Presented at the American Meteorological Society
8th Conference on Aviation, Range, and Aerospace Meteorology
Wyndham Anatole Hotel, Dallas, TX January 10–15, 1999

P8.1 THE BENEFITS OF USING NEXRAD VERTICALLY INTEGRATED LIQUID WATER AS AN AVIATION WEATHER PRODUCT *†

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1.0 INTRODUCTION

Over the past five years in which the Integrated Terminal Weather System (ITWS) testbed prototypes have been operational, there have been regular discrepancies noticed between the ASR–9 six–level precipitation product and the NEXRAD six–level maximum composite reflectivity product[1]. (1. The NEXRAD composite product used in this study is the NEXRAD maximum composite reflectivity product which both the FAA and the ITWS use for weather data.). At the three prototypes in Memphis, Orlando and Dallas, staff have recognized that in certain situations the NEXRAD composite reflectivity product, which is the ITWS 100 and 200 nm long–range product, can be as much as three Video Integrator and Processor (VIP) levels higher than the ASR–9 precipitation product. This situation has caused some confusion for users of the ITWS system and concern on the part of system safety monitors.

The confusion occurs because the two products do not agree with each other. Rhoda and Pawlak (1998) show that more aircraft will deviate around cells of ASR–9 VIP level 4 or greater than will penetrate them. There is also an aviation rule–of–thumb that pilots and air traffic specialists use which states cells of VIP level 3 or greater should be avoided if possible. This rule is a good guide but cannot be applied to the NEXRAD composite product. While the NEXRAD composite may show a cell with an intensity of level 3 or 4, the cell may contain very little of the higher–intensity precipitation while the bulk of the cell contains only level 2. This problem is magnified in the winter months when bright–band effects contaminate the radar data. Clutter [especially anomalous propagation (AP)] contamination of the composite reflectivity product is also a concern (especially when the AP is adjacent to actual weather returns).

Differences between the two products will become more apparent with the fielding of the new ITWS situation display which has the capability of displaying both NEXRAD composite reflectivity and ASR–9 data side by side. In this study, we compare the NEXRAD composite reflectivity product with data from both the ASR–9 weather channel and an ASR–9 mosaic product as well as a Vertically Integrated Liquid water (VIL) product generated from NEXRAD base data.

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* This work was sponsored by the Federal Aviation Administration under Air Force Contract No. F19628–95–C–0002. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.
† Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Air Force.

2.0 ANALYSIS METHODOLOGY

The two radars used for this research were the ASR–9 and the NEXRAD. The ASR–9 is an S–band fan beam radar with a beamwidth of 1.4 by 4.8 degrees (Weber, 1986). The NEXRAD is an S–band pencil beam radar with a 1 degree beamwidth (Rinehart, 1991) which uses as many as 16 tilts to build the two–dimensional composite product. The ASR–9 weather channel data are filtered and smoothed before they are displayed (Weber, 1986 and Puzzo, et al., 1989). The data are also a vertically weighted average over the beam's extent, with compensation for beam filling (Engholm and Troxel, 1990). Conversely, the composite data from the NEXRAD indicate the highest reflectivity found within a given cell.

Our study suggests a way in which the NEXRAD precipitation product can more nearly approximate the ASR–9 product and better reflect the severity of the storm ASR–9 data. By running a VIL algorithm on the NEXRAD data and applying a simple conversion to determine the corresponding VIP level for representation onto a two–dimensional precipitation display (Table 1), it more closely resembles the fan beam characteristics of the ASR–9 weather channel precipitation product while retaining the well documented advantages of VIL: VIL is less impacted by bright band contamination; a VIL product is a better indicator of the strength and longevity of cells; VIL gives indications of turbulence within a cell because high VIL values indicate strong updrafts and thus strong turbulence; and the NEXRAD VIL product would significantly reduce ground clutter and AP contamination which affect the NEXRAD composite reflectivity product.

Table 1.
VIL to VIP Conversion

VIL (Kg/m^2)	reflectivity dBZ	VIP LEVEL
0.05	<18	0
0.14	18	1
0.76	30	2
3.5	41	3
12.0	50	5
32.0	>57	6

Simplified conversion used to convert VIL values into corresponding VIP levels (Weber, et al., 1998).

