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INTEGRATING WIND PROFILER DATA INTO FORECAST AND WARNING OPERATIONS AT NWS FIELD OFFICES

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I. INTRODUCTION

A network of 29 wind profilers (the Wind Profiler Demonstration Network, or WPDN) in the central United States provides tropospheric wind data to National Weather Service (NWS) field offices. The data are characterized by better horizontal resolution than that provided by the existing rawinsonde network and provide much better vertical and temporal resolution.

Twelve of the WPDN profilers are located within the NWS Southern Region. The goal of the WPDN is to provide the NWS an opportunity to assess the utility of wind profiler data in an operational setting. The results of that assessment may help determine whether the WPDN will be followed by a national network, and if so, will provide the basis for designing and establishing such a network later this decade. Ten NWS offices in the Southern Region have a formal role in the assessment. They are WSOs Amarillo and Tulsa, and WSFOs Albuquerque, Fort Worth, Lubbock, Norman, Little Rock, Memphis, Jackson, and New Orleans Area. Fourteen Central Region WSFOs are also taking part in the formal assessment.

The scheduled end of the formal assessment after Fiscal Year 1992 gives some offices less than a year to provide input on the utility of real-time wind profiler data. Nevertheless, judicious application of profiler data at the field level will enhance the forecast and warning program for as long as this technology is available.

Four training manuals and associated videotapes have been developed by the Program for Regional Observing and Forecasting Services (PROFS) in Boulder, CO. The first training manual (van de Kamp 1988) deals with principles of wind profiler operation, while the second manual (Brewster 1989) discusses quality control of profiler data. The third (Brady and Brewster 1989) deals with warm-season applications of profiler data to analysis and forecasting, and the fourth (Jewett and Brady 1989) discusses cool-season applications.

General Sciences Corporation (GSC) and the NWS Techniques Development Laboratory developed a comprehensive applications software system (Battel et al. 1991) for displaying profiler winds and derived products on AFOS (see Section III).

The purpose of this memorandum is to combine important information from the training manuals, the AFOS profiler applications software, and some of the relatively few research papers dealing with profilers, and to help establish guidelines for NWS field offices to integrate wind profiler data into local forecast operations. The importance of producing solid documentation (by forecasters) of the utility of profiler data is also discussed. The data and the software for displaying them on AFOS are still relatively new and unfamiliar to the majority of forecasters. The procedures outlined on the following pages are intended to help smooth the transition to routine utilization of this new data source and introduce its tremendous potential.

II. THE PROFILER NETWORK

A. Operating Principles

Wind profilers are relatively low-power Doppler radars that measure the atmospheric winds (including vertical motion) above a profiler site. They are highly sensitive "clear-air" radars that operate with wavelengths from about 33 cm to 6 meters. The WPDN profilers operate with a wavelength near 74 cm, which corresponds to the profiler frequency of 404.37 MHz (van de Kamp 1988).

Stable pulses emitted by the profiler continually scatter small amounts of energy back to the antenna as they encounter fluctuations in the radio refractive index (caused by turbulent mixing of volumes of air with slight differences in temperature and moisture content). The profilers are most sensitive to turbulent eddies with dimensions around one-half the wavelength of the emitted signal, or about 37 cm. Since the eddies are embedded in the wind flow, a slight Doppler shift of the emitted signal is produced and the wind speed can be measured.

The WPDN profilers use a phased array antenna to emit signals in three directions, or beams: a vertical beam and two off-vertical beams pointing generally north and east. The actual directions have been slightly altered to minimize interference with the operational geostationary satellites. The elevation angle of the off-vertical beams is 73.7 degrees (i.e., 16.3 degrees off the vertical beam). The vertical beam is used to measure the w-component of the wind (vertical velocity), while the off-vertical beams are used to measure the u- and v-components.

The profiler operates in a low mode and a high mode, measuring winds every 250 m in the vertical from a minimum sampling height of 500 m. Internal electronic constraints prevent the WPDN profilers from measuring winds below that height. The height resolution is 350 m in the low mode and 1,000 m in the high mode. Therefore, winds measured by the profiler are an average within each resolution "volume" (350 m or 1,000 m), centered every 250 m vertically. Winds are measured in the low mode from 500 m to 9.25 km AGL, while high mode sampling extends from 7.5 to 16.25 km AGL (note the overlap between 7.5 km and 9.25 km).

A critical assumption in the use of wind profiler data is that the horizontal wind field is uniform, or homogeneous, across all three beams. This is not necessarily true at any given moment, since the horizontal separation between the "north" and "east" beams is equal to four-tenths of the sampling height. For example, at a height of 15,000 feet, these beams are separated by 6,000 feet, or more than one mile. Obviously, variations in the wind field often exist across horizontal distances this large, especially if there is convection in the area.

B. The Data

The profiler produces a vertical wind profile every six minutes, sampling for two minutes (about one minute in the low mode and one minute in the high mode) in each of the three beams. Non-uniformity in the wind field across the beams can be a problem for such short averaging times, but the assumption of uniformity is usually valid for longer periods of time. Hence, the six-minute measurements are used to produce an hourly measurement through a process known as "consensus averaging," designed to filter out any unrepresentative six-minute measurements (Brewster 1989).

Each profiler sends data (via satellite or dedicated phone lines) to the central Hub computer in Boulder at the end of each six-minute averaging period. The data are in the form of "spectral moments," which consist of estimates of radial velocity, returned power, and spectral width for each height, beam position and resolution mode. The spectral width represents the spread in velocity values and is related to shear and turbulence.

The Hub computes the wind profiles from the six-minute data, using basic quality control routines consisting of consensus averaging, median filter and vertical consistency checks. The profiles are transmitted to Suitland, MD, and placed on the NWS Gateway for distribution over the AFOS system (in WSFO Norman's case, they are transmitted via ISPAN). The WPDN profilers produce high-quality wind profiles with an accuracy of better than 1 m/s. In a one-month reliability test with a research profiler, over 96 percent of the wind measurements were judged to be good measurements. The WPDN profilers are expected to equal or exceed that performance. Nevertheless, it is important to recognize the limitations of the data and some of the more common sources of problems.

Spurious measurements represent the greatest data problem. They can be produced by a number of things. The profiler radar, like other radars, produces side lobes of emitted energy as well as the primary focused beam. If a side lobe encounters highly reflective targets such as aircraft, trucks, buildings, mountains, rain shafts, etc., the energy returned to the radar can overwhelm the clear-air return in the main beam. Returns from fixed objects (ground clutter) can be removed, but ground clutter algorithms cannot screen out moving objects. Returns from unwanted objects can also be received through the main beam (aircraft, birds, etc.).

One of the most important causes of spurious returns is precipitation contamination. If precipitation is falling in all three beams, at a uniform fall speed, the geometric relationships allow for removal of the vertical contribution due to the fall speed, and the u, v and w components can be successfully retrieved. In the case of precipitation falling in only one or two of the beams, or if the fall speed is highly variable, the correct wind values cannot be retrieved. Quasi-stationary wave activity can also produce highly variable vertical velocities across a profiler sampling domain.

Velocity aliasing (Brewster 1989) is another source of spurious wind measurements. In the case of the WPDN profilers, the Nyquist velocity (the maximum radial velocity that can be measured) is about 30 kt in the low mode and 45 kt in the high mode. Radial velocities greater than these values are "folded" or "aliased."

In practice, aliased velocities are so vastly different from correct measurements that they are usually easy to recognize. This is evident in Fig. 1, which shows folded wind data from the Haskell, OK, profiler above 470 mb under a very strong jet. In early 1992, a "velocity unfolding" algorithm was implemented to correct this problem.

Another problem with the data is unrepresentativeness -- the measurement is valid but the measured phenomenon is small and/or short-lived. Wind fields in the vicinity of thunderstorms will usually be significantly different from the prevailing flow. The measurement of such localized wind fields may be perfectly accurate, but unrepresentative of surrounding conditions; and the forecaster may have a hard time deciding whether the winds are valid or "bad."

The Hub's quality control routines are designed to flag the spurious measurements, while leaving the decision concerning representativeness to the user. Spurious and unrepresentative data often look similar (large change over a small height or time difference). Consequently, "good" data are occasionally judged erroneous by the quality control algorithms (although an improvement in the vertical shear check quality control algorithm in early 1992 has reduced the number of "good" data points being flagged as "bad," especially in the lowest few thousand feet). On the other hand, allowing unrepresentative data to pass may lead to some spurious data passing the checks. Hence, the user must develop skill in recognizing the difference if the data are to be used to their maximum utility.

Brewster and Schlatter (1986) describe automated quality control of wind profiler data in detail. The second profiler training manual (Brewster 1989) also discusses the subject.

In addition to tropospheric wind data, limited surface data are available from the 14 profiler sites equipped with a Profiler Surface Observation System (PSOS). PSOS provides hourly-averaged temperature, relative humidity, rainfall rate and wind measurements.

III. AFOS APPLICATIONS PROGRAMS

A. Overview

Profiler products for AFOS are generated by the GSC/TDL applications software, and are described in the accompanying user's manual (Battel et al. 1991). Programs have also been developed by ERL (PROFS) for displaying profiler data on the Pre-AWIPS system at Norman. Periodic updates to both of these packages will continue for some time.

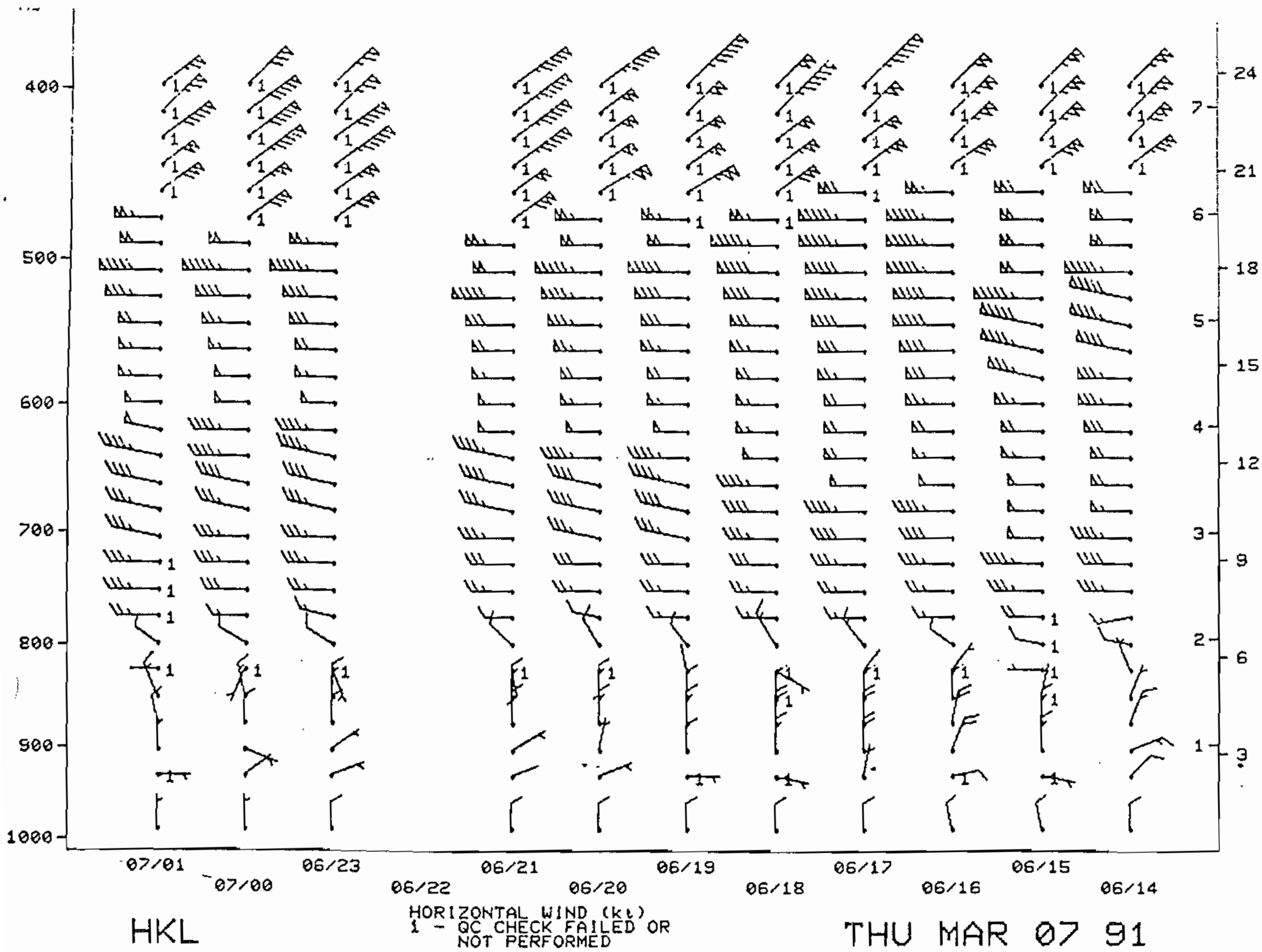

Fig. 1. Folded, or aliased, wind data (Haskell, OK) above 470 mb under a strong jet.

