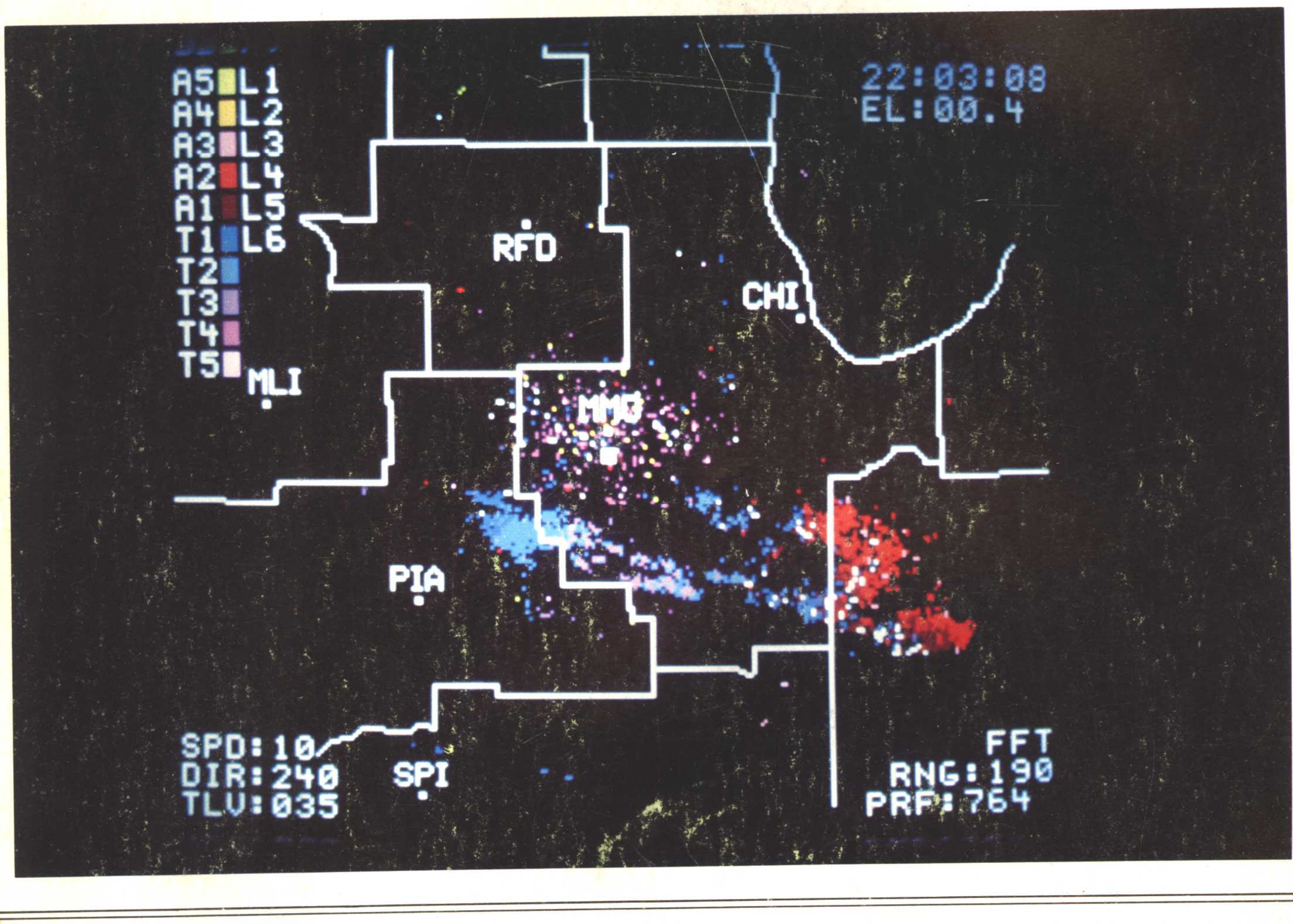
PREPRINTS

21st CONFERENCE on RADAR METEOROLOGY

September 19-23, 1983

Edmonton, Alta., Canada



AMERICAN METEOROLOGICAL SOCIETY

FOREWORD

The present volume contains the papers to be presented at the 21st Conference on Radar Meteorology. Familiarity with its contents will make the exchanges at the Conference so much more effective.

The format of the Conference incorporates some innovations: about half of the sessions are in parallel (with reviews) and half in series; the duration of the sessions is uneven. This flexibility was the solution of this Program Committee to the problem of incorporating into a finite (and constant) time period an ever increasing number of contributions. In order to make the Poster Session more attractive and free of connotations it was made optional to everybody. If you feel that the contents of your paper are more adequate for a Poster please use it!

