RADAR OBSERVATIONS OF A SEVERE WEATHER EVENT FROM DISTRIBUTED COLLABORATIVE ADAPTIVE SENSING NETWORK IN IP1 TESTBED

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Abstract

Adaptive sensing using a dense weather radar network is an emerging concept advanced by the Center for Collaborative Adaptive Sensing of the Atmosphere. The center is founded on the transforming paradigm of Distributed Collaborative Adaptive Sensing (DCAS) networks designed to provide observations at better resolution and mitigate the earth curvature problem of long range radars. IP1 is the first DCAS system testbed, aimed at severe weather and hazardous wind-sensing in southwestern Oklahoma. Some of the first observations of severe thunderstorms from this DCAS network are presented in this paper to highlight the salient sensing concept and sensing node design.

1. Introduction

One of the goals of the Engineering Research Center for Collaborative Adapting Sensing of the Atmosphere (CASA) is to develop a paradigm of networked radar system to improve the coverage of the lowest portion of the atmosphere through coordinated scanning of lowpower, short-range, networked radars (referred to as Distributed Collaborative Adaptive Sensing (DCAS) [2], [3]). The first DCAS System demonstration test-bed was deployed in south-west Oklahoma (USA) and it consists of a network of four, low-power, short-range, dual polarization, Doppler radar units, referred to as Integrated Project 1 (henceforth referred as IP1).

Current weather radar systems, such as the WSR-88D Next Generation Doppler Radar (NEXRAD) system, sample the atmosphere in “sit-and-spin” mode over the same regions according to predefined volume coverage patterns (VCP). This system has been very successful and has performed well in terms of satisfying the performance goals. However this system is fundamentally constrained in sensitivity, resolution, and lower atmosphere coverage [1] and lack the capability to trace and track the storm cells in an adaptive and dynamic manner, specially the small scale and high impact cases such as tornadoes. The Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) is advancing an entirely new paradigm in which distributed collaborative adaptive sensing (DCAS) networks are deployed to overcome fundamental limitations of current approaches to atmospheric hazard detection, prediction, warning, and response [2]. Distributed refers to the use of large numbers of small radars, appropriately spaced to overcome blockage and resolution limitations of today's long range Doppler weather radars. The radars operate collaboratively within a dynamic information technology infrastructure, adapting to changing atmospheric conditions in a manner that optimally meets end-user needs.

The CASA enterprise designs, develops, and deploys system-level test beds to integrate underlying scientific and technical advances and demonstrate the potential to observe, understand, predict and respond to hazardous atmospheric phenomena–with end users involved from the outset. The IP1 test bed in southwestern Oklahoma is the first one of such test beds that was completed in 2006, targeting at monitoring severe convective storms and tornado detection. A 9-week intensive operation experiment, called CASA Spring Experiment 2007 (CSE’07), was conducted in the IP1 test bed in Oklahoma from April 9 to June 10, 2007. The overall objective of this experiment is to demonstrate and evaluate the fundamental concept of Distributed Collaborative Adaptive Sensing (DCAS) and investigate the value added impact of this networked weather radar system compared to conventional weather radar systems. In the following sections, radar observations from IP1 CSE’07 will be used to demonstrate several important radar sensing aspects and the verification of some of the system goals.

2. IP1 Testbed and Infrastructure

The IP1 Test Bed covers a 7,000 square km region in southwestern Oklahoma that receives an average of 4 tornado warnings and 53 thunderstorm warnings per year. This four-node DCAS system is being operated in conjunction with an end user group comprised of the National Weather Service Forecast Office in Norman, OK, a group of seven emergency managers who have jurisdictional authority within and upstream of the test bed area, several private sector entities, and CASA's researchers themselves. The radar nodes are installed Southwest of Oklahoma City, OK, and are under the coverage of the KFDR and KTLX NEXRAD radars. Each radar node is approximately 30 km away from the next unit. A cluster of computers known as System Operation and Control Center (SOCC) is located in the National Weather Center building in Norman, OK. SOCC houses the Meteorological Command and Control (MC&C) that is responsible for the network automated operation. The MC&C continuously ingests and stores the weather moment data files received from each radar node, and detects the relevant weather features in the individual and merged radar data, and creates a list of tasks associated to the detected features [3]. The IP1 radar network is operated in "closing the loop" mode, driven by MC&C.

