19930010420

N93-19609

Spectrum Characteristics of Denver and Philadelphia Ground Clutter and the Problem of Distinguishing Wind Shear Targets from Moving Clutter

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Abstract

Spectral analysis of 1991 wind shear flight data has provided information about the power spectral density, spectral width, and velocity of ground clutter detected by the wind shear radar at several major airports. Ground clutter must be recognized and separated from weather targets before wind shear can be computed. Information will be presented characterizing and comparing ground clutter and weather target spectra. The information includes: (1)spectral widths of stationary ground clutter seen at various scan snd tilt angles, (2)power spectral density and velocity of moving ground clutter relative to the stationary ground clutter, and (3)spectral widths and velocities of weather targets. The presentation will also include summary numerical results in the form of histograms and example numerical results in the form of spectral plots.

OUTLINE

- DATA FRAME AND RANGE BIN GEOMETRY

- STATIONARY GROUND CLUTTER SPECTRA
  - Velocity Compensation
  - Spectral Width

- WEATHER SPECTRA: WIND SHEAR EXAMPLE

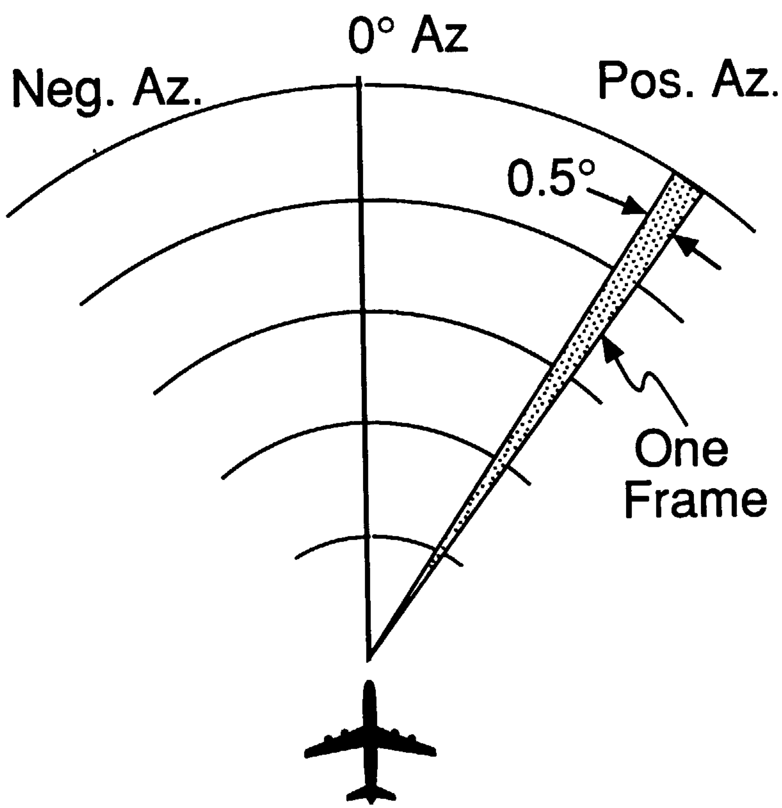
- MOVING GROUND CLUTTER SPECTRA
  - Histogram of Velocities
  - Histogram of Power Spectral Densities Relative to Stationary Ground Clutter
  - View Across the Scan

Data Frame and Range Bin Geometry

In the usual mode of operation, the radar antenna scans in azimuth while keeping a fixed tilt. During the transmission of 128 pulses, the antenna moves through 0.5 degrees of its scan. Data collected from these transmitted pulses are called one data frame. Range bins are spherical shells concentric about the radar. Each bin is 144 meters thick. During one data frame, 128 samples are collected from each range bin.

