A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although portions of this report are not reproducible, it is being made available in microfiche to facilitate the availability of those parts of the document which are legible.

3

LA-UR - 90-2161

LA-UR--90-2161

DE90 013152



TITLE: OBSERVATIONS OF TORNADOES AND WALL CLOUDS WITH A PORTABLE FM-CW DOPPLER RADAR: 1989 - 1990 RESULTS

AUTHOR(S): Wesley P. Unruh, MEE-3
Howard B. Bluestein, University of Oklahoma

SUBMITTED TO 16th Conference on Severe Local Storms
October 22 - 26, 1990
Kananaskis Prov. Alta., CANADA

*Preprints, 16th Conference on Severe Local Storms, 22-26 Oct 1990 Kananaskis Prov. Park, Alta., Canada*

# OBSERVATIONS OF TORNADOES AND WALL CLOUDS WITH A PORTABLE FM-CW DOPPLER RADAR: 1989-1990 RESULTS

Howard B. Bluestein
School of Meteorology
University of Oklahoma
Norman, Oklahoma 73019

Wesley P. Unruh
Mechanical and Electronic
Engineering Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

## 1. INTRODUCTION

Little is known about the wind field in tornadoes near the ground. Photogrammetric analysis (Golden and Purcell 1977, 1978; Hoecker 1960) of tornadic debris clouds does not reveal the internal structure of the tornado vortex. Estimates of wind speeds based on damage analysis often contain large uncertainties (Doswell and Burgess 1988). Direct measurements made by an instrument placed in the path of a tornado are extremely difficult to obtain (Bluestein 1983a; Bluestein 1983b; Burgess et al. 1985). Several measurements of tornadic wind fields near cloud-base level have been made when supercell tornadoes have formed on rare occasion near the National Severe Storms Laboratory's Doppler radar (Zrnic and Doviak 1975; Zrnic et al. 1977; Zrnic and Istok 1980; Zrnic et al. 1985). Measurements of the wind field below cloud base have been made in non-supercell tornadoes in Colorado (Roberts and Wilson 1989; Wakimoto and Martner 1989; Wakimoto and Wilson 1989).

Little is also known about how tornadoes form within the mesocyclone of a supercell thunderstorm. Although it is believed that solenoidally generated horizontal vorticity along the forward flank downdraft is tilted and stretched under the main updraft to increase vorticity at the surface (Klemp and Rotunno 1983), it is not known how the smaller-scale tornado forms. Actual measurements of the sub-cloud base wind field and the relationship between the wind field and sub-storm scale features such as the wall cloud, tail cloud, and laminar inflow bands are lacking.

The purpose of this paper is to report on our progress using a portable, 1 W, FM (frequency modulated)-CW (continuous wave) Doppler radar developed at the Los Alamos National Laboratory (LANL), to make measurements of the wind field in tornadoes and wall clouds along with simultaneous visual documentation. Results using a CW version of the radar in 1987-1988 are given in Bluestein and Unruh (1989).

## 2. METHODOLOGY

Our field experiments were held during April, May, and June in 1989 and 1990. Our chase vehicles were vans carrying four to six crew members. In addition to the radar, we also carried along a barometer, a psychrometer, video camera recorders, conventional photographic equipment, and a portable radiosonde unit (Bluestein et al. 1988). Sondes were released when possible to obtain thermodynamic soundings in the storms' environment.

The radar was modified to have FM-CW capability prior to the 1989 season. The theory of the FM-CW radar and its signal processing is detailed in Strauch (1976). The radar sends out a continuous signal, whose frequency is swept linearly upward and reset, periodically. The sweep repetition frequency (15.575 kHz) of the LANL radar, which operates at 3 cm, is controlled by the sweep repetition frequency of a VCR, which records the data. The sweep repetition frequency of an FM-CW radar is analogous to the pulse-repetition frequency of a pulsed Doppler radar. For the aforementioned parameters and a sweep width of 1.9 MHz, the maximum unambiguous range of the radar is 5 km; the maximum unambiguous velocity is +/- 115 m/s ; the range resolution is 78 m. Since the half-power beamwidth of the antennas is 5 deg, the resolution volume at 2.5 km is 218 m X 218 m X 78 m.