3. Clutter Mitigation

Ground clutter contamination can lead to misinterpretation of radar observations and induce a series of wrong actions within this closed-loop system. An advanced spectral approach (Gaussian Model Adaptive Processing, GMAP [4]) is employed in IP1 Test Bed. In this spectral filtering methodology, clutter spectral coefficients are notched with a spectral filter based on a Gaussian model for the clutter spectral density. A Gaussian weather spectral density is recursively fit to the remaining points and the notched spectral coefficients are interpolated with the model. As a result of the recursive interpolation, the bias in reflectivity and velocity due to notch filtering is minimized. The performance of clutter mitigation using GMAP can be seen in Fig.1. In Fig.1(a) and Fig.1(c) are shown the measured reflectivity and velocity, with clutter contamination highlighted in circles. Fig.1(b) and Fig.1(d) show the filtered reflectivity and velocity after real time implementation of GMAP. Note that the beam height for these clutter targets is only about 200~400m. A circulation is clearly observable in the filtered velocity plot.

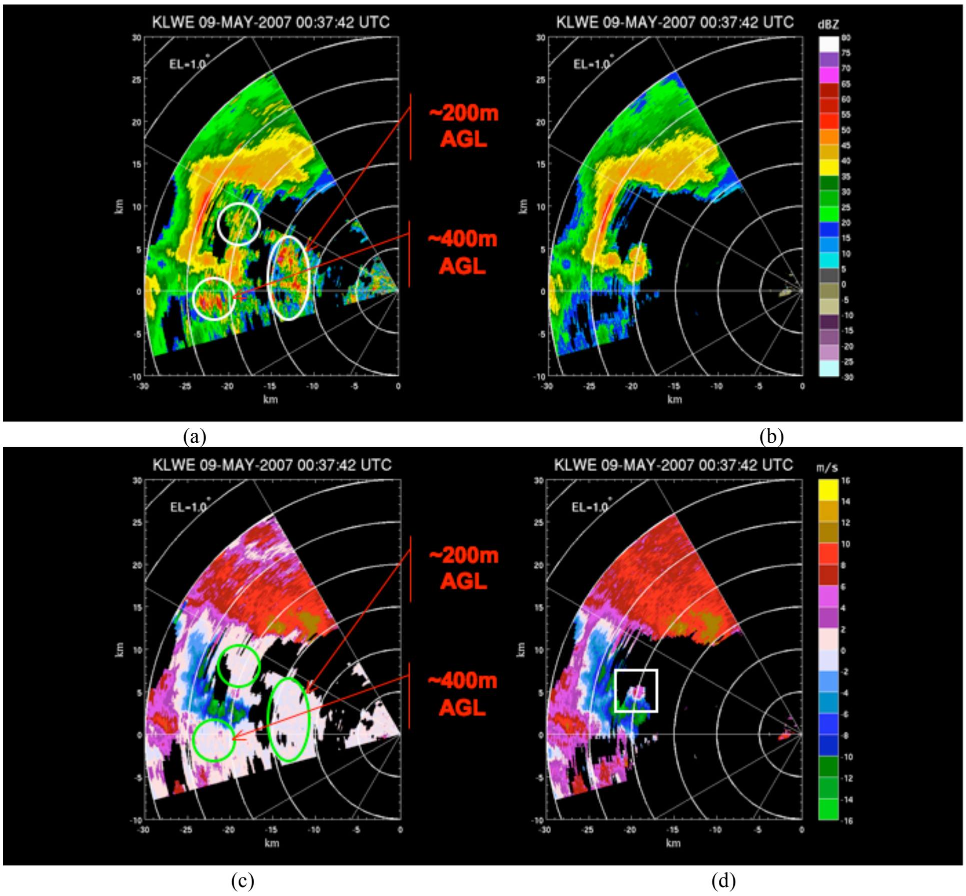


Fig.1 Ground clutter contamination in IP1 observations and clutter filter using GMAP. Radar reflectivity is shown in (a) before and (b) after filtering; Radial velocity is shown in (c) before and (d) after filtering. Ellipses highlight the clutter echoes and square marks a circulation.

4. Attenuation Correction

Rain attenuation remains a significant challenge for X-band radar. The attenuation correction is solved in two aspects, based on the self-consistence of dual polarization observations or networked radar observations. A robust dual-polarization attenuation correction is currently employed to retrieve corrected reflectivity values in real time during rain. The dual-polarization algorithm retrieves the specific attenuation and the specific differential attenuation from the attenuated reflectivity measurements with constraints imposed by the differential propagation phase. The attenuation correction algorithm has been designed specifically to improve the accuracy of the correction for heavy rain, to ensure robustness during light rain, and to meet the IP1 real-time operational requirements [5]. Its performance is demonstrated in Fig.2. The radar observed reflectivity is shown in Fig.2(a), with heavy attenuation in comparison with S-band NEXRAD observation shown in Fig.2(c). After correction for rain attenuation, the lost intensity is almost completely recovered. With rain attenuation formulated simultaneously for multiple radars, a network-based attenuation correction was devised in CASA. This marks a paradigm shift from single radar node to networked radar environment, based on the inherent constraints in networked radars rather than on the dual polarization signatures. Over the same dataset, the radar reflectivity after network based correction is shown in Fig.2(d). This evaluation was done off-line while the algorithm is being tuned for real time implementation. Note that this new technique can be used in radar network of single polarization systems.