The profiler data are transmitted over AFOS in a format called Binary Universal Form for Data Representation (BUFR) via the product identifier NMCWPDERL. The data include station information, surface (PSOS) data, and tropospheric wind data. The AFOS programs decode and process NMCWPDERL, then display the data using time-section (time versus height), cross-section (horizontal distance versus height), and plan view (plots of data from several stations at various atmospheric levels) formats.

With all 29 WPDN profilers operational, the product NMCWPDERL has to be split into three parts in order to handle the volume of data. In other words, the message will be sent three times each hour. Therefore, in order to save 24 hours of data, it is necessary that 72 versions of the product be saved in the data base.

The programs can be run as stand-alone programs with appropriate switches, or they can be run automatically after user-specified options have been inserted into an AFOS preformat. Automatic AFOS schedulers such as WATCHDOG can be used for running the decoder and other parts of the software system. Detailed instructions, along with a description of the various options available to the user, are outlined in the user's manual which accompanies the software. The software system is quite diversified and offers a great many options for creating and utilizing the products. The user's manual contains specific instructions for loading and using the software.

Following is a brief overview (incorporating ideas gained from actually using these programs) of important steps necessary for generating some of the more commonly used, or potentially useful, profiler graphics. The reader should consult the user's manual for the fine details.

Most of the files necessary for running the programs should reside in an RDOS directory other than SYSZ. For convenience, a little-used APPL or USER directory is best. It is essential that one file -- WPDATA (the file that contains the decoded data) -- not reside on SYSZ, since that file can grow to a size of 1200 RDOS blocks if 24 hours' worth of data from all 29 profilers are stored. Many offices might very well want to store that much data. While no single office would want (or be able, for that matter, due to the AFOS time required) to routinely create time-sections for all 29 stations, most offices will probably want the capability to generate plan view plots of data from the entire network on a routine basis.

One of the first steps in tailoring the system to a specific office's needs is to decide what stations to decode and how many hours' worth of data to store. If plan view plots covering the entire network are desired, the default value (i.e., decode all stations) should be retained. Most offices will likely want to retain the default value of 24 hours of stored data. These options can be changed through the WPSET program. However, it only takes about 75 seconds for the WPDEC program to decode all data from all 29 profilers for one hour. If WPDEC is scheduled (via WATCHDOG) to run every hour, this amount of time should not be a problem. Obviously, if WPDEC hasn't been run for a while, decoding 29 stations could require lots of time -- up to half an hour to decode 24 hours of data.

In creating a basic set of routinely-generated products, the AFOS preformat C-CCMCPWPD (Fig. 2) is used to specify the type of output desired (products, levels, hours, contour intervals, station selections, etc.). The preformat is three pages long on AFOS, with each menu (time-section, cross-section and plan view) on a separate page. Type M:WPD, and fill out the header block CCCWPDxxx. After the desired options have been selected and have been saved in the product CCCWPDxxx, the program CWPCF can be executed to create a corresponding "options file" -- WPCF.nn, where nn can range from 00 to 99. Therefore, up to 100 different WPCF.nn files, representing 100 different sets of option selections, can be created.

Example: RUN:CWPCF 03/e
RUN:WPSET 03/e

The first command takes the most recent CCCWPDxxx (output from the preformat screen) and creates the options file WPCF.03. The second command "points" the system to that specific options file when subsequent programs are run.

How does one keep track of the different options that have been selected in the various option files (created from the AFOS preformats)? Each time CWPCF is run to create a WPCF.nn file, a corresponding file called SAVPF.nn is created. The contents of a particular WPCF.nn file can be seen by displaying the SAVPF.nn file on AFOS:

For example, the command DSP:SAVPF.99 at an ADM will reveal the contents of WPCF.99 (actually, the contents of the CCCWPDxxx from which WPCF.99 was created). Or, simply run the program PWPCF.SV as described in the user's manual.

Most offices will probably need only a limited number of different option files, depending on the forecast situation. The desired products for the desired set of stations can be selected by simply running WPSET (RUN:WPSET nn/e) at an ADM.

Forecasters at most offices will likely find that there is not enough AFOS time to locally produce all the products they would like to see. The software was designed in modules so that different offices could share the workload. For example, a WSFO may wish to run only time-sections and plan views, while letting one of its WSOs produce cross-section products. There is great flexibility in how the program load may be distributed among offices. A local switch enables data base products to be routed between offices on the same SDC.

```
JANMCPWPD
TTAA00 KTDL 171719
                         TIME SECTION AND WIND ALERT THRESHOLD MENU
PRODUCTS                 STA    BASE HT  HOURS    CONTOUR  ALERT      FLAGGED   HEIGHT
                                (M*100) #   END   INTERVAL THRESHOLD   DATA?    INTERVAL
HORIZONTAL WIND          [ ]    [  ] [  ] [  ]                         [ ]      (M*250)
HORIZONTAL SPEED         [ ]    [  ] [  ] [  ]  [  ]A  [    ]G
THERMAL WIND             [ ]    [  ] [  ] [  ]                                  [   ]E
WIND SPEED SHEAR         [ ]    [  ] [  ] [  ]  [  ]A  [    ]D                  [   ]E
WIND DIRECTION SHEAR     [ ]    [  ] [  ] [  ]  [  ]I                           [   ]E
U/V-WIND COMPONENTS      [ ]    [  ] [  ] [  ]  [  ]A                 KINEMATIC STATION
W-WIND COMPONENT         [ ]    [  ] [  ] [  ]  [  ]H  [    ]B           SELECTIONS
PERTURBATION WIND        [ ]    [  ] [  ] [  ]
RETURNED POWER           [ ]    [  ] [  ] [  ]  [  ]F                 [W]=[  ,  ,  ]
DERIVED DIVERGENCE       [    ] [  ] [  ] [  ]  [  ]C                 [X]=[  ,  ,  ]
DERIVED VERT. VEL.       [    ] [  ] [  ] [  ]  [  ]H                 [Y]=[  ,  ,  ]
DERIVED VORTICITY        [    ] [  ] [  ] [  ]  [  ]C                 [Z]=[  ,  ,  ]
  DEFAULTS: STA - NONE; HEIGHTS - MSL; HOURS - 16 TO PRESENT; FLAGGED DATA? - Y
A - 10 KT             F - 10 DB                  STATION SELECTIONS
B - 30 CM/S           G - 100 KT    [1]=[  ,  ,  ,  ,  ,  ,  ,  ,  ,  ]
C - .00004 RAD/S H - 10 CM/S        [2]=[  ,  ,  ,  ,  ,  ,  ,  ,  ,  ]
D - 25 KT/250 M   I - 40 DEG        [3]=[  ,  ,  ,  ,  ,  ,  ,  ,  ,  ]
E - 1000 M BETWEEN LAYERS           [4]=[  ,  ,  ,  ,  ,  ,  ,  ,  ,  ]  [ ]

                                  PLAN VIEW MENU
PRODUCTS                 PRESSURE  HOUR    #HOURS   CONTOUR   FLAGGED  HEIGHT
                          LEVELS            DIFF    INTERVAL   DATA?   INTERVAL
HORIZONTAL WIND            [ ]     [  ]                         [ ]     (M*250)
HORIZONTAL SPEED           [ ]     [  ]             [  ]A
W-WIND COMPONENT           [ ]     [  ]             [  ]B
STREAMLINES                [ ]     [  ]
DERIVED VORTICITY          [ ]     [  ]             [  ]D
DERIVED DIVERGENCE         [ ]     [  ]             [  ]D
THERMAL WIND               [ ]     [  ]                              [   ]E
TIME DIFF OF U-WIND        [ ]     [  ]     [  ]    [  ]A
TIME DIFF OF V-WIND        [ ]     [  ]     [  ]    [  ]A
TIME DIFF OF W-WIND        [ ]     [  ]     [  ]    [  ]B
TIME DIFF OF DIV.          [ ]     [  ]     [  ]    [  ]D
TIME DIFF OF VORT.         [ ]     [  ]     [  ]    [  ]D
RETURNED POWER             [ ]     [  ]             [  ]C
  DEFAULTS: HEIGHTS - STD; HOUR - CURRENT; #HOURS DIFF - 3; FLAGGED DATA? - Y
A - 10 KT                              PRESSURE LEVEL SELECTIONS
B - 10 CM/S                         [1]=[ , , , , , , , ]
C - 5 DB                            [2]=[ , , , , , , , ]
D - .00004 RAD/S                    [3]=[ , , , , , , , ]
E - 1000 M BETWEEN LAYERS           [4]=[ , , , , , , , ]
                                                                     [ ]

                       CROSS SECTION MENU
PRODUCTS                 STATION   BASE HT   HOUR   CONTOUR   FLAGGED   HEIGHT
                          GROUPS   (M*100)          INTERVAL   DATA?    INTERVAL
HORIZONTAL WIND          [    ]    [  ]     [  ]                [ ]     (M*250)
ORTHOGONAL COMPONENTS    [    ]    [  ]     [  ]   [  ]A
W-WIND COMPONENT         [    ]    [  ]     [  ]   [  ]B
THERMAL WIND             [    ]    [  ]     [  ]                        [   ]C
RETURNED POWER           [    ]    [  ]     [  ]   [  ]D
  DEFAULTS: STATIONS - NONE; BASE HT - MSL; HOUR - CURRENT; FLAGGED DATA? - Y
  A - 10 KT                            STATION SELECTIONS
  B - 10 CM/S                       [W]=[  ,  ,  ,  ,  ,  ,  ,  ]
  C - 1000 M BETWEEN LAYERS         [X]=[  ,  ,  ,  ,  ,  ,  ,  ]
  D - 5 DB                          [Y]=[  ,  ,  ,  ,  ,  ,  ,  ]
                                    [Z]=[  ,  ,  ,  ,  ,  ,  ,  ]
```

Fig. 2. AFOS preformat CCCMCPWPD. From Battel et al. (1991).

B. Product Description

Time-sections:

These products provide the forecaster with a vertical profile of the wind every hour. Time increases from right to left to simulate a west to east cross-section (more correctly, an "upstream" to "downstream" cross-section). The height (y-axis) is labeled in both km and kft, as well as in corresponding pressure levels for a standard atmosphere. The user can specify the base height (default is mean sea level), then up to 7,250 m or 24,000 feet of data are plotted. The number of hours can also be selected (default is 16 hours). The following time-section plots are available:

- horizontal wind velocity
- horizontal wind speed
- u, v, w wind components
- thermal wind
- perturbation wind
- wind direction and wind speed shear
- returned power
- relative vorticity
- horizontal divergence
- derived vertical velocity

Cross-sections:

The background format for cross-section displays (from stations located along a vertical plane) is similar to that used for time-sections. It should be remembered that, when selecting a base height, elevation varies from station to station. One hour of data (selected by the user) is displayed for each station for each product. The default hour is the most recently decoded hour. The following cross-section plots are available:

- horizontal wind velocity
- orthogonal and parallel wind components
- w wind component
- thermal wind
- spectral peak power

Plan Views:

Plan view plots, similar to standard-level plots of rawinsonde winds, are of great value in supplementing information supplied by the time-section products. In fact, the use of the two together can be critical to an understanding of more subtle phenomena that are not obvious on one type of display alone.