The radar can be mounted on its tripod by two crew members and set up for operation in several minutes. The radar's umbilical cord is connected to batteries and to the video and audio recorders housed in a carrying case, which can be transported by two crew members (Fig. 1). The brightness of the video camera image must be adjusted manually. The level of the CW signal is monitored on the audio recorder and adjusted manually on the radar unit; the audio recorder's dynamic range is at least 60 db, while the radar's dynamic range is 70 db. In the FM-CW mode the signal quality is monitored on the video screen. The dynamic range of the VCR is only 30-40 db. Overloaded signals appear as unsynchronized, torn-up looking frames. Considerable qualitative information can be obtained from visual examination of video frames. "Good" signals appear as tilted lines. The range of the target is inversely proportional to the spacing between lines; the velocity of the target is given by the slope and sense of tilt of the lines. Target volumes in which there is complex wind structure appear as criss-crossed hatched lines. Range folding appears as an abrupt change in the slope of the lines. Further interpretation of the video picture will be given elsewhere.

The FM-CW radar data (i.e., the video signals resulting from mixing the transmitted FM-CW signal with the backscattered signal) are recorded on videotape, and voice documentation is recorded on audio tape and on the audio channels of the videotape. When the radar operates in the CW mode, actual bore-sighted video of the cloud features and tornado are recorded on video tape, while radar data are recorded on the stereo audio tape and on the stereo audio

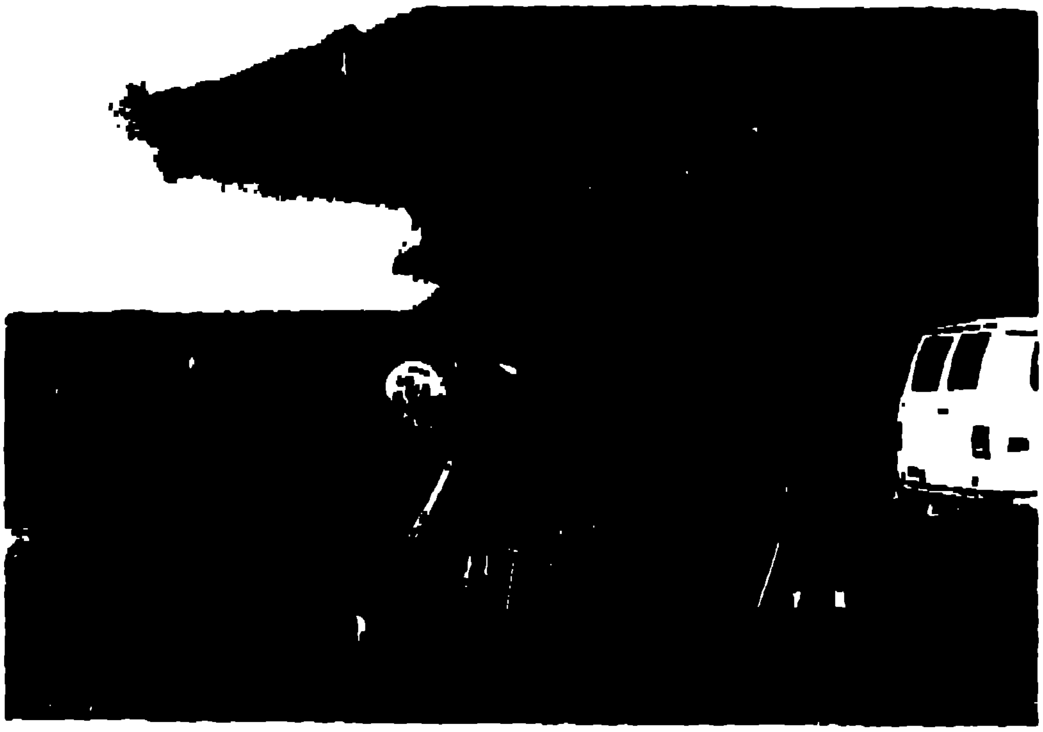

*Fig. 1: An example of data collection with the portable FM-CW Doppler radar. Crew member adjusting power of radar, other crew members checking [illegible] (lower left) of box which houses receivers and batteries, and adjusting wide angle [illegible] recorder [illegible]. Chase vehicle off to the right. [illegible] McLean, Texas [illegible]. Photo [illegible] Steve [illegible].*

[illegible] The radar can be switched [illegible] between CW and FM-CW [illegible] in a second.