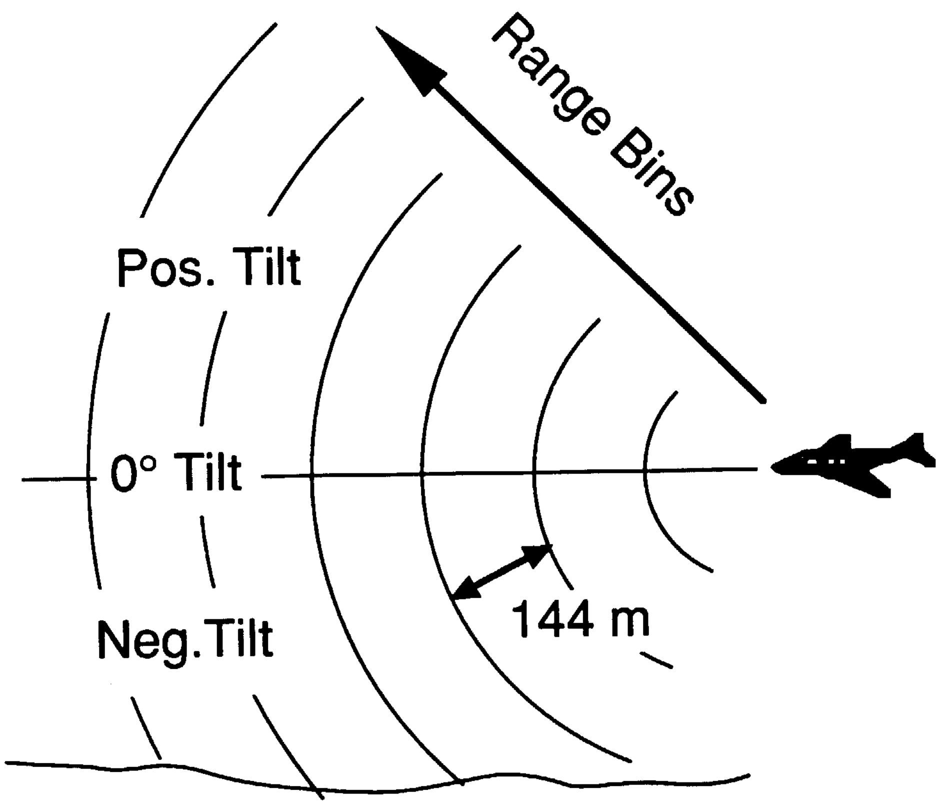
DATA FRAME AND RANGE BIN GEOMETRY

TOP VIEW



128 pulses transmitted during one frame

SIDE VIEW

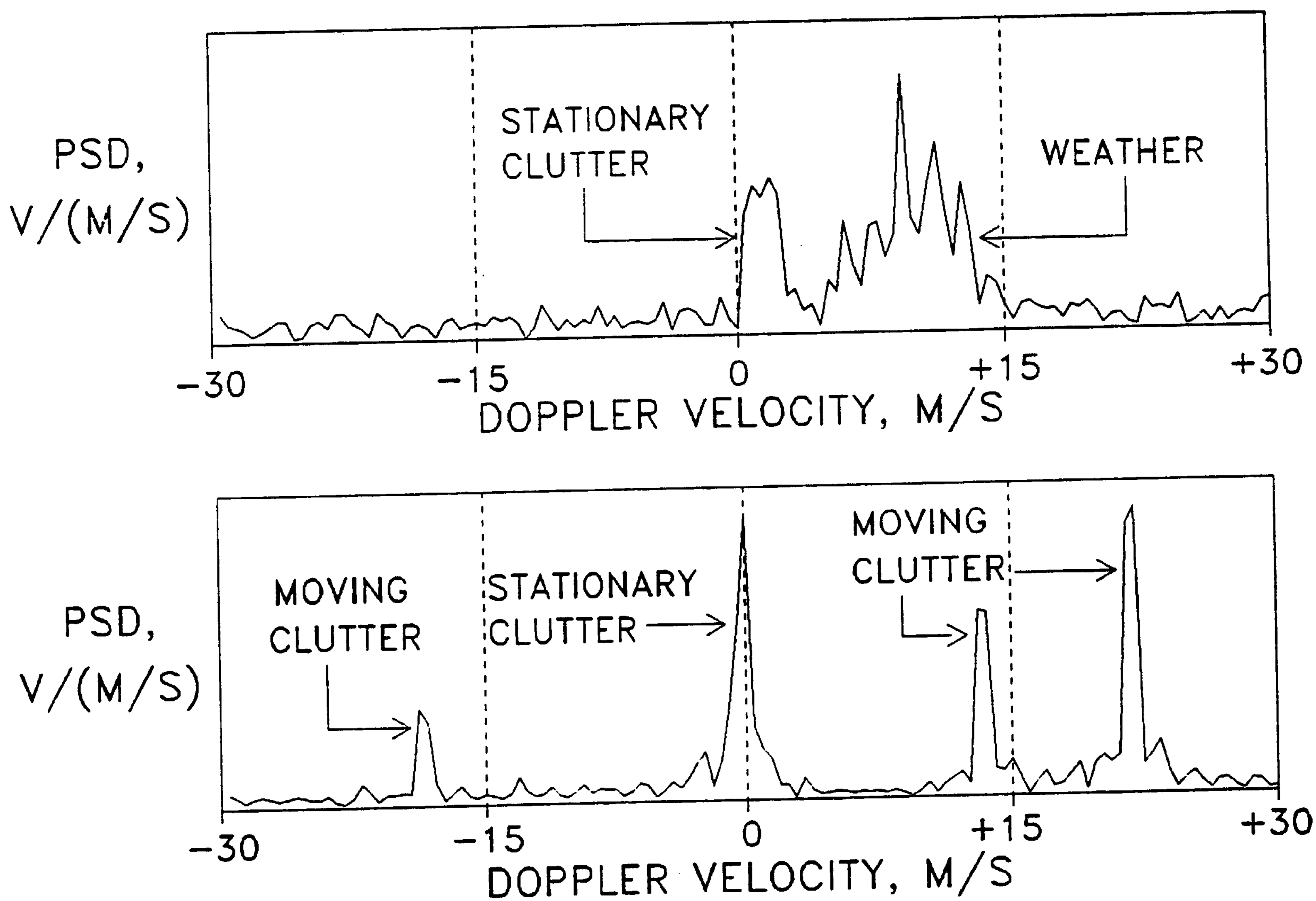


128 samples received from each range bin

Comparison of Weather and Clutter Doppler Spectral Shapes

After an FFT has been performed on a 128-point I,Q voltage time series, a 128-point Doppler velocity spectrum may be drawn from the magnitudes of the results. The spectrum represents power spectral density versus the detected radial velocities of targets in one range bin. A pulse repetition frequency of 3755 Hertz yields a velocity Nyquist interval of -30 to +30 meters per second. The lower plot shows a typical stationary ground clutter spike, which appears as a tall, pointed peak. The upper plot shows a typical weather spectrum, which looks like a collection of adjoining peaks in one area of the total spectrum. Moving clutter may appear as one or more distinct velocity peaks. Clutter may have higher or lower power spectral density than the weather target.

