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UNCERTAINTIES IN WSR-88D MEASUREMENTS AND THEIR IMPACTS ON DIAGNOSING STORM STRUCTURE

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Introduction

The National Severe Storms Laboratory (NSSL) has developed various products and algorithms for the diagnosis of storm-cell-based attributes such as mesocyclones, storm top, maximum reflectivity, vertically integrated liquid (VIL), along with many others. Radar measurement uncertainties associated with many of these parameters have been documented and are recognized, however their impacts on the *trends* of storm features are not as well documented or understood. Howard et al. (1997) found that detailed examinations of radar-measured life cycles of thunderstorms occurring in Arizona indicated substantial limitations in the WSR-88D's capability to accurately depict certain aspects of a storm's evolution. They clearly showed how radar-determined trends were often substantially different from those of a model storm. In extreme cases, trends from the radar and the model storm can be of opposite sign. This Technical Attachment summarizes findings regarding this problem, and includes an example of the problem from a storm which occurred in the Western Region.

Methodology

During studies conducted as part of the Southwest Area Monsoon Project (Maddox et al. 1997), thunderstorm cell-based attributes and life cycle trends were examined for storms occurring over central Arizona. The data used were from the WSR-88D located at KIWA (William's Air Park near Phoenix) during the summers of 1993-1995. The examination of thunderstorm life cycles for more than 1100 separate storm cells showed that 1) storms in central Arizona typically exhibit short-lived single-cell characteristics, and 2) radar sampling and/or algorithm limitations can result in unreliable life cycle characteristics on the attribute trend tables. Because they noticed unusual life cycle characteristics for a large number of the storms investigated, the authors felt it necessary to examine the measurement uncertainties introduced because of the character of the radar and scanning strategies used operationally by the NWS.

Figure 1 indicates the center of the beam axes for volume coverage pattern-21 (VCP-21) and VCP-11 elevation scans. Although the WSR-88D algorithm determines the storm-top height computed to be along the beam centerline, the actual storm top may be higher. This uncertainty can be seen by an example of storm-top height (defined as the maximum height of the 30-dBZ core). If one looks at a cell with a 30-dBZ echo top of 10 km at a range of 55 km when scanned by a WSR-88D radar operating in VCP-21, the measured storm top will be almost exactly 10 km. However, if the storm-top height remains constant and the cell's range increases just enough so that the 9.9° elevation scan does not detect the 30-dBZ echo, the next radar volume scan would indicate that the 30-dBZ echo top has fallen to about 6 km. The trend of the echo-top from the two consecutive volume scans would indicate a rapidly decreasing storm top; whereas, in this simple example, the actual top of the 30-dBZ echo would not have changed at all. Operating the WSR-88D in the VCP-11 mode greatly diminishes the magnitude of the uncertainty inherent in the measurement of "heights". It is important that the user understands that the horizontal movement of cells can produce large "trends" that may or may not be cause by actual storm evolution.

The authors then used a simple computer program to simulate idealized thunderstorm life cycles and the radar depiction of the idealized storm as measured by the WSR-88D. The initial idealized storm was 8 km high at 7 minutes, reached a maximum height of 14.3 km at 21 minutes, and then descended to 3.4 km at 42 minutes (Fig. 2). "Radar-determined" 30-dBZ echo top height trend plots were simulated for cells initially located at ranges of 25, 50, 100, 150, 200, and 250 km from the radar. The cells were defined as stationary or moving toward the radar at 5-10 m/s. Since many urban areas are located 50-100 km from the nearest WSR-88D, storm-top trends for cells initially located at these ranges were discussed specifically.

Results

With a stationary storm at a range of 100 km, the radar-determined storm top (using VCP-21) was characterized by a relatively flat trend in storm-top height during the critical portion of the storm's life cycle (from 7-21 minutes). Only during the initial and termination stages of the storm's life cycle does the radar-determined trend closely agree with the storm's actual evolution (Fig. 3). <u>With a 5 m/s movement toward the radar, radar-determined trends indicated a descent in the storm top during the period when the storm was actually growing to its maximum storm-top height</u>. This trend was further amplified when the model echo moved with an increased velocity toward the radar.