The following plan view plots are available:

- horizontal wind velocity
- streamlines
- horizontal wind speed
- thermal wind
- relative vorticity
- horizontal divergence
- w wind component
- time difference fields
- returned power

C. Utility of the Products

This subject is described in more detail in the user's manual. The following show just a few examples of how profiler data -- and derived products -- may be used for analysis and forecasting. Some specific examples and cases are described in the next section (Section IV).

wind velocity

- fronts (location, passage, slope)
- troughs (" " ")
- ridges (" " ")
- jet streams
- low-level jets
- mesoscale circulations
- enhancing constant-level NMC charts

streamlines

- centers of cyclonic/anticyclonic flow
- lines of strong convergence/divergence

wind speed & wind direction shear

- mature/decaying stages of MCCs
- intensity of thunderstorms

thermal wind

- warm/cold advection
- location of warm or cold air

perturbation wind

- small features exaggerated (enhanced)
- passage of vorticity maxima

derived absolute vorticity
- -regions of positive/negative vorticity advection
- -frontal passages
- -forecasting thunderstorms/MCCs

derived divergence
- -frontal passages
- -forecasting thunderstorms/MCCs

derived vertical velocity
- -thunderstorm development
- -precipitation intensity

w-wind component
- -warm frontal passages
- -type/intensity of precipitation
- -thunderstorm development
- -update NMC model guidance forecasts

returned power
- -frontal zones
- -tropopause*
- -warm frontal passages

* An objective method for determining tropopause height using returned power measurements (VHF radars) is described by Gage and Green (1982).

IV. SELECTED OPERATIONAL APPLICATIONS

In this section we will examine in some detail selected applications where profiler data can prove quite valuable in enhancing operational analyses and forecasts. Specific examples, or cases, of the real-time application of profiler data are cited.

Examples include:

- Augmenting conventional surface and upper air observations
- Modifying conventional soundings
- Identifying jets and jet structure
- Identifying synoptic-scale and mesoscale signatures
- Determining air mass characteristics

- Evaluating model performance

- Diagnosing vertical motion

A. Augmenting Conventional Surface and Upper Air Observations with Profiler Data

The 0000 UTC and 1200 UTC profiler winds are very useful in enhancing conventional mandatory-level analyses because the profilers provide much better temporal (once an hour) and spatial resolution (Figs. 3a, b) than the rawinsonde network. The spacing between rawinsonde observations often allows considerable latitude in the placement of short wave troughs, vorticity lobes, etc. If there is a profiler site in the gap between rawinsonde sites, a time-section plot can be run for that station. Even if an office doesn't routinely run time-sections for that profiler site (i.e., it's not contained in the local WPCF.nn options files), a time-section plot for the site can be easily generated by running TSPLOT in the command line mode. Then the forecaster can determine the very hour (nearly) that the feature passed the profiler site, allowing the location of the feature to be placed much more accurately on the mandatory-level analysis.

Fig. 4 is an example of this type of application. In Figure 4a, the 500 mb trough is shown passing the Okolona, MS, profiler about 1000 UTC. Actually the data plotted at 1000 UTC represent an hourly average (consensus average) between hours 0900 and 1000, so the trough could have passed as early as around 0900 UTC. This would indicate that on the 1200 UTC 500 mb plot (Fig. 4b), the trough areas should be placed just east of Centreville, AL, since it passed Okolona only two or three hours earlier. Without the profiler data, the short wave might be placed much farther east.

Eberwine (1990) discusses a case where profiler data were "blended" with the existing upper air network observations during a synoptic-scale winter event. Using profiler data, forecasters were able to gain additional insight into the development and structure of the weather system.

The enhanced spatial resolution of the plan view plot will also be of great help, especially when used in combination with the time-sections. After a feature's location has been pinpointed, the hourly temporal resolution afforded by the profiler network can be used to track the feature throughout the forecast shift (or a succession of shifts).

Although the 14 PSOS sites will not contribute significantly to the resolution of surface data provided by the conventional network of surface observations, there will certainly be occasions when data from one or more of the PSOS sites will be quite useful. There are enough gaps (some substantial, especially at night) within the conventional network that a PSOS observation will occasionally be extremely helpful in determining the location of a front, or the onset of a significant weather condition, despite the relatively small number of PSOS-equipped profiler sites.

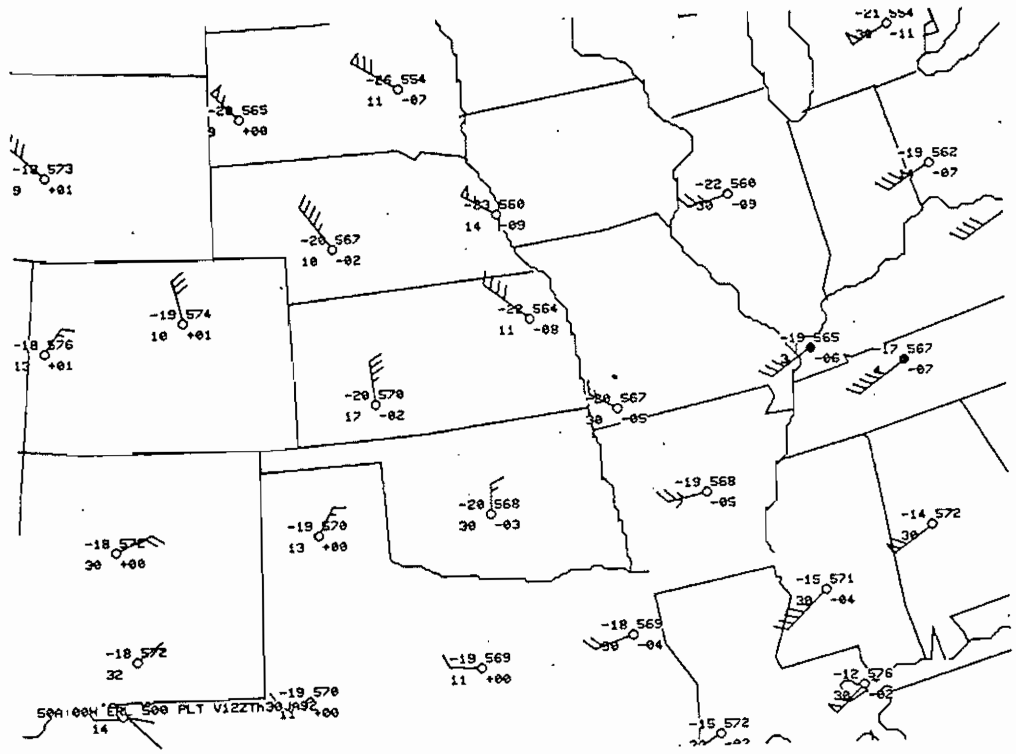

Fig. 3a. Standard 500 mb plot without profiler winds.

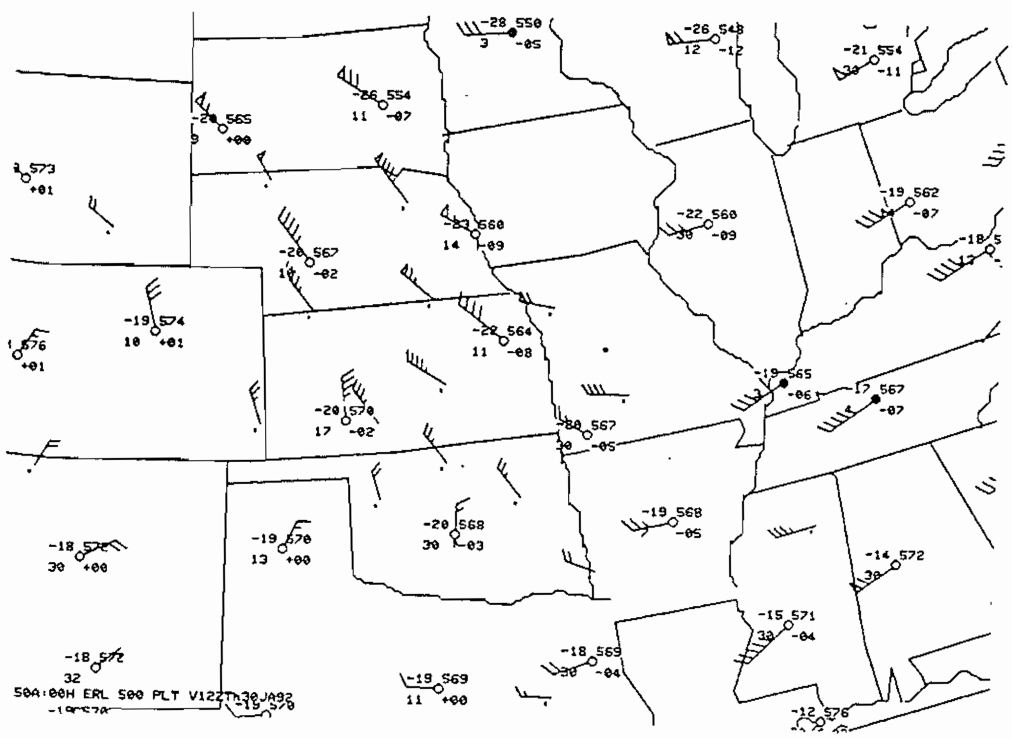

Fig. 3b. Overlay of 500 mb profiler plan view plot on standard plot shown in 3a.

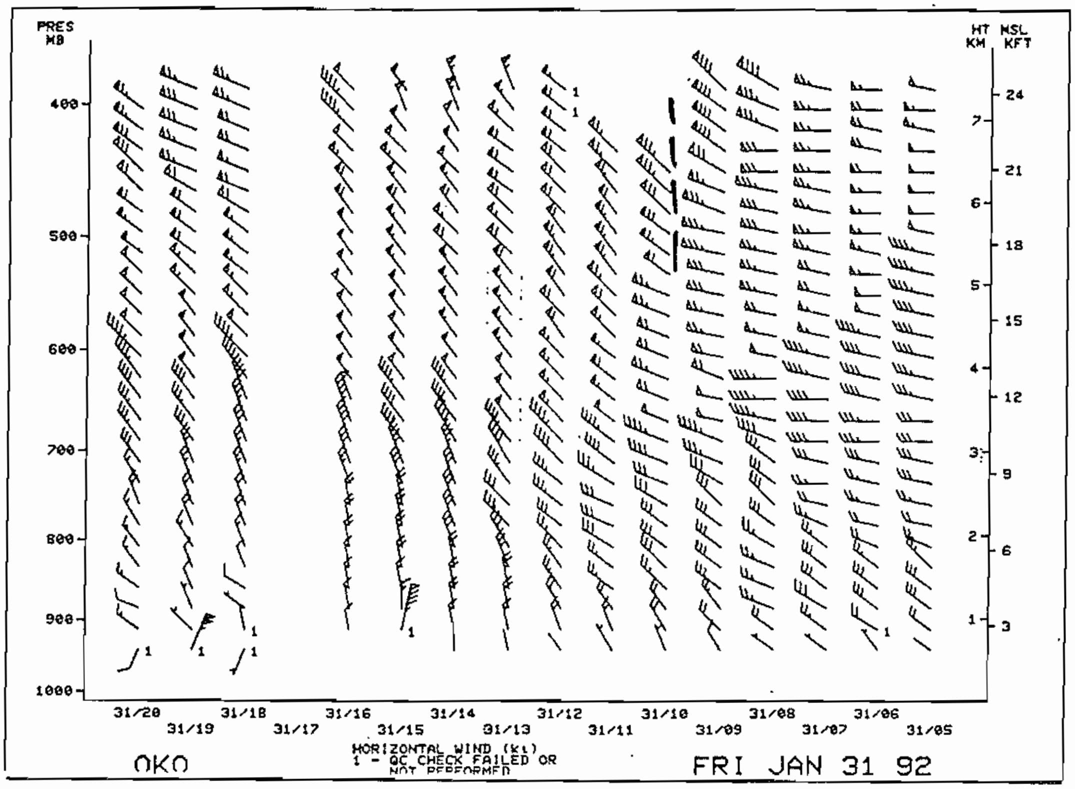

Fig. 4a. Okolona, MS, time section. Note passage of short wave trough at 500 mb between 0900 and 1000 UTC.