COMPARISON OF WEATHER AND CLUTTER DOPPLER SPECTRAL SHAPES



The Effect of Velocity Compensation on Stationary Ground Clutter

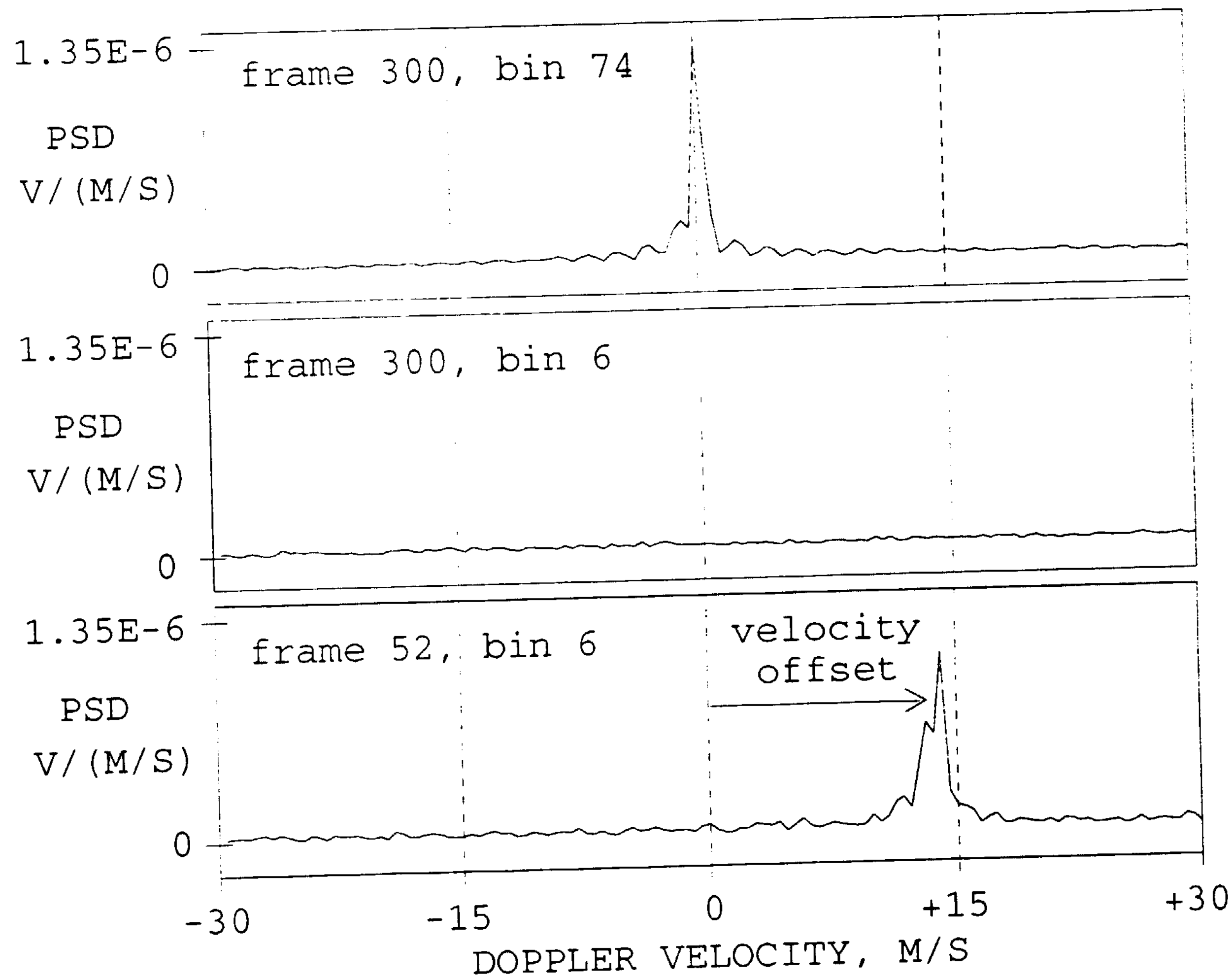
The radar receiver compensates in hardware for the apparent motion of the ground toward the airplane at the center of the antenna beam. For most range bins, this compensation puts the stationary ground clutter at the center of the velocity spectrum, which is zero meters per second. The velocities of stationary ground clutter not near the beam center will appear with an offset from zero, given by the equation at the bottom of the opposing page. The spectra shown are from a landing approach to the Philadelphia Airport. In most cases, stationary ground clutter from the near range bins, such as bin 6, is too far down on the antenna beam power pattern to be seen above the noise. However, an occasional very highly reflective object may appear in the spectrum with a velocity offset. Case 3 shows one of these occurrences.

THE EFFECT OF VELOCITY COMPENSATION ON STATIONARY GROUND CLUTTER

CASE 1:
MID OR FAR
RANGE BINS

CASE 2:
"USUAL"
CLUTTER IN
NEAR RANGE
BINS

CASE 3:
"UNUSUALLY
REFLECTIVE"
CLUTTER IN
NEAR RANGE
BINS



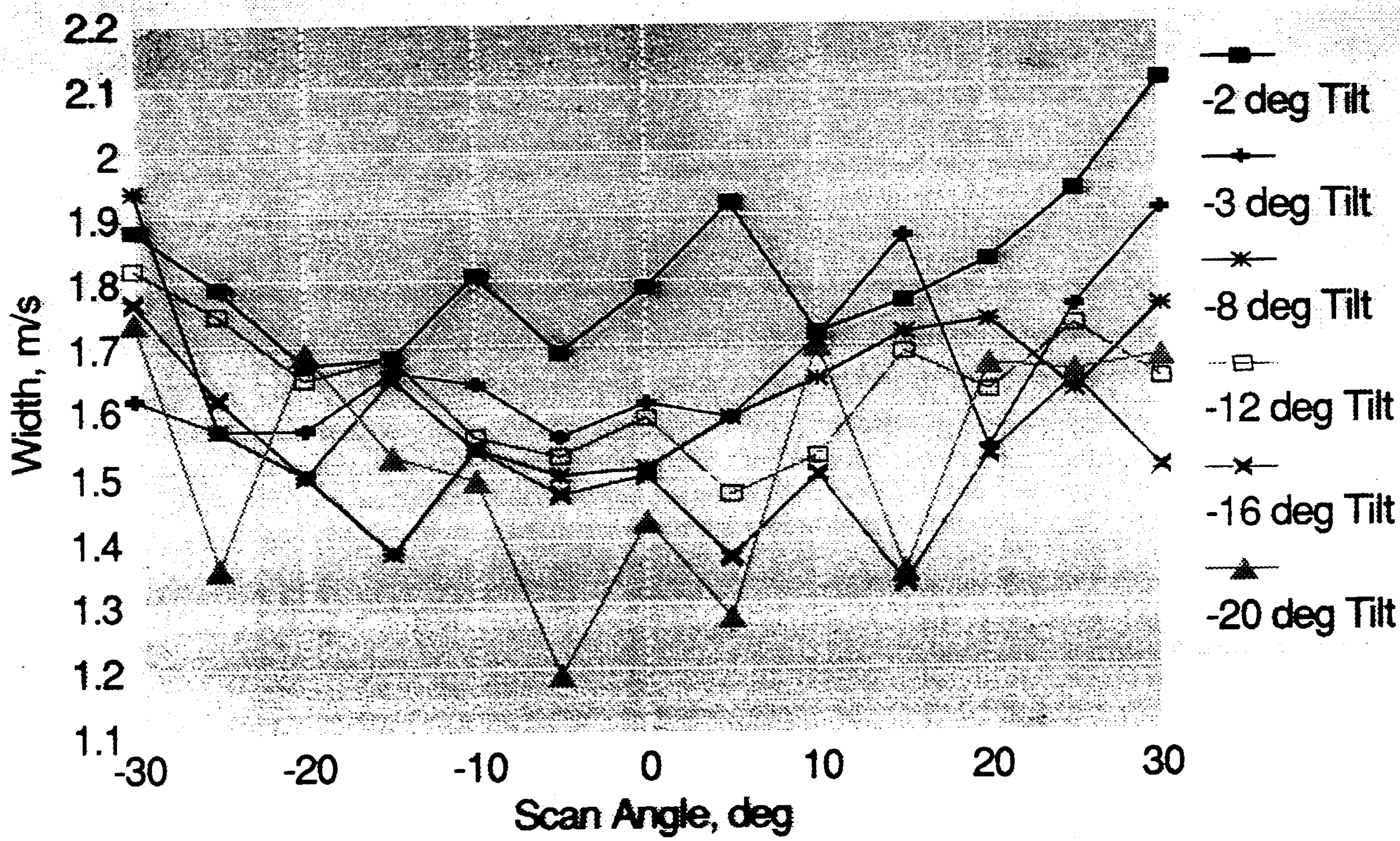
VELOCITY OFFSET = GROUNDSPEED * [COS(BORESIGHT DEPRESSION ANGLE)
- COS(CLUTTER DEPRESSION ANGLE)]

