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HIGH TEMPORAL AND SPATIAL RESOLUTION 2D WIND AANALYSIS OF CASA AND WSR-88DRADAR DATA USING THE ARPS 3DVAR

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1. Introduction

The advantages of using Doppler weather radar to track and forecast mesoscale severe weather events are widely recognized. With the use of the Next Generation Radar (NEXRAD) Doppler network, meteorologists can provide better information to the public, ultimately saving lives and property, by remotely observing the internal structure of thunderstorms at high resolution. Despite the tremendous capabilities of NEXRAD, it is unable to view much of the lower atmosphere (< 3 km AGL) because of the Earth's curvature and the distance between radars. To completely understand and analyze the atmosphere, especially convective thunderstorms, the boundary-layer wind field is critical. To address this problem and provide improved surveillance of severe weather, a National Science Foundation Engineering Research Center, the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), was established in 2003 to develop low-cost, high spatial density and dynamically adaptive networks of Doppler radars for sensing the lower atmosphere (McLaughlin et al. 2005; Brotzge et al. 2007). This project is a joint effort between the University of Massachusetts-Amherst, the University of Oklahoma, Colorado State University, and the University of Puerto Rico at Mayaguez. The first CASA test bed was deployed in Oklahoma and consists of four scanning polarimetric Doppler radars located on average 27 km apart with a radar range of 40 km. The network was designed to maximize dual-Doppler wind coverage and within certain parts of the network, triple Doppler wind coverage is also available (Fig 1).

Data from four CASA radars and two WSR-88D radars were collected in real-time during the spring of 2007 and 2008. Using radial wind and reflectivity data from these CASA radars, along with NEXRAD, Oklahoma Mesonet, satellite and conventional data, some real-time data assimilation and forecast experiments were performed at 1-km grid resolution using the Advanced Regional Prediction System (ARPS; Xue et al. 2000, 2001) and ARPS Data Analysis System (ADAS; Brewster, 2003a, b) in 2007 and ARPS 3DVAR data assimilation system in 2008 (Gao et al. 2002, 2004, 2008; Ge and Gao 2007; Schenkman 2008). These were run in near-real time using a local cluster of Pentium4 Linux computers. Gao et al. (2008) demonstrated a potentially significant benefit of CASA radar to provide real-time low-level wind analysis, in addition to the WSR-88Ds. However, due to constraints associated with real-time analysis, problems remain associated with the quality control during the analysis.

In this paper, we will discuss the progress in our 2008 low-level wind analysis experiment and address several issues related to it. Our purpose is to identify any existing problems and demonstrate the importance of quality control and other necessary adjustments recently applied to the low-level wind analysis. Our major effort within the next few years will be to provide reliable, real-time low-level wind analysis product to end-users for improving severe weather detection and prediction using data from the CASA network together with other data sources. Section 2 provides a brief description of experiments and future work is discussed in Section 3.

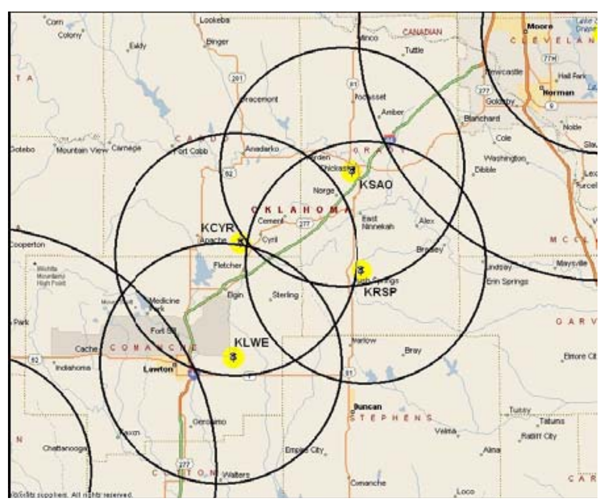

Fig. 1. The 4-node CASA test bed in Oklahoma –CASA radar network and analysis domain. (The analysis domain is about 140X140 km).