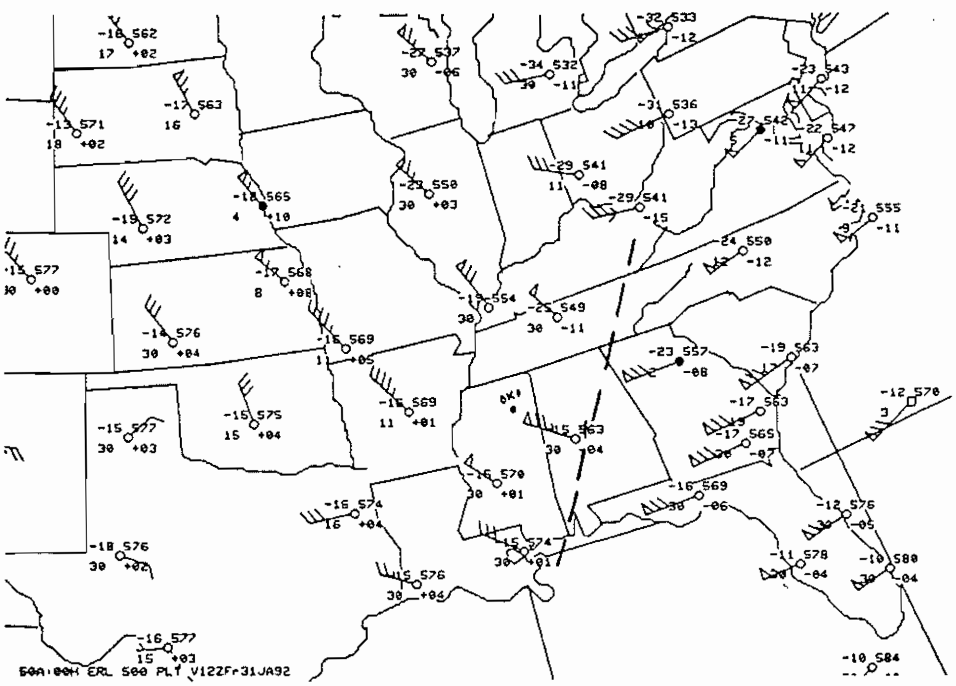

Fig. 4b. Standard 500 mb plot of rawinsonde data.

The hourly rainfall accumulation from PSOS sites should have obvious application in the monitoring of significant rainfall events and potential flash flood situations. PSOS data can be obtained by specifying pressure level zero (for the horizontal wind product) in the plan view preformat menu of the AFOS applications software.

Tracking features such as short waves through an array of profilers will enable forecasters to more accurately forecast the end of precipitation associated with such features. Forbes et al. (1989) found that a mesoscale "jet" (10 knots or more) of perturbation easterlies or southerlies appears in the lowest few kilometers of the atmosphere an hour or so before precipitation begins. This layer will deepen as precipitation intensifies. In most instances, the signature seems to be related to overrunning. A similar signature, a shifting of the perturbation winds to the west or north, often indicates the end of precipitation. Eberwine (1990) identified these characteristic signatures in a case study. These signatures are quite apparent in Fig. 5 (southeasterlies after 1600 UTC, shifting to the north between 1.5 and 4 km after 0400 UTC), and were well-correlated with the beginning and ending times of precipitation in this case.

B. Modifying Conventional Soundings with Profiler Data to Diagnose Severe Weather Potential

Wind profiler time-section plots allow monitoring of changes in the vertical wind profile as frequently as once per hour, or plotting hourly hodographs if desired. This can be done easily and quickly using the **Sharp Workstation** PC software developed by the NWS Eastern Region (Hart and Korotky, 1991). Profiler data can also be used to update output produced by the Southern Region's Helicity Analysis and Forecast Programs (Woodall 1990).

Even a cursory glance at the profiler winds can reveal obvious changes between the times of conventional soundings. Fig. 6 illustrates how the low-level directional shear and tropospheric speed shear, as in this instance at Platteville, CO, can change dramatically over a period of a few hours (note the change between 0800 and 1700 UTC), increasing the potential for severe thunderstorm development. In this case, tornadoes and large hail were reported in Northeast Colorado after 2000 UTC.

Kitzmiller and McGovern (1990) conducted a 44-day experiment to evaluate potential hail predictors using wind profiler measurements. They looked at wind speed, u and v wind components, wind speed shear, wind vector product shear, and thermal advection, all averaged over various layers, as potential predictors. They demonstrated that profiler winds observed during the late morning possessed predictive information with regard to hail occurrence. They also showed that even a single profiler site might provide useful information for distinguishing between marginal and high potential for large hail when the synoptic situation is favorable for severe weather.

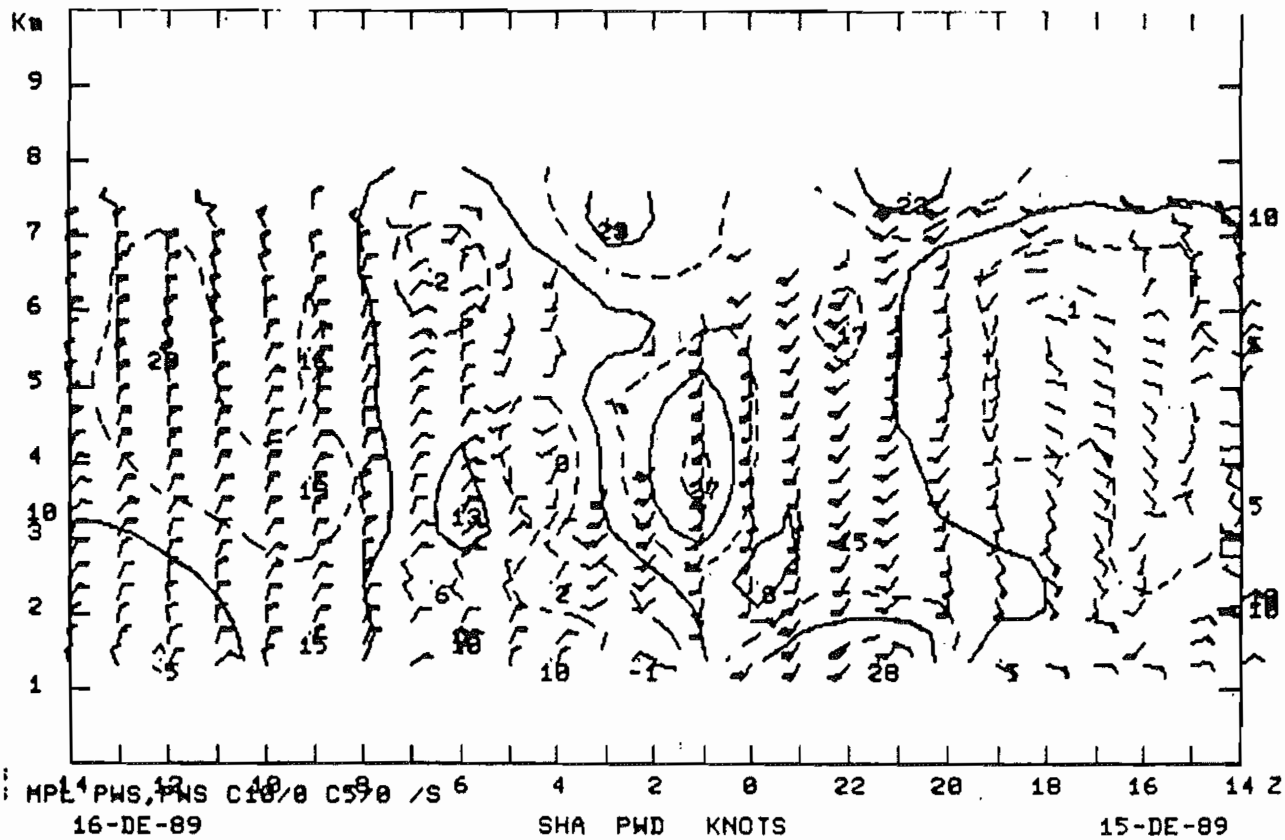

Fig. 5. Perturbation wind, Shanty, PA. From Eberwine (1990).

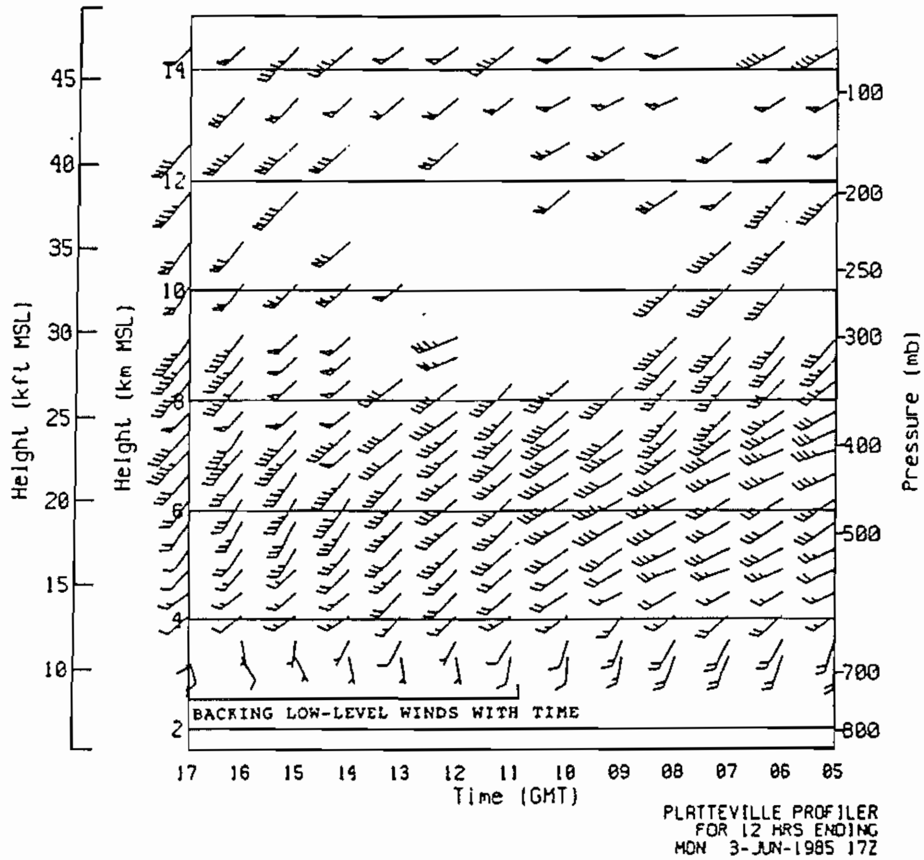

Fig. 6. Platteville, CO, time section. From Brady and Brewster (1989).

Dunn (1986) examines a case in which profiler winds contributed to real-time experimental forecasts of severe convective weather in the Denver area. Profiler data helped pinpoint the most likely area for severe convection.

C. Identifying Jets and Jet Structure

1. Low-level jets

Profiler winds allow quick and easy diagnosis of low-level jet development, evolution, strength and depth. Data from the Lamont, OK, profiler (Fig. 7) show a good example of a rapidly developing low-level jet.

2. Jet streaks

Jet streaks are easily recognizable in the profiler data (time-section plots of horizontal wind). Fig. 8 is one of several excellent examples from the profiler training manuals.

Comparison of time-section plots from several profiler sites can be used to help pinpoint the location of jet maxima and corresponding areas of upper-level divergence. Aside from more obvious applications, such as forecasting severe weather, identification of jet streaks has other implications as well. For example, Thaler (1991) examined a case where ageostrophic circulations associated with the left entrance region of a jet streak apparently transported high-momentum air down to the surface, resulting in a sudden high wind event at Denver. The profiler data in this case were used in a post-mortem sense and not as a forecast tool. However, the post-analysis led to a better understanding of what may trigger some high wind events in that area.

3. Descending jets

The approach of an upper-level speed maximum also results in the appearance of a "descending" jet in the profiler winds (Fig. 9). Wind speeds at upper levels increase and descend as the jet maximum approaches, resulting in enhanced vertical speed shear. Combined with increasingly favorable low-level veering of the winds, this should quickly alert the forecaster to increasing severe weather potential.

Eberwine (1990) describes how profiler data (from a three-profiler network) supplied to WSFO Philadelphia by Penn State University revealed a descending jet streak that resulted in surface winds gusting to over 60 mph in parts of western Pennsylvania. This is another example of how profilers can aid in detecting features on a smaller scale than the existing upper air network.