ASR–9 and NEXRAD data from both DFW and MEM were analyzed. For each case, visual comparisons of the two–dimensional precipitation products from the ASR–9, the DFW ITWS ASR–9 mosaic product, the NEXRAD composite reflectivity, and the NEXRAD–derived VIL were performed. The DFW ITWS ASR–9 mosaic product is created by mosaicking three ASR–9 radars and then applying a median filter to help reduce anomalous propagation (AP) from any one radar. The NEXRAD VIL was constructed by converting each complete NEXRAD volume scan into horizontal layers, applying an algorithm which fills in missing data, and integrating the vertical liquid content for each bin. A bin size of 0.5 km was chosen for the case study analysis. Lastly, the conversion from Table 1 was applied to the data.

Vertical cross–section plots were also created from the horizontal layers used in the VIL process by applying an algorithm which produces a Range Height Indicator (RHI) or cross–section type product. These data were then superimposed with the approximate areal coverage of the ASR–9. This was done to show how much of the echo's vertical region was covered by the radar. The RHI data were also used to analyze the vertical structure of the individual cells scrutinized in the case studies.

3.0 CASE STUDIES

3.1 January 26th, 1998

On this day, storms began to develop ahead of an intensifying surface cool front in the DFW area. An upper–level disturbance contributed to the rapid development of convective cells. Due to the lowered wintertime tropopause, echo tops reached only to about 8 km. However, a deep moist layer allowed for the development of cells containing VIP level 6. The NEXRAD composite product reveled this level 6, while the ASR–9 and mosaic products detected precipitation intensities up to 3 VIP levels lower.

Figure 1 shows a four–panel plot with each of the radar products analyzed: the ASR–9 precipitation from the DFWE ASR–9 (A); the ASR–9 mosaic product (B); the NEXRAD composite product (C); and the VIL from the NEXRAD base data (D). Line A in Figure 1C bisects a cell to the north of the DFW airport which contains some level 6 precipitation in the NEXRAD composite data while the DFWE ASR–9 has a maximum intensity of level 4 (A). Line B in Figure 1C bisects a cell which is also depicted as a level 6 cell in the NEXRAD composite data. The DFWE ASR–9 has most of the cell depicted as level 3 (A). Though the echo tops for both cells ranged between 6 and 7 km, the reasons for the difference between the NEXRAD and ASR–9 are not the same for both cells.

Figure 2A shows the cross section of the layered product along the 225° radial. The coverage area of the ASR–9 (shown by the lines which ascend to the right on each plot) includes most of the core of the cell, which is mainly level 5 in the NEXRAD data; however, Figure 1A shows that the DFWE ASR–9 is depicting the cell with an intensity of level 4. This clearly shows an underestimation of 1 VIP level by the ASR–9. By comparison, the NEXRAD VIL algorithm processes the data much the same as the ASR–9 would, only with a larger volume scan. In this case, the VIL indi-

