Western Region Technical Attachment
No. 95-07
March 14, 1995

# DOPPLER DILEMMA DELINEATES DANGER FROM DIRT

Daniel L. Borsum - NWSFO Boise, ID

## Introduction

Understanding how the WSR-88D derives base products can often aid radar interpretation. This information was crucial on 21 August 1994 as the KCBX WSR-88D indicated an apparent strong thunderstorm developing in a stable airmass. Thunderstorms were not expected over southwest Idaho at this time and aside from the radar, no other source of information supported the existence of a thunderstorm. So was this a thunderstorm or some non-meteorological phenomenon? This Technical Attachment will explore the various alternatives and provide a somewhat surprising answer, one which reaffirms the need for forecasters to understand how the radar handles data.

## Background

Shortly after 0600 UTC, 21 August 1994, thunderstorms moved into northeastern Utah associated with a vorticity maximum in southwest flow aloft. At 0915 UTC, lightning strikes appeared on WLS charts in southeast Idaho. The WSR-88D (operating in VCP-32) detected one cell located in eastern Cassia County at a range of 150 nm. At this time, the only actions taken were to have WSO Pocatello issue a Special Weather Statement and call a few spotters.

Between 0900 and 1000 UTC, lightning increased across southeast Idaho, and at 1015 UTC, a large cell was observed on the radar over southwest Twin Falls County at a range of 100 nm. This surprised the forecasters since a stable airmass had moved into western Idaho with northwesterly flow at the low levels. Since the radar was in VCP-32 at the time, information on the reflectivity structure of the storm was limited. A cross-section was taken of the storm revealing a significant profile with tops to 37,000 feet (Fig. 1). A onetime request of the 8 data level 0.5° reflectivity product allowed the forecasters to examine the reflectivity structure in more detail even in clear air mode. Analysis of this product revealed an area of echoes with reflectivities as high as 57 dBZ and relatively smooth reflectivity gradients (Fig. 2). The radar was commanded to enter VCP-21. As the radar completed its first full scan in VCP-21, a four-panel display was constructed to examine the storm structure. Although not very impressive, it did show echoes in the 0.5°, 1.5°, 2.4°, and 3.4° elevations, with reflectivities of 65 dBZ in the lowest layer.

## Determining the Identity of the Echoes

With the impressive returns on the radar, it was important to rapidly analyze other data to see if a thunderstorm was in the area, or if a non-meteorological source was causing the echoes. Two possible non-meteorological targets were identified in this case: chaff and anomalous propagation (AP).

According to the OSF course student guide, AP is defined as echo returns (from other than normal ground clutter targets) caused by greater than normal bending of the radar beam down to the ground during superrefractive conditions. At first, this seemed to be a strong candidate due to the stability of the airmass. However, the student guide continues to state that AP on reflectivity products should:

1) Have a "mottled" appearance with widely varying reflectivity values over a relatively large area.
2) Lack uniformity or smooth reflectivity gradients.
3) Typically occur in the lowest elevation slices.

The guide also states that AP on velocity products generally has low to zero velocities with isolated higher values embedded.

Considering the three reflectivity properties, this echo had a rather coherent reflectivity structure which extended into the 3.5° elevation. An examination of velocities revealed outbound values as high as 36 knots associated with this area. Consequently, AP was ruled out.

Chaff is often a problem in the KCBX radar range, but close examination over a number of cases has allowed forecasters to observe various signatures. Two of these signatures in particular were absent in this case:

1) Chaff rarely has reflectivity gradients that resemble convection. Usually maximum values can be found throughout the chaff echo.

2) Reflectivity cross-sections, especially at longer ranges, will rarely display any significant vertical structure.

This cell had a coherent gradient with maximum values in the center and a significant vertical structure (Figs. 1 and 2). Therefore, chaff was also ruled out.

No clouds were observed in the area of concern on the 1000 UTC satellite imagery, and no lightning strikes were noted. A time lapse revealed that echoes had been developing in the area since 0914 UTC, but they seemed to be anchored in the same location. Given the above information and the fact that forecasters were trying to issue products and interpret radar, thunderstorms were placed in the TWEB route forecast from Burley to Idaho Falls.

**Anomalous Propagation and Erroneous Velocity Data**

After further examination and despite the velocity data, AP still appeared a possible culprit. A call was placed to the OSF Hotline for interpretation assistance. They agreed that AP was possible, noting that the Sterling, Virginia radar had periodically detected the Barrier Islands at very long distances. A quick look at a terrain relief map showed that a large mountain (unnamed peak, elev. 7765 feet) was located in the area in question.