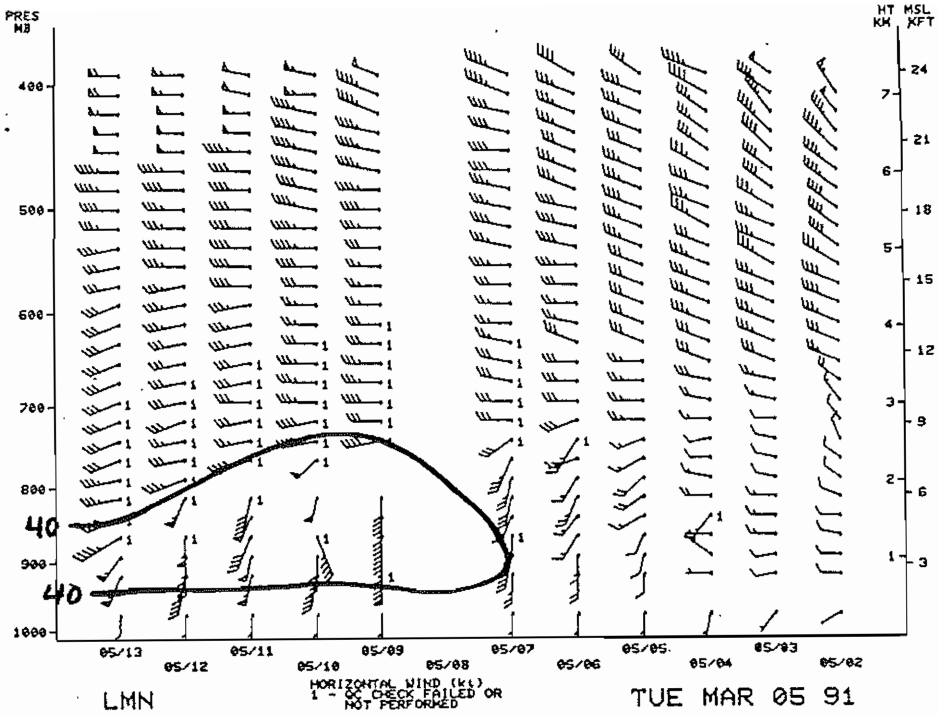

Fig. 7. Rapidly developing low-level jet (Lamont, OK).

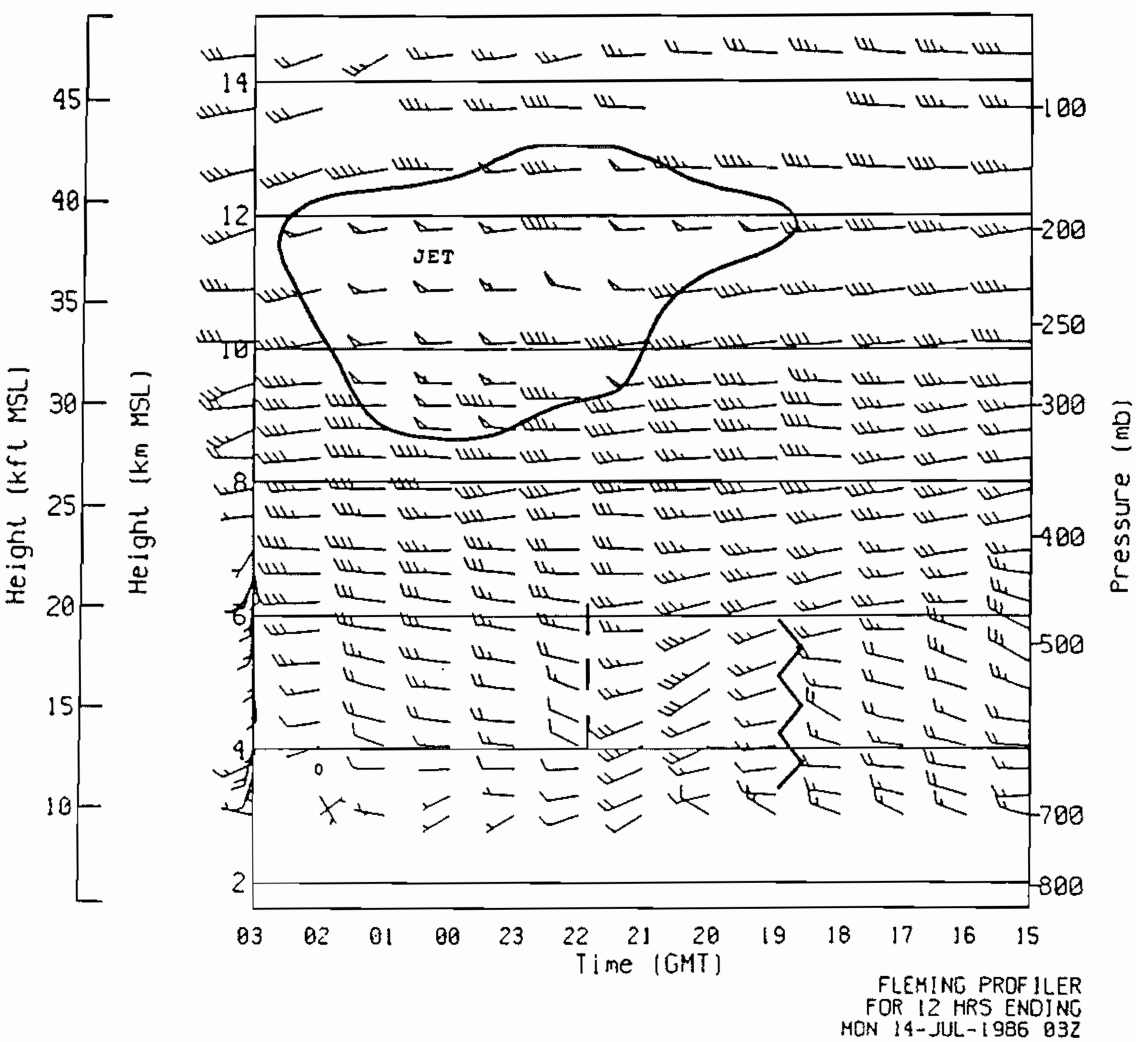

Fig. 8. Jet streak signature. From Brady and Brewster (1989).

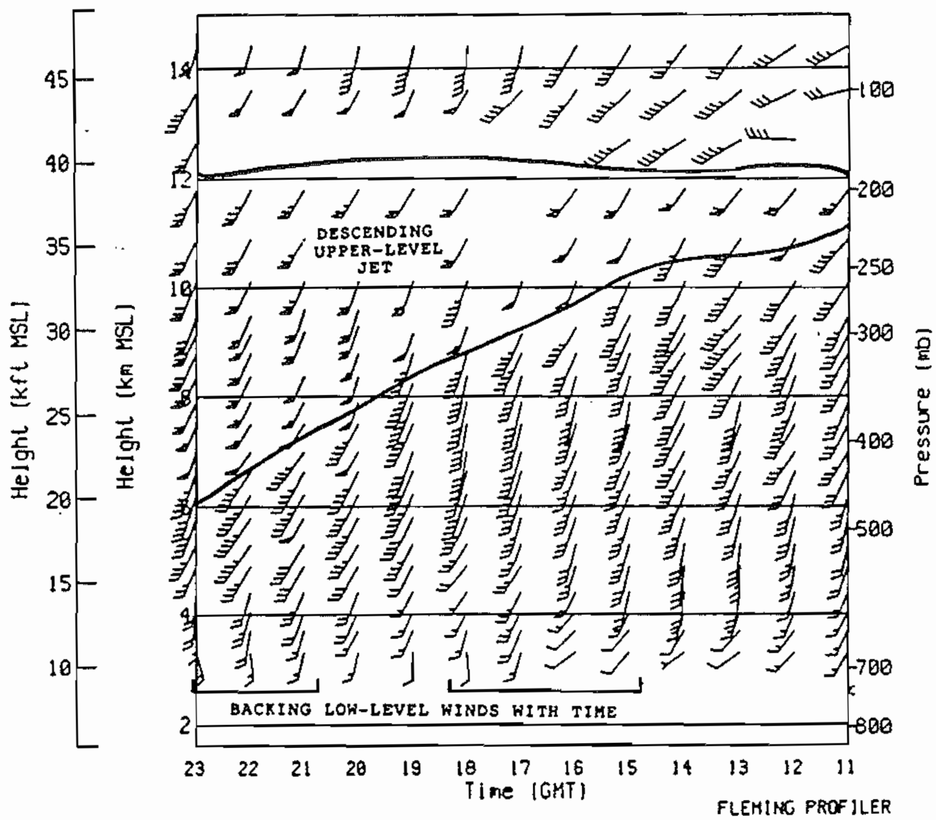

Fig. 9. "Descending" upper-level jet. From Brady and Brewster (1989).

4. Mid-level rear-inflow jets

One application of wind profiler data that should be particularly useful in much of the area covered by the WPDN is in the study of squall line structure. The profilers will allow more research to be conducted on this subject, particularly with respect to the role of the phenomenon known as the rear-inflow jet (Fig. 10), a mid-level jet that develops behind the squall line (Augustine and Zipser 1987). Eventually, air from the jet may flow into the rear of the squall line and become a source of downdraft air at the surface after it cools and sinks when precipitation evaporates into it.

Suppose one observes this feature developing in a profiler time-section upstream of a squall line (say, with thunderstorms of moderate intensity). The forecaster might assume an increasing potential over the next few hours for some of the thunderstorms in the squall line to produce damaging winds as the rear-inflow jet "catches up" with the line of thunderstorms. Not a great deal is known about this rear-inflow jet, but the WPDN should provide unprecedented opportunity for further study of this phenomenon, resulting in improved warning techniques for severe squall line type thunderstorms. Squall line storms are discussed in detail by Hane (1986).

D. Signatures of Synoptic-Scale Features

Synoptic-scale features such as fronts, troughs, ridges, and cyclones exhibit characteristic signatures in profiler time-section plots. Some of these, such as simple west to east trough passages, are easy to recognize and are well-described in the profiler training manuals. There are many more complicated scenarios, however. A knowledge of appropriate conceptual models, combined with experience, will be necessary before most forecasters develop expertise in the interpretation of profiler data. Some of these conceptual models are covered in the training manuals (# 3 and 4), while others will be developed by users who gain experience with the data.

1. Troughs

A simple west to east trough passage (no tilt with height) would generally be characterized by a wind shift from southwest to northwest, at the same time at all levels (Fig. 11). A trough tilting toward the east with height (and moving east) would show a similar wind shift, but the shift would occur earlier at higher levels (Fig. 12). A trough with a northeast to southwest orientation, moving southeast and tilting downstream with height (Fig. 13), would likely result in a wind shift from west to north (at higher levels first), or so a conceptual model would suggest.

The situation can get more complicated. With an inverted trough passing from west to east over a profiler site, a wind shift from southeast to northeast could be expected. Wind behavior due to a closed cyclonic circulation passing directly

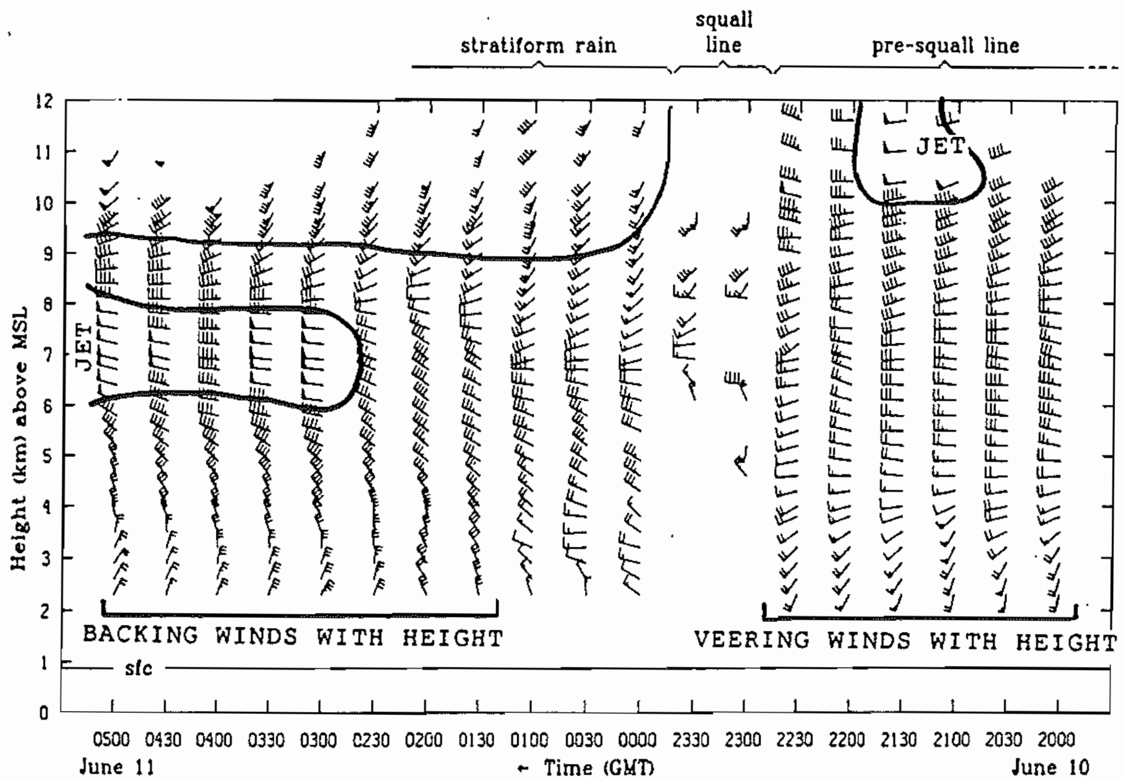

Fig. 10. Mid-level rear-inflow jet near Liberal, KS, June 10-11, 1985. From Augustine and Zipser (1987).