[illegible] video frame of [illegible] data is digitized [illegible] 16384 data points: 128 per line times 128 [illegible] 262 lines per frame. The data [illegible] ramp of each frequency sweep is [illegible] of the video field digitized to 128 [illegible] is filtered [illegible] computing the [illegible] for each [illegible] in a series of lines and [illegible] the average from each one. The [illegible] 128 [illegible] segments [illegible] moving objects in the radar [illegible] perturbations. The series is then range [illegible] to a discrete Fourier transform [illegible] each of 64 [illegible] range bins appears [illegible] 128 points, with the 1st, 64th, and 128th [illegible] m/s, 0 m/s, and [illegible] m/s, and so on [illegible] available from the first 30 m, and from the [illegible] wind spectra [illegible] range [illegible] as shown in Fig. 2.

[illegible] get a feeling for where the highest [illegible]. We then record data in the CW and FM-CW [illegible] the antenna [illegible] horizontally [illegible] in the CW mode so that [illegible] available [illegible] features [illegible] moving. It is necessary to keep the antenna fixed [illegible] seconds before moving it in order to collect [illegible] series for analysis in the CW mode. We used [illegible] increments of approximately 5 deg. [illegible] we focus on the tornado and alternate between CW [illegible] CW mode. Vertical and horizontal scans are [illegible] tornado is close enough to resolve features at the [illegible] tornado scale.

## 3. RESULTS

The data sets we collected are listed in Table [illegible] relatively easy to obtain data sets on wall clouds [illegible] it was found that there is a strong reflectivity [illegible] resolved.

Data on several tornadoes were collected. The [illegible] May [illegible] tornado data set (see cover of *[illegible]*) [illegible] was contaminated because the bias on a preamplifier [illegible] radar was set incorrectly; as a result the [illegible] was overloaded, and the data frames were [illegible] 21 April funnel cloud, [illegible] May [illegible] funnel cloud data sets [illegible] to have some preliminary [illegible] October meeting. The [illegible] May [illegible] data set [illegible] FM [illegible] LP [illegible]

TABLE 1: Significant Data Sets

| Date | Approximate Location | Event | Comments |
|---|---|---|---|
| 13 May 1989 | Hodges, Texas | tornado | data contaminated |
| 14 May 1989 | Coahoma, Texas | wall cloud | data contaminated |
| 6 June 1989 | Floydada, Texas | wall cloud | |
| 23 April 1990 | Turkey, Texas | wall cloud | weak signal |
| 24 April 1990 | McLean, Texas | wall cloud, funnel cloud | |
| 24 April 1990 | Kelton, Texas | wall cloud | |
| 15 May 1990 | Calumet, Oklahoma | wall cloud | |
| 29 May 1990 | Old Glory, Texas | wall cloud | |
| 31 May 1990 | Spearman, Texas | tornado, wall cloud | |
| 15 June 1990 | Liebenthal, Kansas | wall cloud, funnel cloud | |

