RETRIEVAL OF THREE-DIMENSIONAL WIND AND THERMODYNAMIC FIELDS FROM SINGLE-DOPPLER OBSERVATIONS MEASURED DURING PHOENIX II

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1 INTRODUCTION

Retrieval of the unobserved meteorological fields from a single-Doppler radar has recently received considerable attention as the new U.S. weather radar network, NEXRAD, is being installed. One of the promising techniques is the adjoint data assimilation method described in Sun *et al.* (1991, hereafter referred to as SUN91). This technique attempts to determine the unobserved fields by minimizing the difference between single-Doppler observations and the predictions from a dynamic model. In this paper, the applicability of this technique is examined with a gust front case observed in the Phoenix II experiment of 1984. Some prelimilary results are presented.

2 DATA: SOURCE AND PREPARATION

The gust front case to be examined was observed on June 19, 1984 on the high plains of eastern Colorado during the Phoenix II experiment. Two X-band Doppler radars, NOAAC and NOAAD, were used as the primary observing tools. The radial velocity and reflectivity were recorded by both radars at an interval of about two minutes. The reflectivity was enhanced by the use of chaff.

To prepare the data for the retrieval experiments, four processes have been applied. The data were first interpolated to Cartesian coordinates using the algorithm SPRINT (Miller*et al.*, 1986). The resolution of the Cartesian data was 100 m in all three directions. The second step was to relocate each data value to the center acquisition time of each volume according to its individual collection time. The third step consisted of numerical smoothing by one pass of a Leise filter to reduce random noise. The last processing step was a dual-Doppler synthesis to provide the velocity fields for the purpose of verification. The size of the analysis area was 10km×10km×4km. The calculations in the last three processes were accomplished by directly using the software package CEDRIC (Mohr *et al.*, 1986).

3 METHOD

The method of single parameter retrieval by adjoint variational data assimilation has been described in SUN91. The reader is referred to this study for details. Here we will give only a brief description of the model and the cost function.

3.1 *The numerical model*

The governing equations of the numerical model consist of the incompressible Boussinesq dynamics and the conservation of potential temperature and reflectivity. In this model, the prognostic variables are the velocity components u, v, w, the perturbation potential temperature θ, and the reflectivity c. The perturbation pressure π is a diagnostic variable which can be obtained by solving a Poisson equation for pressure.

The model uses a staggered grid and is integrated using second-order Adams-Bashforth time differencing with a time step of 10 seconds. The diffusion coefficients are assumed constant with a value of 100 m^2s^{-1}.

3.2 *Cost function*

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The cost function to be minimized is defined by

$$J = \sum_{T}\sum_{\sigma}[k_v(v_r - v_r^{ob})^2 + k_c(c - c^{ob})^2] + P, \quad (1)$$

where k_v and k_c are weighting coefficients, and v_r^{ob} and c^{ob} are the observations of the radial velocity and reflectivity, respectively. c is the model output of the reflecivity; v_r is the radial velocity defined by the model output of u, v, and w. v_r is given by

$$v_r = u\frac{(x - x_0)}{r} + v\frac{(y - y_0)}{r} + w\frac{(z - z_0)}{r}, \quad (2)$$

where r is the distance between a grid point (x, y, z) and the radar location (x_0, y_0, z_0).

The symbol P appearing in the cost function represents the penalty functions. Two penalty functions were found beneficial to the optimization: the initial non-divergence penalty function with weight ρ_1 and the temporal smoothness penalty function with weight ρ_2. The reader is referred to SUN91 for the exact forms of the penalty functions.

Our object is to find the best initial conditions of u, v, w, and θ that can produce the predictions of v_r and c minimizing J. An iterative method is used to perform the minimization. At each iteration, the numerical model is integrated forward to obtain the trajectory of the dynamic variables to be used in the integration of the adjoint model (see SUN91 for the derivation of the adjoint equations), and the adjoint model is integrated backward to compute the gradient of the cost function with respect to the initial state. A better estimate of the initial variables is then found by moving down the gradient.

