Analysis of Doppler Radar Windshear Data

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I. Introduction

The purpose of this program is to perform a statistical analysis of data obtained by MIT Lincoln Laboratory during FLOWS testing at Huntsville, Alabama, in the summer of 1986. The data that was provided by Lincoln Laboratory included mean velocity estimates, spectral width estimates, reflectivity estimates, signal to noise ratio and other key radar parameters. The analysis performed included an evaluation of windshear event spectral characteristics, a statistical summary of the events examined, a correlation analysis among different data fields, and estimation of F-factor for all isolated events. Seven distinct meteorological events were examined, six representative of microburst activity and one representative of gust front activity.

The motivation for such analysis arises from conflicting reports regarding the spectral characteristics of windshear events. In particular, the spectral width estimates are said to lie anywhere from 1 m/s to 4 m/s. As large spectral widths can significantly degrade many processing algorithm's performance, it is important to try to add statistical validity to preliminary results already obtained. An analysis of a single near event as part of a separate SBIR Phase I effort yielded an average spectral width estimate of 1.5 m/s for events.

II. Objectives

1. Collect Lincoln Laboratory Data For Multiple Events

The objective of this analysis is to process Lincoln Laboratory doppler radar data to characterize windshear events. The processing includes plotting velocity and F-factor profiles, histogram analysis to summarize statistics, and correlation analysis to demonstrate any correlation between different data fields. The data fields examined include velocity, spectral width, signal to noise ratio and reflectivity.

The first objective in performing the analysis is to obtain data from Lincoln Laboratory. The data was collected using the FL-2 radar in Huntsville, Alabama as part of FLOWS testing during the summer of 1986. A principle objective in trying to add statistical validity to preliminary results is to examine multiple events where each event represents as strong an event as is available. In addition, it is desirable for the events to be well distributed in terms of range from the radar, reflectivity and size.

1. Airborne Weather Radar For Windshear Warning, SBIR Phase I Final Report, Sierra Nevada Corp., F. Williams, 10 July 1987
2. Characterize Events And Quantify Key Parameters

Once the data is obtained, the next objective is to isolate the events. This objective involves more than simply examining the data at the documented time and location, as the available documentation only gives a coarse location during one snapshot of the events evolution. Each event has multiple scans, at different times, during the event's development. Adding to the difficulty is the large amount of data being examined, and the relatively small portion of the data that contains event activity. For this program, for example, 1.65 GBytes of data were examined to yield less than 50 MBytes of event data, a ratio of only 3%. For these reasons, each meteorological occurrence, an event, is broken down into subevents which have similar characteristics. A subevent is a set of well matched rays scanning the event, with similar scan time, azimuth and velocity profile. Velocity profile plots are used to interactively evaluate the shear character of each ray of radar data, and those rays with common profiles, strengths, size, location and time are grouped together as subevents. A ray is a single slice of data at any given orientation of the radar. A ray is made up of data points at each range bin, where each data point is a velocity estimate (or other data field) for that range bin. It is estimated that each ray is actually an average of 100 pulsed transmissions from the FL-2 radar.

The primary objective of analyzing the multiple events thus identified is to characterize the spectral width of windshear events, and to compare such estimates with non-event data collected during the same period by the same radar, as well as with preliminary results already obtained. Such a spectral width characterization will help define the turbulent nature of windshear events, which affects the radar signal processing algorithm's ability to calculate accurate velocity estimates, from which shear strength estimates are derived.

A secondary objective is to statistically summarize the range of velocities, reflectivities, signal to noise ratio, F-factor, event size and strength, and other key parameters encountered in windshear events. Such a summarization will add insight into the composition of typical events. These statistics will also be compared to similar results for non-event data.

3. Obtain Insight Into Lincoln Lab Data Processing Algorithms

Another objective is to learn as much as possible from Lincoln Laboratory personnel about their processing technique, including the type of averaging used for data field estimation, the criteria used for calculating event size and strength, and the type of ground clutter filtering used in the FL-2 radar.

4. Perform New Analysis (Correlation Analysis And F-factor)

A final objective is to perform a correlation analysis to demonstrate coupling between different data fields. Such an
analysis should demonstrate any dependencies between data fields, and may be used to predict the performance of certain parameters as a function of independent variables.

