14.8

Adjoint-Method Retrievals of Microburst Winds From TDWR Data*

Qin Xu, Chong-Jian Qiu, Jin-Xiang Yu, Hong-Dao Gu
CIMMS/CAPS, University of Oklahoma

Marilyn Wolfson
Lincoln Laboratory, MIT

1. Introduction

The simple adjoint (SA) method of Qiu and Xu (1992, henceforth referred to as QX92) was recently upgraded and tested with the Phoenix-II data for retrieving the low-altitude winds from single-Doppler scans (Xu et al. 1993a,b, henceforth referred to as XQY93a,b). The major results can be briefly reviewed as follows: (i) Using multiple time-level data with the adjoint formulation makes the retrieval more accurate and less sensitive to the observational error. (ii) Imposing a weak nondivergence constraint can suppress the spurious divergence caused by the data noise and improve the retrieval. (iii) Retrieving the eddy coefficients improves the wind retrieval. (iv) Retrieving the time-mean residual term improves the wind retrieval.

Although the results in XQY93a,b were encouraging, the Phoenix-II data used in XQY93a,b were collected on non-storm days with chaff dispensed from an aircraft. The real challenge is to test the SA method with storm data. A microburst case is selected for the test in this paper.

2. 11 July 1988 Microburst case

On 11 July, a very strong microburst (> 35 m/s differential velocity) occurred at the Denver Airport during the 1988 TDWR (Terminal Doppler Weather Radar) operational test and evaluation (Elmore et al. 1990, Proctor and Bowles 1992). Dual Doppler coverage was provided by the TDWR testbed radar (FL2, operated by MIT Lincoln Laboratory) and the UND (University of North Dakota) radar (see Fig. 1). The operational scan strategy executed by FL2 included a surface sector scan over the airport every minute. This surface scan was matched nearly simultaneously (avg. within 3.5 sec) by UND. The polar data from each radar were thresholded at 5 dB SNR and median smoothed with a 5 gate x 3 degree filter (at least 8 good values out of 15 required). The data were then sampled to a 250 m resolution Cartesian grid (at the level of z = 190 m above the FL2 radar site).

Surface anemometer data from the 12 station Low Level Wind Shear Alert System (LLWAS) were also collected during the experiment (see Fig. 1). Several of the stations in 1988 suffered from wind sheltering problems (Liepins et al. 1990) that have since been remedied by raising the sensor height.

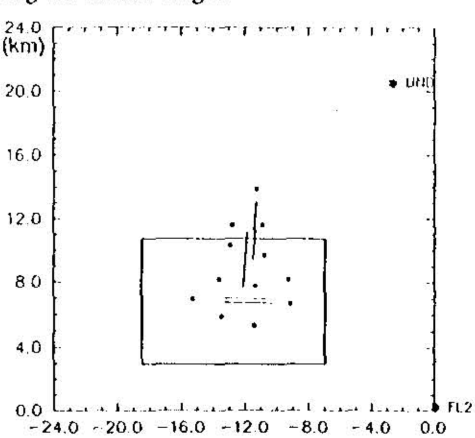


Fig. 1. Locations of airport runways, radars and LLWAS stations. The inner rectangular domain indicates the region where the winds are retrieved in Fig. 2a.

3. Method description

As in XQY93b, the radial-component wind v_r is used as a "tracer" field and is governed by the following approximate radial-component momentum equation:

$$\partial_t v_r + \mathbf{v}_m \cdot \nabla v_r - v_{\alpha m}{}^2/r - K\nabla_H{}^2 v_r = F_m, \quad (1)$$

where v_α is the cross-beam wind, $\mathbf{v}$ the horizontal vector wind, $(\cdot)_m \equiv (1/\tau)\int_0^\tau (\cdot)dt$ the time-mean operator, F the unknown residual forcing (mainly the pressure gradient and vertical advection). The boundary and initial values are given by the observed v_r.

