12.5 DEVELOPMENT AND TESTING OF THE VAHIRR RADAR PRODUCT

Joe H. Barrett III*
NASA Applied Meteorology Unit / ENSCO, Inc. / Cape Canaveral Air Force Station, FL

Juli Miller, Debbie Charnasky and Robert Gillen
ENSCO, Inc., Cocoa Beach, FL

Richard Lafosse, Brian Hoeth and Doris Hood
NOAA/NWS Spaceflight Meteorology Group, Houston, TX

Todd McNamara and William Roeder
45th Weather Squadron, Patrick Air Force Base, FL

1. INTRODUCTION

Lightning Launch Commit Criteria (LLCC) are used for launches at government and commercial spaceports in the United States. They are a set of 12 rules used to avoid natural and rocket-triggered lightning strikes to space vehicles, which can endanger the vehicle, payload, and general public (Roeder and McNamara, 2006). The LLCC are also incorporated into the Flight Rules (FR) to avoid lightning threats during the landing of the space shuttle. The previous LLCC and FR were shown to be overly restrictive, potentially leading to costly launch delays and scrubs. A radar product called Volume Averaged Height Integrated Radar Reflectivity (VAHIRR), along with new LLCC and FR for anvil clouds, were developed using data collected by the Airborne Field Mill II (ABFM II) research project (Dye *et al.*, 2006). The use of the VAHIRR product is expected to lead to increased launch and landing opportunities, while maintaining safety.

2. DEVELOPMENT OF THE VAHIRR PRODUCT

The ABFM II project was conducted during June 2000 and May/June 2001 near Kennedy Space Center (KSC) to develop improved and physically-based LLCC that would be safe but less restrictive than the previous LLCC (Dye *et al.*, 2006). The project investigated the magnitude and duration of electric fields inside thunderstorm anvils, and how they were related to the cloud microphysics and cloud radar reflectivity. Airborne measurements were made by a University of North Dakota Citation II jet aircraft. Radar coverage included the Patrick Air Force Base Weather Surveillance Radar 1974-C (WSR-74C) radar and the Melbourne Weather Surveillance Radar 1988 Doppler (WSR-88D) radar. Total lightning measurements were made with the KSC Lightning Detection and Ranging and the Air Force Cloud to Ground Lightning Sensing systems. More details on these sensors are at Roeder *et al.* (2003).

In the ABFM II project, when the radar reflectivity near the aircraft was less than 5 to 10 dBZ, the magnitude of the three-dimensional electric fields was less than 3 kiloVolts/meter (kV/m). This value poses little threat for rocket-triggered lightning. The VAHIRR product showed a trend of increasing values with increases in the electric field magnitude above 3 kV/m. An extreme value analysis of VAHIRR values ≤ 10 dBZ-km (equivalent to a 5 dBZ reflectivity average in a 2 km-thick anvil) showed that the probability of having an electric field magnitude larger than 3 kV/m was less than 1 in 10,000. The LLCC for anvil clouds were updated in 2005 to incorporate the project's results (Krider *et al.*, 2006).

2.1 Formal Definition of VAHIRR

VAHIRR (units of dBZ-km) is the product of the Volume-Averaged Radar Reflectivity and the Average Cloud Thickness within a Specified Volume relative to a point along the flight track of a space launch vehicle (Merceret *et al.*, 2006).

The Specified Volume is bounded in the horizontal and vertical planes, with perpendicular sides located 5.5 km north, east, south, and west of a point on the flight track, on the bottom by the 0° C level, and on the top by the upper extent of all clouds.

The Volume-Averaged Radar Reflectivity is the arithmetic average (in dBZ) of the cloud radar reflectivity within the Specified Volume. Normally,

* *Corresponding author address:* Joe H. Barrett III, ENSCO Inc., 1980 N. Atlantic Ave., Suite 230, Cocoa Beach, FL 32931, barrett.joe@ensco.com.

a radar processor will report reflectivity values interpolated onto a regular, three-dimensional array of grid points. Any such grid point within the Specified Volume is included in the average if and only if it has a radar reflectivity equal to or greater than 0 dBZ.

The Average Cloud Thickness is the altitude difference in km between the average top and the average base of all clouds within the Specified Volume. The cloud base to be averaged is the higher of (1) the 0° C level and (2) the lowest extent in altitude of all cloud radar reflectivities 0 dBZ or greater. The cloud top to be averaged is the highest extent of all cloud radar reflectivities 0 dBZ or greater (Figure 1). Given the grid-point representation of a typical radar processor, allowance must be made for the vertical separation of grid points in computing cloud thickness: The cloud base at any horizontal position will be the altitude of the corresponding base grid point minus half of the grid-point vertical separation. Similarly, the cloud top at that horizontal position will be the altitude of the corresponding top grid point plus half of this vertical separation. Thus, a cloud represented by only a single grid point having a radar reflectivity equal to or greater than 0 dBZ within the Specified Volume would have an Average Cloud Thickness equal to the vertical grid-point separation in its vicinity.

The VAHIRR measurement must be made in the absence of significant attenuation by intervening storms or by water or ice on the radome itself. It is invalid at any point on the flight track that is within 20 km of radar reflectivities 35 dBZ or greater, at altitudes of 4 km above mean sea level or greater, and at any point within 20 km of any type of lightning that occurred in the previous 5 minutes. The Specified Volume must not contain any portion of the cone of silence above the radar, nor any portion of any sectors that may have been blocked out for payload-safety reasons. A vertical cap is added to the cone of silence restriction to avoid invalidating the VAHIRR values everywhere. The individual grid-point reflectivities used to determine either the Volume-Averaged Radar Reflectivity or the Average Cloud Thickness must be from meteorological targets.

Until the automated VAHIRR product software has been deployed operationally, a work-around is necessary to calculate the VAHIRR values using existing radar products. The work-around is manually intensive and produces a more conservative result. It is described in detail in Merceret *et al.*, 2006.

3. AUTOMATED VAHIRR PRODUCT

The automated VAHIRR product is in a Cartesian format, with a resolution of 1 km for each grid point. It uses the same storage format as the 16-level 1 km composite reflectivity product. It was developed for the WSR-88D radar with the Common Operations and Development Environment (CODE) software (Gillen *et al.*, 2006). The CODE is an environment for implementing and testing new radar algorithms for the WSR-88D and was created jointly by the National Weather Service and Mitretek Systems (now called Noblis, Inc.). A public version of the CODE software is available for free online at http://www.weather.gov/code88d. A computer using the Linux operating system with the CODE software installed is referred to as an "ORPG-clone". An ORPG-clone is identical to the operational Open Radar Product Generator (ORPG), except that it is not connected to a WSR-88D radar. It can create radar products in real-time by ingesting Archive Level II data from a WSR-88D radar. The automated VAHIRR product was developed and tested with build 8 of the CODE software, corresponding to build 8 of the operational ORPG.