Included in these analyses is a calculation of F-factor for all identified events and subevents. F-factor is a nondimensional parameter that quantifies the total impact on an aircraft that might encounter the windshear event. F-factor uses both lateral shear estimates as well as downdraft components in its derivation. One approach is to use Range Height Indicator (RHI) color plots at relatively high elevations to calculate the downdraft component of the velocity field using the cosine of the included angle. This crude approach will be attempted in the current analysis.

III. Work Carried Out

1. Obtaining Data

Data comprising nine events with shear strength of 9 m/s/km or greater, covering ranges from 2 km to 60 km, and with a mix of RHI and PPI color plots available, was requested from Lincoln Laboratory. These events are summarized in Figure 1, based on documentation provided by Lincoln Laboratory. Of the nine requested, seven distinct events, with accompanying color PPI and RHI plots, were delivered. The data shortage has been attributed to incorrect information in the documentation supplied to LaRC by Lincoln Laboratory, from which SNC's original request list was generated. According to the technical representative at Lincoln Laboratory that filled SNC's data request, the missing events do not exist. The seven delivered events are summarized in Figure 2, as are the search regions derived from a review of the associated color PPI plots. The seven delivered events cover a range of 3 km to 47 km, with shear strengths reportedly from 9 m/s/km to 14 m/s/km. The key radar parameters for the FL-2 radar as used during FLOWS testing are summarized in Figure 3. Appendix A includes plots of the scan pattern for each event (azimuth vs. time during event scan periods).

For the seven events analyzed, 20 subevents were identified, with a total of 295 individual azimuth rays. Each subevent averages 42 rays, and each event averages 3 subevents. Note also that for clarity in presentation, within each subevent those rays whose velocity profiles were nearly identical were grouped together, averaged, and plotted as a single line. Thus, although a subevent may average 42 rays of data, the subevent velocity profiles will only show two to four lines. Typically, each line shown on a velocity profile plot is made up of 17 rays of data. Figure 4 summarizes the events locations for the seven events analyzed.
2. Isolating Events

The procedure used to isolate and define the event regions, which for this data comprised less than 3% of the data examined, is outlined below:

a) Likely areas where events are located are determined based on color PPI plots supplied by Lincoln Laboratory. These designated areas are converted to the SNC data structure and downloaded onto hard disk from tape.

Sample color plots are presented in Figures 5, 6, 7 and 8. These plots show a PPI scan of Event 4, with estimates of velocity, spectral width, reflectivity, and signal to noise ratio, respectively. The event is clearly seen in Figure 5 as the area between the green and red regions of concentrated color, at approximately 20 km and an azimuth of 245 degrees. The different colored regions surrounding a small zero velocity field are indicative of outflow from microburst activity.

b) Program FILTER examines the designated area and outputs the maximum shear for each ray of data, for all rays whose shear exceeds a minimum threshold input at run time (typically 5 m/s/km). Output includes a filtered window of data demonstrating event trends (as output from a recursive low pass filter, k=.2), raw data surrounding the window, and header information. This output is used to more precisely locate the event, in terms of volume and ray numbers (which are needed to search the event data base). The data is also used with color PPI plots and other documentation to verify event location.

c) Once likely target areas are isolated with FILTER, program FILT_RAY is used to examine these areas more closely. FILT_RAY will output all shear regions that exceed the input threshold, without limiting the number of shear regions per ray. This output is thus much more voluminous than the output from FILTER, and is used to precisely locate the "center" point (in space and time) of the events development.

d) Once the center point has been determined, data segments of each field are converted to PRO_MATLAB format using GET_DAT. These .MAT files have a limitation of 8188 elements, and as such GET_DAT converts 4143 elements from either side of the isolated center point. In this case, "on either side" refers to before and after the time of the center point, while staying within range bin and ray number constraints. These geometric constraints are also input at GET_DAT run time, and are limited to the more coarse, but similar, limits applied during the initial search with FILTER.

e) The .MAT files generated using GET_DAT are loaded into PRO_MATLAB for evaluation. This interactive evaluation is used
to isolate the data segments that will define the "event". PRO_MATLAB's graphics, digital filtering, histograms and other tools allow this investigation to be relatively timely. Based on PRO_MATLAB review, the event constraints should be well defined. If, however, the review indicates that there is more event activity outside the current .MAT region, new regions are defined and GET_DAT used to convert the new regions to .MAT format. This iterative process continues until the event is defined.

f) Once the event is defined, profile plots are generated to aid in analyzing the event. These 2-D plots show independent parameters vs. range (range bin number), with multiple rays overlayed. The overlay allows a more general characterization for a reasonable azimuth slice. Three dimensional mesh plots are also available to characterize the entire event, and are generated to show the velocity field for a range of azimuths.