Examining a velocity time lapse, an area of range folding was observed 22 nm from the radar along the same radial as the suspect echo located 102 nm from the radar (where there was velocity data) (Fig. 3). Apparently the Range Unfolding Algorithm had erroneously taken the data from 22 nm and placed it at 102 nm. In fact, looking at Fig. 3, the area of range folding at 22 nm proportionally matches the area of velocity data at 102 nm given the widening of the beam with distance. Additionally, the magnitude of velocities at 102 nm would be acceptable values at 22 nm given surrounding velocity data.

## Range Unfolding Algorithm and the Doppler Dilemma

Weather radars send out a pulse of electromagnetic radiation and then listen for a return signal. The radar has no true way to associate the return signal to its corresponding pulse generated by the radar. In most instances, a pulse is emitted and a target returns energy in the listening period that immediately follows the pulse (first trip echo). Periodically, targets at longer ranges return energy after another pulse has been transmitted, producing what are termed second or third trip echoes. The pulse repetition frequency (PRF), essentially the length of the listening period, determines the maximum unambiguous range (Rmax) of the radar for the first trip. Thus, the lower the PRF, the longer the listening period and the greater the Rmax.

With Doppler radars, a low PRF limits the maximum detectable radial velocity. So if the radar operator lowers the PRF to achieve a longer range, the maximum detectable velocity will be lower. If the PRF is increased to produce higher values of detectable velocities, then the Rmax will be shortened. These opposing terms, long range versus detecting higher velocities, are the basis of the Doppler Dilemma.

The WSR-88D uses the Range Unfolding Algorithm to try to partially overcome this dilemma. In VCPs 11, 21, and 32, the two lowest elevation angles are scanned twice. The first scan (termed contiguous surveillance, CS) uses a lower PRF to extend the Rmax to 248 nm. The second scan (termed Contiguous Doppler, CD) uses a higher PRF to allow for higher detectable velocities, though at a reduced range (60 to 80 nm). The Range Unfolding Algorithm essentially "maps" the multiple trip velocity returns from the CD scan onto the longer range reflectivity data from the CS scan. In this way, the WSR-88D can extend the range of Doppler velocities to ranges greater than the Rmax of the CD scan.

In this case, the mapping failed. To see why examine Figs. 4 and 5. Figure 4 displays reflectivity data at 1.5$^{o}$ using the CS scan mode mentioned above. Echo locations out to 248 nm (approximately) can be determined unambiguously in this mode, though our display here is limited to 124 nm. The strong echo is shown just outside the 100 nm range ring. Figure 5 is a plot of possible locations of velocity data detected along this same radial from the CD scan (radial is grossly exaggerated for our purposes) superimposed on the CS scan. The Rmax of the CD scan mode in this case is 80 nm. Thus, the velocity data could have been from the first trip at 22 nm or a second trip at 102 nm.

The final placement of the velocity data is determined by comparing the magnitude of reflectivities of the two echoes shown in Fig. 4 (at 22 nm and 102 nm). An adjustable parameter of the WSR-88D, TOVER, plays a critical role here. The KCBX TOVER was set at 5 dB in this case. Using this threshold, if the return power from the two echoes is within 5 dB, both echoes will be range folded or effectively removed from the display by overlaying a range folding pattern. If there is a greater than 5 dB echo intensity difference, the stronger echo will be assigned the velocity values.

In this case, the echo at 102 nm has relectivities in the 45 to 55 dBZ range, whereas the area at 22 nm was only displaying 10 to 20 dBZ values. TOVER is computed by the following:

$$\Delta dB = dBZ_1 - dBZ_2 - 20\log_{10}(\frac{R_1}{R_2})$$

or

$$\Delta dB = \Delta dBZ - 20\log_{10}(\frac{R_1}{R_2})$$

where $R_1$ and $R_2$ are the ranges to the respective echoes. Using $R_1$ = 102 nm, $R_2$ = 22 nm, $dBZ_1$ = 50, and $dBZ_2$ = 15, the dB difference is approximately 22. This well exceeds the TOVER threshold of 5 dB and so the data was erroneously assigned to the higher reflectivities at 102 nm.