A two-pass algorithm is used to create the VAHIRR product. On the first pass, the cloud top and bottom, number of reflectivity values and average reflectivity above each 1 km grid point are calculated. The grid point is disqualified if the lowest elevation scan (0.5°) lies above the 0° C level or if the highest elevation scan (19.5°) contains non-negative reflectivity (0 dBZ or greater). The height of 0° C is read from the Hail product. The Human Computer Interface (HCI) utility is used to adjust the 0° C level. This is to avoid underestimating the actual VAHIRR value. A grid point is also disqualified if it lies within the cone of silence. The cone of silence parameter used in the product is defined as the highest height of interest in calculating VAHIRR, usually the highest altitude of the anvil cloud. For example, if the cone of silence is set to 15 km, then a grid point will be disqualified if the highest elevation scan above the point lies below 15 km. The default cone of silence value is set to 20 km, but can be adjusted by the radar operator. The top of the anvil cloud is preferred, followed by the tropopause height, with the default 20 km being the last option. On the second pass, the VAHIRR values are calculated for each grid point by averaging the values in the surrounding 5 km in the north, south, east, and west directions. VAHIRR values can only be calculated for grid points in which the complete 11x11 km grid point set is valid.

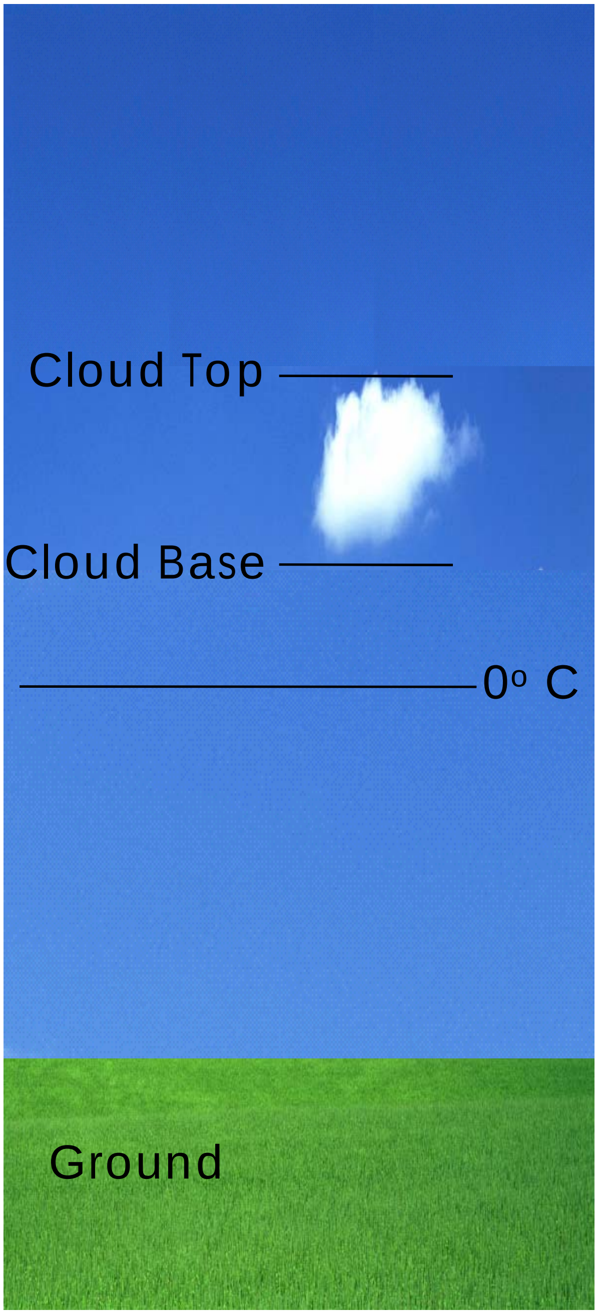

Figure 1. Depiction of the cloud top and base in VAHIRR. To take into effect vertical grid spacing, half a vertical grid spacing is then added to the cloud top and subtracted from the cloud base.

4. REAL-TIME AUTOMATED VAHIRR PRODUCT

The automated VAHIRR product can be displayed with the ORPG-clone's native display software, CODEview Graphics (CVG) (Figure 2). In addition, the VAHIRR product can be displayed in the Advanced Weather Interactive Processing System (AWIPS). Both the Applied Meteorology Unit (AMU) at CCAFS (Bauman et al., 2004) and Spaceflight Meteorology Group (SMG) at Johnson Space Center in Houston, TX localized their AWIPS systems in order to view the VAHIRR radar product in near real-time (Figure 3). VAHIRR values of 0 dBZ-kft or less are displayed in black, while disqualified points are displayed in white. Both the AMU and SMG can acquire Archive Level II data in real-time from a Local Data Manager (LDM) feed from Marshall Space Flight Center. The AMU developed an AWIPS application that will create overlays of the expected launch and landing trajectories, to be plotted on top of the VAHIRR product (Figure 4).

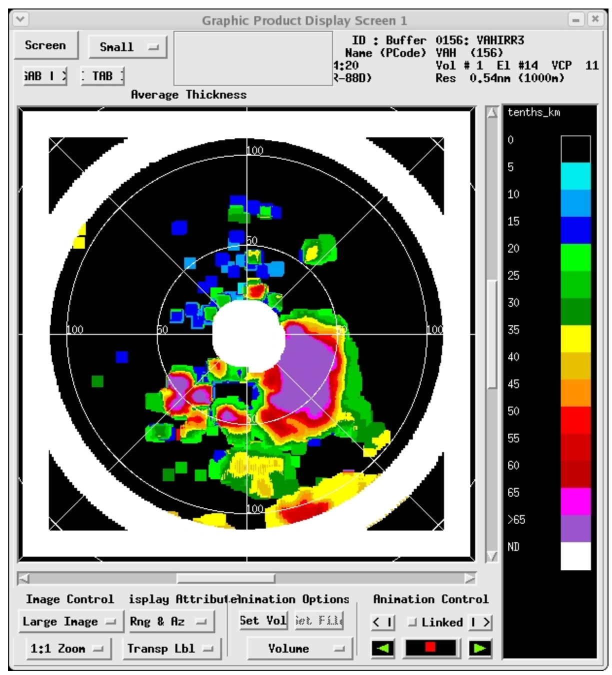

Figure 2. An example of the automated VAHIRR product as viewed on the ORPG-clone. The legend is in dBZ-kft