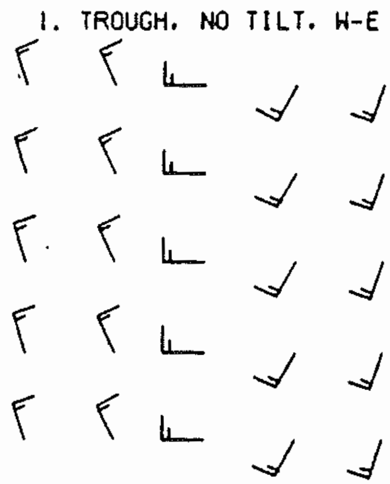

Fig. 11. Conceptual model -- vertically stacked trough moving west to east over profiler site. From Jewett and Brady (1989).

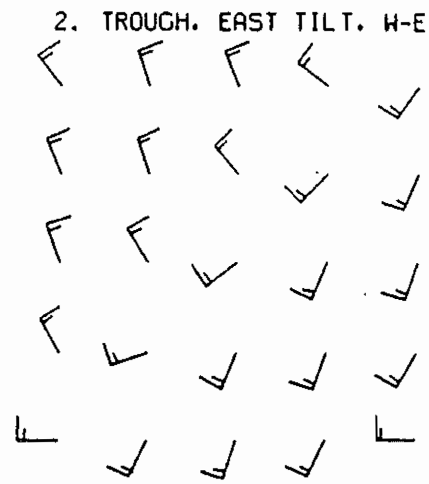

Fig. 12. Conceptual model -- trough tilting east with height, moving west to east over profiler site. From Jewett and Brady (1989).

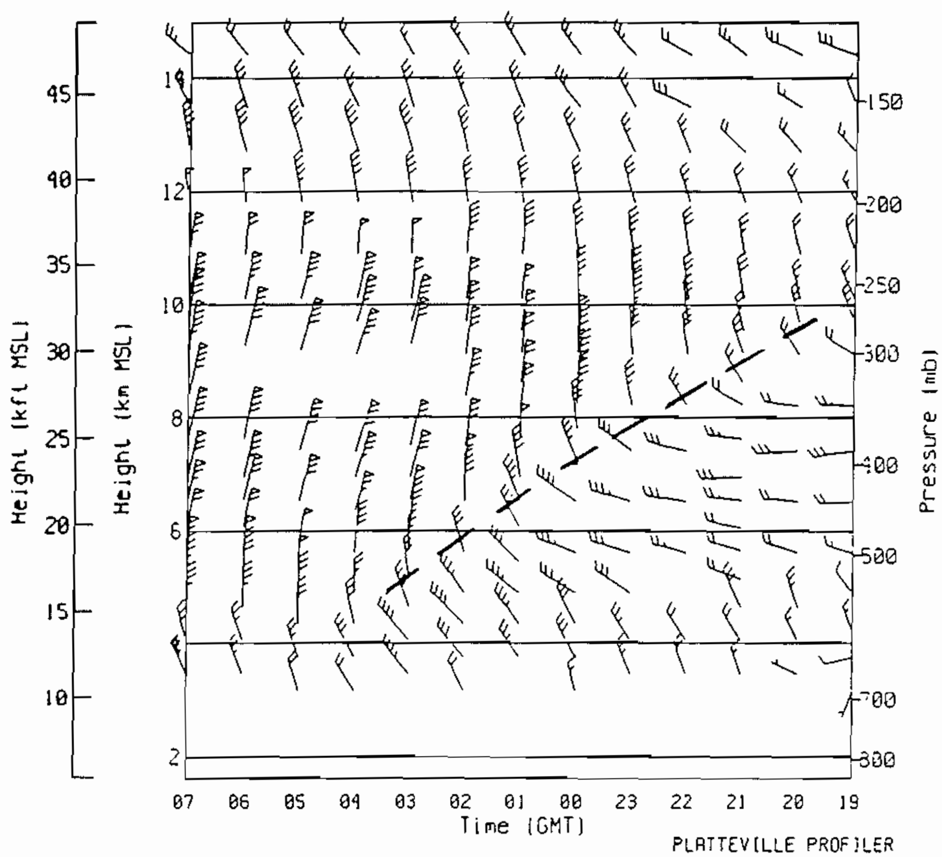

Fig. 13. Trough oriented NE-SW, moving SE (tilting downstream with height). From Jewett and Brady (1989).

over a site is easy enough to visualize, but what about one passing south of a site (moving west to east), or passing to the east of a site while moving southward (Figs. 14 and 15). It will quickly become obvious to the user that profiler time-sections will frequently have to be used in conjunction with plan view plots, as well as with data from other sources (satellite, upper air plots, etc.), if a full understanding of what is happening meteorologically is to be achieved.

2. Ridges

One can apply conceptual models similar to those discussed for troughs and lows to gain an understanding of how the movement of ridges and anticyclones will affect profiler wind displays. The typical pattern associated with an eastward moving ridge axis over a profiler site would be a backing of the wind from northwest to southwest (generally) as the ridge approaches and passes the site. The same behavior would be expected with a closed high moving eastward, but to the south of the profiler (Figs. 16, 17). An eastward-moving closed high passing north of a site would result in a veering of the wind from a general northeast to southeast direction.

A more complicated example would be an eastward-moving high, tilting westward with height, passing to the south of a site. The conceptual model in Fig. 18 illustrates this case.

3. Fronts

Profiler data are useful both in pinpointing the timing of a cold frontal passage and particularly in revealing the depth of the associated cold air mass. Fig. 19 clearly shows the passage of a cold front at Okolona, MS. Although there is much variability in the way frontal signatures appear in profiler time-sections, northwest to north winds can usually be expected following a cold frontal passage. If a "back door" front is involved, winds in the cool air may be northeast to east, or even southeast. Backing of the wind with height, in the lower levels, indicating cold advection, is usually apparent following the frontal passage (Fig. 19).

Shapiro, et al. (1984) describe examples of how profiler data can be used to analyze synoptic-scale features such as surface and upper-level fronts, as well as the mesoscale wind flow associated with upper-level jet streaks (Fig. 20).

E. Signatures of Mesoscale Features

It is well-known that unimpressive, subtle-looking short waves often help initiate significant convection in the warm season when acting in concert with other factors. Profiler time-sections reveal the vertical extent of features of all scales. The data will be especially useful in detecting small-scale features that may be well-defined primarily between the mandatory levels or between rawinsonde sites. For example, a weak short

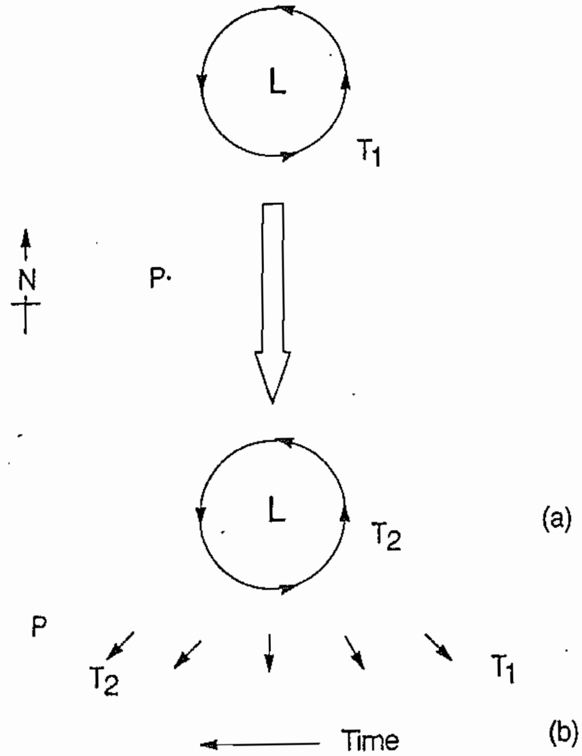

Fig. 14. (a) Schematic illustrating southward movement of a closed low to the east of a profiler site P from time T1 to time T2.
(b) Conceptual winds at profiler site P associated with the southward moving low (arrows not proportional to wind speed). From Brady and Brewster (1989).

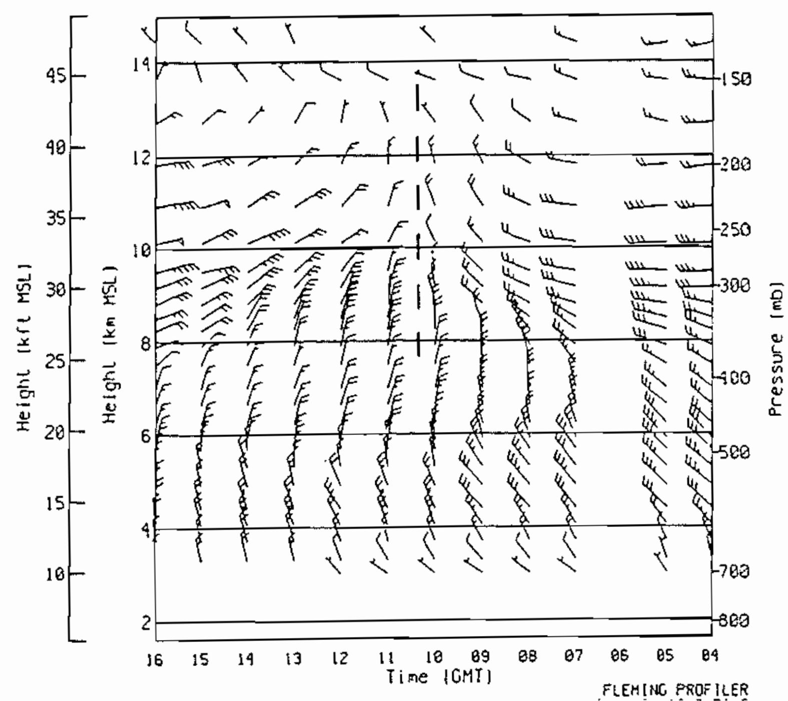

Fig. 15. Actual profiler data resulting from scenario similar to that illustrated in Fig. 14. From Brady and Brewster (1989).

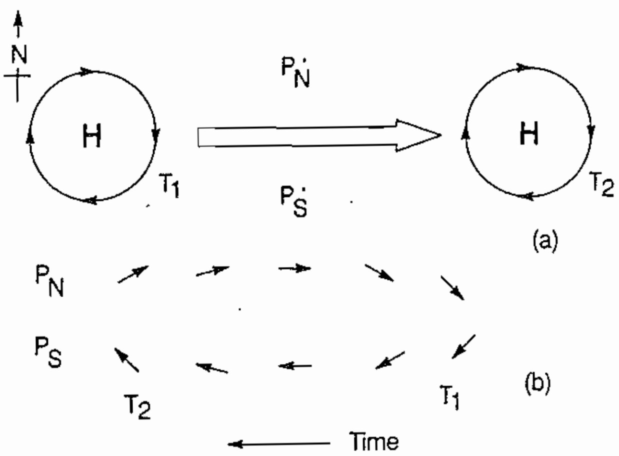

Fig. 16. (a) Schematic illustrating the eastward movement of a closed high between two profiler sites.
(b) Conceptual winds associated with the eastward moving high (arrows not proportional to wind speed). From Brady and Brewster (1989).