2. Experiments and Problems

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The 3DVAR system has the advantage of being able to use single, dual or multiple Doppler wind observations as well as conventional observations (e.g., Oklahoma Mesonet data) and background fields from forecast models to obtain 2D, or 3D wind fields and other model variables as necessary. The effectiveness of the CASA radar network combined with WSR-88D radars for storm-scale data assimilation and forecast is evaluated by utilizing a set of simulated data as well as real data cases in our previous studies (Gao et al. 2005, 2007, 2008). During spring 2008 (7 April – 30 June), the real-time low-level wind analysis were performed using the 4 CASA radars and two nearby WSR-88D radars (KTLX and KDFR). The parameter settings for the analysis domain include 400x400x7 total grid points with grid spacing of 400 m in both the horizontal and the vertical. We use only seven levels in the vertical in order to focus on low-level wind analysis.

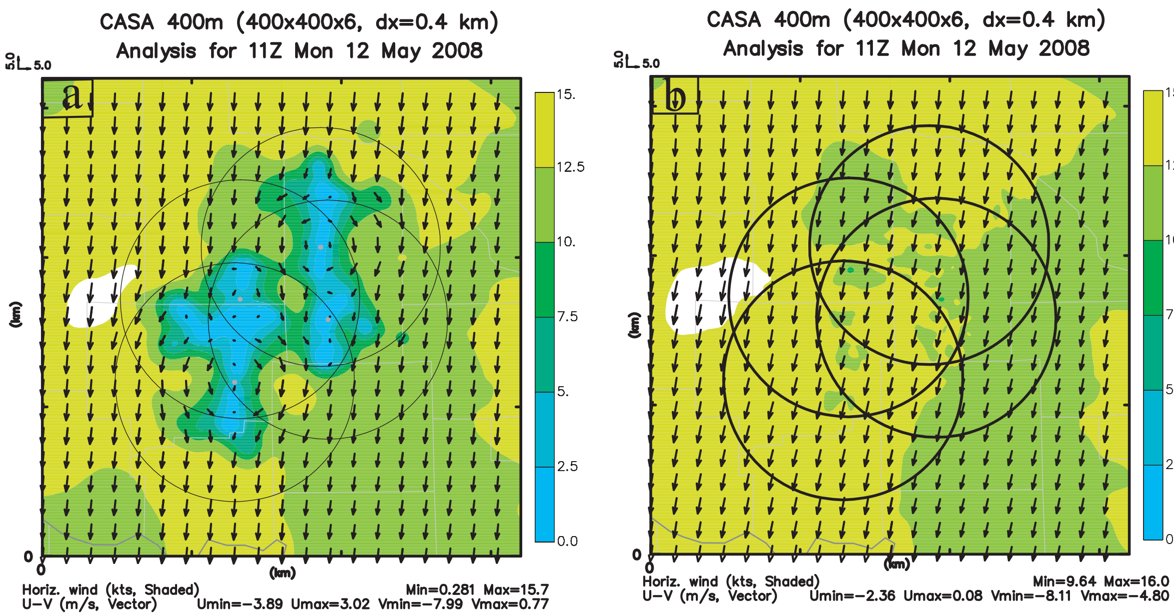

Fig. 2. The analyzed horizontal wind vectors and contours of horizontal wind speed at z=0.5 km using data from WSR-88D and CASA data combined valid at 1100 UTC, (a) before quality control, (b) after quality control.

The CASA radars collected data adaptively by scanning only those sectors covering the most intense convection, with each scanning decision made by an integrated system known as the Meteorological Command and Control (MC&C; Brotzge et al. 2007). Data from each radar were remapped to the model grid points, after screening for clutter and anomalous propagation. The remapping was done using a local least squares fit to a function that is quadratic in the horizontal and linear in the vertical (Brewster et al. 2007). For most of the experiments, it was found that the addition of the CASA radar data provided critical data for filling the low-level wind analysis with much detailed high-resolution information within the analysis domain and within the range of the CASA radar network. It is clear that strong convective storms, including detail of the storm outlines at low-levels, were generally well captured by CASA radars, while sometimes missed entirely by the WSR-88Ds.