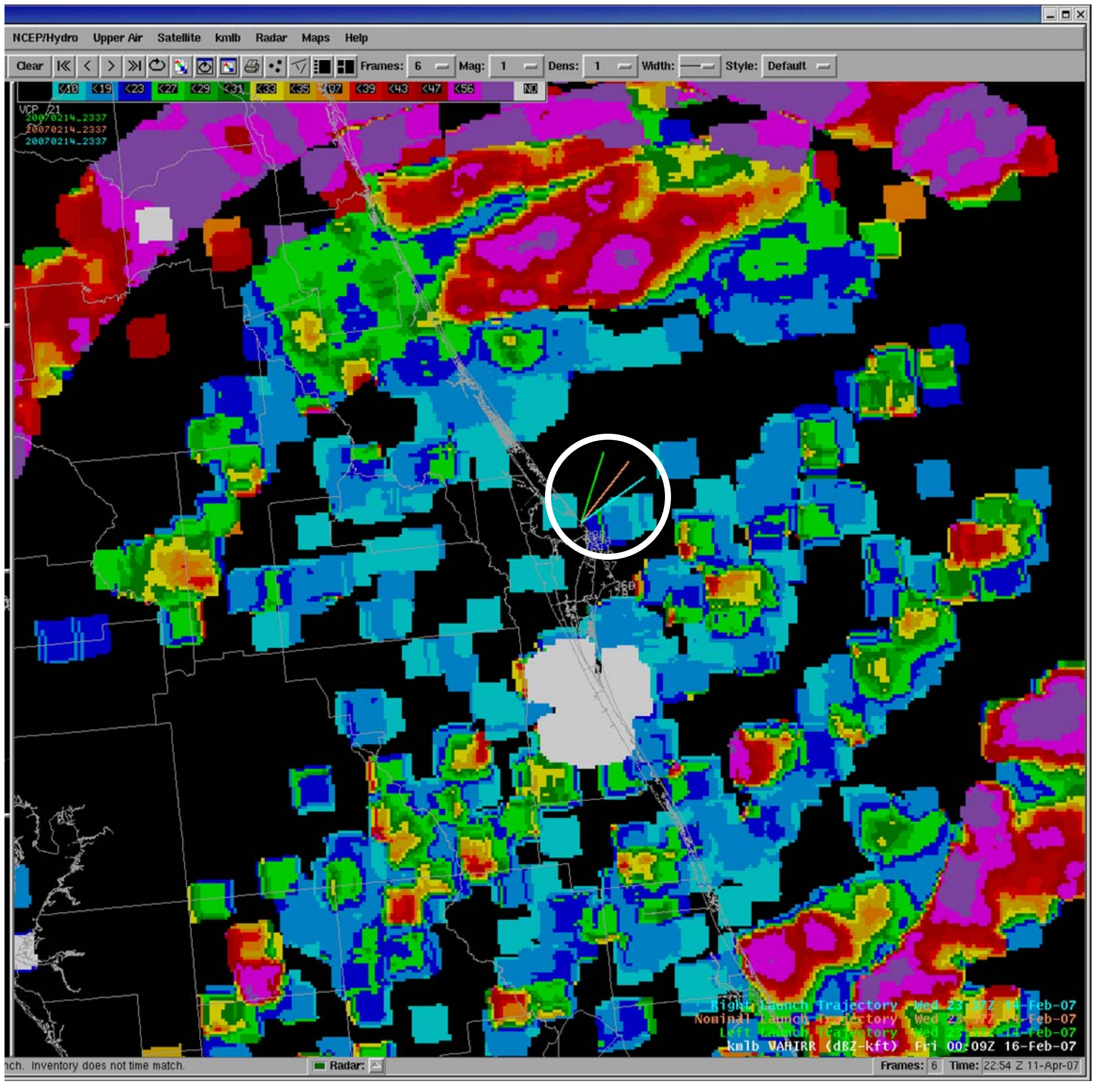

Figure 3. An example of the automated VAHIRR product as viewed in AWIPS. The Archive level II data is not the same as that in Figure 1. A white circle has been drawn around a left, nominal, and right launch trajectory.

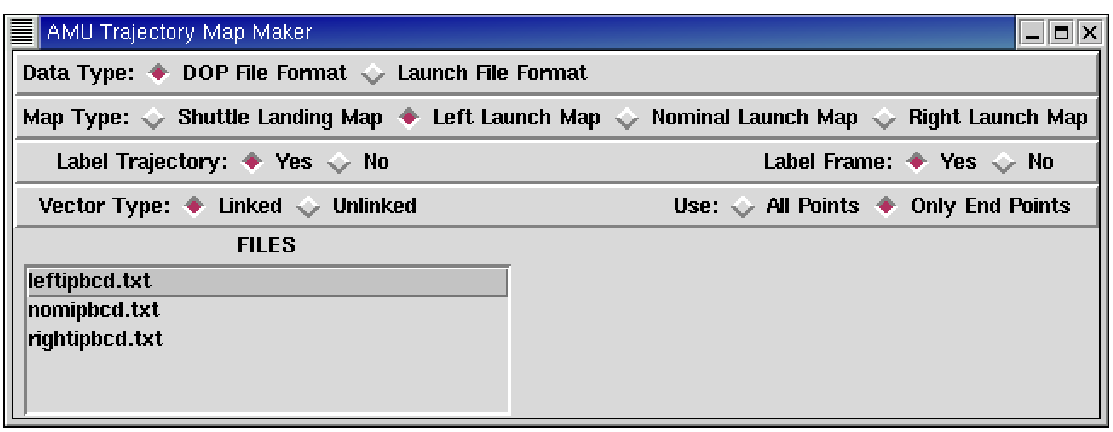

Figure 4. The graphical user interface for the AWIPS application that creates launch and landing trajectory overlays.

5. TESTING THE AUTOMATED VAHIRR PRODUCT

The automated VAHIRR product has undergone a series of tests, using both canned (artificial) and real Archive Level II radar data as input. The tests were done to ensure the correctness and reliability of the product.

5.1 Initial Test

The purpose of the initial test was to verify the VAHIRR values were calculated correctly for all possible input values. A utility on the ORPG-clone created customized Archive Level II base data. Table 1 shows the values of the base data, while Figure 5 shows the resulting VAHIRR product.

Table 1. Custom Archive Level II data for the Initial Test.

Radial (degrees)	***Gates***	***Elevation Angle(s) (degrees)***	***Reflectivity (dBZ)***
45.0-135.0 (inclusive)	0-130	0.5, 1.5, 2.4, 3.4	3.5
	131-229	0.5 – 3.4	-2.0
	all	4.5, 5.3, 6.2, 7.5, 8.7, 10.0, 12.0, 14.0 16.6, 19.5	-0.5
180.0-200.0 (inclusive)	all	0.5 – 3.4	4.0
	all	4.5 – 19.5	-0.5
256.0-260.0 (inclusive)	all	0.5 – 3.4	0.0
	0-61	4.5 – 19.5	0.0
	62-229	4.5 – 19.5	-0.5
322.0-353.0 (inclusive)	all	0.5 – 3.4	2.0
	all	4.5 – 19.5	-0.5
all other radials	all	0.5 – 3.4	0.0
	all	4.5 – 19.5	-1.0

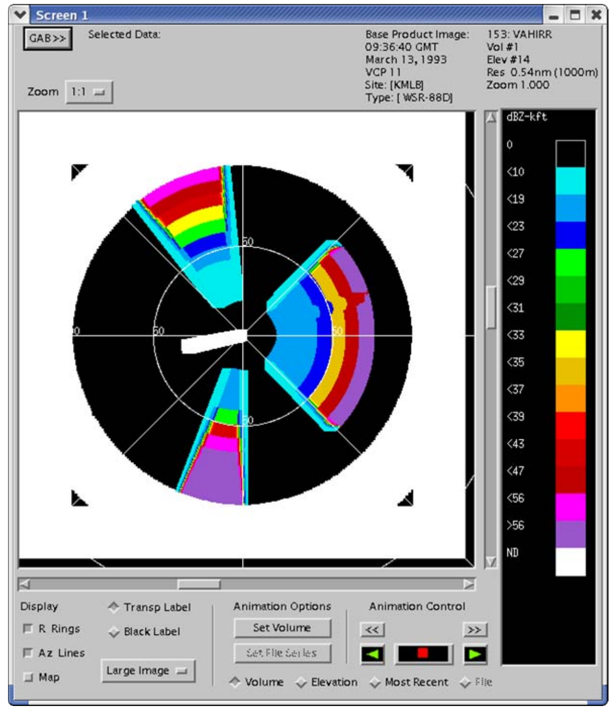

Figure 5. The VAHIRR product in the Initial Test, using the customized radar data.