When the storm was moved to 50 km from the radar, similar life cycle errors in storm-top height were produced, although the storm evolution features are captured somewhat better. The disturbing trend of the wrong sign attached to storm-top height trends did not occur at the 50 km range. When VCP-11 was used, a substantial improvement was noted in the ability of the radar to detect the actual trends. However, the storm-top height was still occasionally substantially underestimated.

Severe errors in measuring storm-top heights occur with storms very near the radar, where the maximum elevation angle of the 19.5° tilt severely restricts the monitoring capabilities of the operational radar. Forecasters are aware that storms whose tops grow into the "cone of silence" (defined as that region above the highest radar tilt), cannot be reliably monitored. However, the impacts on apparent storm trends may not be as obvious to the forecaster. The authors modeled this example (at 25 km from the radar, and with a velocity of 5 m/s toward the radar), and found that the radar trends did not relate to the actual evolution of the model cell at all, except at the beginning and the end of its life cycle. Other situations that can lead to poor radar detection of the actual life cycle evolution of storm cells are (1) storms moving into and through areas where the radar is blocked by man-made objects or by mountainous terrain, (2) for very rapidly moving or evolving storm cells, and (3) for cells at ranges greater than 150 km from the radar. Many of these problem situations occur frequently in the western United States.

An Example From Western Region

The evolution of a severe storm that occurred on 5 June 1997 was examined for similar errors in trend information. The storm examined formed almost due east of the radar and moved from south to north at a nearly constant range (~100 km/60 nm). Figure 4 shows a vertical cross section along the storm path. In the figure, data from the beam center have been mapped across the entire width of the beam; the beam width at 60 nm is roughly 6000 ft. At 1943 UTC, the storm had a solid core of 60 dBZ with the 45 dBZ returns (orange color) extending vertically to 35,000 ft. The data from 28,000 ft to 35,000 ft were from the 4.3 degrees radar beam. In VCP 21 scan strategy (Fig. 1), the next elevation angle above 4.3 degrees is 6.0 degrees. At 60 nm range, there is a vertical gap between the edges of the 4.3 and 6.0 deg angles of about 4000 ft. If the center points of the beam are considered, the gap is nearly 10,000 ft. Based on reflectivity and cloud top temperatures, the storm top (defined as the maximum height of the 30 dBZ return) was estimated to have been about 40,000 to 42,000 ft. The storm top was estimated by the NSSL WDSS to be near 30,000 ft at this time (Fig. 5), *a difference of almost 12,000 ft.*

As seen in Fig. 5, there is little change in the storm top trend. However, a cross section done at 2006 UTC (Fig. 6), shows that the 45 dBZ core had dropped below 24,000 ft with just a few range gates of 30+ dBZ above 28,000 ft. In other words, the storm top was likely fully-detected by the 4.3 deg beam centered at ~31,000 ft. <u>*However, because of the*</u>

sampling gap between 4.3 deg and 6.0 deg, the actual storm top may have decreased as much as 14,000 ft while the algorithm trends indicated little decrease.