Finally, in the name of the Canadian radar meteorology community and our host and cosponsor, the Alberta Research Council, let me welcome you again to this country.

Isztar Zawadzki
Program Chairman

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DOPPLER RADAR STUDY OF THE ANVIL REGION ASSOCIATED WITH A SQUALL LINE

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1. INTRODUCTION

Long-lived intense squall lines are sustained and propagated by the initiation of discrete convection on their leading (downshear) faces. As the convective cells mature and decay, they are sometimes observed to merge into a mesoscale region (area ≈ 10^5 km^2) of relatively homogeneous cloud and precipitation (hereafter called anvil) which trails the line of active convection. Such squall lines have been observed in middle latitudes (e.g. Newton and Newton, 1959; Sanders and Paine, 1975; Ogura and Liou, 1980; and Matejka and Srivastava, 1981, 1982) and in the tropics (e.g. Zipser, 1969, 1977 and Houze, 1977). Newton and Newton conjectured that mesoscale descending air motions occur throughout the depth of the anvil. Zipser, and Houze, however, postulated that mesoscale descent is confined to the lower levels, while mesoscale ascent occurs in the upper levels. The existence of the descent was deduced from the divergent nature of the wind below the cloud base and because the wet-bulb potential temperature in the lower levels was found to be characteristic of the air in the mid-troposphere. The descent was attributed to cooling due to evaporation (Riehl, 1965, 1969 and Zipser, 1969, 1977). The mesoscale ascent in the upper layers was postulated to explain the persistence of clouds and widespread light precipitation for several hours after the cessation of the active convection. The physical reason for the ascending motion is not clear, although it has been reproduced in certain numerical simulations (Brown, 1979). The descent in the lower levels has also been reproduced in the numerical simulations and shown to be probably due to evaporative cooling.

Sanders and Paine (1977) and Ogura and Liou (1980) were among the first to make calculations of winds and vertical air motions in the anvil from observations. These authors used radiosonde observations to provide strong evidence for the existence of mesoscale ascent and descent of some tens of cm s^{-1} in the upper and lower levels, respectively, of the anvil. In their analysis, they used the technique of compositing a time-sequence of radiosonde observations to deduce spatial variations of the wind from which the divergence and vertical air velocity could be computed; therefore, their results depend upon the assumption of steadiness (in a frame of reference attached to the squall line).

Matejka and Srivastava (1981) studied an anvil associated with a squall line, observed during Project NIMROD with three Doppler radars, by an extension of the VAD method (EVAD) and found a region of widespread descent and ascent in the lower and upper levels, respectively, of the anvil. The EVAD method uses single Doppler radar data and yields practically instantaneous profiles of winds, divergence, and vertical air velocity and, therefore, is not dependent upon an assumption of steadiness; however, the computed profiles are horizontal averages over the VAD analysis circle. In this paper, we use triple Doppler radar data for the same anvil to calculate horizontal winds, divergence and vertical air velocity over an area 120 km x 120 km by 9 km deep. The objectives of these calculations are to verify the results of the EVAD analysis and to provide a more detailed picture of the variations of winds, divergence and vertical air velocity in the anvil behind the squall line.

2. THE SQUALL LINE

According to satellite imagery (not shown here), the squall line began to intensify rapidly at about 1630 CDT, approximately 250 km northwest of the Project NIMROD network (Fig.1), along a nearly stationary cold front that stretched from the Great Lakes to the Texas Panhandle. By 2000 CDT, the convection formed a band over 2000 km in length, from northeast to southwest, and varying in width between 70 and 200 km. The line moved southeastward through northern Illinois at approximately 15 m s^{-1}, faster than the cold front; as a result, the line and the anvil passed through the network between 2100 CDT on 17 June and 0300 CDT on 18 June well before the cold frontal passage at 0700 CDT on 18 June.

The synoptic situation in which the squall line formed is shown in Fig.2. At the 850 mb level, a tongue of warm air was being advected over the lower midwest ahead of a well defined trough. At the 700 mb level and the 500 mb level (not shown), the flow above the warm tongue was westerly, and cold air advection was occurring well ahead of the surface cold-frontal position. The squall line therefore formed in a zone where differential advection was destabilizing the atmosphere, ascent on the eastern side of a short-wave trough and frontal zone was probably occurring, and the vertical shear of the wind was directed southeastward-conditions favorable for the organization of the squall line.