In the test, the VAHIRR values between 45°-135° and 180°-200° azimuth increased with distance from the radar. This is because the cloud thickness increases as the beam thickness increases with distance from the radar. The white bar between 256°-260° is where reflectivity on the highest elevation scan was nonnegative for the first 61 range gates, violating the condition that reflectivity on the highest elevation scan must be negative. The range gates between 62 and 229 are black since the reflectivity was -0.5 dBZ for all elevations. In the fourth sector (322°-353°), the VAHIRR values also increased with distance as the beam thickness increased.

However, the values were lower than the other sectors, since the reflectivity was 2.0 dBZ between 0.5° and 3.4°. The small black triangles near the four corners of the display occur as a result of displaying spherical data in a two-dimensional array.

5.2 Factory Acceptance Test

The VAHIRR Factory Acceptance Test was composed of five different test procedures:

- Baseline,
- 0° C,
- Cone of Silence,

- Reflectivity Average for Multiple Tilts, and
- ABFM Comparison.

5.2.1 Baseline Test Procedure

The purpose of this test was to demonstrate the accuracy of the VAHIRR product for a basic set of input data. Figure 6 depicts the baseline input dataset used, and Figure 7 shows the expected results. A 0° C height of 10 kft (3.048 km) Mean Sea Level (MSL) and a cone of silence height of 35 kft (10.668 km) Above Ground Level (AGL) were used. The following describe the input data:

- Between 0.0° and 180.0° azimuth at radar elevation 4, VAHIRR results are produced from the identified uniform reflectivity values in Figure 6. For radar elevations 1-3 and 5-9, reflectivity of -10 dBZ was used.
- Between 180.1° and 225.0° azimuth at radar elevations 8 and 9, VAHIRR results are produced from a cloud top above the highest elevation scan and a cloud bottom above than the 0° C level. For radar elevations 1-7, reflectivity of -10 dBZ was used.
- Between 225.1° and 270.0° azimuth at radar elevations 1-9, VAHIRR results are produced from a cloud top above the highest elevation scan and a cloud bottom below the 0° C level.
- Between 270.1° and 315.0° azimuth at radar elevations 1-3, VAHIRR results are produced from a cloud top lower than the highest scan and a cloud bottom lower the 0° C level. For radar elevations 4-9, reflectivity of -10 dBZ was used.
- Between 315.1° and 359.9° azimuth at radar elevation 1, VAHIRR results are produced from a cloud top lower than the 0° C level. For radar elevations 2-9, reflectivity of -10 dBZ was used.

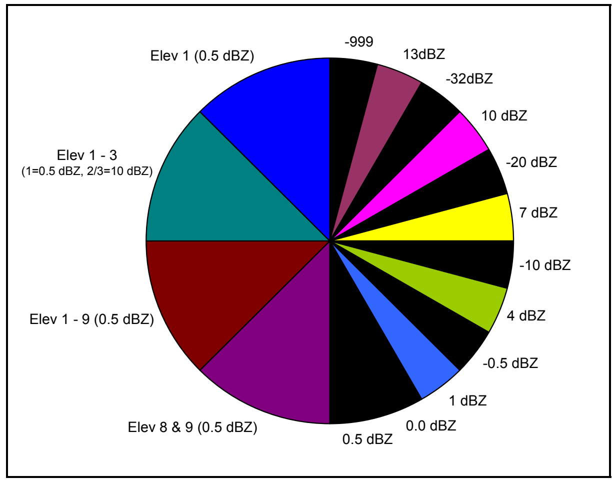

Figure 6. Baseline dataset. Elevation 1 is the lowest elevation scan (0.5°).

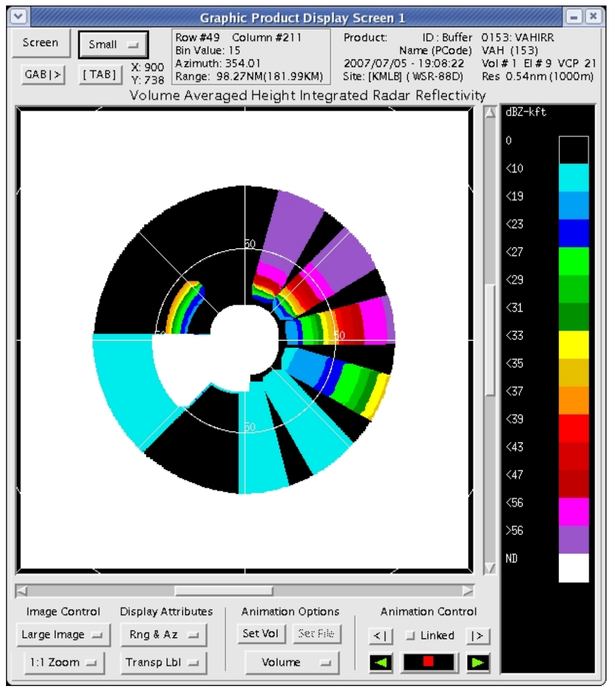

Figure 7. The VAHIRR product in the Baseline Test procedure.

5.2.2 0°C Height Test Procedure

The purpose of this test was to demonstrate that the VAHIRR radar product produces the correct results when varying the 0° C height. The baseline dataset in Figure 6 was used again in this procedure. The cone of silence height was set to 35 kft (10.668 km) AGL. The following five test cases were conducted:

1. 0° C height of -0.1 kft(for boundary testing outside the acceptable range),
2. 0° C height of 0.0 kft MSL,

3. 0° C height of 15 kft (4.572 km) MSL,

4. 0° C height of 22.9 kft (6.98 km) MSL (the maximum allowed height of the freezing level in the automated VAHIRR product), and

5. 0° C height of 23.3 kft (7.102 km) MSL (for boundary testing outside the acceptable range).

In the first test case, an error message was correctly written to a log file and the VAHIRR product was not produced. In the second test case, an error message was also written to a log file stating that the radar height (using the WSR-88D Melbourne radar) of 120 ft MSL was above the freezing level. All of the grid points were disqualified because the lowest elevation scan (0.5°) was above the freezing level. The VAHIRR product was still produced, resulting in the graphic depicted in Figure 8. Figures Figure 9 and Figure 10 show the VAHIRR product resulting from the third and fourth test cases. In the fifth test case, an error message was correctly written to a log file since the freezing level was set to an out-of-range value. No VAHIRR product was produced.

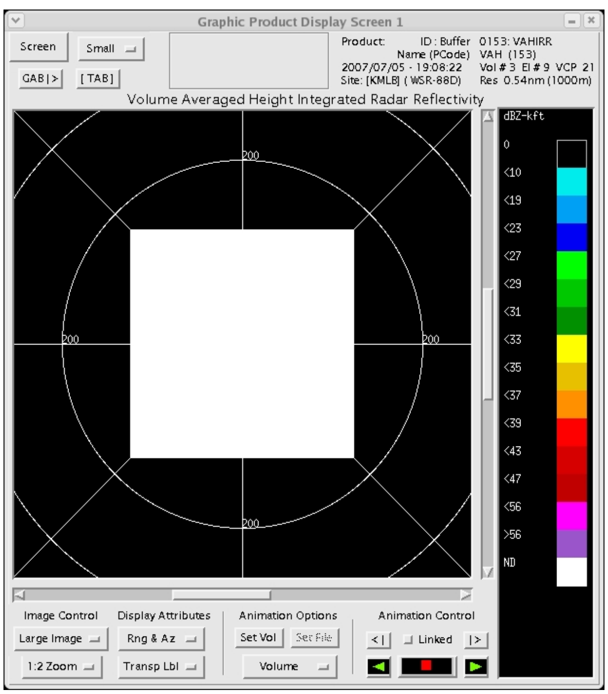

Figure 8. VAHIRR product when the 0° C height was set to 0 kft.