PROFILER AT P_N

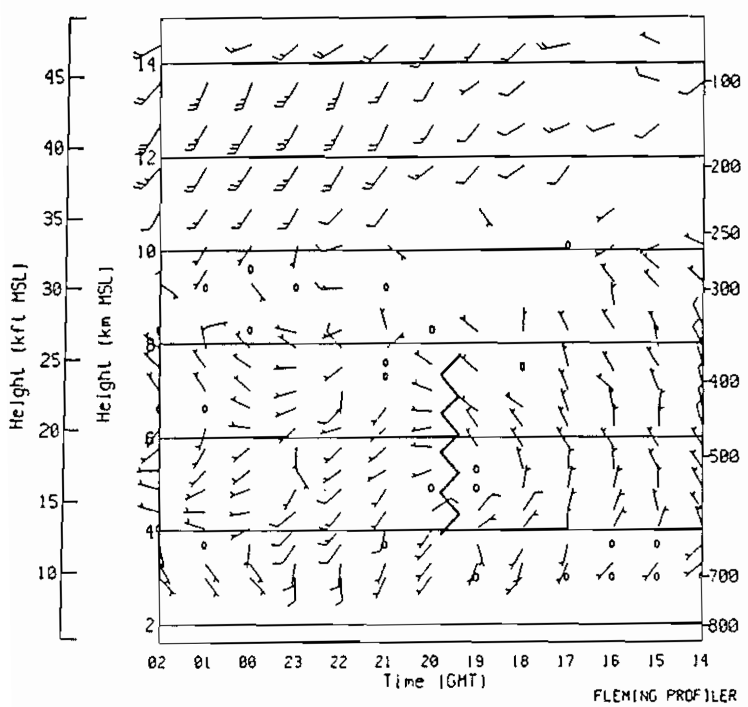

Fig. 17. Actual profiler winds resulting from scenario similar to that illustrated in Fig. 16. From Brady and Brewster (1989).

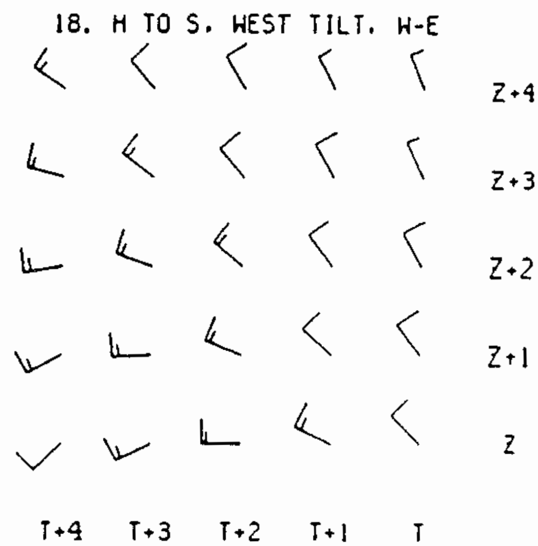

Fig. 18. Conceptual model -- eastward moving high, tilting west with height, passing to the south of a profiler site. From Jewett and Brady (1989)

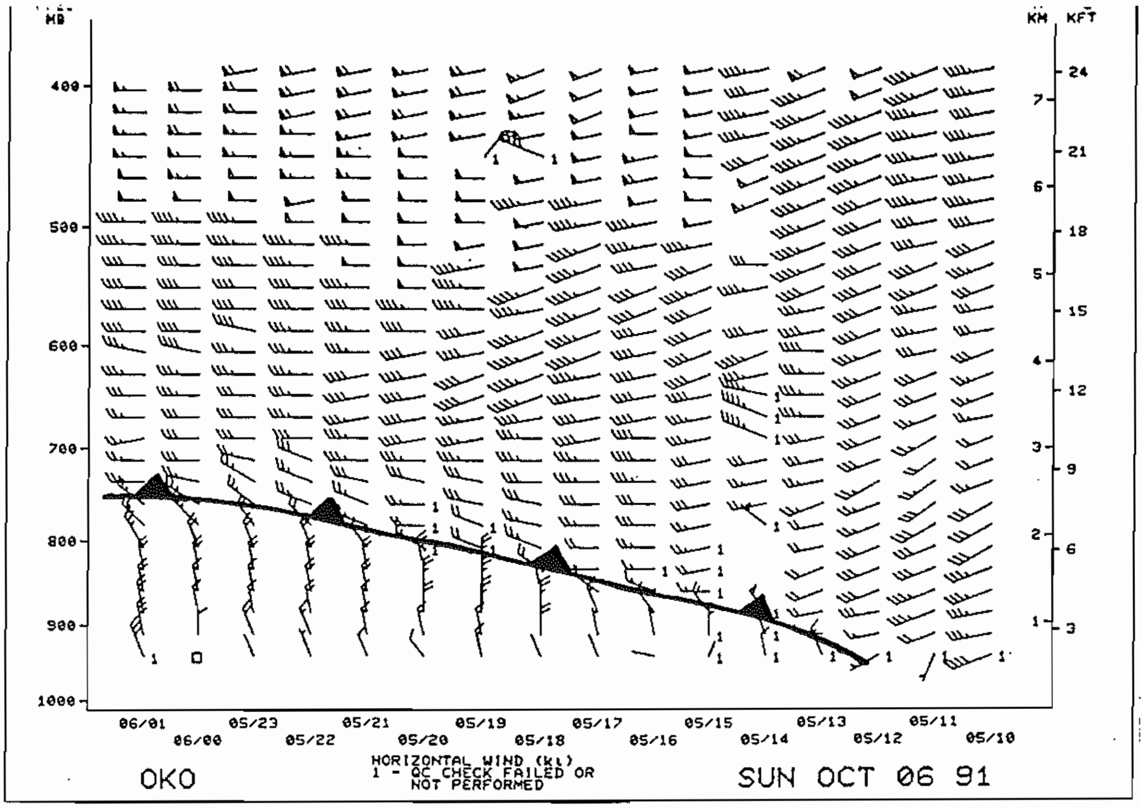

Fig. 19. Cold frontal passage at Okolona, MS. Note increasing depth of cold air with time (distinct top of cold "dome"), and backing of low-level winds with height (cold advection) during first few hours after passage of front.

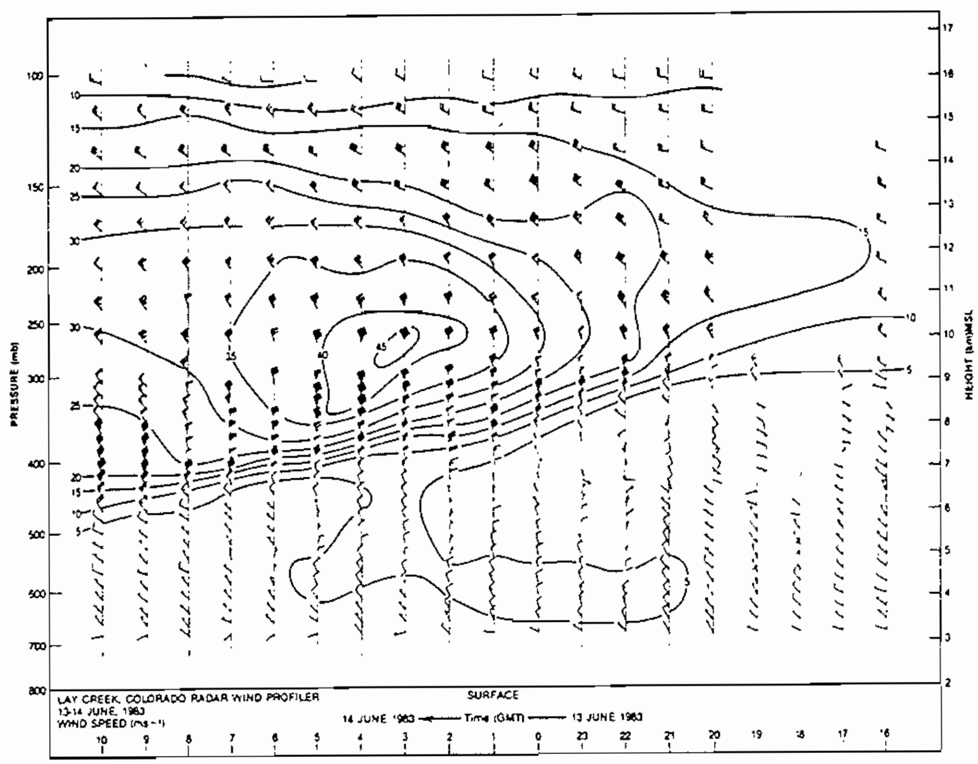

Fig. 20. Analysis of wind speed (m/sec) and wind vector plot for the Lay Creek, CO, VHF radar wind profiler June 13-14, 1983. From Shapiro et al. (1984).

wave may be evident at 600 mb in the profiler winds but not clearly indicated in the 500 mb or 700 mb rawinsonde data. Even if it were well-defined at, say 500 mb, it still might be located between rawinsonde sites and remain undetected without profiler data.

A good point to remember when using profiler data to analyze either mesoscale or synoptic-scale features is this:

Profilers represent just one of the new data sources that will provide vast amounts of information on time and space scales not seen before by forecasters. The result will be many new ***patterns*** in meteorological data that forecasters will have to learn to recognize on sight. In particular, patterns caused by significant systems - or small-scale systems that are likely to result in significant weather - will need to become especially familiar on sight if the proper response (by forecasters) is going to occur. This is where conceptual models become especially important.

F. Air Mass Diagnosis

1. Depth of air masses

Following the passage of a cold front, the depth of the cold air over a site will increase with time for a period following frontal passage, assuming the front continues moving away from the site. A decrease in the depth of the cold air mass may be an indication the front is retreating back toward the station as a warm front.

Using the profiler time-section graphics, the depth of the cold air mass (indicated by the top of the cold "dome") is easier to define in some cases than in others. Generally with a frontal passage, winds will change significantly enough through a narrow layer so that the top of the cold air mass is easily recognizable from the wind field (Fig. 19), at least for a period of hours following the passage of the front. Eventually this boundary (top of the cold air mass) will become indistinct.

2. Isentropic lift

Profiler winds showing a developing southerly flow over a shallow layer of cool air, indicating the beginning of an isentropic lifting process (overrunning), could be a valuable clue that precipitation may develop sooner than expected. All offices occasionally get caught by much earlier than expected precipitation due to overrunning. This is another example of how the increased time-resolution of the profiler data can be of importance.

3. Cold air damming

Dunn (1987) describes how profiler data (from a dense network) can be useful in identifying cold air damming along the east side of the Front Range of the Rockies and how this information can help in forecasting locally heavy snows.

Although cold air damming is not relevant for most of the WPDN area, this subject could have important implications for the future, should an expanded profiler network be implemented.

4. Sea/lake breezes

The use of profilers to study, analyze, and forecast sea breeze structure and behavior is another excellent potential application of this technology, should profilers be implemented in coastal areas (a hurricane profiler network?) in the future.

G. Model Diagnostics and Validation

Profiler data can be invaluable for confirming the existence of features forecast (or for that matter, analyzed) by the NMC numerical models. The profiler data can also reveal features that the models miss or handle poorly. Beckman (1990) demonstrates the importance of near real-time profiler (and satellite) data to supplement the rawinsonde network and operationally evaluate the performance of the NMC models.

He describes a case in which profiler winds were used operationally during a heavy snow event, with emphasis on the forecast problems of timing, location, and maximum amount of heavy snow. Fig. 21 shows an hourly time-section of profiler winds at Stapleton International Airport in Denver. Prior to 2100 UTC, there was a sharp change in wind direction near 700 mb, with north winds below this level and south winds above. Between 1800 and 2200 UTC, the upper-level winds changed from south to north indicating trough passage and deepening of the lower level cold air. In this case, the evolution of winds aloft were related to the passage -- just to the south of the profiler -- of a closed circulation tilting westward with height. The increase and deepening of the north winds at lower levels occurred in connection with the development of a new circulation center east of the profiler site. The profiler data in this case were used with real-time satellite data to enable forecasters to determine that the NGM was handling the developing snow event better than the other models.

H. Vertical Motion Diagnostics

Earlier, in the outline demonstrating the utility of the various AFOS products, it was indicated that the vertical motion (w-component) product could be used to estimate and forecast precipitation intensity. Gage and Nastrom (1985) compared vertical motion measurements using a VHF wind profiler with rainfall rates measured at two surface stations during an intense Colorado upslope spring storm. They found that subsynoptic-scale vertical motion and averaged precipitation rate over a several-hour period were well-correlated (Fig. 22), after some smoothing was applied to the small-scale temporal structure.