4 RETRIEVAL EXPERIMENTS

The case to be examined occurred on the afternoon of June 19, 1984 when a gust front was formed by a thunderstorm outflow. The outflow propagated northwestward at a speed of approximately 7.2 m/s and moved into the dual-Doppler analysis area at about 2227 UTC. Soundings were taken before and after the gust front passage. The planetary boundary layer extended to 1.2 km where it was capped by a small inversion. The air behind the gust front was about 3^0C cooler near the surface.

The sounding before the gust front passage is used to provide the basic state of the atmosphere. The boundary conditions of u and v needed to integrate the model are given from the dual-Doppler observations. The experiments are conducted on a 8km×8km×4km domain within the dual-Doppler analysis area. The grid spacing is 400 m in the horizontal and 200 m in the vertical. The dual-Doppler derived wind field with this resolution is shown in Fig. 1. The success of the retrieval is evaluated by the relative mean vector wind error

$$err(V) = \frac{\sum_1^N \sqrt{(u - u^{ob})^2 + (v - v^{ob})^2}}{\sum_1^N \sqrt{u^{ob^2} + v^{ob^2}}}, \quad (3)$$

where N is the total number of grid points at which observations are available. Since the vertical velocity derived from the dual-Doppler observations is not as reliable as the horizontal components, it is not used for the evaluation of the accuracy of the retrieval. Two experiments are conducted using observations from NOAAC and from NOAAD, respectively. Both of them assimilate two volumes of data, 222930 UTC and 223110 UTC. The first experiment uses only the radial velocity observations from NOAAC while the second uses both the radial velocity and reflectivity observations from NOAAD. In experimnet 1, k_v is set to 1 and k_c is set to 0. In experiment 2, k_c is set to 0.05. The ratio between k_c and k_v reflects the relative accuracy of the predicted c and v_r. It is found that this ratio is closely related to the error variance of the fields c and v_r at the final time of the integration period. In both of the experiments, the penalty constants ρ_1 and ρ_2 are set to 1000 and 1, respectively. The minimization is started with zero first guess, and the optimal solution is considered to be found as the curve of the cost function levels out, which generally occurs around 30 iterations.

The retrieved horizontal wind field from experiment 1 after 30 iterations is shown in Fig.

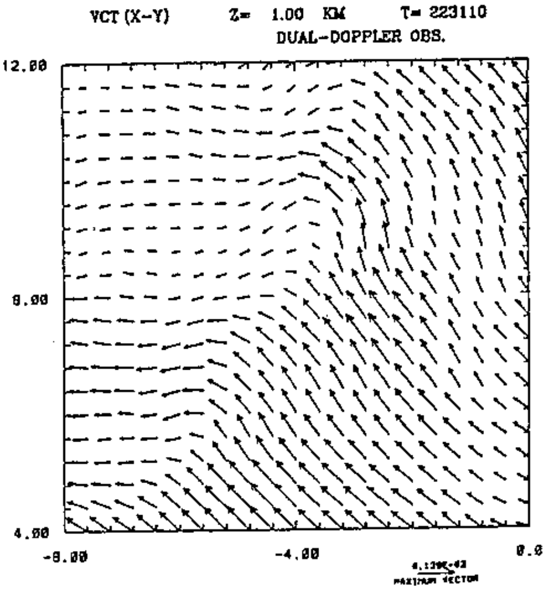

Fig. 1. Dual-Doppler observed horizontal wind at z= 1 km at 223110 UTC. The labels are measured in km. NOAAC is located at (0.0, 0.0, 0.0) and NOAAD is located at (4.5, 12.6, -0.09).