Conclusions

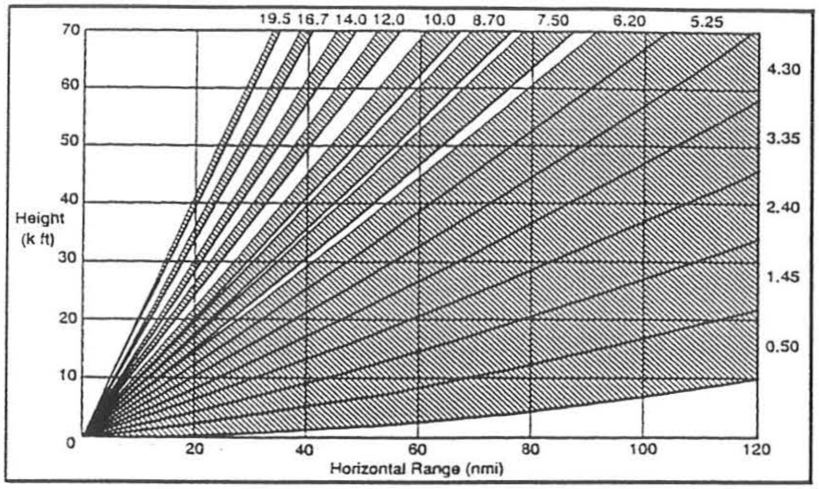
Howard et al. conclude that while the WSR-88D's uncertainties are an inherent aspect of the system, it is important that the user remain aware of the impacts of these uncertainties inherent in radar-derived trends for parameters such as storm top, height of maximum reflectivity, storm base, and cloud top, as these errors can be substantial as illustrated by these few simple examples. These uncertainties must be considered when using the observations to characterize thunderstorms and their trends. In some operational situations, the trends of radar-derived storm features, such as storm top, can be reasonably accurate and of significant use to forecasters, however, in other situations the trends can be incorrect and potentially confusing. They advise caution on the part of the user when investigating model trend fields.

The potential for false trends in a real life example from a severe thunderstorm in the Western Region was illustrated as well. Errors of up to 12,000 feet difference in storm top, along with a trend of a nearly steady storm top masking a drop in storm top of up to 14,000 ft, underscore the need for the WSR-88D to be operated in VCP 11 whenever any significant storm develops, be it severe or not. The large gaps in scanning angles in VCP 21 allow for significant errors to be possible in storm trend tables, which could potentially result in misdiagnosing a severe thunderstorm.

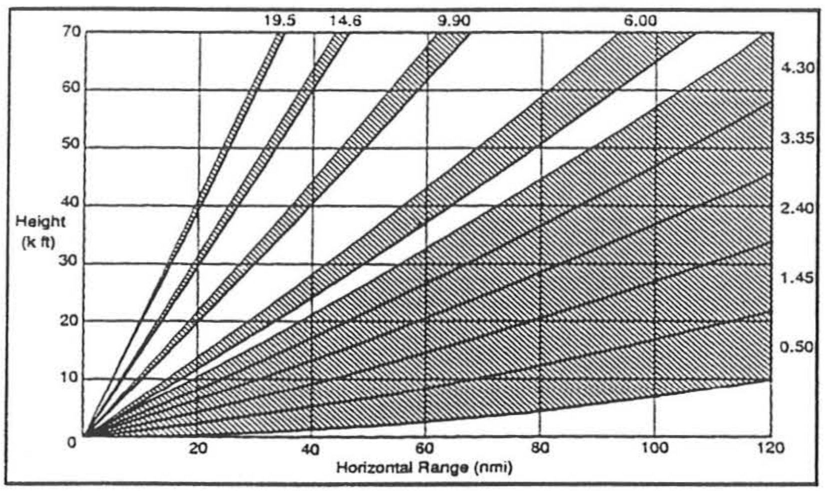
References

Howard, K.W., J.J. Gourley, and R.A. Maddox, 1997: Uncertainties in WSR-88D measurements and their impacts on monitoring life cycles. *Wea. Forecasting*, **12**, 166-174.

Maddox, R.A., C.L. Dempsey, and K. W. Howard, 1997: Intense convective storms with little or no lightning over central Arizona--A case of inadvertent weather modification? *J. Appl. Meteor.*, **36**, 302-314.



a



b

Figure 1: (a) Radar beam geometry (range vs height) for VCP-11. There are 14 different elevation scans with a 5-min update rate, (b) same figure for VCP-21, which has only nine different elevation scans with a 6-min update rate.

