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J1J.4 MULTIPLE DOPPLER WIND ANALYSIS AND ASSIMILATION VIA 3DVAR USING SIMULATED OBSERVATIONS OF THE PLANNED CASA NETWORK AND WSR-88D RADARS

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1. Introduction

The advantages of using Doppler weather radar to track and forecast mesoscale severe weather events are widely known to both meteorologists and the public. With the use of Doppler radar, 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 its highly advanced capabilities, Doppler radar can only directly measure the spectrum width, reflectivity, and the radial component of wind velocity. Thus, there is no direct measurement of the three-dimensional (3-D) wind field. To completely understand and analyze the atmosphere, the 3-D wind field must be known. To solve this problem and provide the better surveillance of severe weather, A new 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. 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. The first test bed to be deployed in Oklahoma named IP1-A will consist of four scanning polarimetric Doppler radars located on average 30 km apart with ranges of the same distance. The network was designed to maximize dual-Doppler wind coverage and at certain parts of the network, triple Doppler wind coverage is also available.

By using two or multiple Doppler radars scanning the same atmospheric volume simultaneously, it is possible to determine the 3-D wind. Gao et al. (1999) described a variational approach (3DVAR) that uses mass continuity and smoothness constraints by incorporating them into a cost function yielding the 3-D wind. In this study, this 3DVAR analysis method is adapted to perform multiple Doppler wind analysis for CASA radars, together with data from the Oklahoma City (KTLX) and Fredrick, Oklahoma (KFRD) WSR-88D radars using simulated data, sampled from model-simulated thunderstorms. The KTLX and KFRD radars provide coverage at the upper levels, and are located respectively to the northeast and southwest of and about an equal distance from the CASA network.

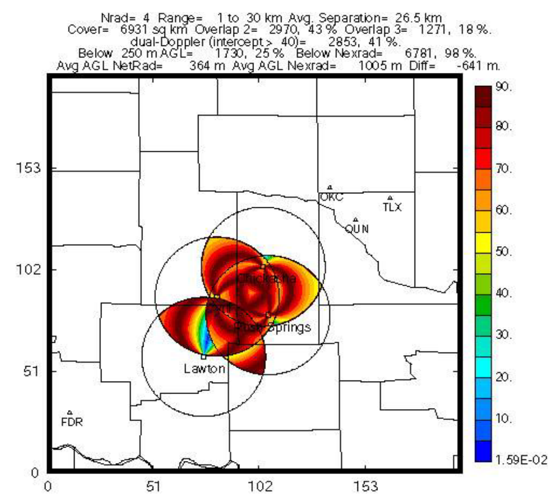

FIG. 1. Proposed layout of initial 4-radar network for the CASA Project in southwest Oklahoma. Circles show anticipated 30-km maximum range.

Experiments are performed in which the CASA radar data are collected using different scanning strategies, including different spatial resolutions and scanning modes, with a goal of determining the optimal scanning strategies within the current analysis and assimilation framework. This technique is often called Observation System Simulation Experiments (OSSE). This paper is organized as follows: Section 2 provides a brief description of the methodology of this study; Section 3 presents analyses and results; Section 4 contains a summary and concluding remarks.

2. Methodology

a. Overview of variational technique

As mentioned earlier, there are many different methods available to obtain a multi-Doppler analysis. This study utilizes a variational technique developed by Gao et al (1999) that performs an analysis in a Cartesian

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coordinate system and permits flexible use of radar data in combination with other information, such as soundings. Furthermore, it allows for the use of mass continuity and smoothness constraints by incorporating them into a cost function. In particular, by applying the anelastic mass conservation equation as a weak constraint, the severe error accumulation in the vertical velocity can be reduced because the explicit integration of the anelastic continuity equation is avoided. This technique performs well in both idealized OSSE and real data cases.

b. Simulated data

The effectiveness of the NETRAD radar network combined with WSR-88D radars is evaluated by utilizing a set of simulated multiple-Doppler data. A simulated supercell thunderstorm is modeled by the Advanced Regional Prediction System (ARPS; Xue et al. 2000, 2001, 2003) developed by the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma. A well-documented tornadic supercell storm that occurred near Del City, Oklahoma, on 20 May 1977 is used for the experiments (Ray et al. 1981). This storm was chosen to provide the reference wind field because it has been studied extensively, using both multiple-Doppler analysis and numerical simulations. Ray et al. (1981), Klemp et al (1981), and Klemp and Rotunno (1983) provide detailed analyses on its morphology and evolution.

