SCALE DECOMPOSITION OF PRECIPITATION PATTERNS AND NOWCASTING IN A HIGH-RESOLUTION X-BAND RADAR NETWORK

Evan Ruzanski, Yanting Wang, and V. Chandrasekar

Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, Colorado 80523-1373, USA
email: ruzanski@engr.colostate.edu

1. INTRODUCTION

Measuring the atmosphere at high temporal resolution with radar requires scanning at high rates of speed in order to detect small time-scale characteristics of and precursors to severe weather. Such high-speed scanning necessitates the use of computationally efficient algorithms to accurately perform functions such as nowcasting in an operational network setting. This paper describes the operational implementation of the Dynamic and Adaptive Radar Tracking of Storms (DARTS) nowcasting system within the Collaborative and Adaptive Sensing of the Atmosphere (CASA) X-band radar network. A comprehensive performance analysis is presented using results from the 2008 and 2009 Integrative Project 1 (IP1) experiments. The results from storm event data collected in 2008 show the DARTS algorithm provides a runtime reduction factor of 10 compared to the Growth and Decay Storm Tracker cross-correlation-based algorithm [1] and about the same level of nowcasting precision (actually about a 5% improvement) for lead times up to 10 minutes.

It is well-known that precipitation patterns include variability over a range of scales and that smaller scales are less predictable due to shorter lifetimes. It has been shown that nowcasting precision can be improved by decomposing precipitation patterns by scale and either tracking those scales most representative of pattern motion or removing nonpredictable scales after tracking which degrade nowcasting accuracy. A previous study showed improvement in nowcasting precision by applying an elliptical spatial filtering procedure to NEXRAD reflectivity images input to a cross-correlation-based nowcasting algorithm to track the storm scales believed to better represent the physical characteristics and motion of precipitation patterns [1]. Another study used the wavelet transform to develop measures of predictability at each scale and designed adaptive wavelet filters to remove nonpredictable scales from predicted NOWrad continental scale reflectivity images [2]. This paper will present the basis for a modified approach relating features of these two methods applied to small-scale features observed in high-resolution CASA reflectivity images in efforts to improve nowcast accuracy and characterize the physical properties of severe weather.

2. THE CASA OPERATIONAL NOWCASTING SYSTEM

2.1. System Architecture

The DARTS algorithm, which generates a storm motion vector field by estimating the parameters of a linear model built on the flow equation modified for nowcasting in the frequency domain, was implemented within the CASA X-band radar network to provide end-users with real-time predicted reflectivity images for lead times up to 15 minutes during the 2008 CASA IP1 experiment. Attenuation correction and clutter removal algorithms are employed at each of the 4 CASA radar nodes at Chickasha (KSAO), Rush Springs (KRSP), Cyril (KCYR), and Lawton, Oklahoma (KLWE). The System Operations Control Center (SOCC) located at the University of Oklahoma at Lawton, OK, receives the radar node data, performs conversion to Network Common Data Format (NetCDF), and sends the data to the University of Massachusetts at Amherst via a Local Data Manager (LDM). After the radar data files are suitably synchronized by the ingester, the individual radar data files are gridded and merged. These files serve as input to the DARTS nowcasting module, which provides the predicted reflectivity images to the end-user via an Internet-based display.

2.2. Performance Results

Reflectivity data collected from the CASA radar network from a severe storm event occurring Nov. 5, 2008, was used as input to the operational DARTS and GDST nowcasting algorithms. The temporal resolution of the data set is approximately 1 min., gridded to an average spatial resolution of 0.5 km. Fig. 1 shows the Critical Success Index (CSI), Probability of Detection (POD), and False Alarm Ratio (FAR) scores [3], respectively, for lead times up to 10 minutes. Fig. 1 shows DARTS exhibits an average improvement of 5.6% in CSI scores with similar improvement in POD and FAR scores.

3. SCALE DECOMPOSITION OF PRECIPITATION PATTERNS IN THE CASA RADAR NETWORK

The high-resolution radar data collected by the CASA radar network motivates the need for specialized techniques to optimally enhance or remove the observed small-scale precipitation patterns.

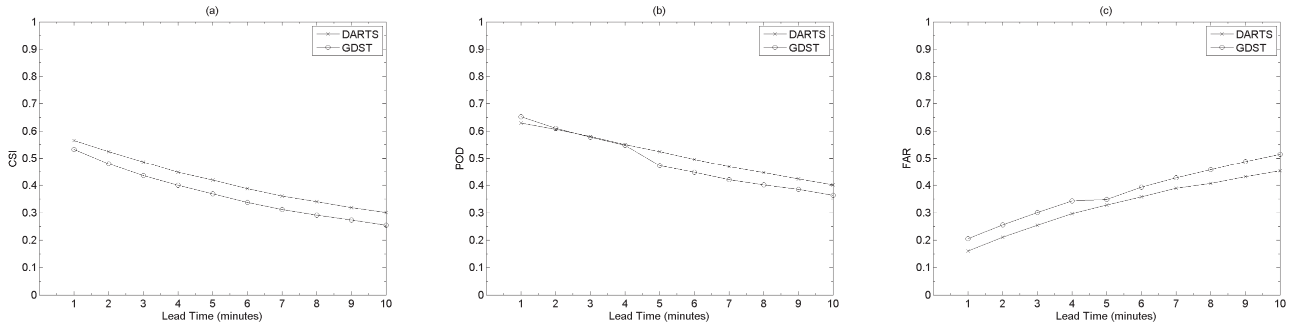

Fig. 1. (a) CSI, (b) POD, and (c) FAR nowcasting skill scores for (operational) DARTS and (offline) GDST nowcasting algorithms for the Nov. 5, 2008 CASA storm event.