This procedure is used to define all event segments. Once these segments have been isolated, they are grouped based on time, event character and location, into subevents. To better characterize subevents for moving events, the subevent rays are displaced whatever small range amount is necessary to allow the crossover range positions (where the velocity changes from positive outflow to negative outflow) to coincide.

3. Analyzing All Available Data

As the events and subevents are being identified and downloaded to SNC format, the statistical analysis of all available data, termed the Non-Event Data, is performed.

Histogram analysis of all data received from Lincoln Laboratory is conducted to realize a statistical summary of the type of data being reviewed. This analysis simply runs through all the data received (approximately 1.65 GBytes), ignoring data points annotated as "missing or deleted", or data points whose SNR is less than 10db. Histograms are generated for each field, VE, SNR, SW, and DBZ. The program HIST generates the histogram files and calculates the mean and standard deviation based on selected data regions. The program MERGE_HIST merges multiple histogram files in order to generate histograms for very large data segments, or data from a variety of files. TRANS_HIST translates the histogram data into .MAT format, and scales the data for plotting. The histograms are plotted and printed using PRO_MATLAB.

4. Analyzing Event Data

The next analysis conducted is of the event data, as follows.

i) Velocity Profiles

The events are analyzed on a subevent basis, as well as a composite for each event and for all events.
ii) Histogram Analysis

The histogram analysis performed on non-event data is repeated for the event data. This allows a comparison of the differences in the environment surrounding an event vs. during the event.

iii) F-factor Profiles and Histograms

The F-factor for Delta VE samples between adjacent range bins for each event are calculated and a histogram generated. The histogram shows the number of occurrences for a given range of F-factor, and the maximum F-factor encountered. The F-factor is calculated based on the following formula:

\[ F = \frac{\Delta \text{VE}}{\Delta r} \cdot \frac{V}{g} \]

where: \( \Delta \text{VE} \) is the change in radial velocity between adjacent range bins;
\( \Delta r \) is the change in range between adjacent range bins;
\( V \) is the airspeed (taken to be 150 knots);
\( g \) is gravity.

Color RHI plots are presented in Figures 9, 10, 11 and 12 of Event 4 at azimuth slices of 242, 243, 244 and 245 degrees. The vertical axis in these plots is height above sea level, in 5 km grids. By examining the zero elevation rays, one can see the outflow region of the microburst (approximately 20 km). By examining the region above this outflow, for example at 20 km of range and 2.5 km of height (-8000 ft), one can try to estimate the velocity vector oriented toward the radar, and from this calculate the downdraft component. However, since the radial velocity component includes both the horizontal and radial components of the downdraft this estimate would be difficult to calculate and may not be accurate.

iv) Correlation Analysis

A correlation analysis is performed to study the effects of the various data fields due to VE, range, DBZ, and storm size. For VE, range and DBZ, the study is performed on a subevent and event basis, with a composite result for all events also generated. For storm size, the study is simply performed for all events. Program CORR determines the following functional relationships:
Dependent Variables | Independent Variables
---|---
SW, DBZ, SNR | VE
SW, DBZ, SNR | Range
VE, SW | DBZ
VE, SW | Event Size

TRANS CORR converts the results to .MAT format, and the plots are generated and printed using PRO_MATLAB.

5. Interacting With Lincoln Lab Personnel

Based on an interaction with Lincoln Laboratory personnel, it was determined that the FL-2 radar uses a 39 pole FIR high pass filter with an estimated cutoff of 1.5 m/s for ground clutter suppression. The coefficients are described in the publication "Ground Clutter Cancellation For NEXRAD"\(^2\). It was also determined that the criteria Lincoln uses for detecting windshear activity is 2.5 m/s/km. Other criteria, such as how the event size and strength are defined, was not known by the personnel contacted. It has also been estimated that approximately 100 pulsed radar transmissions were averaged for every ray of data estimates.