Spectral Width Versus Scan Angle

An initial look at Denver stationary ground clutter has yielded these spectral widths estimated by pulse pair processing. The data were taken from six level flights in clear weather over the Stapleton Airport, each flight with the antenna set at a different tilt angle. Average spectral widths were calculated versus scan and tilt angle, using those range bins where the antenna boresight intersected the ground. Data frames were excluded if their spectral width was more than 3.5 meters per second, since higher widths indicated the presence of moving clutter. The plot shows the width increasing toward the edges of the scan and decreasing as the antenna is tilted further downward.

SPECTRAL WIDTH VS SCAN ANGLE

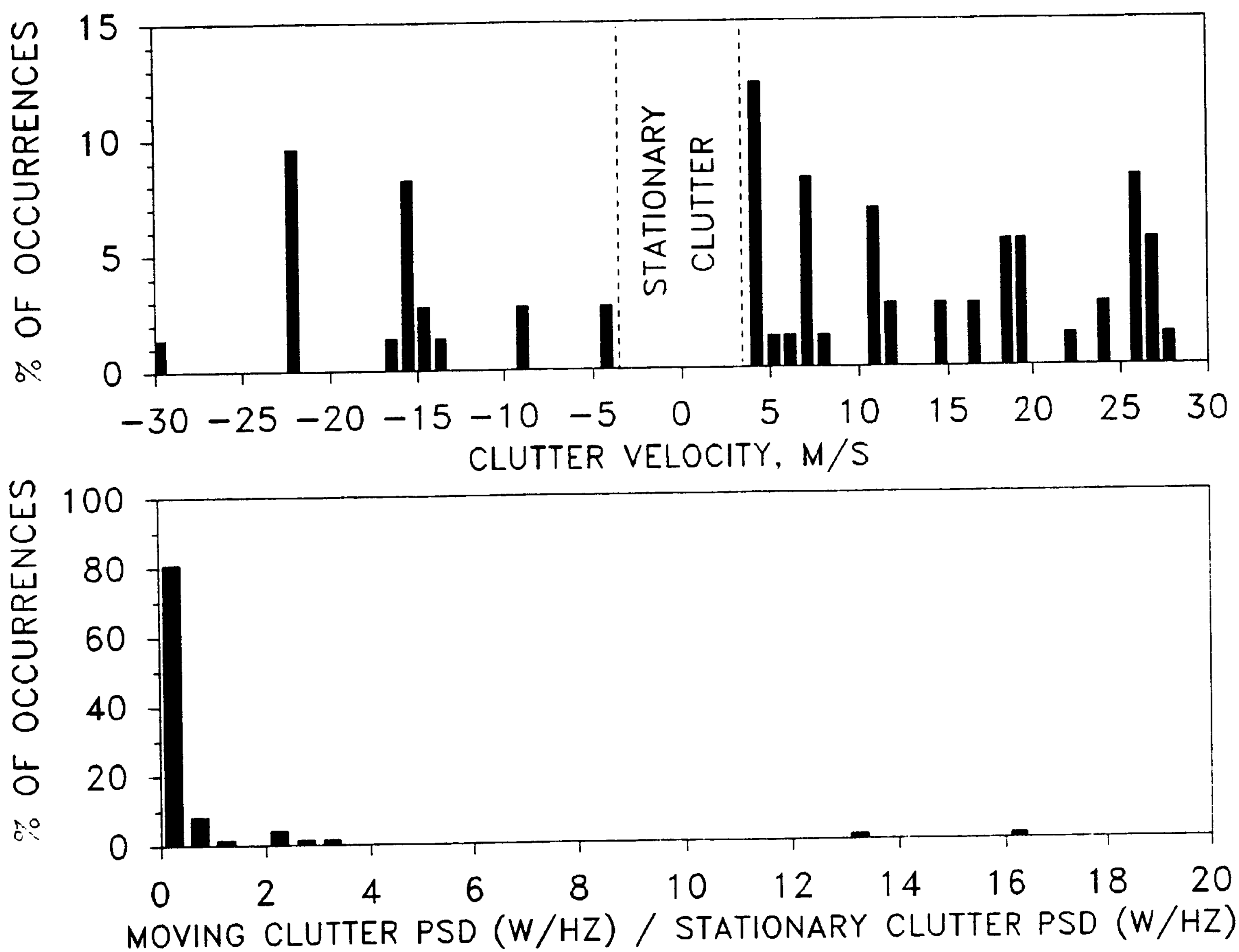
Stationary Clutter at Denver



Moving Clutter Seen in 30 Seconds of Flight Over Philadelphia: -3 Degree Tilt, ±30 Degree Scan

A moving clutter velocity histogram was produced by counting instances of moving clutter detected during 30 seconds of level flight over Philadelphia. In one range bin, each frame was searched for the largest clutter peak on each side of zero where the power spectral density of the peak was more than four times the average power spectral density for the entire frame. A power spectral density histogram was produced by comparing the power spectral density of each peak to the power spectral density of the stationary clutter in the same frame. In over 90 per cent of cases, the moving clutter was less reflective than the stationary clutter. In the other 10 per cent of cases, the moving clutter was up to 16 times more reflective than the stationary clutter.