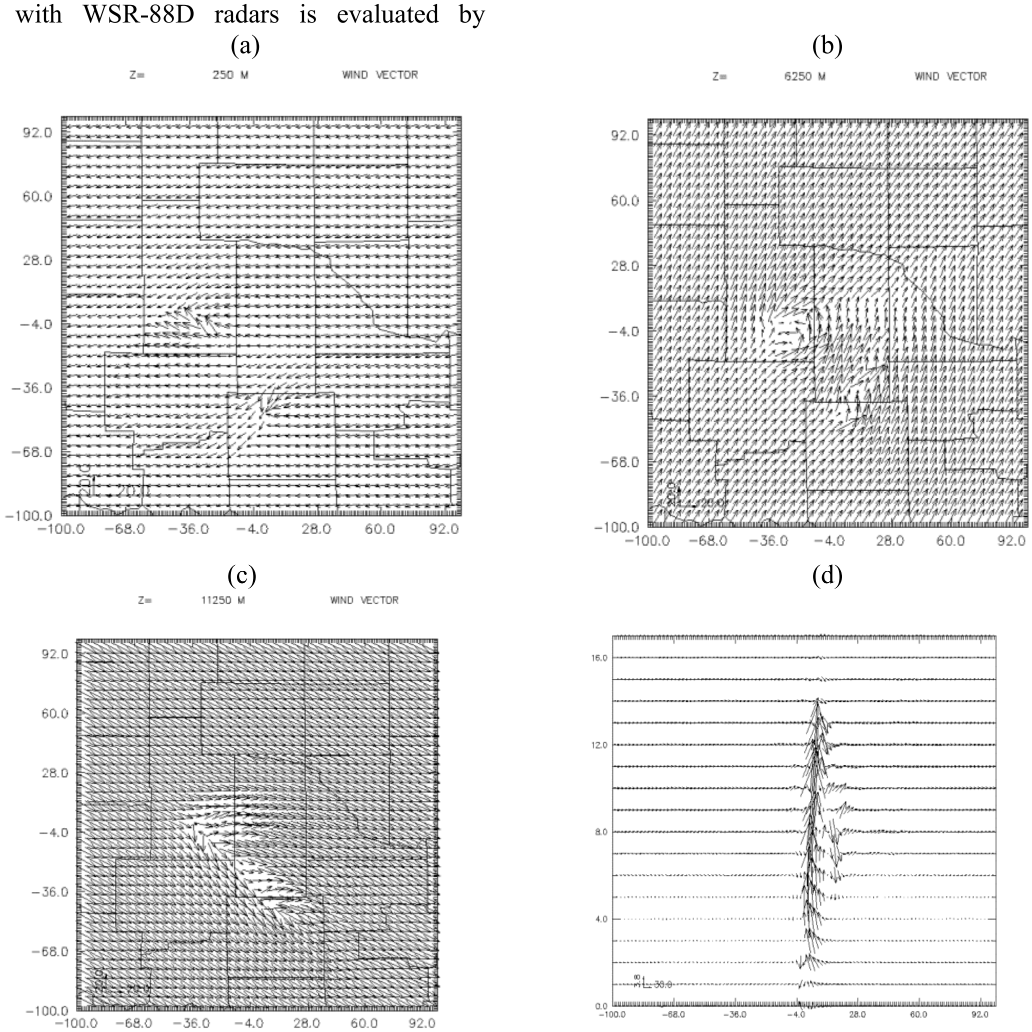


FIG. 2. Output of ARPS model-simulated wind vectors of the 20 May 1977 supercell storm at t = 2 hr: horizontal cross-sections are shown at (a) z = 250 m, (b) z = 6 km, and (c) z = 12 km; and (d) vertical cross-section corresponding to the center of the domains in (a)-(c).

Parameter settings for the ARPS model include 201x201x35 total grid points with grid spacing $dx = dy$ =1 km in the horizontal and dz =500 m in the vertical. Two hours into the simulation, the initial storm has undergone a splitting process. The right-mover storm remains near the center of the domain, and the left-mover propagates to the northwest. Figure 2 shows the horizontal and vertical cross-sections of the wind and vertical velocity at $t = 2$ hr. The circulation features associated with the left-moving and right-moving storms are evident. The cyclonically-rotating updraft and low-level downdraft can be seen in the bottom-center of the domain. The evolution of the simulated storm is qualitatively similar to that described by Klemp and Wilhelmson (1981). By two hours, the storm has developed a structure typical of mature supercell storms. The simulated 3-D convective-scale wind field at 2-hr is sampled by several pseudo-radars, including the four NETRAD radars and two WSR-88D radars, KTLX and KFDR. The locations of these radars relative to the grid are shown in Fig. 1.