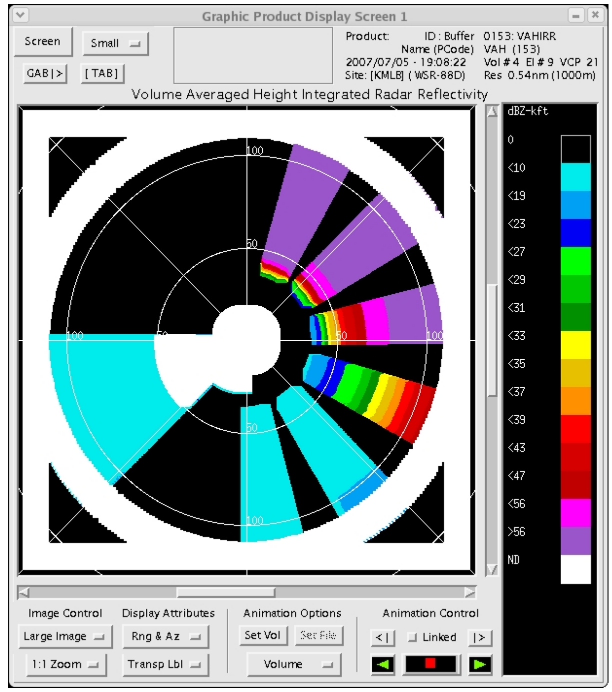

Figure 9. VAHIRR product when the 0° C height was set to 15 kft (4.572 km).

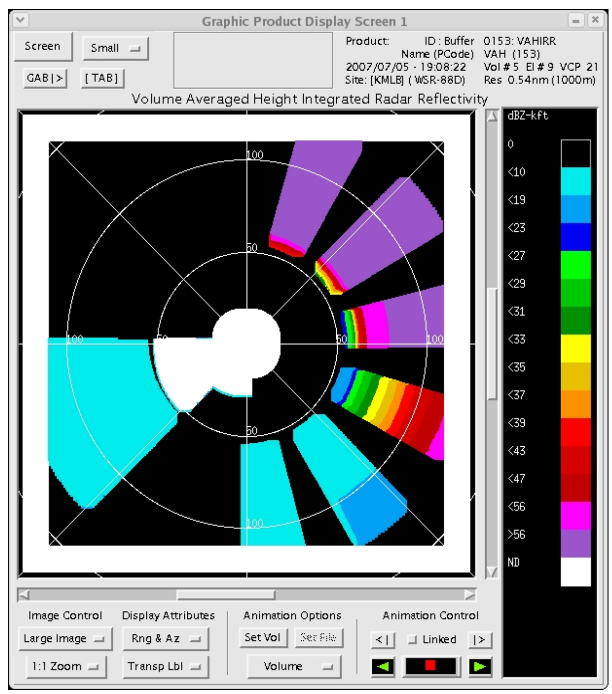

Figure 10. VAHIRR product when the 0° C height was set to 22.9 kft (6.98 km).

5.2.3 Cone of Silence Test Procedure

The purpose of this test was to demonstrate that the VAHIRR product produces the correct results when varying the cone of silence height. The baseline data set (Figure 6) and a 0° C height of 10 kft (3.048 km) MSL were used in each of the following test cases:

1. Missing cone of silence height (for boundary testing outside the acceptable range),
2. Cone of silence height of -0.1 kft AGL (for boundary testing outside the acceptable range),
3. Cone of silence height of 0.0 kft AGL (boundary testing using the lowest cone of silence height acceptable by the software),
4. Using grid points 5 km from the cone of silence,
5. Using grid points 6 km from the cone of silence,
6. Cone of silence height of 65.616 kft (20 km) AGL (for boundary testing the highest cone of silence height acceptable by the software)
7. Cone of silence height of 65.7 kft (20.025 km) AGL (for boundary testing outside the acceptable range)

In the first test case, an error message was correctly written to a log file, stating that the configuration file containing the cone of silence height could not be opened. The default cone of silence height of 65.616 kft (20 km) was used. Figure 11 shows the results of this case. In the second test case, the cone of silence height was correctly set to the default value of 20 km. The resulting VAHIRR product was the same as in the first case. In the third test case, the cone of silence height was set to 0.0 kft AGL. The resulting VAHIRR product is shown in Figure 12.

In the fourth test case, grid points 5 km from the cone of silence were correctly disqualified, as shown in Figure 13. The fifth test case demonstrated that VAHIRR values were calculated for grid points that are 6 km from the cone of silence, as shown in Figure 14. Figure 15 and Figure 16 use range rings in AWIPS to show that VAHIRR values were not calculated for grid points within 5 km of the cone of silence.

In the sixth test case, the cone of silence was set to the highest value, 20 km, acceptable by the software. The resulting VAHIRR product was the same as in the first case (Figure 11). In the seventh test case, the cone of silence was set to a value higher than the acceptable range. The cone of silence was correctly set to the default value of 20 km. The resulting VAHIRR product was the same as in the first case (Figure 11).

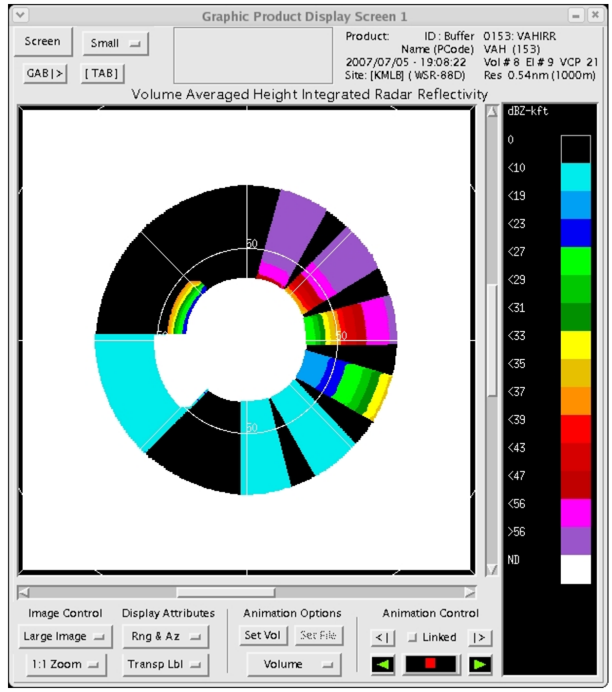

Figure 11. VAHIRR product when the default cone of silence height, 20 km, was used.