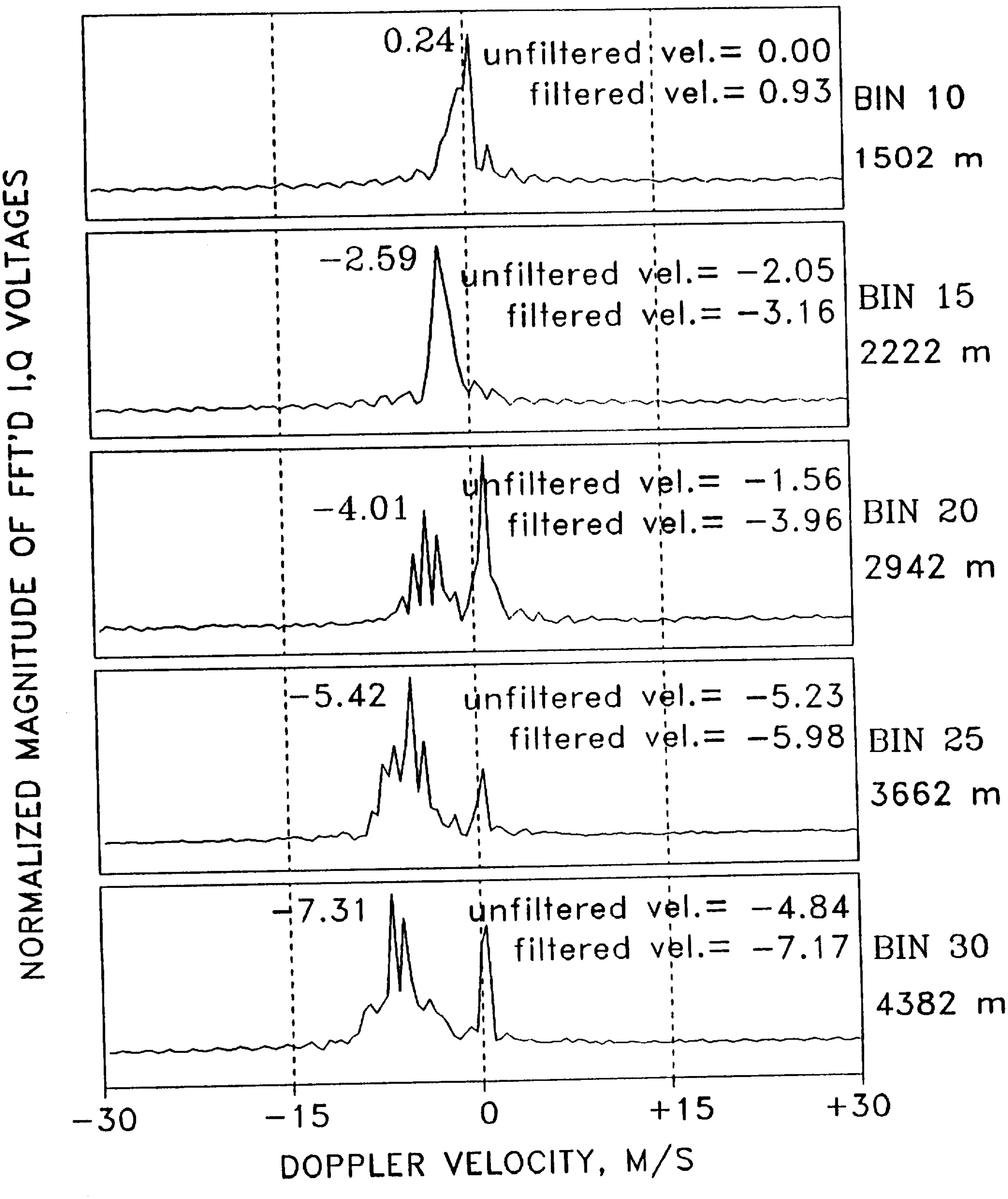
MOVING CLUTTER SEEN IN 30 SECONDS OF FLIGHT OVER PHILADELPHIA : −3 DEG. TILT, ± 30 DEG. SCAN