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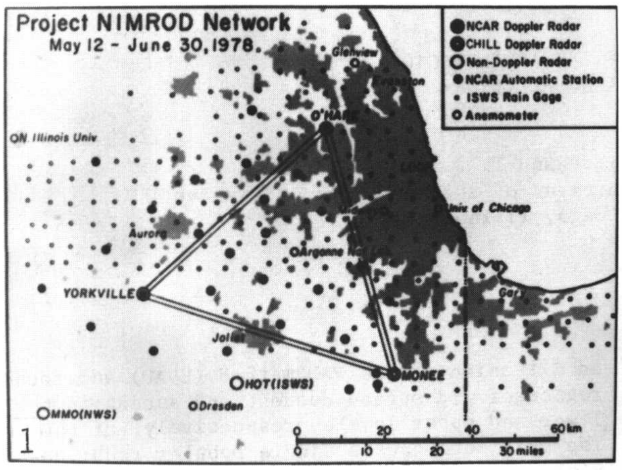

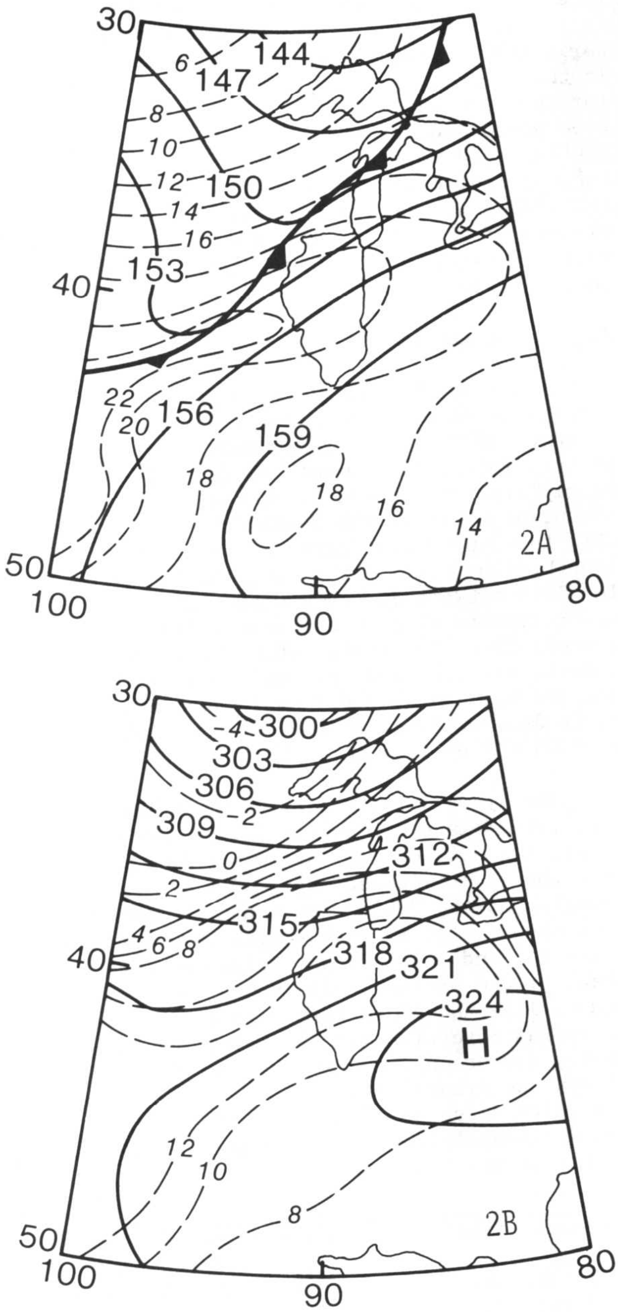

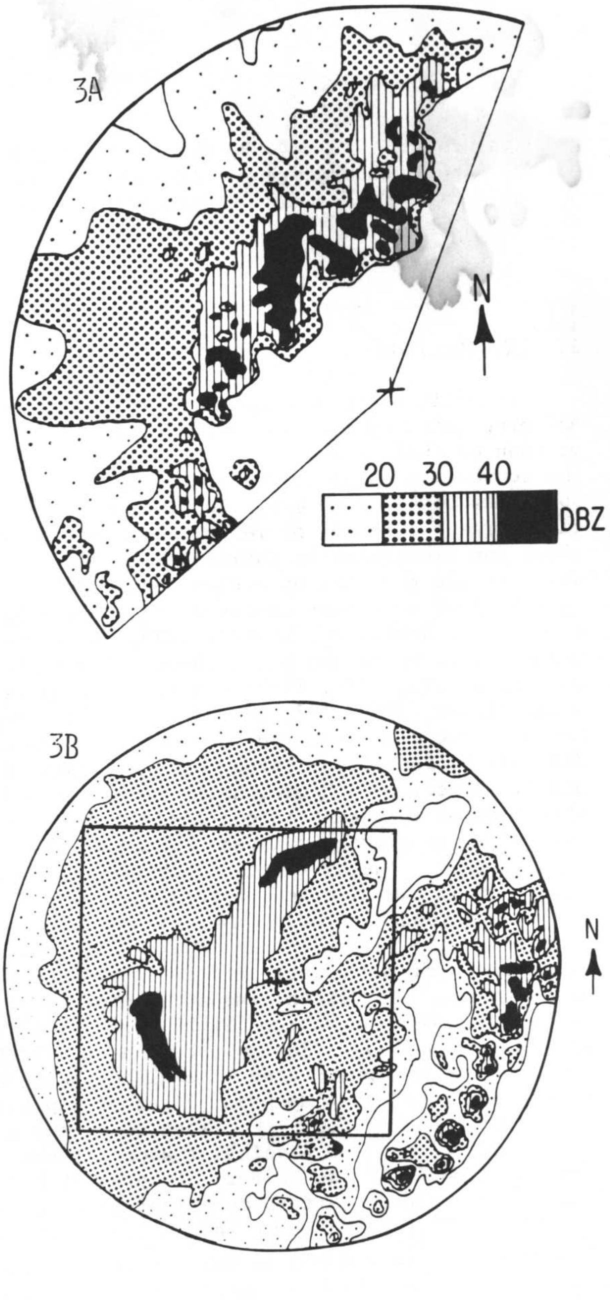

Fig.1(top left). The NIMROD network. The CP3 radar is at Yorkville, the CP4 radar near O'Hare airport and the CHILL radar is near Monee.

Fig.2(lower left). 850 mb (a) and 700 mb (b) synoptic analysis for 1900 CDT on 17 June 1978. Longitude (°W) and latitude (°N) are indicated. Height contours (dam), solid lines, and isotherms (°C), broken lines, are shown.

Fig.3(right). PPI display of CP3 radar reflectivity factors. Maximum range from CP3 radar (+) is 108 km. Top figure is for 2215 CDT, elevation angle 4.5 deg. Bottom figure is for 2346 CDT, elevation angle 3.5 deg. The square is the 120 km x 120 km area of multiple Doppler radar analysis. Note there is a change of range scale between the two figures.

A study of radar data showed that the individual thunderstorm constituting the squall line moved northeastward nearly parallel to the line. The southeastward advance of the line was due primarily to the formation of new convective elements up to 25 km ahead of the line. The southeastward propagation of the line combined with the northeastward motion of the individual thunderstorms was apparently responsible for the merger of the decaying thunderstorms into the anvil behind the line. Fig.3a shows the squall line at 2215 CDT at a stage when the anvil is just starting to become extensive. By 2346 CDT (Fig.3b), the line of convection has weakened, and the anvil has spread to a distance of at least 150 km behind the line.