The objective is to find the best estimate of $(\mathbf{v}_m, K, F_m)$ in (1) that gives the best "prediction" of the radial wind v_r in terms of minimizing the following cost-function

$$J \equiv \{\{P_1\Delta^2 + P_2\Delta_m{}^2 + P_3 d_m{}^2 + P_4\zeta_m{}^2\}\}_m. \quad (2)$$

Here $\{\{(\cdot)\}\} \equiv (1/\Omega)\iint(\cdot)d\Omega$ is the area-mean operator over the retrieval domain Ω; P_1 and P_2 are nondimensional weights, $\Delta \equiv v_r - v_{rob}$, $\Delta_m \equiv v_{rm} - v_{robm}$, and $(\cdot)_{ob}$ the observed value of $(\cdot)$; P_3 and P_4 are dimensional weights (in unit m^2), $d_m \equiv \nabla_H \cdot \mathbf{v}_m$ the divergence, and $\zeta_m \equiv \mathbf{k}\cdot\nabla_H \times \mathbf{v}_m$ the vorticity. The minimum of J can be approached by numerical iteration along the gradient of J with respect to $(\mathbf{v}_m, K, F_m)$. The gradient is computed at each step of iteration by a explicit expression derived from the adjoint formulation similar to (2.7) of XQY93b.

The optimal retrieving time period τ should cover 4 sequential scans, i.e., $\tau = 3\Delta\tau$. The weights are given by

$$\begin{aligned} P_1 &= [\tau/(t+\Delta t)]^{1/2}, \\ P_2 &= 0.02P_{1m} \text{ with } P_{1m} \equiv (P_1)_m, \\ P_3 &= k_3\sigma_{vr}{}^2 P_{1m} \text{ with } k_3 = 30 \sim 200\,\text{m}^2, \\ P_4 &= k_4\sigma_{vr}{}^2 P_{1m} \text{ with } k_4 = 100 \sim 600\text{m}^2, \end{aligned} \quad (3)$$

where σ_{vr} is the root mean square amplitude of v_r. The choice of the time-dependent form for P_1 was explained in QX92. With the above specified value for P_2, the weak form of the constraint $\Delta_m = 0$ can reduce the error in the estimated cross-beam wind. The relative strength of the weak divergence (or vorticity) constraint is controlled by k_3 (or k_4). As long as k_3 (or k_4) is in the optimal range shown in (3), the retrieval is not very sensitive to k_3 (or k_4). The weights in (3) are consistent with those in XQY93a,b, but k_4 and the last term in (2) are new here.

4. Results

The SA method is tested with the microburst data for a continuous period (22:04-22:33). The averaged (over 25 time-levels) RMS errors and correlation coefficients between the retrieved and observed variables are listed

*A portion of this work was sponsored by the Federal Aviation Administration. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.

in Table 1. When the observed radial winds are used in the final results, the vector RMS errors for $\mathbf{v}_m$ reduce to those for $v_{\propto m}$ in Table 1. The retrieved wind field is compared with the observed in Fig.2a-b. The correlation diagram is shown in Fig. 3, where the RMS error and correlation coefficient between the retrieved and observed wind components are also listed. The retrievals from FL2 radar data are better than those from UND radar data.

The accuracy of the retrievals are affected mainly by three factors: the data noise, the temporal fluctuation of the residual forcing (i.e., the equation error), and the wind direction relative to the radar beam.

Using the wind field retrieved at the previous time level as an initial guess can reduce the CPU cost, but may not always improve the accuracy. Extrapolating the LLWAS data to the grid level of z = 190 m and using it as a weak constraint may (or may not) improve the retrieval, if the surface winds are well (not well) correlated to the Doppler radial winds at the the grid level.

Table 1. Statistics of the retrievals (with FL2 radar)

	$\mathbf{v}_m$ m/s	$v_{\propto m}$ m/s	d_m $10^{-3}s^{-1}$	ζ_m $10^{-3}s^{-1}$	F_m $10^{-2}m/s^2$
FL2 radar:					
RMS error	3.30	2.99	4.75	3.16	1.25
Correlation	0.92	0.83	0.60	0.22	0.77
UND radar:					
RMS error	4.53	4.37	5.34	3.32	1.41
Correlation	0.84	0.65	0.48	0.17	0.68

5. Conclusion

In addition to the earlier findings reviewed in section 1, it is found in this paper that using the weak vorticity constraint also improves the retrieval, especially for microburst cases. Using the previous time-level retrieval as an initial guess can reduce the CPU cost. Optimal uses of the surface wind data need further investigations.

Acknowledgment

This work is supported by the NOAA contract NA90-RAH00078 and NSF Grants ATM-9113906 at CIMMS and ATM-8809862 at CAPS, University of Oklahoma.

References

Elmore,K.L., M.K. Politovich, and W.R. Sand, 1990: The 11 July 1988 Microburst at Stapleton International Airport, Denver, CO. Preprints, 16th Conf. on Severe Local Storms, Kananaskis Park, Amer. Meteor. Soc.,368-372.