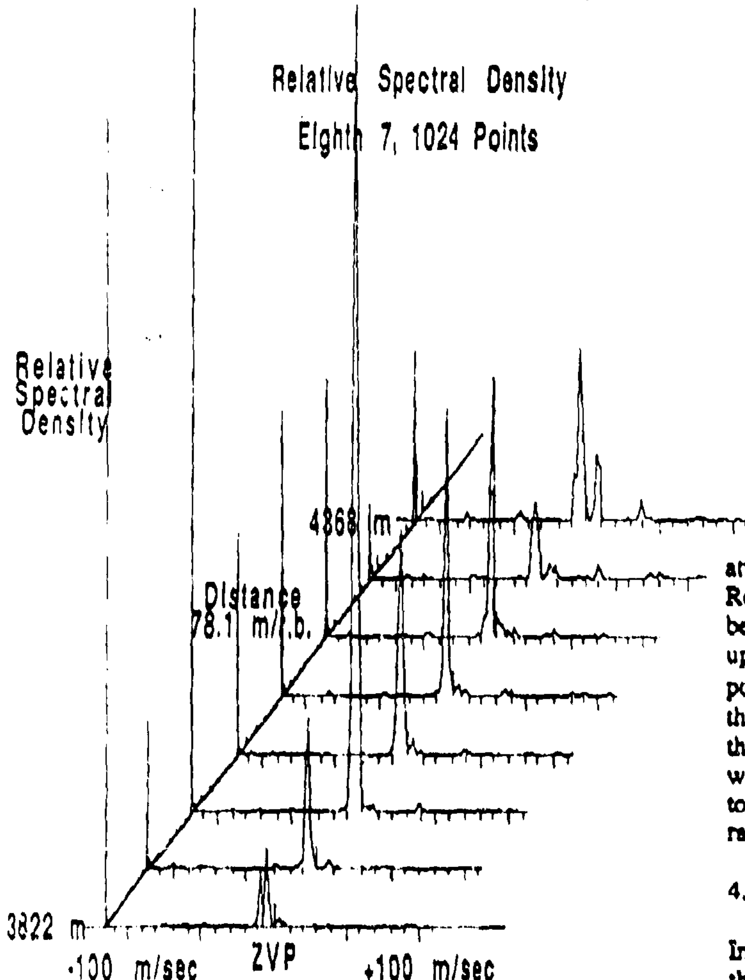


*Fig. 2: Relative spectral density as a function of Doppler velocity in a wall-cloud associated with an occluded mesocyclone on 6 June 1989 in Floydada, Texas; for range bins between 3.8 km and 4.4 km away from the radar, looking towards the wall cloud. In this example the mean flow is towards the radar at speeds of only 10 m/s or less. ZVP is the zero-velocity point. A tornado had dissipated earlier in a previous wall cloud. We are looking at flow from the rear flank downdraft around the circulation.*

was 22 km long and as wide as 1.6 km (Steven Cooper, NWS, Amarillo, Texas, personal communication). We were situated within 10 km from the tornado, and may have to correct for range-folded velocities in the FM-CW mode. We made a hasty exit from our location when the wall cloud of the occluded mesocyclone came almost overhead and 6-cm diameter hail began to fall.

There were a number of data sets that we failed to collect, but came close to collecting. On 6 June 1989 we arrived in Plainview, Texas approximately 10-15 minutes too late to record data on a tornado that we observed dissipating ahead of us. We attempted to gather data on a tornado south of Calumet, Oklahoma on 15 May 1990, but the tornado had lifted by the time we set up the radar. On 26 May 1990 we attempted to collect data on a funnel cloud northwest of El Reno, Oklahoma and on a tornado near Hinton, Oklahoma; it began to rain on both of these occasions as soon as we set up the radar, and consequently we had to move from our positions, which were southeast and east, respectively, of the storms. On 31 May 1990 we observed a tornado moving through Spearman, Texas (this tornado formed in a storm which formed after the one which had produced the F3 tornado); by the time we got close enough to set up the radar, the tornado had dissipated.

## 4. SUMMARY

In 1989 we had difficulties getting enough experience with the radar, owing to a relatively low number of tornadoes in Oklahoma, our home base of operations. A problem with the radar hardware was identified and corrected. We did obtain a good wall cloud data set which allowed us to experiment with the processing of a real FM-CW data set.

In 1990 we obtained a number of wall cloud data sets and a tornado data set. Results are forthcoming.

Based on our experiences we suggest that the following modifications to the radar system and to our method of operations be made:

a. The current maximum unambiguous range of 5 km is a bit too restrictive. The system should be modified so that a longer maximum unambiguous range, at the expense of the tornado is greater than 5 km away.

b. An automatic exposure video camera should be substituted for the current manual-exposure camera. We found it difficult and too time consuming to adjust the exposure, especially in bright light.

c. Automatic gain-controls should be used in the video and audio recorders to make it easier for us to prevent overloading the recorded signal. It is more important to obtain high-quality relative reflectivity data than to obtain absolute reflectivity data.

d. Our base of operations should be more mobile. By restricting ourselves mainly to Oklahoma and nearby regions we missed out on several opportunities to collect data elsewhere.

e. Consideration should be given to processing the Doppler spectra in real time, and recording the spectra rather than the actual raw signal. This would allow us to realize the full benefit of the wide dynamic range of the radar, which is necessary in the face of ground clutter.