The rainfall rate, wind speed and direction, and wet bulb potential temperature measured at two of the PAM (Portable Automated Mesonetwork) stations are shown in Fig.4. Fig.4a is for a site over which the core of a thunderstorm happened to pass. The burst of heavy rainfall occurred shortly after the characteristic wind shift and thermodynamic changes signalling the passage of the gust front. A thunderstorm core did not pass over the PAM site of Fig.4b. It is seen that light precipitation occurs for a considerable time after the passage of the line of active convection.

3. METHOD OF ANALYSIS OF DOPPLER RADAR DATA

3.1 The Extended VAD (EVAD) Method

The VAD method can yield average values of winds and divergence over the VAD circle. For the calculation of the divergence, it is necessary to use VAD scans at low elevation angles, so that the contribution of the particle fall speed to the Doppler velocity can be neglected (Browning and Wexler, 1968). In the EVAD method, scans at several elevation angles, and not confined to low elevations only, are used to calculate both the particle vertical velocity and the horizontal divergence. This method is described in Matejka and Srivastava (1981). The height profiles of divergence and vertical air velocity computed by this method using CP3 radar data for a period of approximately 9 minutes are reproduced from Matejka and Srivastava in Figs.5 and 7. The profiles are averages over a VAD circle of radius approximately 30-40 km centered over the CP3 radar.