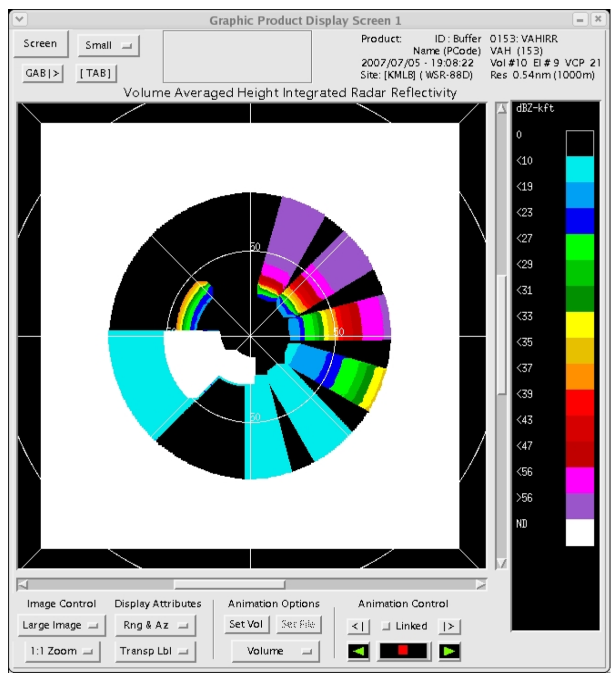

Figure 12. VAHIRR product when the cone of silence height was set to 0.0 kft.

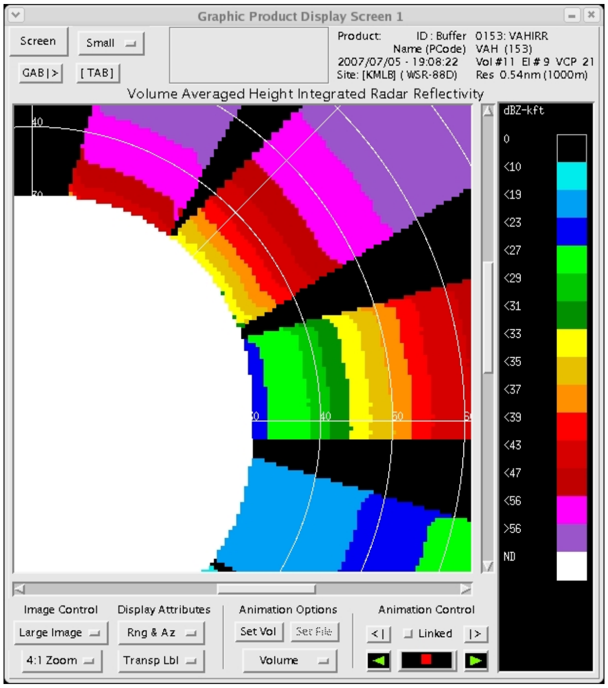

Figure 13. VAHIRR product when the cone of silence height was set to 59.74 kft (18.209 km).

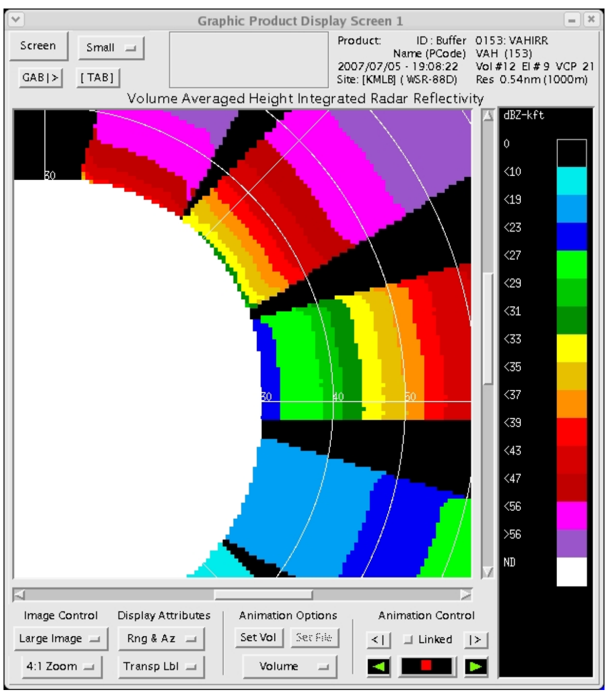

Figure 14. VAHIRR product when the cone of silence height was set to 58.62 kft (17.867 km).

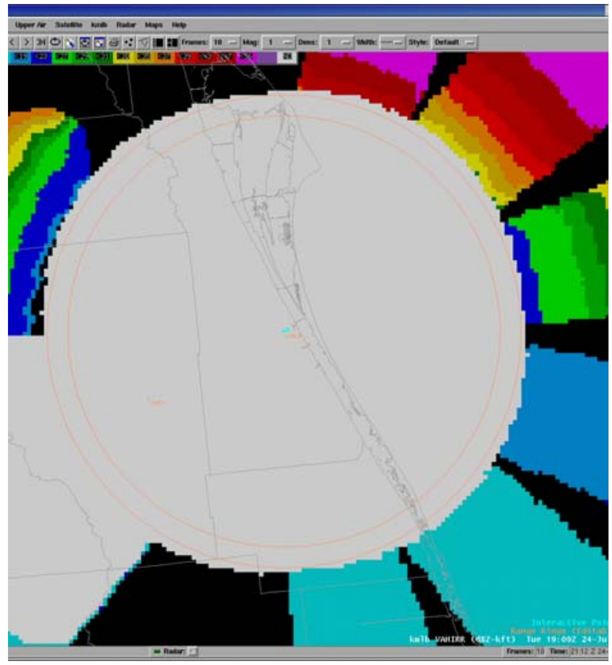

Figure 15. VAHIRR product in AWIPS with a cone of silence height of 59.74 kft (18.209 km). The inner range ring shows the calculated horizontal extent of the cone of silence. Invalid grid points are displayed in light gray. The radius of the outer range ring is 5 km larger than that of the inner range ring.

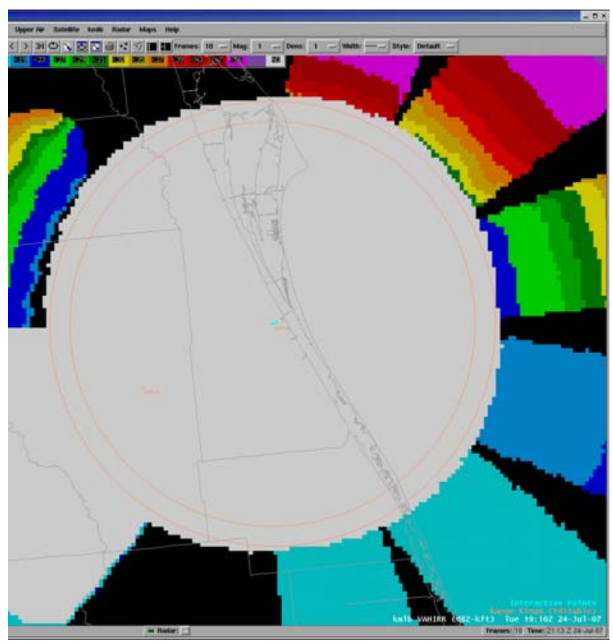

Figure 16. VAHIRR product in AWIPS with a cone of silence height of 58.62 kft (17.867 km). The inner range ring shows the calculated horizontal extent of the cone of silence. The radius of the outer range ring is 5 km larger than that of the inner range ring.