IV. Results

1. Velocity Profiles

Figures 13 through 27 present the velocity profiles for all 20 subevents making up the seven events. In Figure 13 for example, subevents 1a and 1b are shown. In Figure 14, subevent 1c and a composite of all three subevents that make up Event 1 are shown. For each velocity profile shown, there are two plots. On the left is the actual velocity profile for all rays being examined. Again, note that for clarity of presentation each line shown is typically a composite of 17 rays of data. Note also that these individual lines have been shifted slightly in range so that their positive to negative velocity crossover points coincide. This is to compensate for the movement of the event during its evolution, and for typical microburst activity this adjustment did not exceed one or two range bins. On the right of each set of figures is the average of the individual plots on the left.

2. Ground Clutter Cancellation For The NEXRAD System, J.E. Evans, 19 October 1983, Lincoln Laboratory Report ATC-122
useful for characterizing the shear strength of the event and for F-factor calculations.

Figures 25-27 show the velocity profiles for Event 7. Note that event seven is representative of gust front activity, while the other six events are representative of microburst activity. The differences are readily apparent by examining Figure 28. As shown, the movement of this event during its evolution is substantial. The movement of the event center by three kilometers took less than four minutes. The typical microburst examined would have moved less than one half of one kilometer in the same time.

Also shown in Figure 28 is the aliasing that was evident in Event 7 data. In this event the radar had a PRF of 700 which gave an unambiguous velocity limit of +18 m/s. As the velocity estimates exceeded this limit, they would fold over into the other end of the spectrum. Thus velocities of -30 m/s would show up as approximately -6 m/s. This required that for Event 7 an automatic de-aliasing algorithm be incorporated into the data retrieval software.

Though Event 7 is representative of gust front activity rather than microburst activity, it was examined in the same manner, where possible, in order to compare results. Note that the data from Event 7 was not incorporated into the All-Event data.

Different techniques can be used to calculate the event’s shear strength and size. Figure 29 summarizes such information based on a peak to peak measurement. The maximum and minimum velocity estimate locations on either side of the divergence are located, and the distance between them used to estimate event size. Their velocity difference divided by the event size gives the shear strength estimate.

Using a peak to peak technique tends to lower the magnitude of both size and strength estimates. A method that bases its estimates on the stronger shear region near the divergence point has been used to generate the tables in Figures 30 and 31. For both tables, the shear strength is measured on a bin to bin basis, starting at the point of divergence, and moving in opposite direction away from that point one pair of range bins at a time. In this manner, the maximum instantaneous shear location can be found (not necessarily the point of peak velocity), and a moving average can be generated to demonstrate the weakening of the shear strength as one is further removed from the point of divergence. Figure 30 presents such data as a moving average, with each subsequent range bin pair equally weighted in the calculation of the mean. Figure 31 presents the instantaneous shear for any given range bin pair, with no averaging. Using these two tables, an algorithm could be generated to automatically estimate shear strength, perhaps by monitoring the rate of change of the averaged shear strength estimate, or other method.
2. **Histogram Analysis**

Figure 32 shows the histograms for VE, SW, DZ and SNR for all (Non-Event) data. Figure 33 shows the same histograms for events one through six combined. Appendix A contains the same histograms for each event and subevent. Note that data fields whose SNR was below 10 dB were not included in the analysis.

Figure 34 summarizes the mean values for all data fields, and F-factor, for all event and nonevent data.

Figures 35 through 38 summarize the first four moments for all event, subevents, and nonevent data, for the four data fields analyzed (VE, SW, DZ, and SNR, respectively). These calculations present information about the distribution of the data, as otherwise shown in the histogram plots.

3. **F-factor Analysis**

Figures 39 through 46 show the instantaneous radial component of F-factor profiles for each event and subevent. These calculations were performed on a bin to bin basis, assuming an aircraft airspeed of 150 knots, with no averaging of multiple adjacent (along a ray) bins. Included in Appendix A are similar plots for all events that show the effects of averaging 2 adjacent range bins (along a ray) per point, and 3 range bins per point. Such averaging is representative of the effects low pass filtering may have on real time F-factor calculations. No azimuthal (spatial) averaging was performed. Note that these F-factor profiles only include the radial component of F-factor.