**Conclusion**

In summary, an echo that apparently was due to partial returns from a distant mountain exhibited velocity values other than zero. Obviously, anomalous propagation of the radar beam was occurring since echo tops of 37,000 feet were displayed by the WSR-88D from a mountain which rises to only 8,000 feet. The target, however, did not produce the normal pattern of reflectivity associated with AP, leading forecasters to believe it could have been a true weather target. Examination of other tools (satellite, surface reports, synoptic data, etc.) helped to steer the forecasters to the true nature of the suspicious "storm".

The WSR-88D is a very important tool for operational forecasters. However, it is not perfect and can generate spurious data. The WSR-88D uses a number of preprocessing data algorithms to maximize the amount of information available to the forecaster. A knowledge of how the WSR-88D operates and handles data ambiguities can prevent forecasters from using incorrect information.

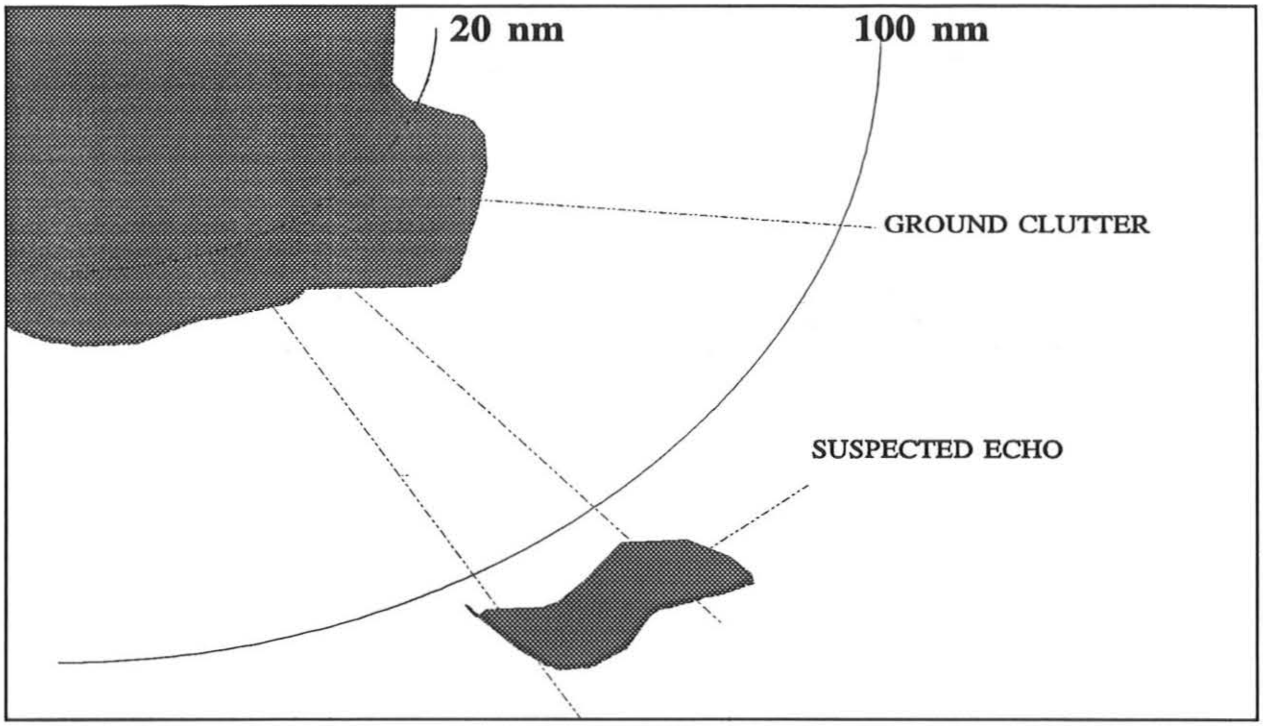


**Figure 4**

Plot of reflectivity data from CS Scan.