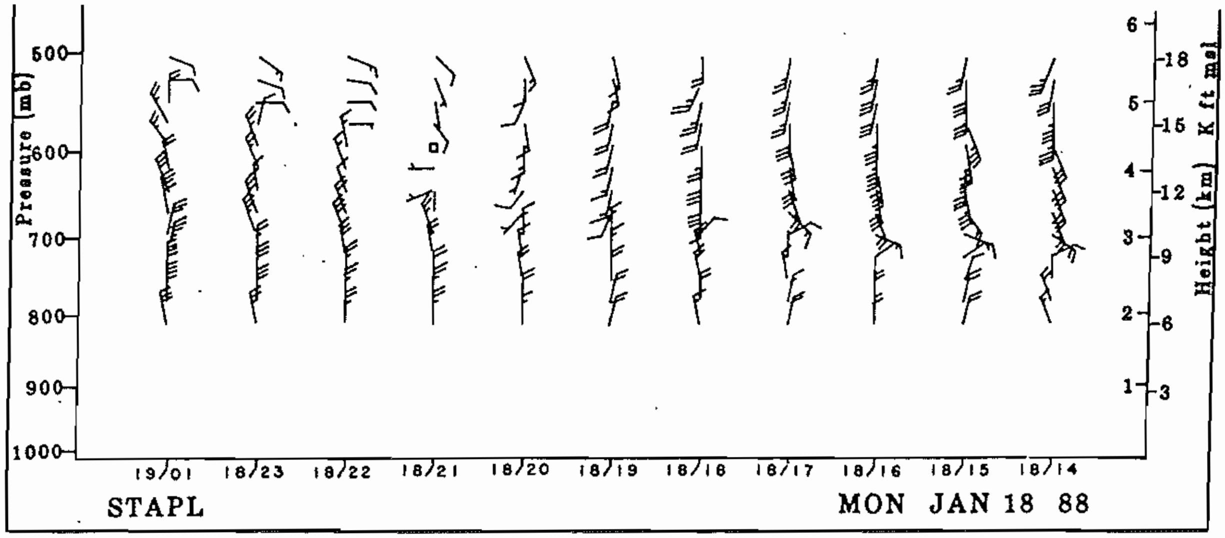

Fig. 21. Time section of winds from the Stapleton, CO, profiler January 18-19, 1988. From Beckman (1990).

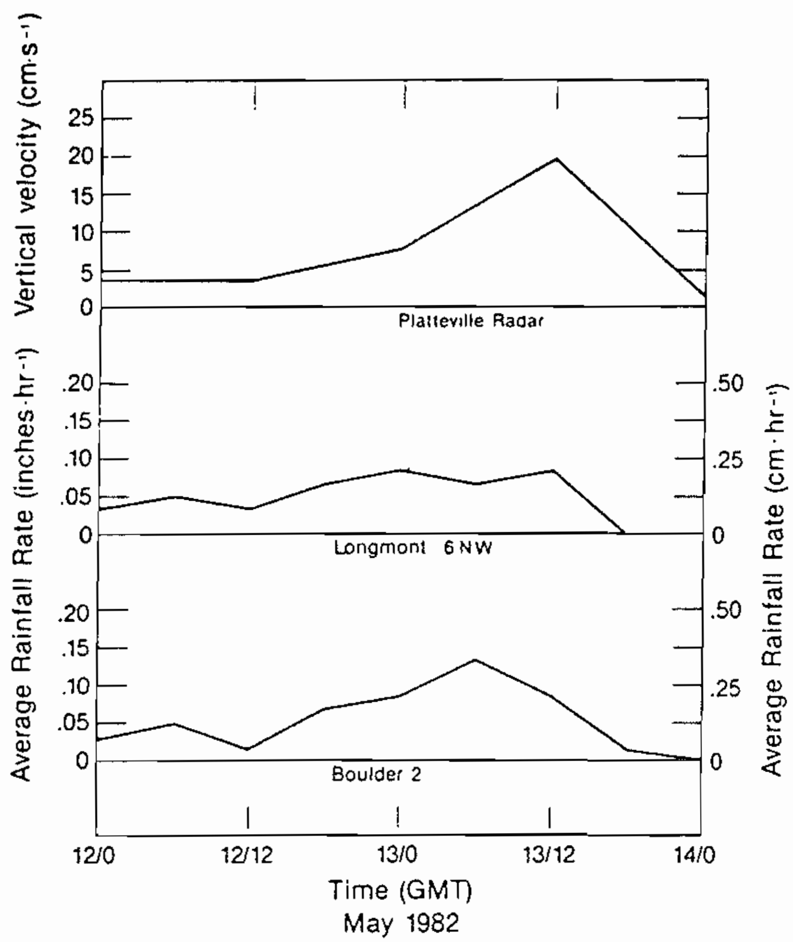

Fig. 22. Comparison of averaged rainfall rates near Longmont and Boulder, CO, with averaged vertical velocity observed at Platteville (top of figure). From Gage and Nastrom (1985).

1. Thermal advection

Thermal advection can often be inferred from horizontal time-section plots. Veering winds within a layer imply warm advection in the layer, while cold advection is suggested by backing winds. However, thermal advection can be occurring even if these patterns are not obvious in the time-section plot. As indicated in the earlier outline, the thermal wind product is useful for identifying areas of warm or cold advection (as well as the location of warm or cold air).

The perturbation wind can often help as well. In one case (Eberwine 1990), the perturbation wind revealed substantial veering winds in the lower levels (which one would expect to see with low-level warm advection), whereas the veering was not evident in the time-section plot. Consequently, the perturbation wind revealed low-level warm advection which was not suggested by the horizontal wind time-section plot. The perturbation wind product often reveals small-scale features not evident in the traditional wind field.

2. Vertical structure of vorticity advection

The time-section plot displaying derived absolute vorticity can clearly indicate the vertical structure of vorticity, unlike any other vorticity display currently in use. Therefore, this product is useful for identifying areas where PVA is increasing with height, which often results in precipitation. This is in contrast to the standard 500 mb vorticity chart, which indicates vorticity advection at only one level and therefore is a poor indicator of vertical motion when used by itself.

Since vertical motion is a function both of the change of vorticity advection with height ***and*** thermal advection (actually, the Laplacian of the thermal advection), one can get a better indication of the vertical motion field by using the profiler-derived absolute vorticity in conjunction with other data such as analyses and forecasts of vorticity advection by the thermal wind (PIVA) and analyses of Q-vectors.

Dunn (1991) discusses subjective evaluation of vertical motion in more detail (including the potential impact of numerical model gridded output on operational forecasting of vertical motion). The Q-vector approach is a better method (than either PVA or PIVA) for estimating vertical motion, but Q-vectors can be accurately generated from observed data only, and not from prognostic graphical model output. A good explanation of the Q-vector approach can be found in Sanders and Hoskins (1990).

V. DOCUMENTATION AND ASSESSMENT

As mentioned previously, about two dozen forecast offices in the Southern and Central Regions, along with their WSOs, will be involved in the formal assessment of data provided by the 29-unit WPDN. Solid, written documentation from forecasters at these offices will be essential if a future expanded profiler network is to be justified, especially with current and projected budget climates.

Profiler focal points at the WSFOs are providing written summaries every six months to a profiler assessment program leader at the Central Region Headquarters. These summaries should alert CRH to any case studies, write-ups, articles, or rules of thumb that have been developed at the WSFO. The program leader will communicate these back to all WSFOs. Local MICs and focal points should strongly encourage continued studies and other efforts to help assess profiler utility.

The State Forecast Discussion (SFD) is one of the primary vehicles for communicating ***how*** the data are used at individual offices. Profiler data should be mentioned in the SFD when used in forecast or warning preparation. When the use of profiler data actually makes a difference in the forecast (when it tells the forecaster something he or she wouldn't have otherwise known), this should be documented in writing. Profiler data may occasionally lead a forecaster astray, especially until the data become more familiar, but we can learn from that as well. The CRH profiler assessment program leader will rely heavily on reviewing SFDs.

Naturally, finding time to document these things can be a major problem in the operational environment. Case studies, some even leading to publication, are encouraged whenever possible. In addition, one page (or less) write-ups or memos, or even hand-written paragraphs, are acceptable and even appropriate for the type of information that is needed (evidence that the profilers make a positive difference).

As an example, a two-pronged effort is under way at WSFO Jackson. First, forecasters are being encouraged to produce significant event documentation with special emphasis on the application of profiler data. Secondly, all forecasters and interns are expected to participate in an effort to produce a local catalog or reference book of profiler graphic interpretation. The goal is to increase the forecasters' ability to interpret what they are seeing in the profiler data so that the data can be more efficiently integrated into forecast and warning operations.

REFERENCES

Augustine, J. A. and E. J. Zipser, 1987: The use of wind profilers in a mesoscale experiment. *Bull. Amer. Meteor. Soc.*, 68, 4-17.

Battel, G. F., M. A. Leaphart and J. T. Moeller, 1991: AFOS Profiler Software System. Draft, NWS Techniques Development Laboratory, Silver Spring, MD, 176 pp.

Beckman, S. K., 1990: Operational use of profiler data and satellite imagery to evaluate the NMC numerical models in predicting heavy snow. *Wea. Forecasting*, 5, 259-277.

Brady, R. H. and K. A. Brewster, 1989: *Profiler Training Manual No. 3 - Subjective Uses of Wind Profiler Data in Warm-Season Analysis and Forecasting*, Boulder, CO, NOAA/ERL (PROFS), 103 pp.

Brewster, K. A., 1989: *Profiler Training Manual No. 2 - Quality Control of Wind Profiler Data*, Boulder, CO, NOAA/ERL (PROFS), 39 pp.

Brewster, K. A. and T. W. Schlatter, 1986: Automated quality control of profiler data. *Preprints, 11th Conference on Weather Forecasting and Analysis*, Kansas City, MO, Amer. Meteor. Soc., 171-176.

Dunn, L., 1986: An example of subjective interpretation of network profiler data in real-time forecasting. *Wea. Forecasting*, 1, 219-225.

Dunn, L., 1987: Cold air damming by the front range of the Colorado Rockies and its relationship to locally heavy snows. *Wea. Forecasting*, 2, 177-189.

Dunn, L. B., 1991: Evaluation of vertical motion: past, present, and future. *Wea. Forecasting*, 6, 65-75.

Eberwine, J. A., 1990: Some local applications of profiler data. NWS Eastern Region Technical Attachment No. 90-10A, 11 pp.

Forbes, G. S., D. W. Thomson, J. J. Cahir, C. A. Carlson, P. J. Neiman, S. R. Williams and A. A. Person, 1989: *Analysis of significant weather on meso-alpha scales using conventional and remotely-sensed data. Geophysics Laboratory Report GL-TR-89-0179*, Air Force Geophysics Laboratory, Hanscom Air Force Base, MA, 224 pp.

Gage, K. S. and J. L. Green, 1982: An objective method for the determination of tropopause height from VHF radar observations. *J. Appl. Meteor.*, 21, 1150-1154.

Gage, K. S. and G. D. Nastrom, 1985: Relationship of precipitation to vertical motion observed directly by a VHF wind profiler during a spring upslope storm near Denver, Colorado. *Bull. Amer. Meteor Soc.*, 66, 394-397.

Hane, C. E., 1986: *Extratropical squall lines and rain bands. Mesoscale Meteorology and Forecasting*, Amer. Meteor. Soc., Boston, 359-389.

Hart, J. A. and J. Korotky, 1991: *The Sharp Workstation v1.50 - User's Manual.* 58 pp. (Available from Scientific Services Division, NWS Eastern Region Headquarters, Bohemia, NY).

Jewett, B. F. and R. H. Brady, 1989: *Profiler Training Manual No. 4 - Subjective Uses of Wind Profiler Data in Cool-Season Analysis and Forecasting*, Boulder, CO, NOAA/ERL (PROFS), 92 pp.

Kitzmiller, D. H. and W. E. McGovern, 1990: Wind profiler observations preceding outbreaks of large hail over northeastern Colorado. *Wea. Forecasting*, 5, 78-88.

Sanders, F. and B. J. Hoskins, 1990: An easy method for estimation of Q-vectors from weather maps. *Wea. Forecasting*, 5, 346-353.

Shapiro, M. A., T. Hample and D. W. van de Kamp, 1984: Radar wind profiler observations of fronts and jet streams. *Mon. Wea. Rev.*, 112, 1263-1266.

Thaler, E. R., 1991: On using wind profiler data in an operational environment. Case Study, WSFO Denver, CO, 6 pp.

van de Kamp, D. W., 1988: *Profiler Training Manual No. 1 - Principles of Wind Profiler Operation*, Boulder, CO, NOAA/ERL (PROFS), 49 pp.

Woodall, G. R., 1990: *Qualitative analysis and forecasting of tornadic activity using storm-relative environmental helicity.* NOAA Technical Memorandum NWS SR-127, 57 pp.