Liepins, M.C., M.M. Wolfson, D.A. Clark, and B.E. Forman, 1990: A comparison of anemometer and Doppler radar winds during wind shear events. Preprints, 16th Conf. on Severe Local Storms, Kananaskis Park, Amer. Meteor. Soc., 356-361.

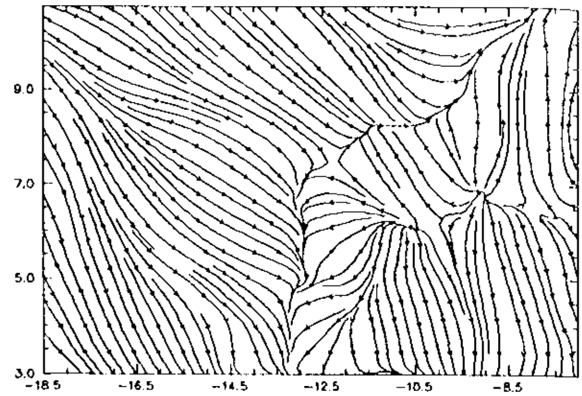
Proctor, F.H. and R.L. Bowles, 1992: Three-dimensional simulation of the Denver 11 July 1988 microburst-producing storm. Meteorol. Atmos. Phys., 49, 107-124.

Qiu, C. J. and Q. Xu, 1992: A simple adjoint method of wind analysis for single-Doppler data. *J. Atmos. & Oceanic Technology*, **9**, 588-598.

Xu, Q., C. J. Qiu, and J. X. Yu, 1993a: Adjoint-method retrievals of low-altitude wind fields from single-Doppler reflectivity measured during Phoenix II. (Conditionally accepted) *J. Atmos. & Oceanic Technology.*

Xu, Q., C. J. Qiu, J. X. Yu, 1993b: Adjoint-method retrievals of low-altitude wind fields from single-Doppler wind data. (Conditionally accepted) *J. Atmos. & Oceanic Technology.*

(a) Retrieved



(b) Observed

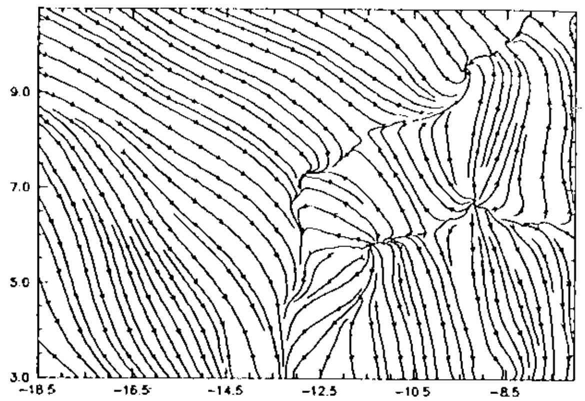


Fig. 2. Comparison between the (a) retrieved (from FL2 data) and (b) dual-Doppler observed time-mean wind fields at z = 190 m for 22:10-14, 16, July 11, 1988.

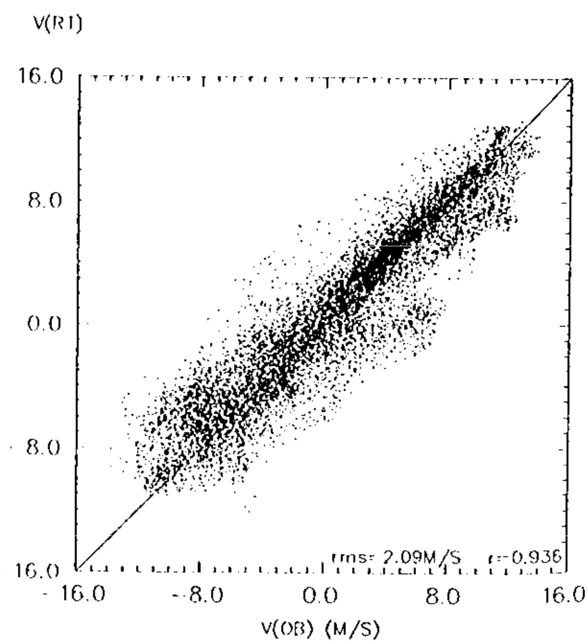


Fig. 3. Correlation diagram between the retrieved and dual-Doppler observed winds (for every 5th time-level during the period of 22:04-33).