Multimoment Doppler Display for Severe Storm Identification

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ABSTRACT

A single-Doppler data display has been developed which allows simultaneous presentation of the principal moments of the Doppler spectrum while retaining ease of viewing and interpretation. Display severe storm signatures are described and an example of data collected in a tornadic storm is presented. A tornado signature is identified, its evolution is followed, and comparisons between the signature and the tornado damage track are made.

1. Introduction

Doppler radar's use as a severe storm and tornado warning tool was forecast over a decade ago (Atlas, 1963; Lhermitte, 1964). Recent advances in real-time Doppler moment estimation (Rumpler, 1968; Sirmans and Doviak, 1973) have advanced Doppler weather radar toward realization of the anticipated goal. Accuracy, small memory requirements and computational efficiency of these techniques compared to discrete Fourier transform methods permit (at low cost) Doppler spectrum moment fields to be displayed in real time, thus offering means to identify tornadic storms (Doviak et al., 1974). Both black and white (Sirmans and Doviak, 1973) and color (Gray et al., 1975) single moment displays have been introduced.

We describe a black and white single-Doppler data display which allows simultaneous presentation of the Doppler spectrum's three principal moments while retaining ease of viewing and interpretation. Doppler radar provides considerably more information about the precipitation echo spectrum than just spectrum power (zeroth moment) which is proportional to the reflectivity factor Z found in conventional radar data. Two additional moments of special interest are mean Doppler velocity (first moment) and velocity spread (i.e., spectrum width—second moment) of precipitation particles within the pulse volume. The threefold increase in data provides a challenge for Doppler information display techniques. Increasing the number of displays by a factor of 3 either physically or sequentially is the most obvious solution. However, simultaneous Doppler moment displays have distinct advantage for severe storm identification because, although all three moments contain signatures, all signatures do not necessarily appear at one observation time.

Severe storm zero-moment (reflectivity) signatures are well known. Some notable examples are hook or finger-like echoes, bounded weak echo regions and power return magnitude. First- and second-moment severe storm signatures are less well understood but do exist. After Donaldson (1970), a vortex may be identified from the quasi-horizontal mean velocity field if there is significant localized azimuthal shear persisting for at least half the vortex revolution. Further confirmation is achieved if the shear pattern extends vertically to a height greater than its diameter and the shear pattern remains localized and well defined at different viewing angles. Using the above criteria, numerous thunderstorm vortices have been identified and sizes compare favorably with the mesocyclone (Fujita, 1963). A very high percentage of these vortex signatures are accompanied by damaging hail, strong straight wind or tornadoes (Burgess, 1976). Additionally, pulse-volume-to-pulse-volume changes in the first Doppler moment and large second-moment magnitude have been judged potentially important as tornado signatures. Intense azimuthal shear of mean velocity between adjacent pulse volumes, tentatively labeled as gate-to-gate shear (GGS) but more recently named tornadic vortex signature (TVS), has already revealed the position of one tornado (Burgess et al., 1975). Large Doppler spectrum width coincident with tornado location has been documented by Kraus (1973) and Zrnic and Doviak (1975). All signatures mentioned may be revealed simultaneously by using the new multimoment single-Doppler display.

2. Display description

A minicomputer-graphic display terminal has been interfaced to a National Severe Storm Laboratory (NSSL) 10 cm Doppler radar having characteristics given by Brown et al. (1971). The algorithms necessary to estimate Doppler moments and display controls are accomplished through use of the minicomputer. Magnetic tape also records displayed data.

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To simultaneously present the three principal Doppler moments for each pulse volume, a field of arrows is displayed where arrow length is proportional to the log of received power, arrow direction to velocity and arrowhead size to Doppler spectrum width. For the preliminary examples presented here, arrowhead size is programmed to be proportional to Doppler wind shear, a significant contributor to spectrum width.

Fig. 1 illustrates the above relations. Zero velocity is a horizontal arrow pointing right and nonzero velocities are proportional to the angle between the arrow and its zero position. Clockwise rotation from the zero position denotes negative velocities (toward the radar) and counterclockwise rotation denotes positive velocities (away from the radar). The horizontal arrow pointing left corresponds to the maximum unambiguous velocity ($\pm 34$ m s$^{-1}$) resolved by the radar. As the velocity increases beyond $\pm 34$ m s$^{-1}$, the arrow rotates smoothly and appears as a lower velocity of opposite sign (e.g., $38$ m s$^{-1}$ appears as $-30$ m s$^{-1}$). Arrowhead width reflects the largest absolute velocity difference between the sample volume under consideration and the four surrounding volumes. Due to the limited unambiguous velocity, the velocity difference is computed by

$$\Delta V = \begin{cases} |V_1 - V_2| & \text{when } |V_1 - V_2| \leq 34 \text{ m s}^{-1} \\ 68 - |V_1 - V_2| & \text{when } |V_1 - V_2| > 34 \text{ m s}^{-1} \end{cases}$$


Fig. 2. Multimoment display for Stillwater storm of 13 June 1975 before tornado formation. Time, elevation angle, range interval ($dR$) and azimuth interval ($dAZ$) at the nearest range between arrows are given across display top. Mesocyclone center is indicated by (+).

The display (Fig. 2) is a B-SCAN (range vs azimuth) presentation of Doppler moments where ranges in kilometers and azimuths in degrees are given along the left and bottom margins, respectively. Top headers show time, radar elevation angle, kilometer range interval ($dR$) and kilometer azimuth interval ($dAZ$) between whole degrees. The display sector is limited to 15X16 pulse volumes but range and azimuth spacing between displayed pulse volumes is variable and the sector limits can be changed quickly. Thus it is possible to check large storm regions for severe storm signatures.