During spring 2008, the 3DVAR wind analyses was run continuously, with data provided in real-time to the 2008 NOAA Hazardous Weather Testbed Experimental Warning Project (HWT; Stumpf et al. 2008) led by National Severe Storms Laboratory and Storm Prediction Center. The low-level wind analysis was displayed in real-time to visiting National Weather Service forecasters participating in the HWT for evaluation. Overall, participants found the wind analysis particularly helpful and praised its ease of use. One such event occurred on 7 May 2008 when an area of strong to severe winds moved across the southern half of the CASA network. The region of strong winds could be tracked easily in real-time across the study area domain. Comments from forecasters included: "If I had [CASA] I would be much more confident about issuing a warning. It would be a no brainer, right?", "With NEXRAD, you may be inferring that the winds are higher, but [with CASA] the answer is right there".

These comments indicated at least some additional value provided by the low-level wind analysis.

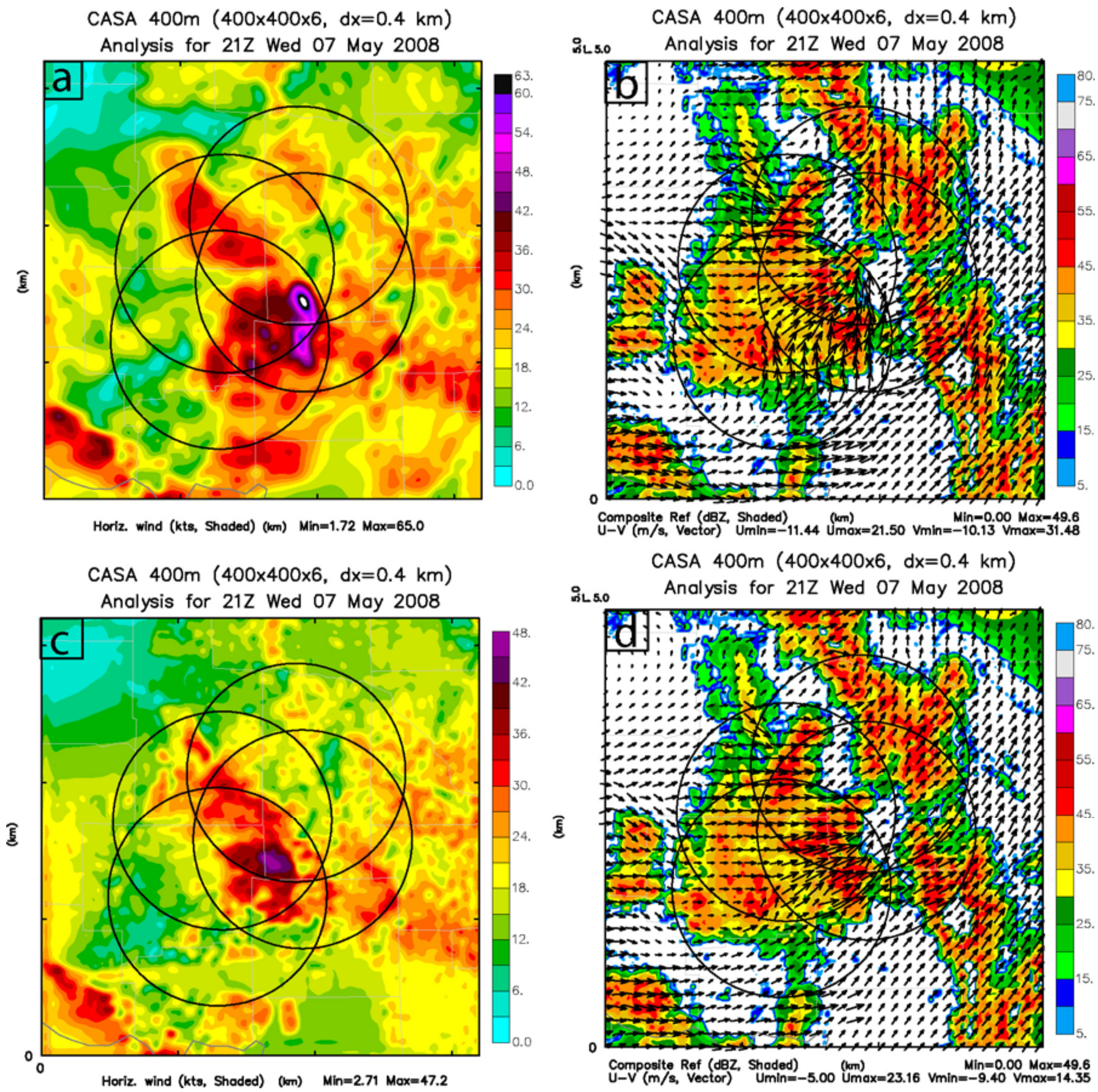

Fig. 3. The analyzed contours of horizontal wind speed (panel a, and c); and the analyzed wind vectors with imposed reflectivity filed (panel b, and d) using data from WSR-88D and CASA data combined valid at 2100 UTC, (a) and (b): before quality control. (c)and (d): after quality control and some adjustments.

However, several problems that limited the quality of the low-level wind analysis emerged during the 2008 spring experiment period. These problems included the deficiency of the 3DVAR data assimilation program (for example, some parameters related to wind analysis were not well tuned), and poor CASA data quality sometimes caused by either CASA radars' software or hardware problems. One such example occurred during 11-12 May 2008, when some abnormal low-level wind analyses with very low wind speed (very close to zero) were observed within the CASA radar analysis domain for several hours. The 11 UTC analysis, 12 May is shown in Fig 2a. By the careful examination of both the 3DVAR program and CASA radar data, we found that the problem was caused by poor data quality errors within the CASA radar data itself. Because the CASA radars are experimental and not of operational quality, the data occasionally still contain some quality control errors. One ad hoc quality control procedure was applied to the real-time data stream that flags data where the neighborhood data are near zero (Fig 2b). However, as the quality of radar data improves, this ad hoc treatment can be removed.

