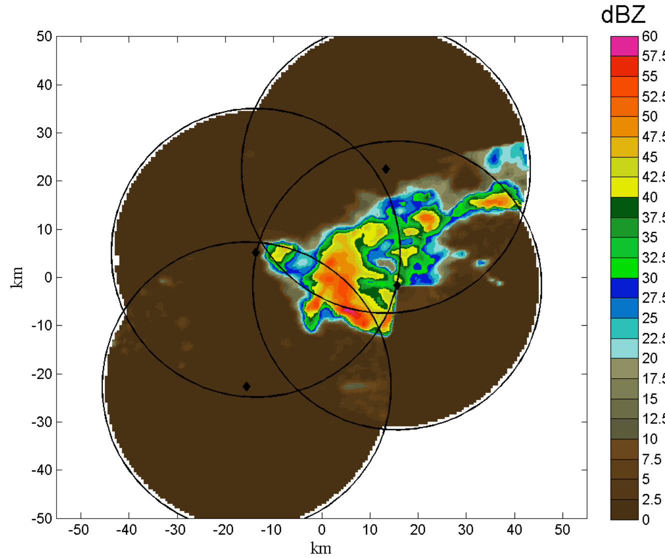

Fig. 6. Composite of retrieved reflectivity from four radars

Fig. 7. Frequency distribution of the execution time