A Cressman (1959) scheme is used to interpolate the wind components from the model grid points to the sampling locations along the radar beams with the influence radius R = 2.5 km, and are projected to radial direction to obtain radial velocities according to a technique described by Mohr (1988). The elapsed times for the volume scans of the radars are neglected, and thus we presume that the radial wind observations are simultaneous. There must also be a method to gauge the accuracy of the analyzed wind field compared to the reference created in the numerical simulation. Three parameters—the root mean squared (RMS) error, relative error (RE), and a correlation coefficient (CC) between the analyzed field and the reference field are calculated for the horizontal velocity, V_H and the vertical *w*-component. Successful reconstruction of the wind field by the simulated radars will be defined as a correlation coefficient of 0.60 or greater.

2. Analysis and results

This section presents the results from the OSSE experiments described in the previous section. The analysis domain is the same as the domain used in the ARPS simulation described in Section 2b. The experiments, their specifications, and their statistical parameters are listed in Table 1.

All tests use a total of six radars (e.g., the four NETRAD radars, KTLX, and KFDR), except IDEAL2, which used only the NETRAD radars. The NETRAD radars begin their scans at an elevation angle of 0.5 deg unless otherwise noted. In all tests, KTLX and KFDR were simulated running Volume Coverage Pattern (VCP) 12, which consists of 14 elevation angles ranging from 0.5 deg to 19.5 deg. AZIM1 and AZIM2 investigate the effects of reducing the number of elevation angles used in NETRAD scans. RUN1, RUN2, and RUN3 are performed to examine the effects of scanning azimuthally every 2.0 deg and different numbers of elevation angles. For comparison, an experiment (ACTUAL) using the planned surveillance settings of the NETRAD radars was also investigated. In this test, the NETRAD radars scan azimuthally every 1.0 deg in a complete circle. The planned surveillance settings utilize elevation angles of 0.0 deg, 0.5 deg, 1.0 deg, 2.0 deg, 3.0 deg, 4.0 deg, and 5.0 deg. The gate spacing for CASA radars is 100m and for WSR-88D is 250m respectively. The variational method used in this study performed well in nearly every situation.

Tests IDEAL1 and IDEAL2 have the best coverage in scanning volume. IDEAL2 is included as a comparison to all other tests. The CC value for this test falls below the success criteria of 0.60 described in Section 2a. This is primarily due to the small scanning radius of the NETRAD radars. These radars are not able to scan the high levels of the atmosphere. Thus, there is no analysis result from that portion of the storm. This illustrates the need for the WSR-88D scans over the CASA test site due to the higher elevation scans that they perform. Combined with the NETRAD data, a more accurate 3-D wind field can be retrieved.

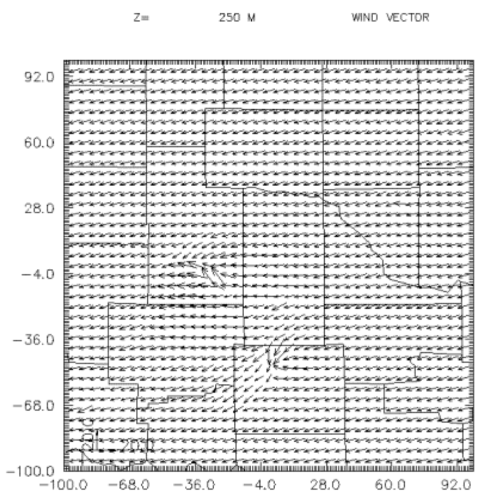
TABLE 1. List of experiments and their statistical results.

Test	Azi. Interval	Elev. Interval	Horizontal wind (*V*)			Vertical wind (*w*)		
			RMS	RE	CC	RMS	RE	CC
IDEAL1	1.0	1.0	1.72	0.01	0.99	2.61	0.77	0.72
IDEAL2	1.0	1.0	2.10	0.11	0.99	2.96	0.87	0.56
AZIM1	1.0	1.0	2.11	0.12	0.99	2.95	0.77	0.66
AZIM2	1.0	1.0	2.23	0.12	0.99	2.73	0.80	0.62
RUN1	2.0	2.0	1.64	0.01	0.99	2.61	0.77	0.75
RUN2	2.0	2.0	1.79	0.01	0.99	3.16	0.93	0.66
RUN3	2.0	2.0	2.19	0.12	0.99	2.62	0.77	0.65
ACTUAL	1.0	varies	2.21	0.12	0.99	2.69	0.79	0.62