Any remote-sensing data, such as radar or satellite data, usually have low error variances. If these data are used together with NWP products as background and other traditional datasets to produce an analysis, the minimization process may lead to over-fitting to the remote-sensing data. Fig 3 gives such an example which shows a low level wind analysis at 21 UTC on May 7, 2008. An extremely large wind speed analysis increment appeared near the center of the CASA radar domain (Fig 3a) due to some spurious south wind increments assigned just outside the area of radar reflectivity and hence just outside the region of available radar radial velocity data (Fig 3b). To get rid of the problem, a threshold value is added so that all the analysis increments larger than the maximum innovation will not be allowed in the quality control step. Also, to ensure a smooth analysis and avoid over-fitting the radar data, the specified variance for CASA radar data was increased from 1 ms^{-1} to 3 ms^{-1} to avoid over-fitting to radar data. In Fig 3c, d, the quality of the analysis for this time level is improved.

3. Summary and future work

In this paper, we describe a real-time, low-level wind analysis enabled by CASA technology and several issues related to the process. Although good progress has been demonstrated, several outstanding problems were identified. Some quality control steps and other necessary adjustments were applied. Our major effort in the next few years will be to provide a reliable and robust real-time low-level wind analysis product to end-users for improving the severe weather detection and prediction using data from the CASA network together with other data sources including the WSR-88D radar network.

In a related study, the analyzed winds from CASA radar network were fed into a storm-scale numerical weather prediction (NWP) model, through intermittent assimilation cycles, at frequencies comparable to that of volume scans. The impact of the wind observations on the analysis of convective storms and the subsequent forecast has been tested (Schenkman et al. 2008). These kinds of experiments may be implemented in future real-time experiments. It is also our plan to feed the analyzed winds into severe weather detection algorithms and to assess the benefit of using analyzed 3D winds.

Several new features including direct reflectivity assimilation, anisotropic filter and some equation constraints are also being developed for this system. Other new developments will include mapping the model data into the observation locations considering the impact of beam pattern scanning. Successful enhancements will be used in real-time low-level wind analysis, and real-time forecast experiment for spring 2009.

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REFERENCES

Brewster, K. A., 2003a: Phase-correcting data assimilation and application to storm-scale numerical weather prediction. Part I: Method description and simulation testing. *Mon. Wea. Rev.*, **131**, 480-492.