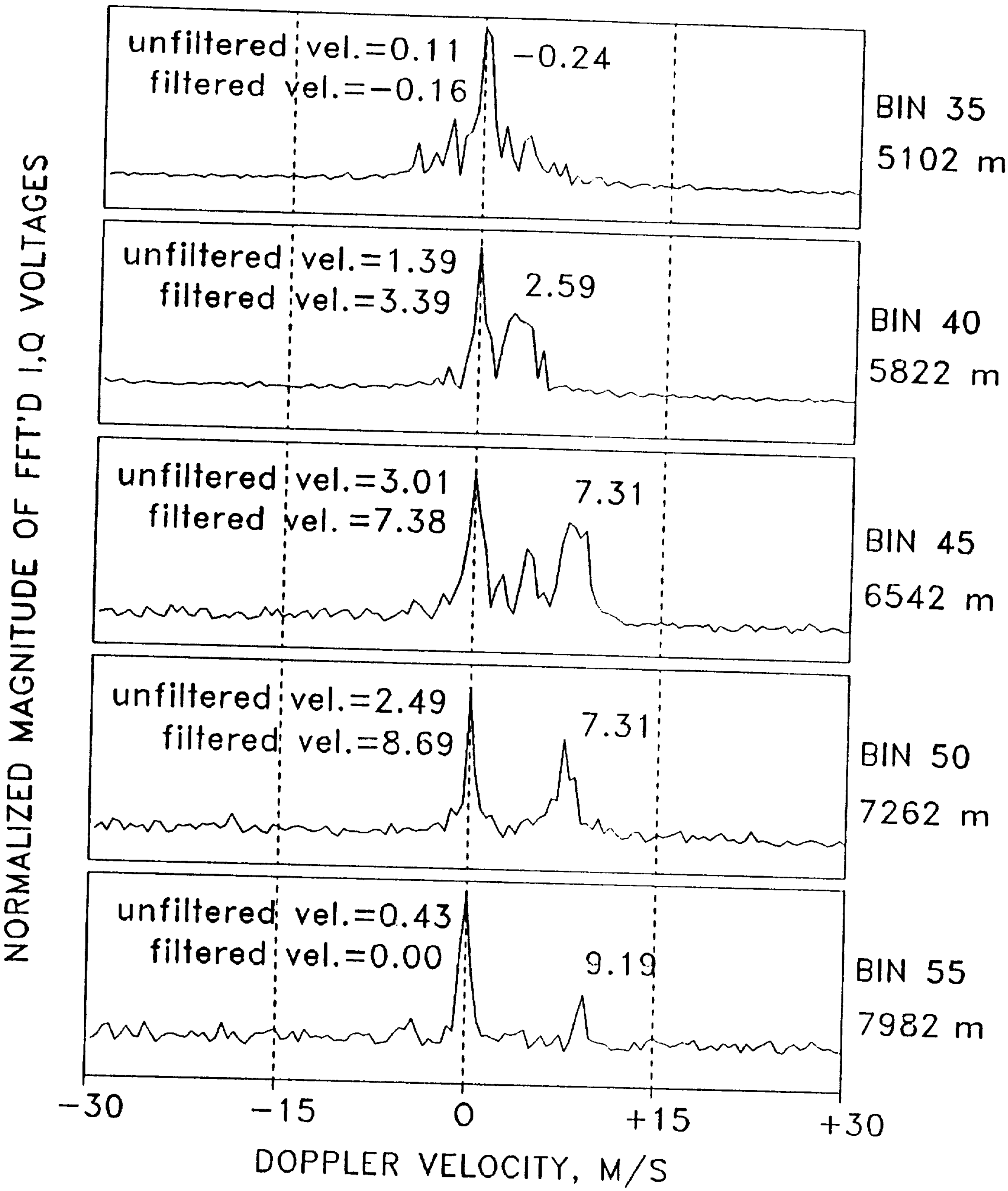
Wind Shear Viewed Along the 0.25-Degree Azimuth Line

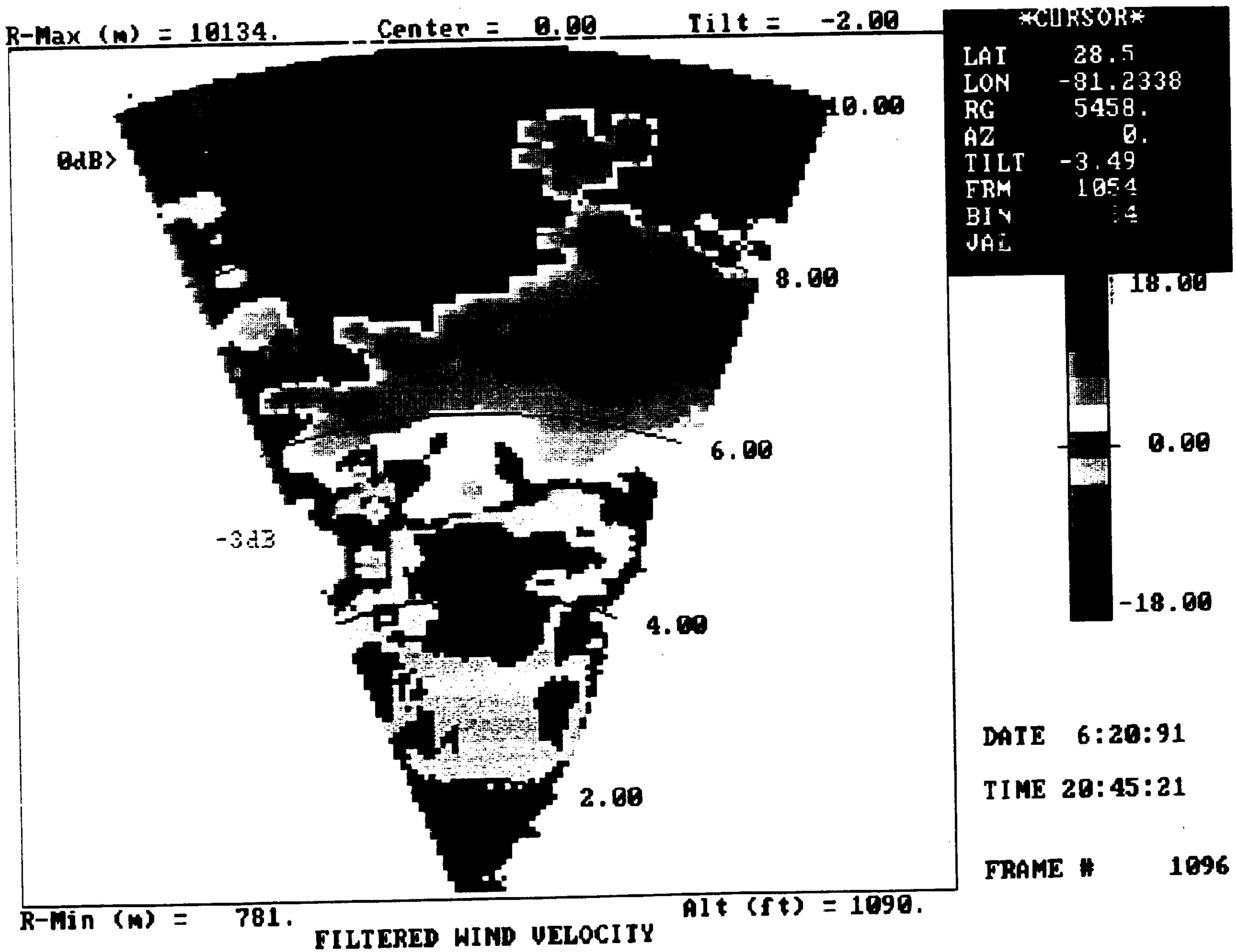
Looking along the 0.25-degree azimuth frame from range bins 10 to 55, we see weather velocities changing from near zero meters per second to -7 meters per second to +9 meters per second. Stationary ground clutter is also present in each bin. Pulse pair processing estimates of mean wind velocity are biased by stationary clutter velocity if no filtering is done. Improved wind velocity estimates are obtained by filtering out the stationary clutter prior to pulse pair processing. The filtered velocity map labeled "frm 1054" in the upper right corner shows weather velocities calculated for the above mentioned range bins in the center of the scan.