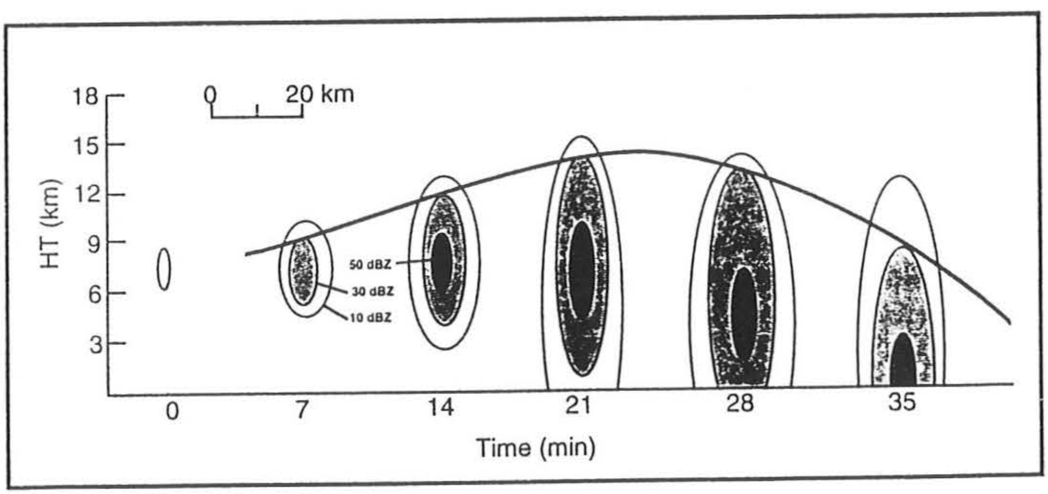


Figure 2: Vertical reflectivity structure during the life cycle of a pulse-type thunderstorm. Contours are 10-, 30-, and 50-dBZ reflectivity. The solid line denotes the evolution of the height of the 30-dBZ echo core.