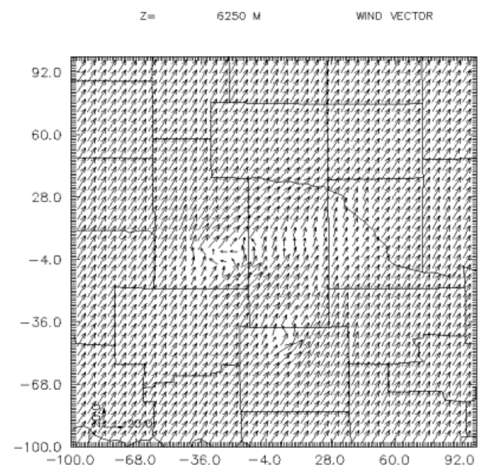
To examine the quality of the multi-Doppler retrieval, Fig. 3 shows the retrieved wind fields using the ACTUAL test settings described above. The horizontal cross-sections of the retrieved wind are very similar to the reference wind (see Fig. 2). The horizontal scans clearly show the rotating updrafts and associated low-level downdrafts. The vertical wind field is not resolved as well as the horizontal wind. However, the same vertical motions seen in the reference field (see Fig. 2) can be seen in Fig. 3.

Every experiment shows that the correlation between the retrieved wind field and the reference field is much better for the horizontal wind than that for the vertical wind component. This is primarily due to the horizontal wind is well observed by the radars and vertical velocity has to be derived by the mass continuity equation. However, Fig 3d shows that the overall structure of vertical wind field is reasonable retrieved.

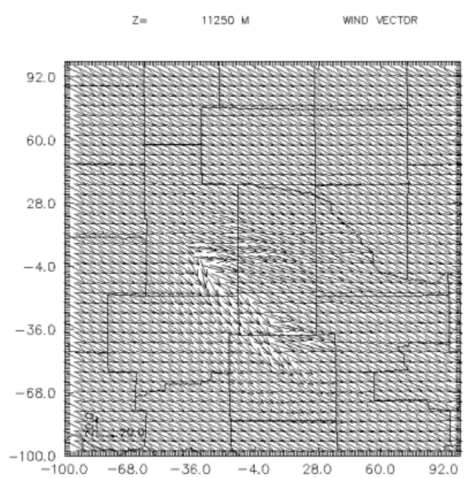
(a)



(b)



(c)



(d)

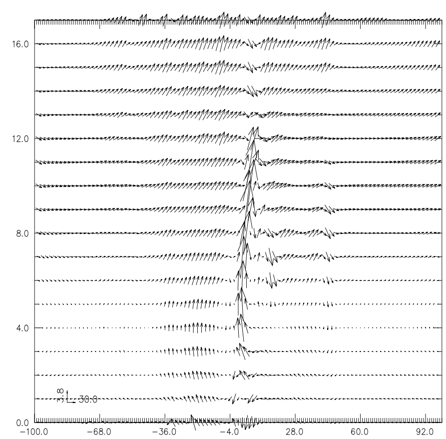


FIG. 3. Wind vectors retrieved from data sampled by the four NETRAD radars, KTLX, and KFDR (see Fig. 1) during the ACTUAL test run. Horizontal cross-sections are shown at (a) z = 250 m, (b) z = 6 km, and (c) z = 12 km; and (d) vertical cross-section corresponding to the center of the domains in (a)-(c).

3. Summary and conclusion

In this study, a three-dimensional variational (3DVAR) analysis method is adapted to perform multiple Doppler wind analysis for CASA radars, together with data from the Oklahoma City (KTLX) and Fredrick, Oklahoma (KFRD) WSR-88D radars. Experiments are performed in which the CASA radar data are collected using different scanning strategies, including different spatial resolutions and scanning modes, with a goal of determining the optimal scanning strategies within the current analysis and assimilation framework.

The main conclusions of this study are as follows. The implementation of NETRAD radar network helps to obtain complete three components of wind field which are much needed for understanding the stormscale phenomenon. The actual planned scanning strategies of the NETRAD radars are sufficient for retrieving the horizontal wind field. It is important to incorporate data from nearby WSR-88D radars because of their ability to scan the high levels of the atmosphere which is beyond the capability of NETRAD. It has been shown in this study and others that the variational technique utilizing anelastic mass continuity (Gao et al. 1999) reduces error in the vertical wind and is suitable for analyses in simulated data and real-life cases. The first NETRAD radar is scheduled for installation in late-2005. Once the NETRAD network is fully operational, more studies will be necessary to evaluate the performance of this method of multiple-Doppler analysis under actual real-life and real-time conditions.

In our on-going study, the analyzed winds from CASA radar network are 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 will be assessed and reported in the conference. It is also our plan to feed the analyzed winds into severe weather, such as tornado, detection algorithms and to assess the benefit of using analyzed 3D winds.

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