## 5. ACKNOWLEDGMENTS

This project was funded by NSF grant ATM-8902594, with a subcontract to LANL, and by ISRD grant X14U at LANL. Our crews consisted of OU undergraduate student Herb Stein, and OU graduate students Jim LaDue, Greg Martin, Bill McCa..., Steve Hrebenach, and Sam Contorno. OU graduate students Steve Parker and Keith Brewster also contributed to intercept missions. Mike Wolf and Roger Bracht contributed to the design and modification of the radar. Chris Doniec, one of LANL's summer students, was especially helpful in making the FM-CW modification. Nowcasting support was provided by the National Weather Service (NWS) in Norman. Tim Hughes (OU) helped considerably with the maintenance of some of our electronic equipment and with some computer work. Our radiosonde unit and videocamera were purchased with OU Associates Funds and OU Research Council funds, respectively. We also acknowledge Steven Cooper, NWS, Amarillo, and Dave Oliver, Channel 7, Amarillo, for sharing with us their documentation of the Spearman tornadoes. The NWS in Dodge City, Kansas and Wichita Falls, Texas graciously allowed us to use their facilities.

## 6. REFERENCES

Bluestein, H. B., 1983a: Surface meteorological observations in severe thunderstorms. Part II: Field experiments with TOTO. *J. Clim Appl. Meteor.*, *22*, 919-930.

Bluestein, H. B., 1983b: Measurements in the vicinity of severe thunderstorms and tornadoes with TOTO: 1982-1983 results. *Preprints, 13th Conf. on Severe Local Storms*, Tulsa, Okla., Amer. Meteor. Soc., 89-92.

Bluestein, H. B., E. W. McCaul, Jr., G. P. Byrd, and G. R. Woodall, 1988: Mobile sounding observations of a tornadic storm near the dryline: The Canadian, Texas storm of 7 May 1986. *Mon. Wea. Rev.*, *116*, 1790-1804.

Bluestein, H. B. and W. P. Unruh, 1989: Observations of the wind field in tornadoes, funnel clouds, and wall clouds with a portable Doppler radar. *Bull. Amer. Meteor. Soc.*, *70*, 1514-1525.

Burgess, D. W., S. V. Vasiloff, R. P. Davies-Jones, D. S. Zrnic, and S. E. Fredrickson, 1985: Recent NSSL work on wind speed measurement in tornadoes. *Proc., 5th U. S. Nat'l. Conf. on Wind Engineering*, Texas Tech., Lubbock, 1A-53-1A-60.

Doswell, C. A., III, and D. W. Burgess, 1988: On some issues of United States tornado climatology. *Mon. Wea. Rev.*, *116*, 495-501.

Golden, J. H. and D. Purcell, 1977: Photogrammetric velocities for the Great Bend, Kansas tornado of 30 August 1974: accelerations and asymmetries. *Mon. Wea. Rev.*, *105*, 485-492.

Golden, J. H. and D. Purcell, 1978: Airflow characteristics around the Union City tornado. *Mon. Wea. Rev.*, *106*, 22-28.

Hoecker, W. H., 1960: Wind speed and airflow patterns in the Dallas tornado of April 2, 1957. *Mon. Wea. Rev.*, *88*, 167-180.

Klemp, J. B. and R. Rotunno, 1983: A study of the tornadic region within a supercell thunderstorm. *J. Atmos. Sci.*, *40*, 359-377.

Roberts, R. D. and J. W. Wilson, 1989: Multiple Doppler radar analysis of the 15 June 1988 Denver tornadoes. *Preprints, 24th Conf. on Radar Meteor.*, Tallahassee, Amer. Meteor. Soc., 142-145.

Strauch, R. G., 1976: Theory and Application of the FM-CW Doppler radar, Ph. D. thesis, Dept. of Electrical Engineering, Univ. of Colo., Boulder, 97 pp.

Wakimoto, R. and B. Martner, 1989: Photogrammetric/radar analysis of the 2 July tornado during CINDE. *Preprints, 24th Conf. on Radar Meteor.*, Tallahassee, Amer. Meteor. Soc., 62-65.

Wakimoto, R. and J. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.*, *117*, 1113-1140.

Zrnic, D. S. and R. J. Doviak, 1975: Velocity spectra of vortices scanned with a pulse-Doppler radar. *J. Appl. Meteor.*, *14*, 1531-1539.

Zrnic, D. S., R. J. Doviak, and D. W. Burgess, 1977: Probing tornadoes with a pulse Doppler radar. *Quart. J. Roy. Meteor. Soc.*, *103*, 707-720.

Zrnic, D. S. and M. Istok, 1980: Wind speeds in two tornadic storms and a tornado, deduced from Doppler spectra. *J. Appl. Meteor.*, *19*, 1405-1415.

Zrnic, D. S., D. W. Burgess, and L. Hennington, 1985: Doppler spectra and estimated windspeed of a violent