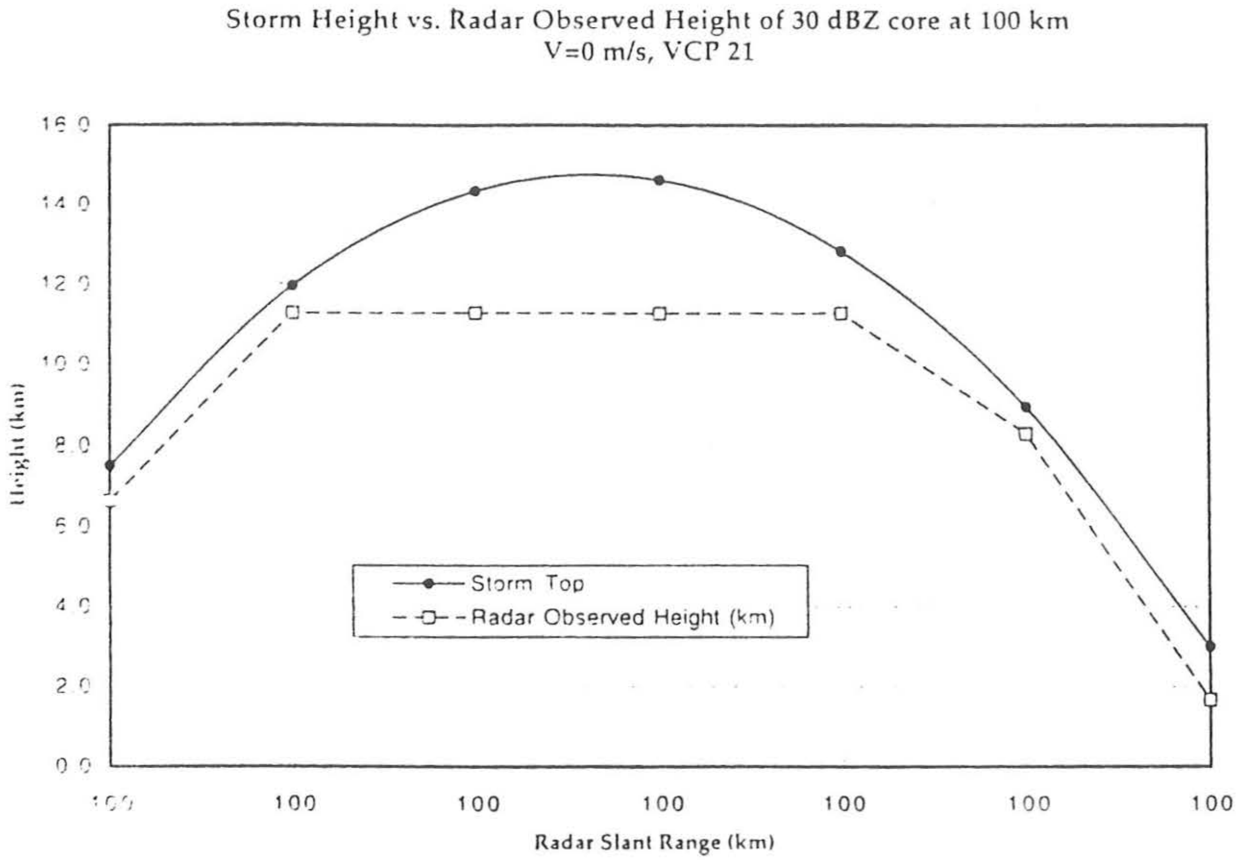


Figure 3: Model storm height versus the radar observed height of the 30 dBZ core at 100 km (V=0 m/s, in VCP 21).