5.2.4 Reflectivity Average for Multiple Tilts Test Procedure

The purpose of this test was to demonstrate that the VAHIRR product averages the reflectivity values ≥ 0.0 dBZ at or above the 0° C level, in all elevation scans above a grid point. The test ensures that the VAHIRR radar product does not stop calculating a vertical average when negative reflectivity is encountered. This could happen when there is a break in a cloud or multiple cloud layers. The procedure also demonstrates varying cloud thicknesses in relation to the 0° C height. Figure 17 shows a profile of the test data. The cone of silence height was set to 35.0 kft (10.668 km) and the 0° C height was set to 10.5 kft (3.2 km). The resulting VAHIRR radar product is shown in Figure 18.

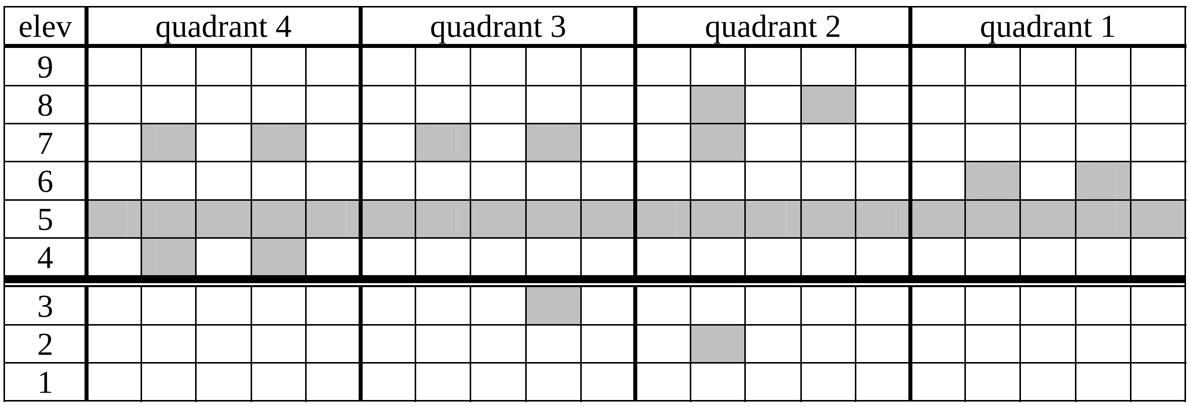

Figure 17. Representative profile of the test data in the Multiple Tilts Test Procedure. All reflectivity values are 2 dBZ (shaded). The bold line between elevations 3 and 4 represents the 0° C level.

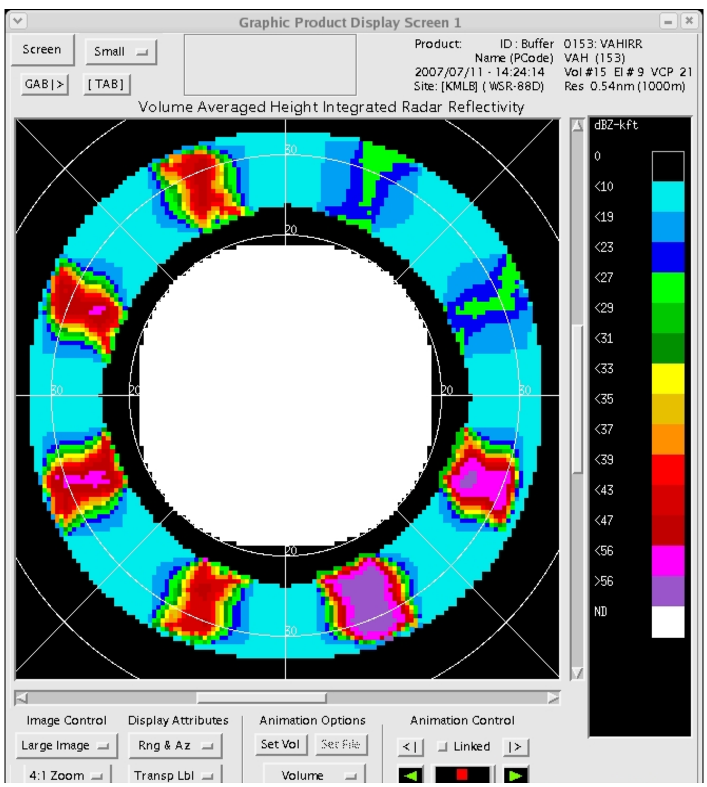

Figure 18. VAHIRR product in the Reflectivity Average for Multiple Tilts Test procedure.

5.2.5 ABFM Comparison Test Procedure

The purpose of this test was to compare ENSCO's automated VAHIRR radar product to the Volume Integral 11x11_0 product from the ABFM II project. The "11x11_0" suffix means that the Volume Integral was calculated over an 11 by 11 km horizontal grid, and only reflectivity values of 0 dBZ or greater were used to calculate the Volume Averaged Reflectivity. Hereafter, the automated radar product is referred to as the VAHIRR product, while the Volume Integral 11x11_0 product is referred to as the Volume Integral product. VAHIRR and Volume Integral values are shown in dBZ-kft instead of dBZ-km, since the output from the VAHIRR product is in dBZ-kft.

Data from the ABFM II project were downloaded from their website at http://abfm.ksc.nasa.gov. In order to have a large enough data set, data from multiple case study days were obtained. Only case study days without data quality issues or aircraft instrumentation problems were considered. Figure 19 shows a scatter plot of Volume-Averaged Reflectivity from the ABFM II project, versus the Volume-Averaged Reflectivity in the VAHIRR product. The best-fit linear regression line is plotted in the figure, along with the linear regression equation. The R^2 (coefficient of determination) value is displayed below the equation. As seen in the figure, good agreement can be seen in the volume averaged reflectivity between the Volume Integral and VAHIRR products. In the sample data set, the volume averaged reflectivity was just over 5.7 dBZ in the VAHIRR product and just over 5.3 dBZ in the Volume Integral product. Therefore, the VAHIRR product had a positive bias around 8%.

As shown in Figure 20, there were large differences in average cloud thickness between the two products for individual data points. The average cloud thickness was nearly 2.6 km in the VAHIRR product and just over 2.1 km in the Volume Integral product. This produced a positive bias around 23% in the VAHIRR product. Figure 21 indicates a somewhat better linear regression fit between the VAHIRR and Volume Integral values. The average VAHIRR value was 43.9 dBZ-kft. In order to calculate the averages and linear regression equations, all VAHIRR values ≥ 56 dBZ-kft were estimated to be 65 dBZ-kft. The average Volume Integral value was 33.1 dBZ-kft. This gives a positive bias around 33%.