WIND SHEAR VIEWED ALONG THE 0.25° AZIMUTH LINE



WIND SHEAR VIEWED ALONG THE 0.25° AZIMUTH LINE (CONTINUED)

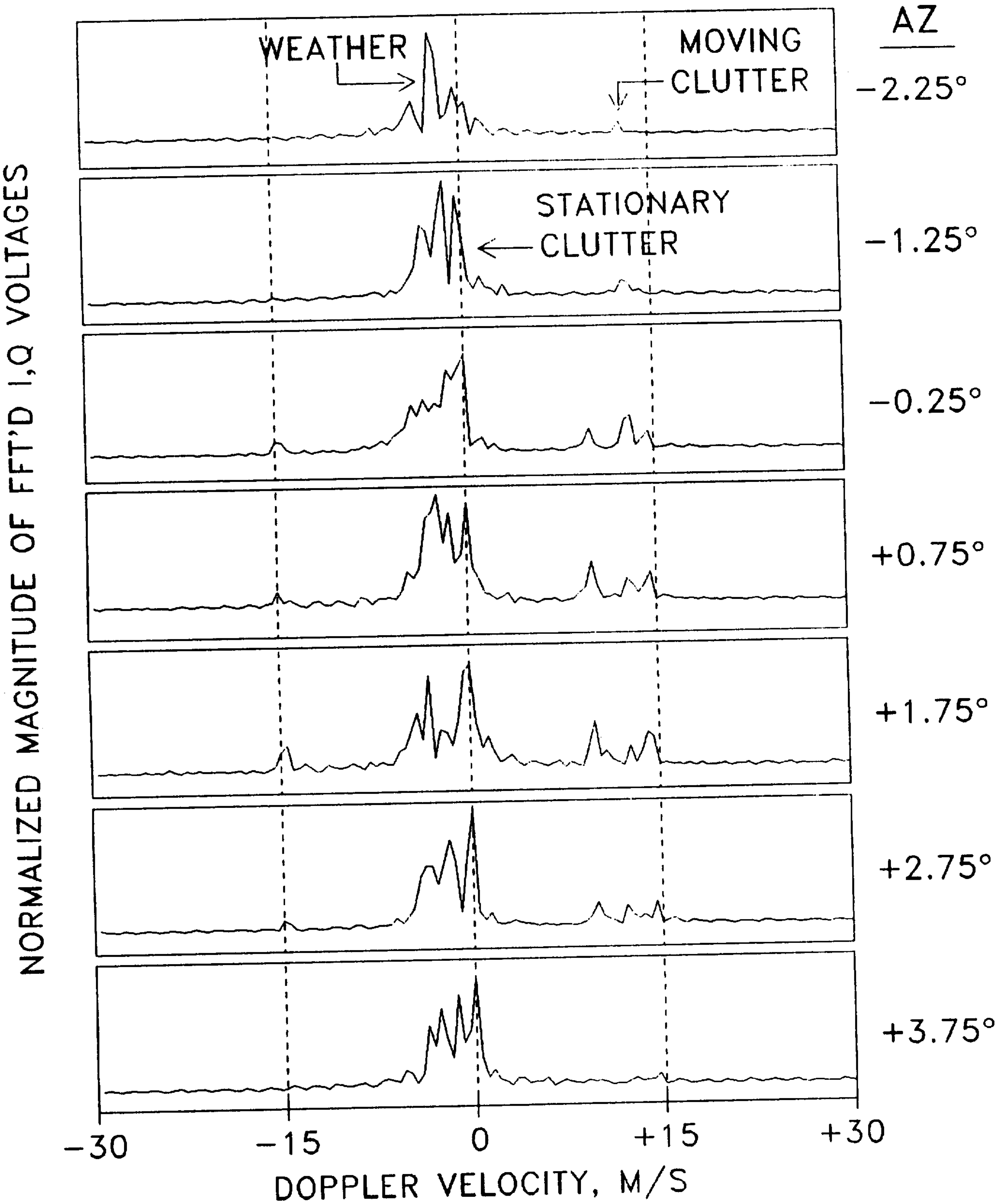


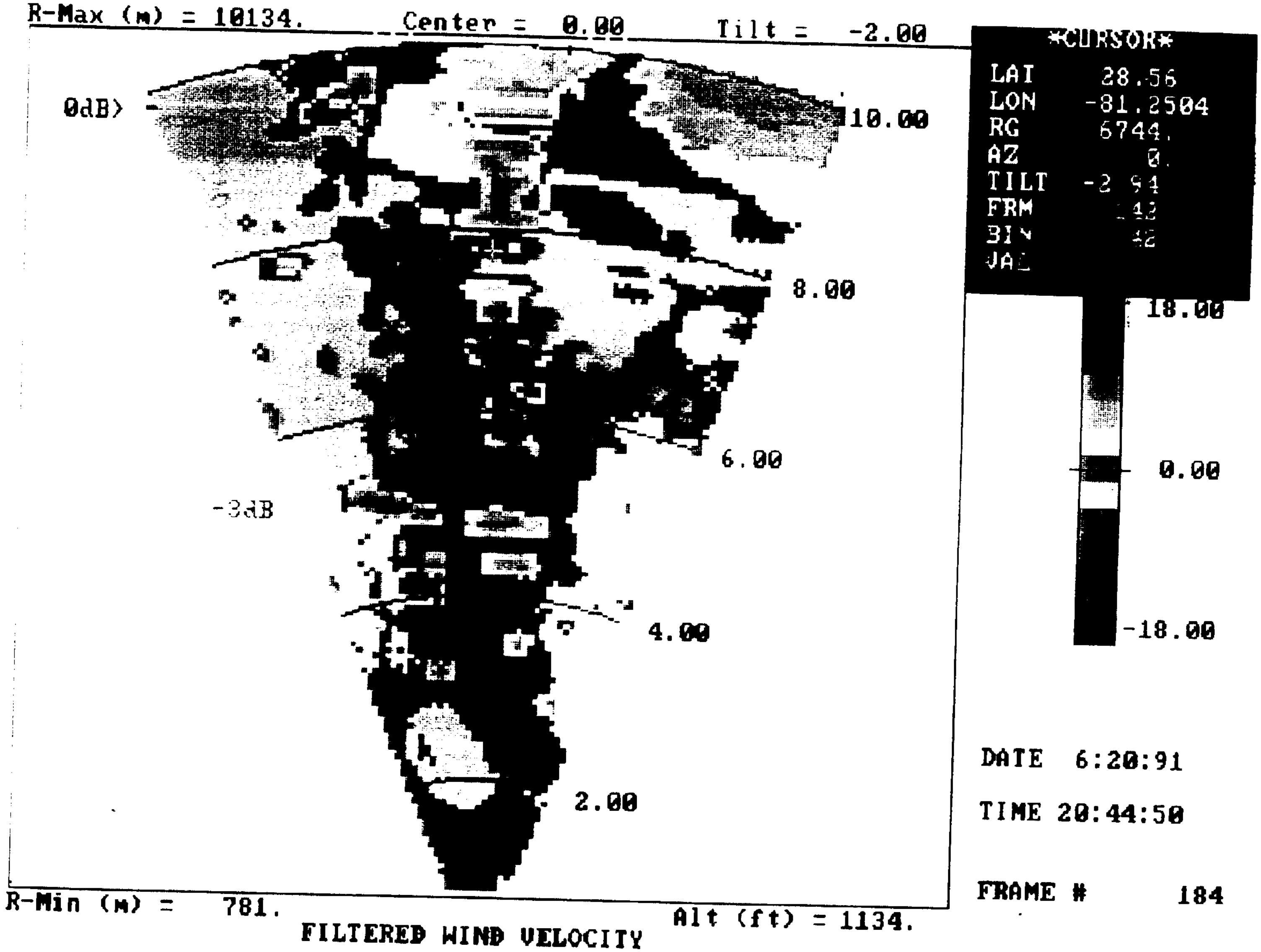

R-Max (m) = 10134.
Center = 0.00
Tilt = -2.00
CURSOR
LAT 28.5
LON -81.2338
RG 5458.
AZ 0.
TILT -3.49
FRM 1054
BIN
VAL
18.00
0.00
-18.00
0dB>
10.00
8.00
6.00
4.00
2.00
-3dB
DATE 6:20:91
TIME 20:45:21
FRAME # 1096
R-Min (m) = 781.
Alt (ft) = 1090.
FILTERED WIND VELOCITY

Comparison of Doppler Spectra from Range Bin 55 at Various Azimuth Angles

Looking at range bin 55 across a series of frames at -2.25 to +3.75 degrees in azimuth, we see weather accompanied by stationary ground clutter in every frame. Moving clutter appears, grows stronger, and fades as the antenna scans across a highway. In the filtered velocity map labeled "frm 142" in the upper right corner, the highway appears as a series of contrasting recatangular areas in a line down the center of the scan. Since only stationary clutter was filtered out before calculating the map velocities, some of the velocity estimates on the map are biased by the moving clutter. However, the areas of moving clutter are physically small in comparison to the areas of measurable weather. Thus, unbiased weather velocities are readily discernable in large areas of the map, despite the presence of moving clutter in other areas.

COMPARISON OF DOPPLER SPECTRA FROM RANGE BIN 55 AT VARIOUS AZIMUTH ANGLES





R-Max (m) = 10134.
Center = 0.00
Tilt = -2.00
0dB>
-3dB
10.00
8.00
6.00
4.00
2.00
CURSOR
LAT 28.56
LON -81.2504
RG 6744.
AZ 0.
TILT -2.94
18.00
0.00
-18.00
DATE 6:20:91
TIME 20:44:50
FRAME # 184
R-Min (m) = 781.
Alt (ft) = 1134.
FILTERED WIND VELOCITY

CONCLUSIONS

- Spectral width of stationary ground clutter is about 2 m/s at the edges of a $\pm$30-degree scan.
- In all range bins, stationary ground clutter can be eliminated by velocity filtering.
- Weather spectra usually have greater spectral width than ground clutter spectra.
- Weather spectra may have higher or lower power spectral densities than clutter spectra.
- Although weather and clutter may be indistinguishable in single data frames, they may be distinguished in a map of the entire scan, due to the wider physical extent of the weather phenomenon.