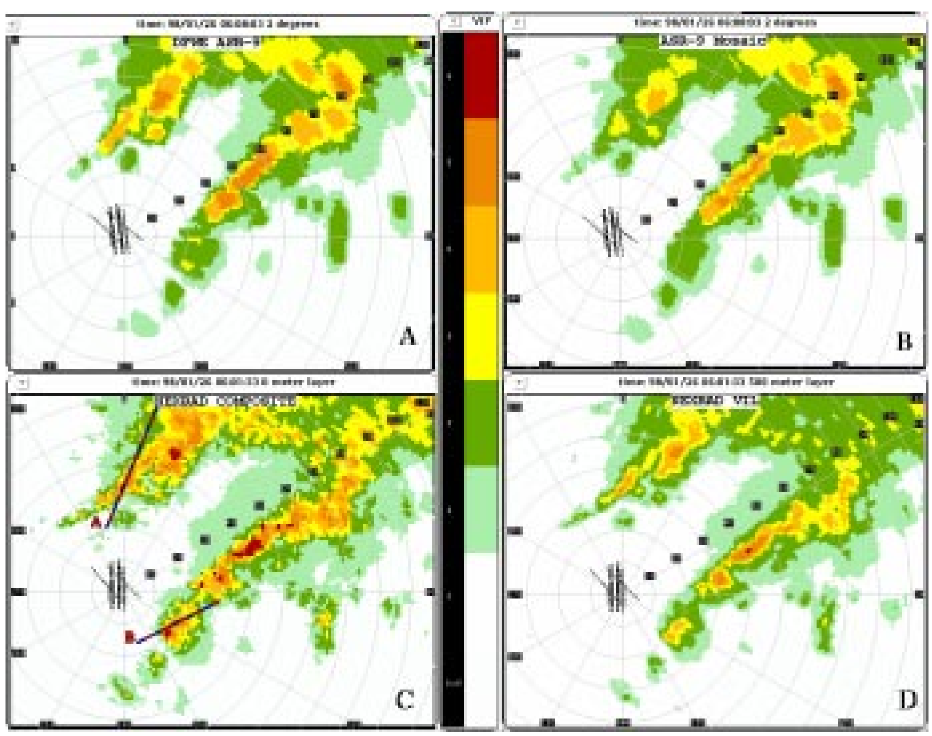

Figure 1. A through D show the radar products analyzed for the January 26th case at 0608 UT. A is the DFWE ASR–9 weather channel data, B shows the DFW ASR–9 mosaic product, C is the NEXRAD composite reflectivity product, and D shows the NEXRAD VIL product. Each panel has a product time above the image. The time stamps are different for the ASR–9 data and the NEXRAD data because the time stamps on the ASR–9 products represent the time at the end of the NEXRAD scan while the NEXRAD time is at the start.

cates the cell to be a level 5 (Figure 1D) which is a much better representation of the vertical extent of the entire cell than the composite data which had level 6 returns (Figure 1C).

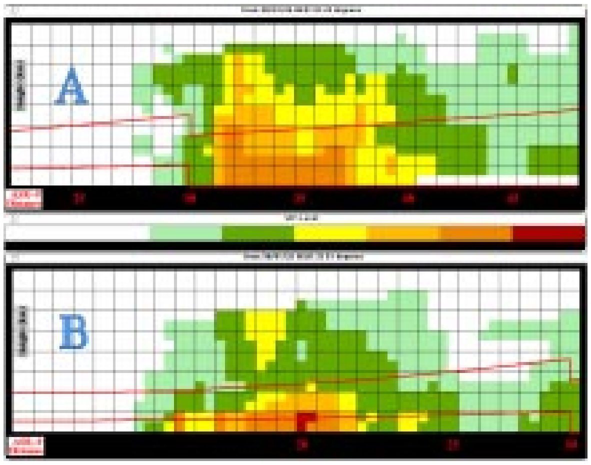

Figure 2. A and B are cross–section plots of two of the cells studied for the January 26th case. A and B correspond to the lines A and B in Figure 1C. The lines ascending to the right through the cells indicate the ASR–9 beam coverage.

Figure 2B, shows the cross section of the layered product along the NEXRAD 61° radial. Since the cell is much closer to the DFWE ASR–9 radar site, the ASR–9 would use the high–beam portion of its scan for detection purposes. As a result, the beam is overshooting the very low core of this cell, which is detected as level 6 by the NEXRAD composite (Figure 1C). This illustrates the beam–filling problem inherent to the ASR–9 (Engholm and Troxel, 1990). Reflectivities within the radar beam area were level 3 to 4. However, the ASR–9 indicates the cell as level 2 with embedded level 3 (Figure 1A), another indication that the ASR–9 is underestimating the cell by 1 VIP level. By comparison, the NEXRAD VIL indicates the cell to be a level 3 to 4. Since the NEXRAD composite shows this cell to be level 6 and the NEXRAD VIL shows the cell to be VIP level 3 to 4, one could make a hypothesis that the cell is dissipating. This is proven by the cross section (Figure 2B) which shows that the core has dropped, indicating that the cell was decaying. This shows that the NEXRAD–based VIL product is a better indicator of overall storm severity and longevity then the NEXRAD composite reflectivity product.