Because of the large differences between the two products, the result from this test procedure was considered a failure. An investigation into the reasoning behind the differences is ongoing. The possible causes include the following:

1. Errors in the latitude/longitude position of the ABFM II's aircraft, Volume Integral values, or the values in the VAHIRR product. This is believed to be a minor issue, since it has been demonstrated that the differences in locations are generally 2 km or less (not shown);
2. Errors in calculating cloud heights in the two products. Standard radar refraction and the curvature of the earth should be taken into account. This has not been tested, but the errors are believed to be minor;
3. The ABFM II project first remapped the Archive Level II base data onto a 1 km x 1 km x 1 km 3-dimensional grid, using the Sorted Position Radar Interpolation (SPRINT) software package written by the National Center for Atmospheric Research (http://box.mmm.ucar.edu/pdas/pdas.html). The VAHIRR product converts the input base data (in radial format) onto a 1 km horizontal Cartesian grid, but does not convert the elevation scans to a 1 km vertical grid. Therefore the vertical grid spacing in the Volume Integral product stays constant at 1 km, while the vertical grid spacing in the VAHIRR product increases with distance from the radar. If the distance between adjacent elevation scans is greater than 1 km, the VAHIRR product should have a positive bias in average cloud thickness compared to the Volume Integral product. Conversely, if the distance between adjacent elevation scans is less than 1 km, the VAHIRR product should have a negative bias in average cloud thickness; and
4. The Volume Integral product uses all reflectivity values ≥ 0.0 dBZ to calculate the average cloud bottom and average cloud top, while the VAHIRR product uses only reflectivity values at or above the freezing level. If the average cloud bottom in the Volume Integral product is less than the freezing level, then the cloud bottom is set equal to the freezing level and 1 km is added to the cloud top since half a vertical grid spacing must be added to both the cloud bottom and cloud top. This partly explains the large positive bias in the cloud bottom and top in the VAHIRR

product. While the VAHIRR product is correct in this regard, the definition of VAHIRR will likely be changed to include all reflectivity values ≥ 0.0 dBZ in calculating average cloud thickness. Both the Volume Integral and VAHIRR product only use reflectivity values at or above the freezing level to calculate the volume averaged reflectivity.

The AMU is currently addressing the third possible cause. They are carrying out two tests:

1. For clouds of a limited range of thickness (thicker clouds are preferred), compute the ratios of average cloud thickness, volume averaged reflectivity, and VAHIRR/Volume Integral for the two products as a function of distance from the radar. Therefore, there will be three variables analyzed as a function of distance from the radar:

$$\frac{\text{VAHIRR Ave. Cloud Thickness}}{\text{Volume Integral Ave. Cloud Thickness}},$$

$$\frac{\text{VAHIRR Ave. Ref.}}{\text{Volume Integral Ave. Ref.}}, \text{ and}$$

$$\frac{\text{VAHIRR}}{\text{Volume Integral}}.$$

   For a fixed cloud thickness, the ratios of average cloud thickness and VAHIRR/Volume Integral should increase with distance from the radar due to beam spreading.

2. For clouds within a roughly fixed distance from the radar such that the beam spacing is significantly greater than 1 km, compute the same three ratios as in the first test, as a function of average cloud thickness. The ratios of average cloud thickness and VAHIRR/Volume Integral should decrease with increasing cloud thickness as long as the vertical beam spacing is significantly greater than 1 km. This is because there should be a greater positive bias in the VAHIRR values for smaller cloud thicknesses.

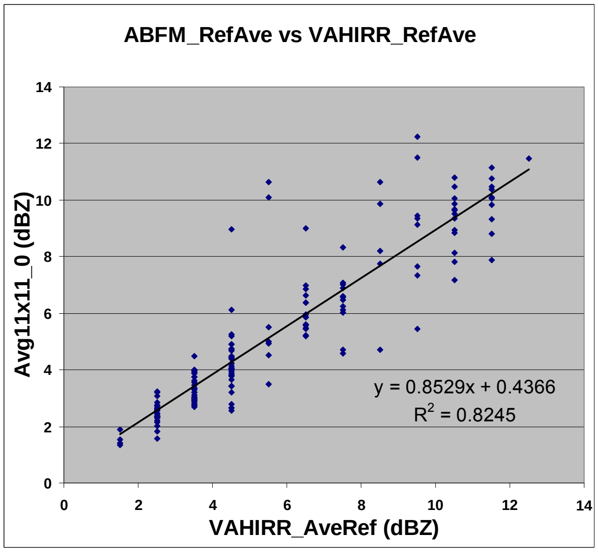

Figure 19. From the ABFM comparison test procedure, the volume averaged reflectivity in the Volume Integral product versus the VAHIRR product.

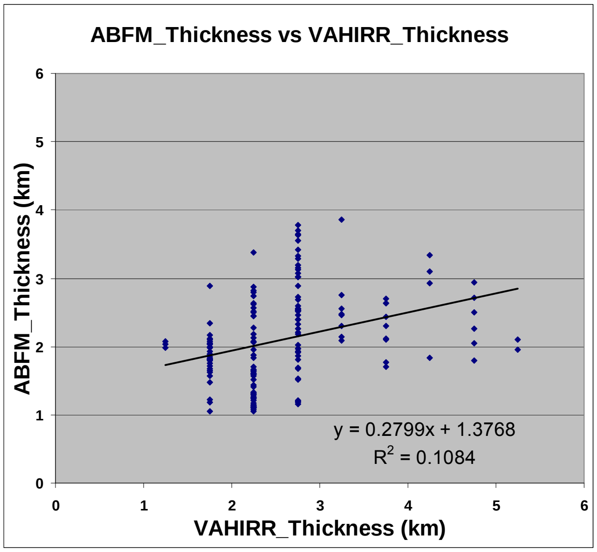

Figure 20. From the ABFM comparison test procedure, the average cloud thickness in the Volume Integral product versus the VAHIRR product.

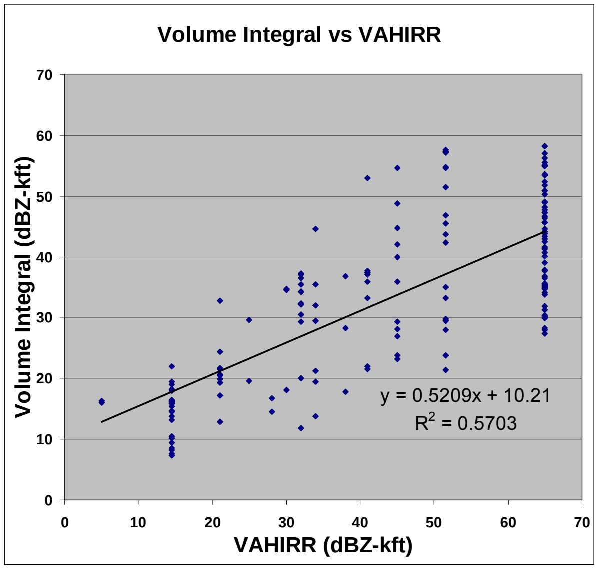

Figure 21. From the ABFM comparison test procedure, the Volume Integral product versus the VAHIRR product. VAHIRR values >= 56 dBZ-kft are estimated to be 65 dBZ-kft.

6. SUMMARY

The LLCC are a set of rules used to avoid natural and rocket-triggered lightning strikes to space vehicles. The previous LLCC were shown to be overly restrictive, potentially leading to costly launch delays and scrubs. The VAHIRR product and the updated LLCC for anvil clouds were developed using data collected by the Airborne Field Mill II project that was conducted in 2000/2001. The use of the VAHIRR product is expected to lead to increased launch and landing opportunities, while maintaining safety.

An automated version of the VAHIRR product was developed for use on the WSR-88D to reduce the operational impact of the anvil cloud LLCC on space launch. Because the VAHIRR product is too complicated to be estimated manually by operational personnel in real-time, and because of the importance of correctly evaluating the LLCC, the automated VAHIRR product was tested thoroughly for correctness and reliability. The VAHIRR product passed all the tests, except for the comparison with the original field experiment results. Several explanations for the difference are possible and are currently being investigated.

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