3.2 The Multiple Doppler Radar (MDOP) Method

The method of analysis of multiple Doppler radar data, developed at the Laboratory for Atmospheric Probing, and as applied to the present problem is briefly as follows: An analysis volume is first selected (in this case an area 120 km x 120 km x the cloud depth, see Fig.3b). The data lying in the volume are classified into narrow height intervals and transferred to different "height" files of a random access medium. Each layer is divided into a 120 x 120 grid with a grid size, 1 km x 1 km. Each grid point is numbered, and each data point is then tagged by an ID# equal to the number of the nearest grid point. The data for each "height" file is then rearranged in order of ascending ID#. After this operation, all the data in any desired neighborhood of a given point can be readily accessed.

The next step in the analysis procedure is editing and unfolding of the Doppler velocities. The unfolding methods described in the literature unfold Doppler velocities for each radar individually. Here we considered all the radars simultaneously in an automated and objective unfolding method. The unfolding process is started by prescribing a range of expected wind vectors. For a given wind vector, the expected radial velocity is calculated and the observed Doppler velocity is "unfolded" to be within the unambiguous velocity range centered at the expected radial velocity. The mean square deviation of the "unfolded" radial velocities, about the expected radial velocity, is computed for a number of wind vectors over small volumes. The wind vector which minimizes the mean square deviation is accepted as the one which is used to unfold the Doppler velocities in that volume. Large values of the minimum mean square deviation indicate regions of sharp shear, questionable data, or noisy data, the last being the case if the mean square deviation approaches that of a uniform distribution of Doppler velocities over the unambiguous velocity interval. Such data are examined and edited or unfolded using an interactive graphics procedure. In the present case, the objective unfolding scheme worked successfully on almost 100% of the data.

After unfolding and editing, the contribution of the particle fall speed is removed from each radial velocity. The particle fall speed was estimated from the radar reflectivity factor and

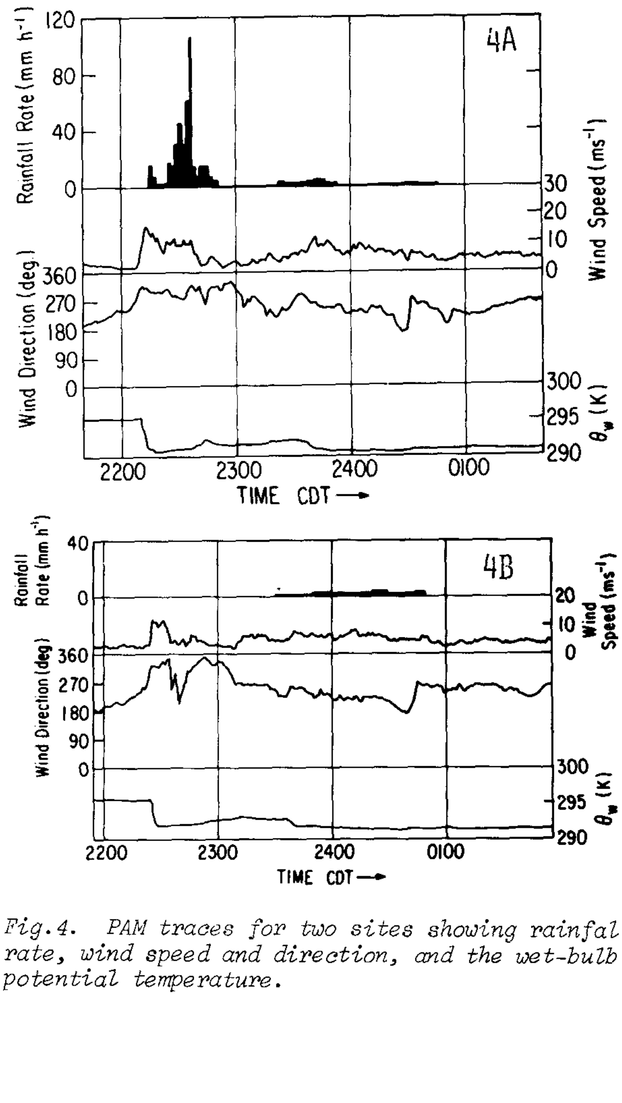

Fig.4. PAM traces for two sites showing rainfall rate, wind speed and direction, and the wet-bulb potential temperature.