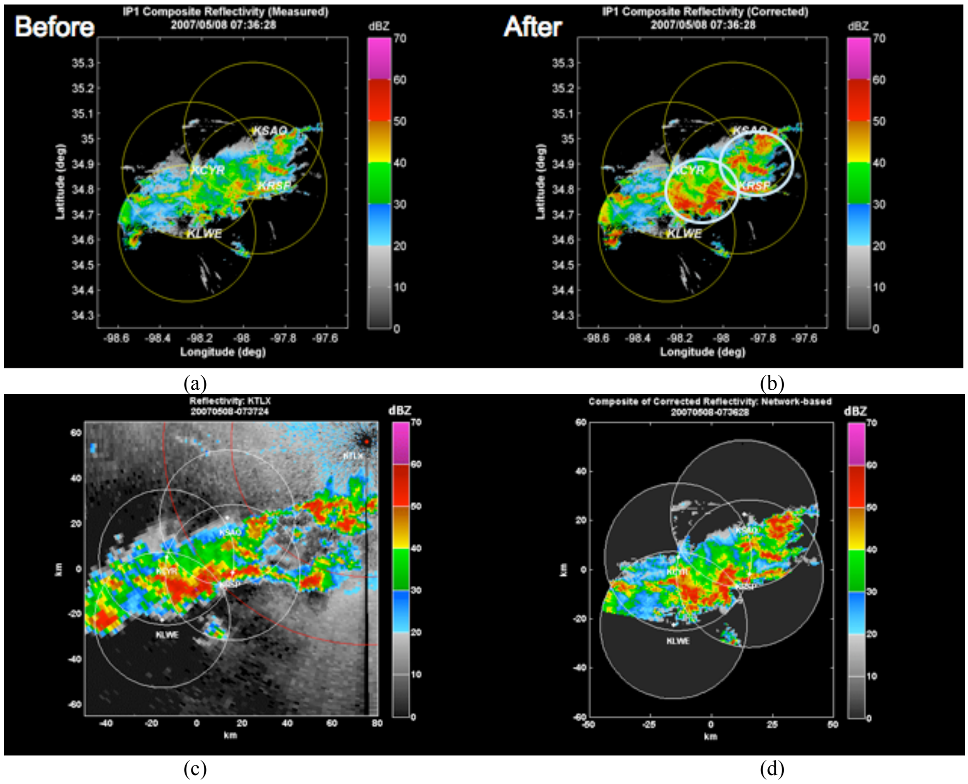
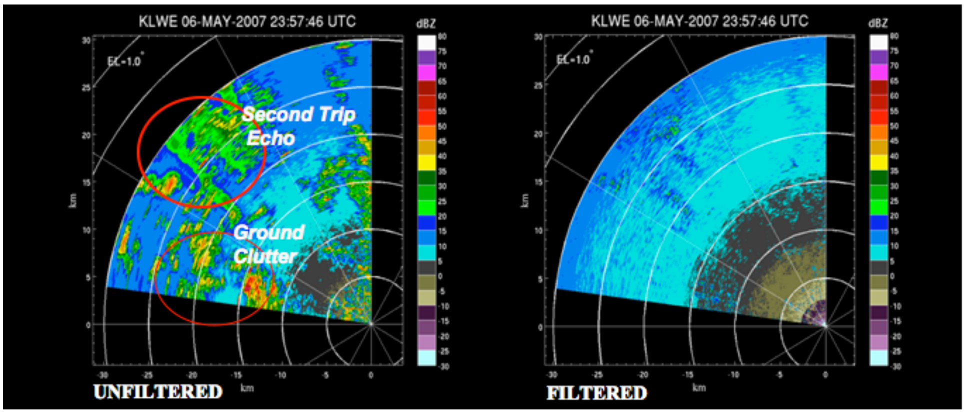


Fig.2 Attenuation correction in IP1 X-band radar systems. (a) Radar measured reflectivity; (b) corrected reflectivity for rain attenuation with dual polarization based technique; (c) NEXRAD measured reflectivity at S-band; (d) same as (b) except with network based technique.

5. Ambiguity Mitigation

Pulse Doppler radar with uniform pulse repetition frequency (PRF) has a fundamental limitation on its maximum unambiguous range (r_a) and maximum unambiguous velocity (v_a). The product of these variables is a constant in proportion to the wavelength. At the short wavelengths where dense radar networks operate, this design constraint becomes more stringent compared to conventional large-sized weather radar systems that operate at longer wavelengths. The IP1 radars were designed with hardware support for random phase coding and dual-PRF processing to extend the unambiguous range and Doppler velocity. The performance of mitigation of range ambiguity, velocity folding, and clutter is related to the specific waveforms adopted. Fig.3 shows a typical example where the second trip echo and ground clutter are simultaneously suppressed. A dual-PRF waveform with PRF1=1.6 kHz and PRF2=2.4 kHz is currently applied which yields a maximum unambiguous velocity of 38 m/s.



(a) (b)

Fig.3 Random phase coding and processing. (a) Second trip echoes and ground clutter in reflectivity map; (b) the radar reflectivity after random phase processing and GMAP filter. Strom was approaching to the network at this observation instant.

6. Conclusion

The NSF ERC for CASA designed and developed a DCAS network in an integrated project (IP) test bed. An intensive operation of 9 weeks were conducted using this DCAS network in the Spring Experiment 2007 for severe weather observations, algorithm validation, cross disciplinary integration, and proof of DCAS concept. Some early results were presented in this paper with focus on the salient sensing features and system design aspects. It was demonstrated that the system of a network of radars is capable of delivering high quality radar products as designed and operating under the command of a MC&C system to support the needs of the distributing, end user and predicting thrusts.

7. Acknowledgments

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