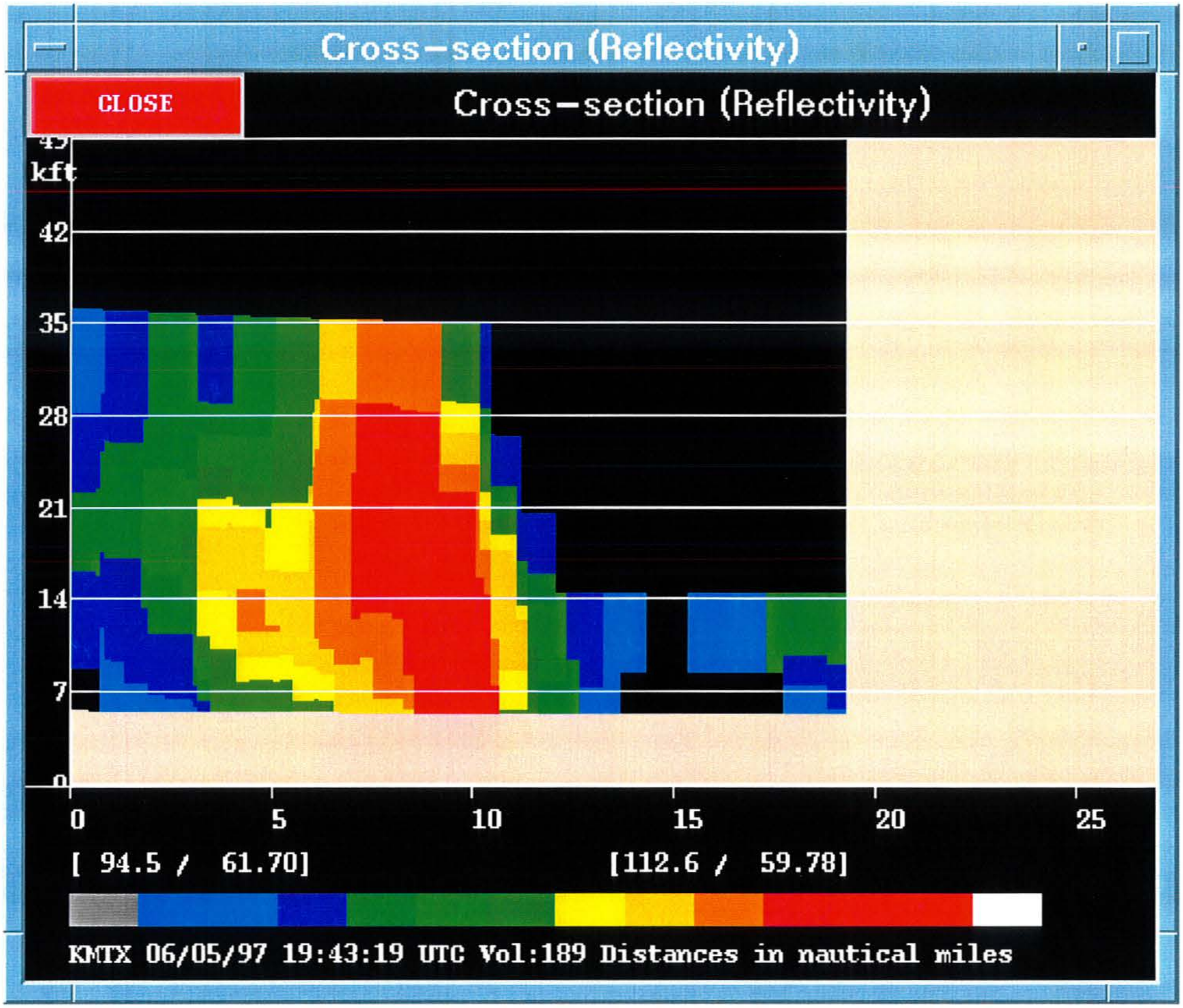


Figure 4: Vertical cross section of reflectivity taken at 19:43 UTC 05 June 1997.

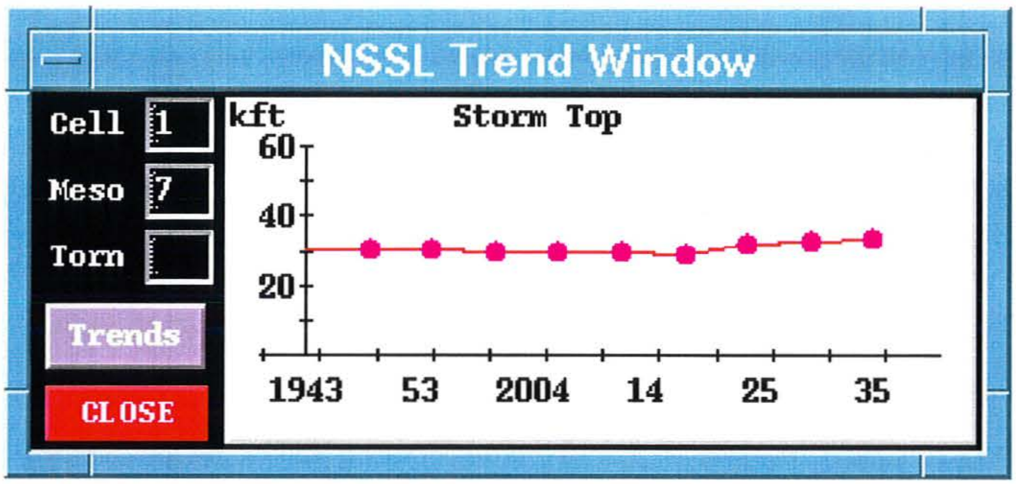


Figure 5: Storm top trend window indicating the height of the storm top (30 dBZ echo top) from 1943 UTC to 2035 UTC 05 June 1997.