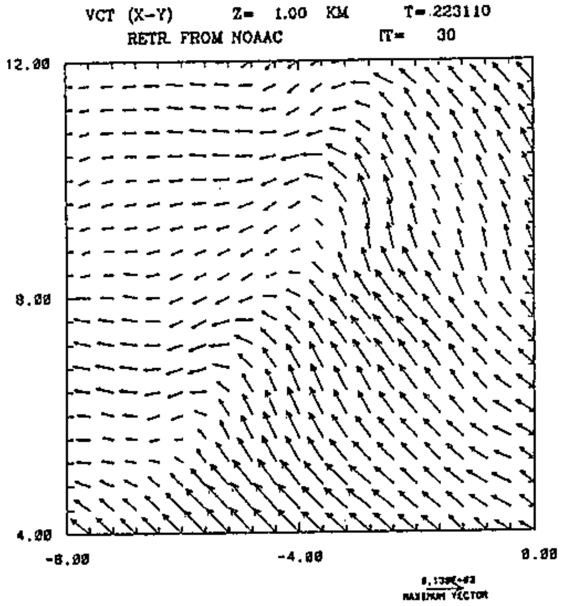

Fig. 2. The same as Fig. 1 but for the retrieved wind after 30 iterations from experiment 1.

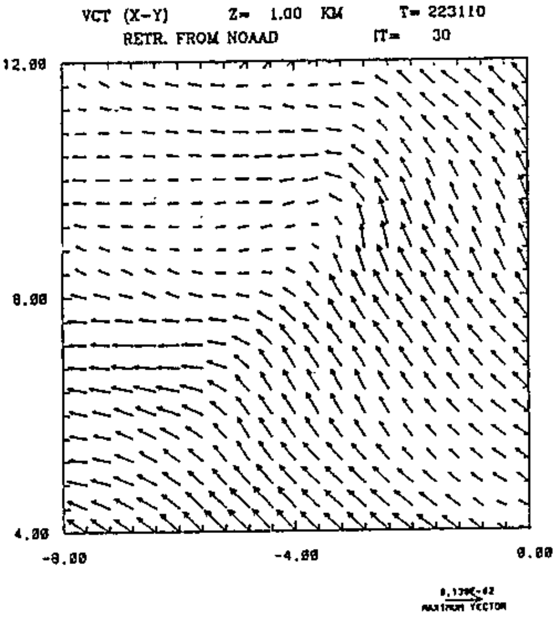

Fig. 3. The same as Fig. 2 but from experiment 2.

2. Comparing it with Fig. 1, it is obvious that the two fields are very close. The relative mean vector wind error is 0.2 and the absolute mean vector wind error is 1.2 m/s. The cost function is reduced by three orders of magnitude in 30 iterations. Fig. 3 presents the retrieved horizontal wind field from experiment 2. As can be seen from this figure, the quality of the retrieved flow field is only slightly worse than that from experiment 1. The relative RMS error of the retrieved horizontal wind is 0.26.

A good retrieval is obtained by using the radial velocity alone from NOAAC, as shown by experiment 1. In contrast, however, the use of the reflectivity data is necessary to obtain an accurate retrieval from NOAAD. Because the beams from NOAAD are almost perpendicular to the wind direction behind the front, the convergence along the gust front is not as well observed as that by NOAAC. In other words, the radial velocity observations from NOAAD do not contain sufficient information about the flow field. In that case, the reflectivity observations must be provided.

In both of the experiments, the general patterns in the retrieved vertical velocity field are similar to those in the dual-Doppler derived vertical velocity field. The ascent along the gust front is well recovered. The retrieved potential temperature field shows a maximum difference of approximately 4 °C between the air before and after the gust front.

5 SUMMARY

This paper presents some of our recent work on applying the adjoint technique to real observations from single-Doppler radar. It is shown that the boundary layer flow can be accurately retrieved from observations of the radial velocity alone when the wind behind the front is well observed. Reflectivity observations are required to obtain a satisfactory retrieval when the post-gust front wind is poorly observed.

6 ACKNOWLEDGMENTS

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