3.2 February 22nd, 1998

On this day, stratiform precipitation impacted the DFW area, and an enhanced echo layer caused by the difference in radar reflectivity of ice and water particles, or a bright band echo, was observed in the NEXRAD base data. The NEXRAD composite reflectivity product indicated a large area of level 5 echo with embedded areas of level 6 (Figure 3C). However, the ASR–9 indicated only a large area of level 3 precipitation (Figure 3A). This bright–band case highlights the problem of a vertically shallow, high–reflectivity region on the NEXRAD composite reflectivity product. Although only a single tilt intersects the level 5 precipitation, the product displays this highest reflectivity encountered. Therefore, the high precipitation levels ob-

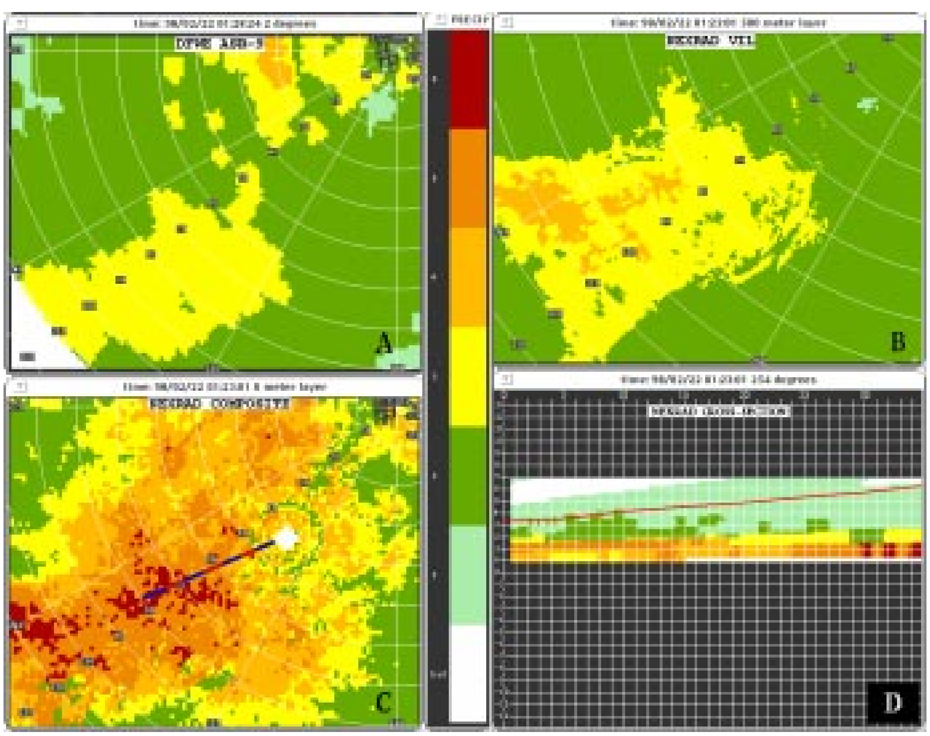

Figure 3. A through D show the data analyzed for the February 22nd case at 0128 UT. Figure A is the DFWE ASR–9 data, B is the NEXRAD VIL product, C is the NEXRAD composite product, and D is a cross–section plot along the 245–degree NEXRAD radial. The line in Figure C indicates the location of the cross section. The black line in D indicates the top of the ASR–9 beam. The time stamp difference is the same as in Figure 1.

served were not a good gauge of storm intensity. Conversely, the fan–beam ASR–9 radar receives returns for the entire volume of the storm (Figure 3D) and thus is a better two–dimensional representation of the reflectivity of all the cells in this case.

An area of echo centered 50 km southwest of the KFWS NEXRAD at 0123 UT, which exhibited bright–band characteristics, was analyzed. Notice the narrow band of level 5 in Figure 3D. This, as well as the circles of level 3 to 5 around the NEXRAD site (Figure 3C), are good indicators that the echo is a bright band (Rinehart, 1991). In this case, the NEXRAD VIL product indicated a large area of level 3 with embedded level 4 echo, which more closely matches that of the ASR–9 (Figures 3A and 3B).

3.3 March 16th, 1998

A small line of thunderstorms developed in the early afternoon and propagated to the east while individual cells tracked north–northeastward, indicating a vertically sheared environment. The NEXRAD composite product contained 3 cells of level 6 intensity (Figure 4C) while the DFWE ASR–9 data indicated up to 3 intensity levels lower (Figure 4A). Figure 4D indicates that the cells were mostly within the ASR–9 beam.