Figures 47 through 54 show the combined F-factor histograms for all subevents, as well as the combined histograms for each event. Shown on each histogram are two additional vertical lines; the solid line is the characteristic F-factor for the event or subevent, whose value is also given at the base of each plot, and the dashed line is the approximate F-factor level considered hazardous, given as .12. The radar, however, measures only the radial component of the hazard, while .12 is a threshold level including the vertical component. Therefore, a threshold level for the radial component only would be lower than the hazard level used here. The velocity profiles of Figures 13 through 27 were used to determine the characteristic F-factor for each event, by first determining a characteristic shear strength line. Included in Appendix A are the velocity profile plots showing the shear strength line used to calculate the characteristic F-factor. Note that for this analysis, the characteristic shear strength was found graphically (see Appendix A), rather than using the peak to peak or moving average methods described earlier.
4. Correlation Analysis

Figure 55 contains a table which summarizes the trends evident in the correlation analysis. As described therein, there are only four relationships examined which appear as though they may be correlated, i.e., SW vs. DZ, SW vs. range, DZ vs. range, and SNR vs. range. These four correlation functions are plotted in Figures 56 through 63 for all events. These plots are scatter plots which show the dispersion of the raw data, with an average line overlayed. Appendix A contains two additional sets of correlation plots. The first set contains the same set of correlation functions as in Figure 56 through 63, but for the twenty subevents. The second set contains those correlation functions that were also examined, but appear to be uncorrelated, for all subevents and events. The other correlation functions examined include SW vs. VE, SN vs. VE, DZ vs. VE, and VE vs. DZ.

Finally, Figure 65 contains the remaining two correlation functions that were examined, and are for all events. Shown are VE and SW as a function of event size. All subevents were characterized for average values of VE and SW from the histogram analysis, and their size was characterized from the velocity profile plots.

V. Conclusions

The range of conclusions that can be drawn from the analysis presented herein exceeds the scope of this report, but there are some preliminary conclusions that should be addressed.

1. Comparing Event vs. Non-Event Data

When comparing event data with nonevent data, the mean value of the spectral width estimate does not change appreciably. As shown in Figure 34, the mean value of SW for event data is 2.047 m/s, while for nonevent data it is 1.847 m/s. This result indicates that the 1.5 m/s mean from the Phase I SBIR analysis was slightly lower than for most events. In that analysis, it was speculated that the spectral width estimate, which is made up of components due to antenna motion, turbulence, non-uniform flow fields, and varying sized rain cell volumes, is dominated by the non-uniform flow fields associated with microburst activity in the outflow region. This analysis neither confirms nor rejects such an hypothesis, but the trend of similar or slight increase in spectral width estimate for events when compared to nonevents is confirmed.

Also as shown in the Phase I SBIR study, events tend to have greater reflectivity than nonevents. The mean reflectivity for events for this analysis was 40 dBz, while the mean reflectivity for nonevents was 25 dBz.
Velocity estimates lie within ±20 m/s for events, with a mean of 2.5 m/s, while nonevents range from ±20 m/s with a mean of -2.06 m/s. Note that the mean velocity estimates for all events is the average of the absolute value of each event's mean velocity, with each event receiving equal weighting. The signed average for events would be -1.2 m/s.

One interesting trend that does differ from the Phase I study is the similarity between distributions of event data and nonevent data for velocity and spectral width estimates. In the Phase I study, the velocity distribution for nonevent data was fairly normal, with a zero mean, while the velocity distribution for event data was skewed toward 10 m/s. In this analysis, both distributions appear normally distributed, centered around zero. This difference is attributed to the larger amount of event data examined, which should tend to have a normalizing effect.