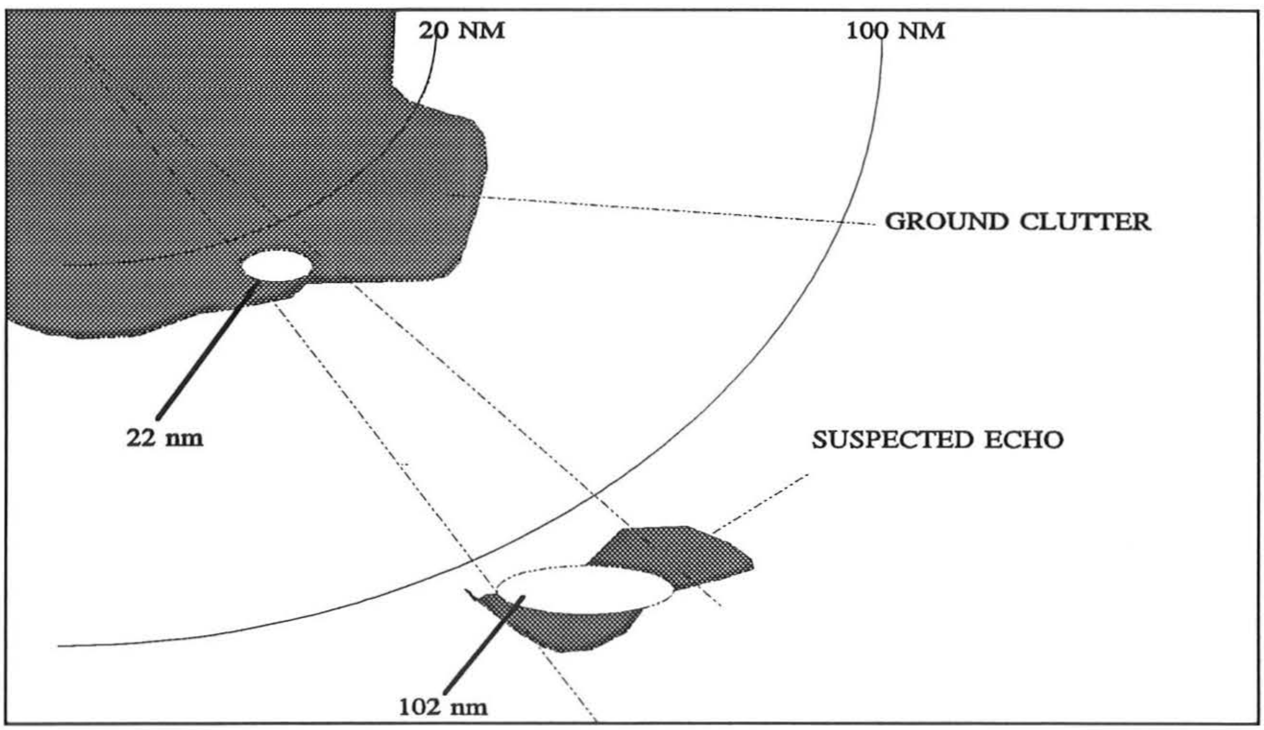


**Figure 5**

Plot of velocity data from CD scan superimposed on CS scan. Compare this figure with figure 2 which is the actual velocity chart from the WSR-88D in this case.