Figure 4D shows that the cells were tilted northward due to the environmental shear. This provided an interesting situation for the ASR–9 weather processor as it takes an integration along a vertical column. When a cell does not have a stacked vertical structure, the ASR–9 will inherently underestimate the precipitation intensity. However, it is apparent that the ASR–9 underestimated the intensity beyond that which can be explained by the vertical structure of the cells. The middle cell in figure 4D has a well–defined vertical column of level 5 from the surface to 3 km, all within the ASR–9 beam. However, the ASR–9 (Figure 4A) indicated that this cell was only level 3 while the NEXRAD VIL product (figure 4B) indicated the cell was level 4. The NEXRAD composite product depicted the cell as level 6 due to one pixel of that level (Figure 4D).

There was only a 1–level differences between the NEXRAD VIL (Figure 4B) and the ASR–9 (Figure 4A). This is not significant and can occur due to data quantization.

3.4 July 4th, 1998

Isolated afternoon convection developed around the DFW area on this day. This case was similar to the March 16th case but differed in that the upper–level winds veered gradually with height, providing the shear needed for thunderstorm development and allowing the storms to grow vertically. Vertical cross sections analyzed for this case indicated cells were vertically stacked, with tops between 7 to 10 km. Therefore, the reasons for the lower VIP levels of cells in this case by the ASR–9 must not be the same as in the March 16th case. Indeed, most of the lower VIP levels were due to beam–filling errors and possibly some attenuation. An in–depth analysis of these problems was done by Crowe, et al. (1997) and is outside the scope of this paper.

For this case, seven individual cells were studied over a period of one hour. When compared to the NEXRAD VIL data, the NEXRAD composite product was 1 to 3 VIP levels higher for most cells. However the data also showed that the DFWE ASR–9 indicated most cells were 1 VIP lev-

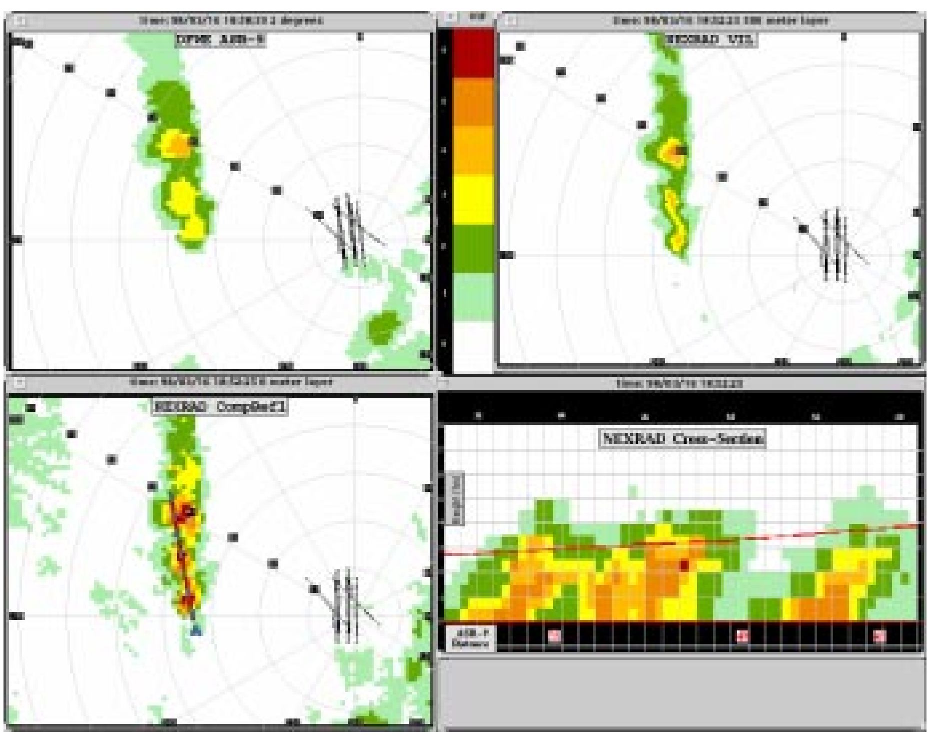

Figure 4. A through D show the data analyzed for the March 16th case at 1852 UT. Figure A is the DFWE ASR–9 weather channel data. B shows the the NEXRAD VIL product. C is the NEXRAD composite product. The cross section in D is along the radial indicated by the line through the cells in C. The black line in D indicates the top of the ASR–9 beam. The time stamp difference is the same as in Figure 1 and 2.

el below what the NEXRAD VIL indicated. When the VIL data were compared to the ITWS mosaic map, most of the cells were the same level or had only a 1–level difference.