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Questions and Answers

Q: Jim Evans (MIT) - One of the important questions in reviewing the ability to reject ground clutter by filtering is what the base noise of your system is. What is the base noise of the system you are using in terms of instability residues?

A: Ann Mackenzie (NASA Langley) - You mean the noise of the receiver system?

Q: Jim Evans (MIT) - Well, it has to do with your transmitter system and the amplitude in phase variations it may apply as it puts out pulses, plus and noise in your local oscillator. What you will see when you analyze the spectrum, if you just sat on the ground and bounced the signals off of a nice target, is a big spike at zero velocity and then you will see a noised floor from anywhere from twenty to fifty or sixty dB down, that is almost flat. It turns out that is one of the expensive items in trying to build a pulse coherent radar, and it is an important element in terms of trying to understand the significance of your results. That is why I asked the question; what is the instability residue of your system? You can not build a system that puts out exactly to a thousandth of a dB the same pulse amplitude every time it transmits.

A: Brac Bracalente (NASA Langley) - I would like to address that. This is a design that was provided to us by Collins. All I can tell you is that it has a very stable low noise level. Our noise sensitivity is down around minus 110 dBZ and we see signals down that low. I can't tell you what the exact number is, that is something you will have to talk to Collins about. All I know is that it is a low number.

Q: Jim Evans (MIT) - That is not the right number. The number I am asking about is signal dependent noise?

A: Brac Bracalente (NASA Langley) - Are you talking about the clutter noise generated by jitter phase instability.

Q: Jim Evans (MIT) - Phase and amplitude instabilities either at the transmitter or the receiver.

A: Brac Bracalente (NASA Langley) - I can not give you the exact number on that. All I know is that it is pretty low. I think it is at a low enough level to not be a problem in the operation of the system.