2. Trends Evident In Correlation Analysis

i) SW vs. DZ

As shown in Figures 32 and 33, events have greater SNR than nonevents. The mean SNR estimate for events is 50 dB, while for nonevents the mean is 30 dB. This is attributed to the greater reflectivity apparent during events compared to during nonevents.

ii) SW vs. Range

Figure 63 shows each event's spectral width plotted vs. range. A review of this figure shows that while spectral width estimates do increase with range, the increase is not as great as expected. Such an increase was expected based on the increased volume contained within each range bin and the non-uniform velocity profiles of the outflow. It is difficult to reach a conclusion here because there are so few events and they have such varying ranges.

iii) DZ, SN vs. Range

Figure 64 shows SNR decreasing with range and otherwise following the reflectivity curve. SNR should vary as a function proportional to reflectivity, and inversely proportional to range squared. As range increases, SNR estimates decrease; at the point that DZ drops dramatically (approximately 30 km) SNR also drops at a higher rate than simply due to increasing range. By correlating the SW vs. range graph with the SNR vs. range graph, one can see that as SNR decreases, SW estimates increase, though slightly. Again, the size of the increase (SW only varies by approximately 1 m/s over 45 km) is attributed to the fact that there are many sources contributing to the SW estimate.
VI. Recommendations

Any recommendations derived from this analysis are limited to future use of the processed data, or other work that can be conducted based on the results presented herein. For these reasons, the recommendations given below do not address specific applications of this analysis.

The data processed in this report could be used to develop and test windshear detection algorithms. As the nature of such events has been better characterized, particularly the spectral width estimates, design criteria for detection algorithms in terms of detection thresholds and false alarm rates can be defined.

The data analyzed from FLOWs testing is of course all ground based data. One possible extension to this analysis is the extrapolation of the ground based data to the airborne case. A potential method for doing this would be to generate simulated I,Q data based on the spectral characterization presented. By reverting back to the time domain, assuming a normal noise distribution, one could add in a bias that would model the effects of ground clutter. Additionally, one could add in the effects of a moving platform. Once all these new effects were modeled in the time domain, the simulated data could be used to test pulse pair processing, or other, algorithms for the airborne case.

Should the opportunity present itself, it is highly recommended that real I,Q data be collected of windshear events, allowing different algorithms to be tested for ground clutter filtering, pulse pair processing or FFT type spectral characterization, etc. Raw I,Q data would be a distinct advantage compared to estimates based on pulse pair processing, as complete flexibility would be retained in terms of processing options that could be tried.
## Lincoln Laboratory Event Description Data

<table>
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<th>Size</th>
<th>Reflect.</th>
<th>Strength</th>
<th>RHI/PPI</th>
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Figure 1
Event Data Supplied By Lincoln Laboratory

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The data as originally supplied by Lincoln Laboratory was contained on eleven 6250 bpi magnetic tapes, totaling approximately 1.65 GBytes of data; the actual event data that was recovered from these tapes totaled less than 50 MBytes of data (less than 3% of the total).

Figure 2
### Radar Parameters Table

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### Constant Parameters

- **Frequency**: 2.88 GHz
- **Horizontal Beam Width**: .96°
- **Vertical Beam Width**: .96°
- **Pulse Width**: .8 usec
- **Latitude**: 20.92°
- **Longitude**: 52.31°
- **Antenna Diameter**: 28 ft
- **Transmitter Power**: 1.1 mw
- **Pulse Repetition Frequency**: 700 to 1200
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Event 1a

Range (km) - Mean Velocity = 2.262

Event 1b

Range (km) - Mean Velocity = -1.364

Event 1a

Range (km) - Event Size = 6.8 km

Event 1b

Range (km) - Event Size = 2.4 km

Fig. 13
Event 1c

Range (km) - Mean Velocity = -0.8951

Range (km) - Event Size = 3.48 km

Event 1

Range (km) - Mean Velocity = -0.7024

Range (km) - Event Size = 3.36 km
Range (km) - Mean Velocity = -1.698
Range (km) - Event Size = 10.2 km
Event 3a