A variable minimum power threshold is used to separate noise from regions where velocity estimates may be obtained. For the examples shown, a signal-to-noise ratio of 3.5 dB is used as the boundary for displayed data.

Velocities are computed using the pulse pair technique to determine spectral moments from signal covariance (Berger and Groginsky, 1973). To reduce computational time, alternate sample pairs (e.g., samples 1 and 2, 3 and 4, etc.) are processed to obtain, from 64 uniformly spaced samples, 16 pulse pairs to estimate Doppler moments. The standard error of velocity estimates is about 0.7 m s$^{-1}$ for spectra width equal to 3 m s$^{-1}$, a typical value. The use of alternate pairs results in a negligible increase of variance over that predicted by Berger and Groginsky if the full 63 sample pairs were processed.$^2$ These errors are within the ac-

$^2$ Private communication, Dr. Dusan Znic, a visiting scientist at the National Severe Storms Laboratory.
accuracy expected when interpreting the velocity display and are considered reasonable for real time use.

3. Tornadic storm data collection

The multimoment display was interfaced with one of NSSL's high-resolution 10 cm Doppler radars before the 1975 data collection program. Severe storms were minimal in Oklahoma during the collection period and prior to 13 June only two non-tornadic mesocyclone signatures with relatively weak shear were observed.

During the late morning of 13 June, thunderstorms formed in a convergence area in north central Oklahoma ahead of a weak cold front. The storms became severe as they spread slowly southeast during the afternoon and evening. One intensifying radar echo moved into Doppler data collection range shortly after 1700 (all times are CST) and sampling along the storm's right flank began (Fig. 3). The strong shear revealed by the first displays focused the attention of NSSL observers on the storm which was nearing Stillwater, Okla.

Early Doppler measurements made at low elevation angles near cloud base are illustrated in Fig. 2. Two important storm features are seen in the display. The

![Fig. 3. Portion of 0° elevation WSR-57 surveillance radar PPI at 1730 on 13 June 1975. Thin range rings are at 40 km intervals and thick range ring denotes maximum unambiguous Doppler data collection limit of 115 km. White outline indicates portion of Stillwater storm seen in Doppler display. Note that a hook-type echo is not visible in the reflectivity field.](image1)

![Fig. 4a. Multimoment display for Stillwater storm during intense tornado (white dot at 021° azimuth and 104 km range).](image2)

![Fig. 4b. Stillwater tornado photograph (courtesy of Rick Bellati, Stillwater News-Press) taken between 1745 and 1750 during intense surface damage.](image3)
first is a cyclonic vortex (mesocyclone) signature with center at 019° azimuth, 105.5 km range. Although the signature is not pronounced, localized cyclonic shear does exist with Doppler component flow definitely toward the radar along azimuths 017° and 018° and away from the radar at azimuths 020° and greater. The signature’s position is coincident with a visually observed rotating region of lowered cloud base [wall cloud, Fujita (1960)] over the northwestern section of Stillwater. The second display feature is a wind shear line between 021° and 022° azimuth and 98–102 km range. However, the shear line, evident only at low levels, does not meet Donaldson’s vortex criteria and is interpreted as the storm gust front. The Doppler observed relative positioning between the mesocyclone wall cloud and gust front is in good agreement with visual observations.

After an intervening tilt sequence where large shear (TVS) is detected aloft, the next low-level observation at 1743 (Fig. 4a) reveals a cloud base TVS (021.25° azimuth, 104.2 km range). The intense shear (compare arrowhead sizes in Figs. 2 and 4a) is at the mesocyclone center, coincident with reported tornado location in Stillwater’s southeast section. Damage done by the mature tornado (Fig. 4b) just after the 1743 observation was severe. Also visible (Fig. 4a) is the gust front signature to the mesocyclone’s right (i.e., between azimuths 023.5° and 024° near 103 km range).

Low-level measurements (Fig. 5a) just before the
tornado’s dissipation again reveal a TVS (021.75° azimuth, 103.6 km range) coincident with rope-like tornado location (Fig. 5b). Shears are still large but have decreased from 1743 values, comparable to weakening tornado strength. The gust front signature is just off the display edge (centered along azimuth 025°) and is evolving in shape and vertical extent to more closely resemble a vortex signature.

Dual-Doppler data collected near 1753 provide the 2 km horizontal wind field (Fig. 6) using techniques described by Ray et al. (1975). Mesocyclonic circulation within the storm is confirmed with a circulation center coincident with tornado location (shown by the + sign in Fig. 6). Additionally, strong convergence is depicted along the previously observed gust front signature. Another vortex is developing along the gust front and higher level wind fields (not shown) portray a developing circulation situated above the convergence area. This concept is supported by observed wall cloud structure (Fig. 5b, background) which developed rotation after 1753.

The described example demonstrates the multimoment display potential for severe storm identification. One mesocyclone evolution during tornado production was outlined and simultaneously the initial development of a second mesocyclone along the storm gust front was noted. Of particular importance is the ability to display regions of intense azimuthal shear. The Stillwater data collection confirms previous observations (Burgess et al., 1975) that the low-level TVS positions trace out the tornado track (Fig. 7). The 1733 low-shear mesocyclone center (prior to tornado formation) and the 1743 and 1753 TVS’s (during the tornado) do indeed correspond in both space and time to tornado location. The new multimoment single-Doppler display can reveal actual tornadic circulations and implications are that after further evaluation and modification for operational use, it could help provide more accurate and timely tornado warnings.

REFERENCES