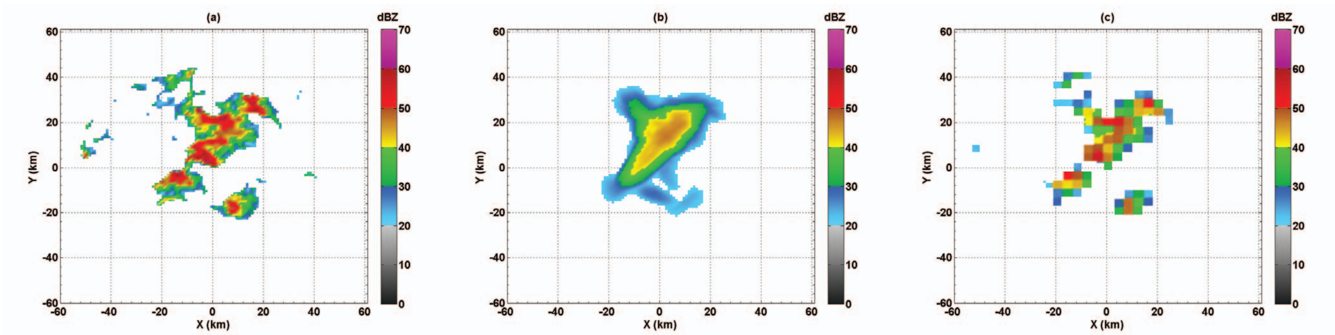

Fig. 2. Illustration of spatial filtering techniques on CASA radar data: (a) unfiltered DARTS-predicted image from Nov. 5, 2008, data set; (b) same image filtered using elliptical filtering procedure; (c) same image filtered using adaptive Haar wavelet filtering method.

Fig. 2 shows an image from the Nov. 5, 2008, CASA data set filtered using the approaches described in [1] and [2]. It is believed a new modified or hybrid scale filtering method based on these larger-scale approaches can be applied to the high-resolution CASA reflectivity images to improve nowcasting performance and better understand the physics of severe weather. Such an approach will be investigated in this paper along with the comprehensive operational nowcasting performance analysis using 2008 and 2009 storm data collected by the CASA network without filtering.

The filtering process used in [1] involves centering an elliptically-shaped area over a point, (x,y), in the original image and assigning the maximum average value of the pixels underlying this area as it is rotated through 180 degrees to be the pixel value at location (x,y) in the filtered image. An elliptically-shaped filter is used to better represent the physical geometry of the storm, as boundary layer forcing for convection tends to organize storms in regions that are often 3-4 or more times longer than wide. The elliptical filter thus allows extraction of these long narrow large-scale regions where a square filter would over-filter the cross-front direction, but does not provide a tractable mathematical basis with which to define a "scale" and thus analyze physical characteristics of precipitation patterns.

Previous studies have shown the application of Fourier lowpass filtering improved nowcast performance [4], [5]. While the Fourier Transform is useful for representing periodic properties, rainfall fields regularly exhibit highly localized features with sharp spatial gradients. Since the basis functions used by the wavelet transform are more effective in representing localized, intermittent fields, the method in [2] considers using a Haar wavelet filtering scheme to improve nowcasting accuracy. The filtered predicted images at longer lead times reflect the lack of predictability of smaller scales associated with higher intensities which are smoothed to lower values over larger areas. The texture of precipitation patterns is lost as small regions of reflectivity are block-averaged with adjacent areas. In this way, as forecast information about smaller storm structures becomes inaccurate, the filtering removes these details in order to reduce errors.

4. REFERENCES

[1] M.M. Wolfson, B.E. Forman, R.G. Hallowell, and M.P. Moore, "The growth and decay storm tracker," *Preprints, 8th Conf. on Aviation, Range, and Aerospace Meteor.* Am. Meteor. Soc., Dallas, TX, pp. 58-62, Jan. 1999.

[2] B.J. Turner, I. Zawadzki, and U. Germann, "Predictability of Precipitation from Continental Radar Images. Part III: Operational Nowcasting Implementation (MAPLE)," *J. Appl. Meteor.,* vol. 43, pp. 231-248, Feb. 2004.

[3] Wilks, D.S., *Statistical Methods in the Atmospheric Sciences, 2e*, Academic Press, 2005.

[4] A.W. Seed, "A dynamic and spatial scaling approach to advection forecasting," *J. Appl. Meteor.*, vol. 42, pp. 381-388, Mar. 2003.

[5] I. Zawadzki and U. Germann, "Scale-Dependence of the Predictability of Precipitation from Continental Radar Images. Part I: Description of the Methodology," *Mon. Wea. Rev.*, vol. 130, pp. 2859-2873, Dec. 2002.