Range (km) - Mean Velocity = -1.939

Range (km) - Event Size = 10.2 km

Event 3b

Range (km) - Mean Velocity = -2.43

Range (km) - Event Size = 12.12 km
Event 3a

- Mean Velocity = -1.47

Event 3b

- Mean Velocity = -2.01

Event 3c

- Mean Velocity = -2.01

Event 3d

- Event Size = 7.7 km

Event 3e

- Event Size = 8.04 km
Event 4a

Range (km) - Mean Velocity = 4.054

Event 4b

Range (km) - Mean Velocity = 2.056

Event 4a

Range (km) - Event Size = 7.68 km

Event 4b

Range (km) - Event Size = 8.52 km

Fig. 19
Event 4c

Range (km) - Mean Velocity = 1.788

Range (km) - Event Size = 9.84 km

Event 4

Range (km) - Mean Velocity = 2.633

Range (km) - Event Size = 9.96 km

Fig 20
Event 5a

Range (km) - Mean Velocity = -3.362

Event 5b

Range (km) - Mean Velocity = -5.74

Range (km) - Event Size = 5.64 km

Range (km) - Event Size = 3.96 km
Range (km) - Mean Velocity = -4.313

Range (km) - Event Size = 3.96 km
Event 6a

Range (km) - Mean Velocity = -0.4546

Event 6a

Range (km) - Event Size = 4.56 km

Event 6b

Range (km) - Mean Velocity = -1.657

Event 6b

Range (km) - Event Size = 4.56 km

Fig 23
Event 6

Range (km) - Mean Velocity = -1.056

Range (km) - Event Size = 4.56 km

Fig 24
Event 7a

Range (km) - Mean Velocity = -12.29

Event 7b

Range (km) - Mean Velocity = -10.62

Event 7a

Range (km) - Event Size = 6.6 km

Event 7b

Range (km) - Event Size = 5.16 km

Fig 25
Event 7c

Range (km) - Mean Velocity = -15.09

Range (km) - Event Size = 11.4 km

Event 7d

Range (km) - Mean Velocity = -12.26

Range (km) - Event Size = 5.52 km

Fig 26
Range (km) - Mean Velocity = -7.977

Range (km) - Event Size = 7.2 km

Range (km) - Mean Velocity = -12.3

Range (km) - Event Size = 8.42 km

Fig 27

ORIGINAL PAGE IS OF POOR QUALITY
### Peak to Peak Measurements

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Fig 29
### Average Event Shear Strength (m/s/km) Starting At Crossover Point

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*Figure 30*
### Instantaneous Event Shear Strength (m/s/km) Starting At Crossover Point

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Fig 33
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**All Events**

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**Non-Event**

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**Fig 34**
## Event Statistics (VE)

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Fig 36
### Event Statistics (DZ)

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| Non Events | 25.2157 | 193.8815 | .1684 | 2.0994 |

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**Fig 37**
### Event Statistics (SN)

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**Non Events**

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Fig. 38
Event 1a (1 Range Bin(s) / Point)

Event 1b (1 Range Bin(s) / Point)

Event 1c (1 Range Bin(s) / Point)

Event 1 (1 Range Bin(s) / Point)

Fig 39
Event 2a (1 Range Bin(s) / Point)

Event 2b (1 Range Bin(s) / Point)

Event 2 (1 Range Bin(s) / Point)

Fig 40
Event Ga (1 Range Bin(s) / Point)

Event Gb' (1 Range Bin(s) / Point)

Event 6 (1 Range Bin(s) / Point)

Fig 44
Fig 45 Range (km)
Event 7e (1 Range Bin(s) / Point)

Event 7 (1 Range Bin(s) / Point)

F Factor

Range (km)

F Factor

Range (km)

Fig 46
F Factor Event 2a

Characteristics Factor = 0.0394

F Factor Event 2b

Characteristics Factor = 0.0944

F Factor Event 2

Characteristics Factor = 0.0472

Fig 48
F Factor Event 4a

Normalized Occurrences

Characteristic Factor = 0.0897

F Factor Event 4b

Normalized Occurrences

Characteristic Factor = 0.0866

F Factor Event 4c

Normalized Occurrences

Characteristic Factor = 0.0551

F Factor Event 4

Normalized Occurrences

Characteristic Factor = 0.0394
F Factor Event 6a

Characteristic Factor = 0.0236

F Factor Event 6b

Characteristic Factor = 0.0472

F Factor Event 6

Characteristic Factor = 0.0512
Characteristics Factor = -0.1471

Characteristics Factor = -0.0725

Characteristics Factor = -0.0277

Characteristics Factor = -0.0563
Figure 54

Factor Event 7e

Normalized Occurrences

Characteristic Factor = -0.1182

Factor Event 7

Normalized Occurrences

Characteristic Factor = -0.0788
### Evaluation of Trends From Doppler Data Correlation Analysis