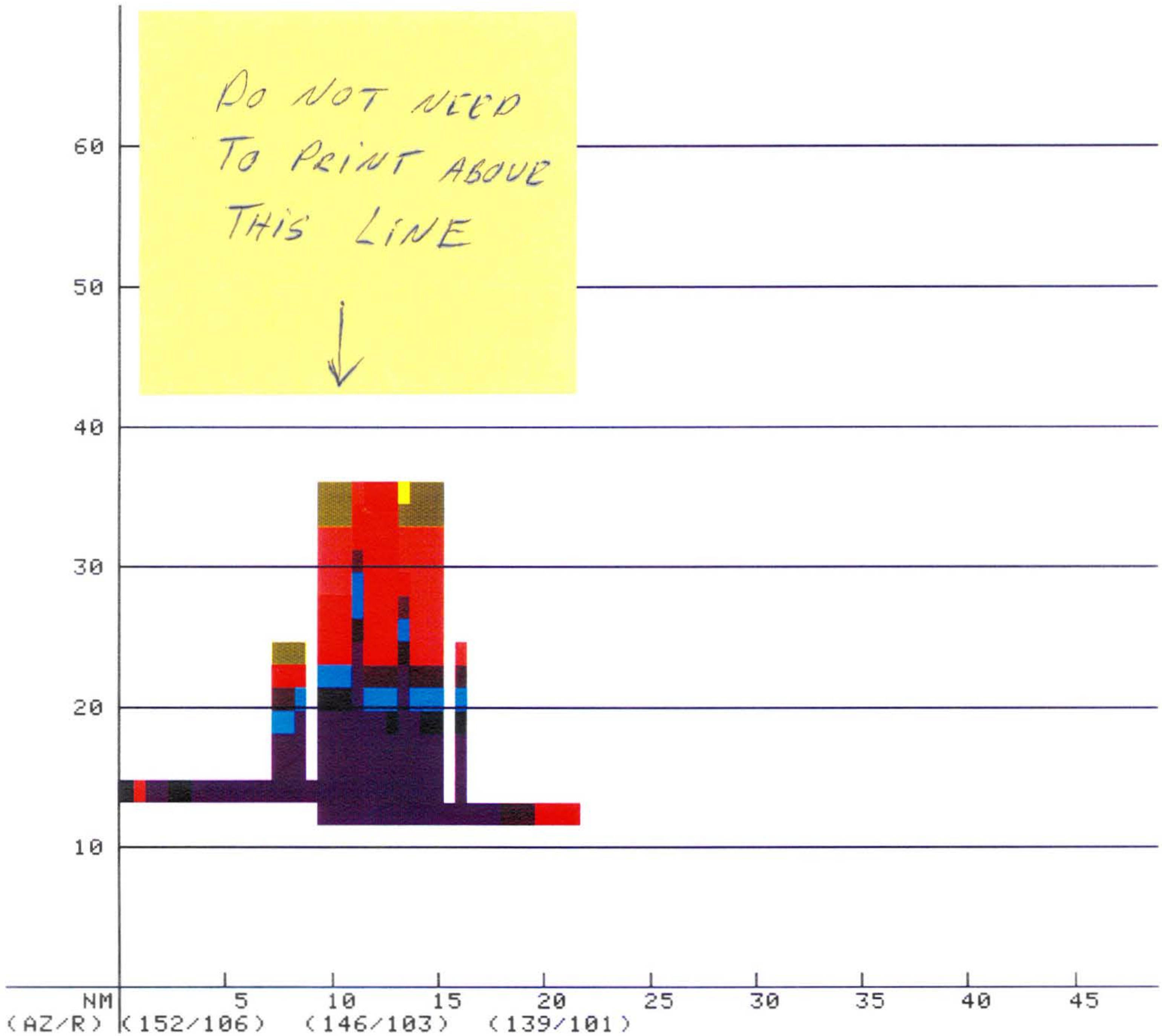


Figure 1

Reflectivity Cross Section of "apparent" thunderstorm 102 nm from the KCBX WSR-88D, 21 August 1994, 1015 UTC.

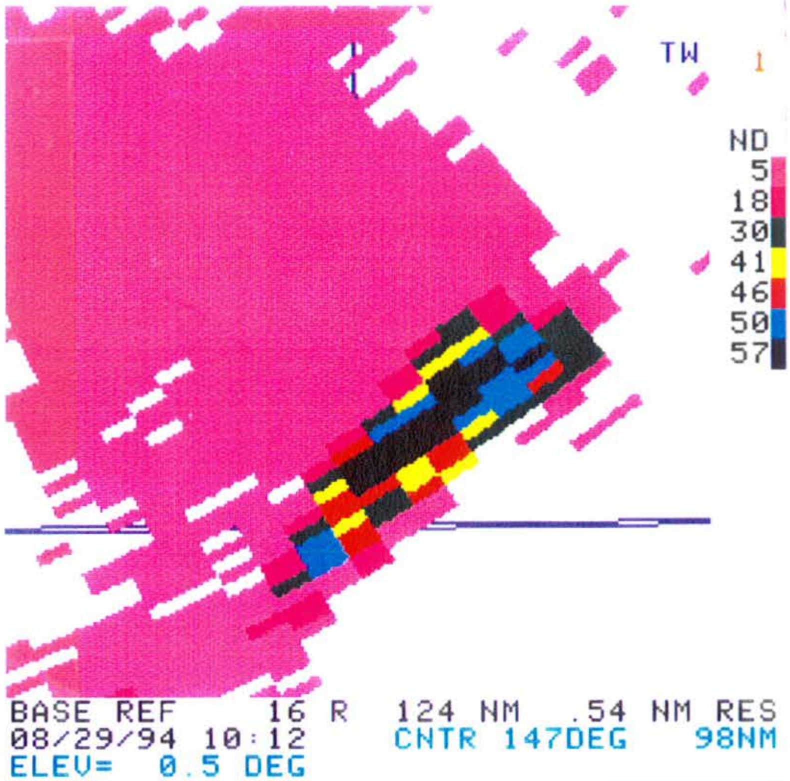


Figure 2

8 Data level reflectivity product of "apparent" thunderstorm. Use of the 8 data level products allows for reflectivities above 28 dBZ to be viewed even in VCPs 31 or 32. In this case a large area of 57 dBZ was revealed.

