NASA Contractor Report CR-2000-208572

Final Report on IRIS Product Recommendations

Prepared By:
Applied Meteorology Unit

Prepared for:
Kennedy Space Center
Under Contract NAS10-96018

NASA
National Aeronautics and
Space Administration

Office of Management

Scientific and Technical
Information Program

2000

Attributes

NASA/KSC POC:
Dr. Francis J. Merceret
AA-C-1

Acknowledgment

The cooperation of Harold Witherow (Computer Science Raytheon) in evaluating product generation times is gratefully acknowledged.

Applied Meteorology Unit (AMU)

David A. Short, author

Table of Contents

List of Figures

List of Tables

List of Acronyms

Term	Description
AMU	Applied Meteorology Unit
CAPPI	Constant Altitude Plan Position Indicator
CCAFS	Cape Canaveral Air Force Station
COMP	Composite
dBZ	decibels of Radar Reflectivity
FCAST	Forecast
FR	Flight Rules
GUI	Graphical User Interface
IRIS	Interactive Radar Information System
KSC	Kennedy Space Center
KXMR	CCAFS Weather Station Identifier
LCC	Launch Commit Criteria
MAX	Maximum Reflectivity
MJJAS	May, June, July, August, September
NASA	National Aeronautics and Space Administration
NDJFM	November, December, January, February, March
PAFB	Patrick Air Force Base
PPI	Plan Position Indicator
QLW	Quick Look Window
RAINN	N-Hour Rain Accumulation
RAIN1	Hourly Rain Accumulation
RHI	Range Height Indicator
ROCC	Range Operations Control Center
RTLS	Return to Launch Site
RWO	Range Weather Office
SMG	Spaceflight Meteorology Group
SLC	Space Launch Complex
SLF	Shuttle Landing Facility
TOPS	Echo Tops
TRACK	TRACK/Forecast
UPI	User Product Insert
VCP	Volume Coverage Pattern
VIL	Vertically Integrated Liquid
WARN	Warning/Centroid
WSR	Weather Surveillance Radar
XSECT	Vertical Cross Section
45 WS	45th Weather Squadron

Executive Summary

This report presents the Applied Meteorology Unit's (AMU) evaluation of SIGMET Inc.'s Interactive Radar Information System (IRIS) Product Generator and recommendations for products emphasizing lightning and microburst tools. The IRIS Product Generator, located in the Range Weather Office (RWO), processes radar reflectivity data from the Weather Surveillance Radar, model 74C (WSR-74C), located on Patrick Air Force Base. The IRIS System was upgraded from version 6.12 to version 7.05 in late December 1999.

The AMU developed recommendations in consultation with personnel from the 45th Weather Squadron and the Spaceflight Meteorology Group. An IRIS Product Generator and display system in the AMU was also used off-line from the RWO IRIS system in the evaluation. A statistical analysis of atmospheric temperature variability over the Cape Canaveral Air Force Station (CCAFS) Weather Station provided guidance for the configuration of radar products that provide information on the mixed-phase (liquid and ice) region of clouds, between 0°C and -20°C. Mixed-phase processes at these temperatures are physically linked to electrification and the genesis of severe weather within convectively generated clouds. The AMU also examined the radar volume-scan strategy to determine the scales of vertical gaps within the altitude range of the 0°C to -20°C isotherms over the Kennedy Space Center (KSC)/CCAFS area. This report proposes modified scan strategies to reduce the vertical gaps as a means for improving radar observations of cloud characteristics in the critical 0°C to -20°C layer.

The following conclusions can be drawn from the evaluation described in this report:

- A simple modification of the present scan strategy can result in a 37% reduction in the average vertical gap over the KSC/CCAFS area.

- Day-to-day variations in the atmospheric temperature profile are of sufficient magnitude to warrant periodic reconfiguration of certain radar products, especially those intended for determination of the lightning and microburst potential of convectively generated clouds and the interpretation of Launch Commit Criteria and Flight Rules.