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<td>SW vs. VE</td>
<td>Symmetric scatter, with uniform distribution for all but Event 2</td>
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<tr>
<td>SN vs. VE</td>
<td>No general trend, appears uncorrelated</td>
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<tr>
<td>DZ vs. VE</td>
<td>Follows SN vs. VE data, and also appears uncorrelated (more specifically, conflicting trends exist)</td>
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<tr>
<td>VE vs. DZ</td>
<td>Two trends appear; i) uniform distribution, ii) positive VE for low DZ flipping to negative VE for high DZ (abs(VE) would likely make distribution uniform).</td>
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<tr>
<td>SW vs. DZ</td>
<td>For approximately 3 events, low DZ has higher SW estimates, while others have uniform or saddle distributions</td>
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<td>VE vs. Range</td>
<td>Disregard in favor of SubEvent VE profiles.</td>
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<tr>
<td>SW vs. Range</td>
<td>In general, SW increases with range, as expected, but there are some dips and some uniformity displayed.</td>
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<tr>
<td>DZ vs. Range</td>
<td>Simply reflects where the weather is. No general correlation.</td>
</tr>
<tr>
<td>SN vs. Range</td>
<td>Also no general trend, though SN follows DZ vs. Range except for very near ranges, where DZ tends to drop off and SN tends to rise.</td>
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Notes: 1) Event 6 appears to have the most erratic behavior (not in scatter as much as in the mean), likely due to substantially fewer points to average when compared to other events.
Fig 57
Event 6

SW (m/s)

DZ (db)

Range (km)

Event 6

EVCN

G

GO

Range (km)

Event 6

Range (km)

Fig. 61
Events 1-6

SW (m/s)

DZ (db)

Events 1-6

SW (m/s)

Range (km)

75
Fig. 63
## Event Description Table

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Fig 66
Analysis of Doppler Radar Windshear Data

Appendix A
# Appendix A

## List of Figures

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<th>Description</th>
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## Appendix A

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Event 6b

VE (m/s)

Occurences

-20 -10 0 10 20

Event 6b

SW (m/s)

Occurences

0 5 10 15 20 25 30 35 40

Event 6b

DZ (db)

Occurences

0 5 10 15 20 25 30

Event 6b

SN (db)

Occurences

0 20 40 60 80
Event 7a

- VE (m/s)

- SW (m/s)

- DZ (db)

- SN (db)
Event 2 (2 Range Bin(s) / Point)

Event 2b (2 Range Bin(s) / Point)

Event 2a (2 Range Bin(s) / Point)
Event 3a (3 Range Bin(s) / Point)

Event 3b (3 Range Bin(s) / Point)

Event 3c (3 Range Bin(s) / Point)

Event 3 (3 Range Bin(s) / Point)
Event 5a (3 Range Bin(s) / Point)

Event 5b (3 Range Bin(s) / Point)

Event 5 (3 Range Bin(s) / Point)
Event 6a (2 Range Bin(s) / Point)

Event 6b (2 Range Bin(s) / Point)

Event 6 (2 Range Bin(s) / Point)
Event 7e (2 Range Bin(s) / Point)

Event 7 (2 Range Bin(s) / Point)

F Factor

0.8

0.6

0.4

0.2

0

-0.2

-0.4

-0.6

-0.8

Range (km)

0.8

0.6

0.4

0.2

0

-0.2

-0.4

-0.6

-0.8

Range (km)
Event 1b

SW (m/s)

DZ (db)

Range (km)

Event 1b

SN (db)

Range (km)
Event 3c

DZ (db)

Range (km)

DZ (db)

Range (km)

Event 3c

SN (db)

Range (km)
Events 1-6

VE (m/s)

SW (m/s)

Events 1-6

VE (m/s)

SN (db)

Λ-101
The objective of this analysis is to process Lincoln Laboratory doppler radar data obtained during FLOWS testing at Huntsville, Alabama, in the summer of 1986, to characterize windshear events. The processing includes plotting velocity and F-factor profiles, histogram analysis to summarize statistics, and correlation analysis to demonstrate any correlation between different data fields.