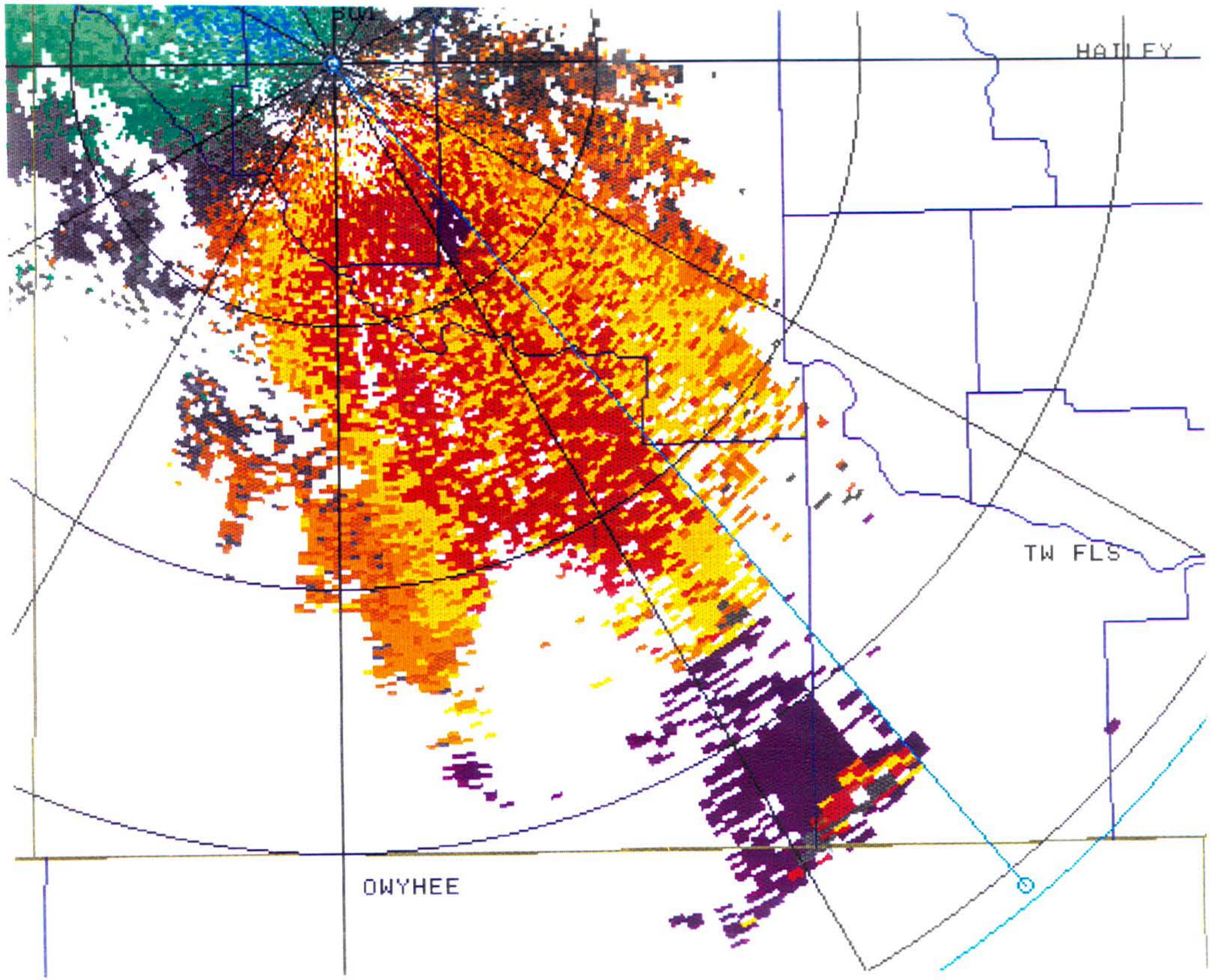


Figure 3

Velocity chart showing area of velocities associated with the echo at 102 nm and area of range folding at 22 nm. The data at 22 nm has been erroneously plotted at 102 nm by the Range Folding Algorithm.