Brewster, K. A., 2003b: Phase-correcting data assimilation and application to storm scale numerical weather prediction. Part II: Application to a Severe Storm Outbreak. *Mon. Wea. Rev.*, **131**, 493-507.

Brewster, K. A., K. W. Thomas, J. Brotzge, Y. Wang, D. Weber, and M. Xue, 2007: High resolution assimilation of CASA X-band and NEXRAD radar data for thunderstorm forecasting. 22 Conf. on weather analysis and forecasting and 18th conf. on numerical weather prediction, Park City, Utah, Amer. Meteor. Soc., CDROM.

Brewster K. A., J. Brotzge, K. W. Thomas, Y. Wang, M. Xue, J. Gao, and D. Weber, 2007: High resolution assimilation of CASA and NEXRAD radar data in near-real time: Results from Spring 2007 and plans for Spring of 2008, 12th Conference on IOAS-AOLS, New Orleans, LA, 15B.7.

Brotzge J., and K. Brewster, V. Chandrasekar, B. Philips, S. Hill, K. Hondl, B. Johnson, E. Lyons, D. McLaughlin, and D. Westbrook, 2007: CASA IP1: Network Operations and Initial Data. 23rd Conference on IIPS, San Antonio, Texas. Amer. Meteor. Soc., 8A.6.

McLaughlin, D.J., et al. 2005: Distributed Collaborative Adaptive Sensing (DCAS) for Improved Detection, Understanding, and Prediction of Atmospheric Hazards. Preprints, 9th Symp. Integrated Obs. Assim. Systems - Atmos. Oceans, Land Surface, Amer. Meteor. Soc., San

Diego, CA. 12th Conference on IOAS-AOLS New Orleans, LA, Jan, 2008

Gao, J., M. Xue, A. Shapiro, and K. K. Droegemeier, 1999: A variational method for the analysis of three-dimensional wind fields from two Doppl radars. *Mon. Wea. Rev.*, 127, 2128-2142.

Gao, J., M. Xue, K. Brewster, and K. K. Droegemeier 2004: A three-dimensional variational data assimilation method with recursive filter for single-Doppler radar, *J. Atmos. Oceanic. Technol.* **21**, 457-469.

Gao, J., C. Nuttall, C. Gilreath, M. Xue, K. Brewster, and K. Droegemeier, 2005: Multiple Doppler wind analysis and assimilation via 3DVAR using simulated observations of the planned CASA network and WSR-88D radars, 11th conf. on mesoscale processes and 32nd Conference on Radar Meteorology, CDROM J1J.4.

Gao, G., G. Ge, M. Xue and K. K. Droegemeier, 2007: Assimilation of CASA and WSR-88D radar data via 3DVAR to improve short term convective weather forecasting, 33nd Conference on Radar Meteorology, Caims, Australia, CDROM P4.8.

Ge, G., and J. Gao, 2007: Latest development of 3DVAR system for ARPS and its application to a tornadic supercell storm, 22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction, on-line publication, 2B.6.

Hu, M., M. Xue, J. Gao, and K. Brewster, 2006: 3DVAR and cloud analysis with WSR-88D level-II data for the prediction of Fort Worth tornadic thunderstorms. Part II: Impact of radial velocity analysis via 3DVAR. *Mon. Wea. Rev*., **134**, 699–721.

Schenkman A. D., and A. M. Shapiro, K. Brewster, M. Xue, J. Gao, and N. Snook, 2008: High resolution assimilation of CASA radar data from a tornadic convective system, *Symposium on recent developments in atmospheric applications of radar and lidar*, Amer. Meteorol. Soc. P1.6.

Stumpf, G., T. Smith, K. Manross, and D. Andra, Jr., 2008: The Experimental Warning Program 2008 Spring Experiment at the NOAA Hazardous Weather Testbed. 24th Conf. Severe Local Storms, 27-31 October., Savannah, GA.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. *Meteor. Atmos. Physics*, **75**, 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. *Meteor. Atmos. Phy.*, **76**, 143-165.