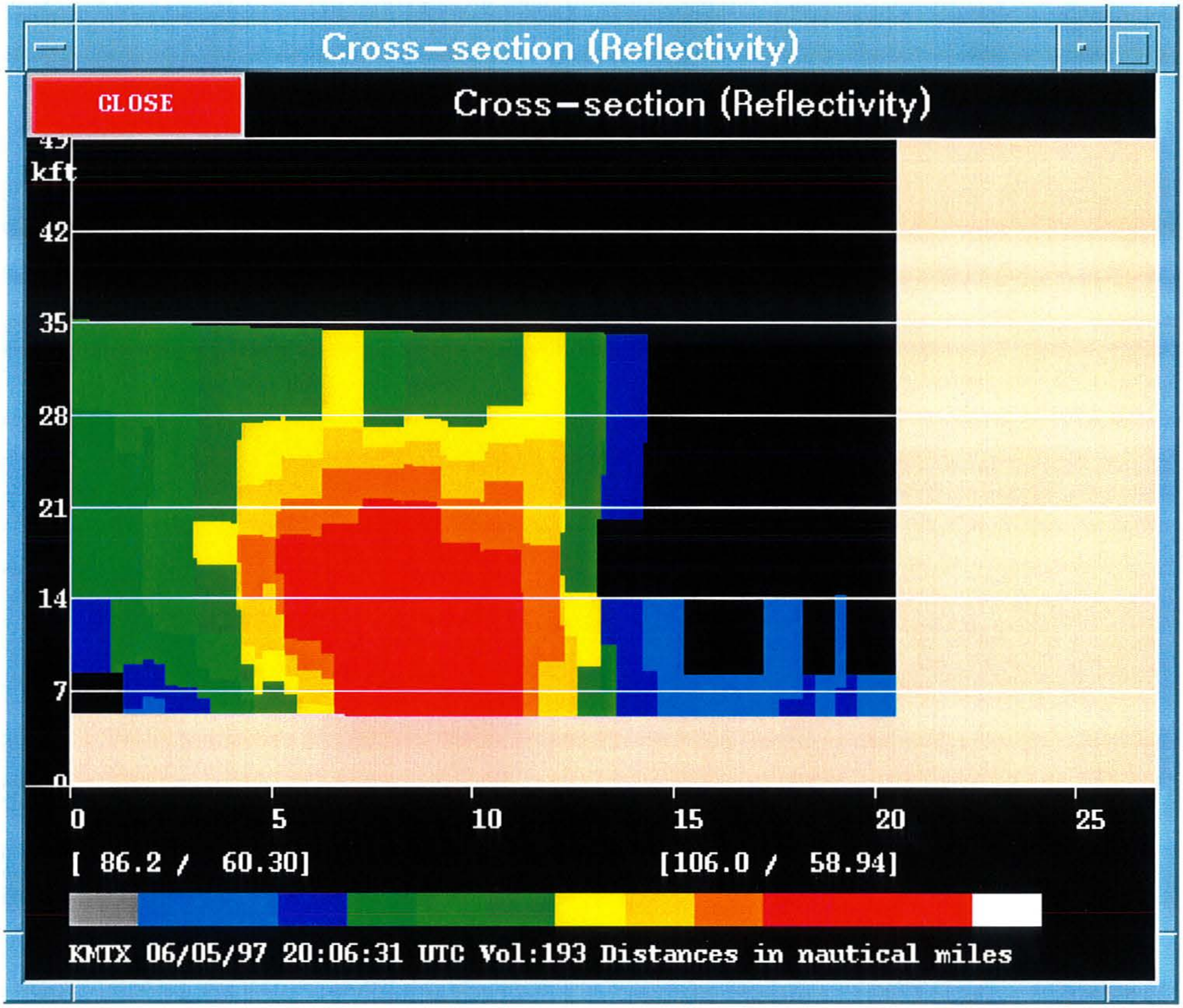


Figure 6: Vertical cross section (same as in Fig 4) taken at 20:06 UTC 05 June 1997.