3.5 Conclusion of Case Analysis

Isolated and embedded cells from winter, spring, and summer storm events were analyzed for this study. Based on vertical cross–sections, we concluded that the ASR–9 radars can underestimate the intensity of precipitation by about 1 VIP level. However, it can also be stated that the NEXRAD composite reflectivity generally indicates cells 2 to 3 VIP levels higher then the ASR–9. Since both products have an inherent bias, they cannot effectively be compared. Therefore, a study of the NEXRAD–derived VIL was used to compare the two radars' data.

4.0 ANALYSIS OF NEXRAD VIL

4.1 ASR–9 as Compared to NEXRAD VIL

A study to determine how well the NEXRAD VIL compared to the ASR–9 weather channel product was completed on three of the ten cases from the Crowe, et al. (1997) study. In the original study, NEXRAD composite reflectivity was compared to the ASR–9. Cells were compared for each NEXRAD volume scan, resulting in a total of 9308 cell comparisons. The study found that only 65.6% of cells compared were within 1 VIP level. The three cases re–examined using the NEXRAD VIL had a total of 2937 cells, of which 140 had a difference of greater than 1 level. Therefore, 95.2% of the cells re–examined were within 1 level of the NEXRAD VIL.

4.2 Comparison of NEXRAD Composite Reflectivity and NEXRAD VIL

The NEXRAD composite reflectivity product is currently used by air traffic specialists for the long–range weather data. The product has advantages over a NEXRAD base data display because it requires little interpretation. The NEXRAD composite product provides a near real–time, two–dimensional, weather display of NEXRAD data.

The NEXRAD VIL product used for this study does not exist as a NEXRAD product at this time. The current National Weather Service (NWS) NEXRAD VIL product has a resolution of 4 km and 5 kg/m^2. This is inadequate for use by the aviation community because it would require to much interpretation by the users. A 1 km product which uses the conversion of VIL to VIP in Table 1, however, would be a product which air traffic specialists could use with little or no interpretation.

There are several system architecture advantages to using NEXRAD VIL as an aviation weather product in addition to the data integrity advantages discussed in Section 2.0. This product could be used not only by ITWS but also by the Weather And Radar Processor (WARP). Also, NEXRAD VIL is currently used by the Terminal Convective Weather Forecast (TCWF) system operating in Dallas (Hallowell, 1999).

5.0 CONCLUSIONS & RECOMMENDATIONS

For the cases considered in this study, the NEXRAD VIL product provided better data integrity (e.g., fewer artifacts due to bright band contamination and/or ground clutter) and a better indication of storm longevity and overall strength than did the NEXRAD maximum composite reflectivity product. Additionally, it provided a closer correspondence to the vertically integrated reflectivity product produced by the ASR–9. Although there is no scientific basis for requiring that the precipitation product used for the NEXRAD agree with the ASR–9 precipitation product, it would be beneficial operationally if the NEXRAD product generally agreed with the ASR–9 product for weather which is not rapidly changing. Achieving correspondence between the precipitation depiction provided by the two sensors has become increasingly important operationally with the new ITWS displays that permit side–by–side comparison of the precipitation products provided by the two sensors on the same range scale.

The current NEXRAD VIL product would not be suitable for operational use by the aviation operational community due to its coarse quantization. We recommend that the NEXRAD product suite be augmented to provide 1 km and 4 km spatial resolution VIL products with the 6–level VIL scale shown in Table 1. Before a formal modification to the NEXRAD commences, an operational evaluation of the proposed product could be carried out at experimental aviation product test locations (e.g., the ITWS prototype sites) which have access to the NEXRAD base data.

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