- The WSR-74C radar reflectivity database is updated every 2.5 minutes. During this time the IRIS Product Generator should be able to complete the suite of products selected by the radar operator. Production time with the recent IRIS software upgrade has been slowed by about 50% compared to the previous IRIS version 6.12. However, a hardware upgrade of the RWO workstation that may mitigate this factor is being evaluated at the present time.

The following recommendations are described in detail in Section 6.

- The AMU recommends a total of 18 products to be added to the reservoir of 130 products currently available to the radar operator. The recommended products fall into two major categories: The first category includes 7 products that can be periodically reconfigured at the radar console using Graphical User Interface tools on the IRIS system. These 7 products are sensitive to variations in the atmospheric temperature profile. The second category includes 11 products that would require use of the IRIS programming language and the IRIS User Product Insert feature. This category includes a cell-trends product and display, modeled after the WSR-88D cell trends display.

1.0 Introduction

1.1 Purpose of this Report

This report is prepared in response to Phase I requirements of the Applied Meteorology Unit's (AMU) IRIS SIGMET Processor Evaluation task. The purpose of this task is to evaluate capabilities of SIGMET Inc.'s Interactive Radar Information System (IRIS) for meeting operational requirements of the 45th Weather Squadron (45 WS) and the Spaceflight Meteorology Group (SMG). IRIS provides display and analysis of radar reflectivity data from the Weather Surveillance Radar, model 74C, (WSR-74C) located at Patrick Air Force Base (PAFB). Included are brief explanations and evaluations of capabilities of the IRIS Product Generator and recommendations of radar products emphasizing lightning and downburst tools for implementation on the IRIS System. The recommendations, based on discussions with weather support personnel from the 45 WS and SMG, are intended to provide a basis for discussions at meetings attended by 45 WS, SMG and AMU personnel. Products and capabilities selected during these meetings will be designed, implemented and tested on the IRIS workstations during Phase II. It is important to note that the SIGMET IRIS software is proprietary and cannot be changed by the AMU. Therefore, it may not be possible for ENSCO to develop some of the recommended tools/products using the current IRIS software. In this case, new algorithms, procedures or software modifications required to develop the recommended products will be forwarded to SIGMET, Inc. for possible implementation in future system builds.

1.2 Background Information

Forecasting of lightning and downbursts with the aid of radar reflectivity data requires detailed observations of the vertical structure of convective cells, anvils, and debris clouds. Updrafts in convective cells that penetrate the 0°C level can produce mixed (liquid and ice) phase processes. This can lead to cloud electrification, in-cloud, cloud-to-cloud and cloud-to-ground lightning, and an environment in which triggered lightning could be initiated. Local experience at Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC) has shown that the reflectivity structure above the level of the -10°C isotherm and the amount of vertically integrated liquid (VIL) above the level of the 0°C isotherm are critically important for lightning forecasts (Pinder 1992; Pinder 1998; Roeder and Pinder 1998; Gremillion and Orville 1999). The "Pinder Principles" (Pinder 1992) emphasize the duration of high reflectivity layers above the level of the -10°C isotherm, with vertical extents greater than 3000 ft, for forecasting lightning.

Convective updrafts are also capable of suspending hydrometeors above the surface, possibly leading to downbursts generated and sustained by evaporative cooling of the air surrounding the hydrometeors and by precipitation loading. Recent AMU reports on cell trends (Lambert and Wheeler 1997; Wheeler 1998) have shown that temporal trends of VIL and reflectivity structure associated with convective cells are useful for forecasting downbursts and hail. The present report represents a follow-up to the cell trends reports, and contains recommendations for developing cell trends type products for the WSR-74C IRIS system.

1.3 Report Overview

Optimal utilization of the WSR-74C radar for continuous monitoring of lightning and downburst hazards over KSC/CCAFS and PAFB requires consideration of several issues including characteristics of hardware/software resources and the natural variability of the atmosphere. Section 2 presents a graphic display of the radar beam coverage over the KSC/CCAFS area and a brief discussion of scan strategy options. Section 3 provides an overview of the atmospheric temperature variability at altitudes between 5000 ft and 30 000 ft over KSC/CCAFS, and its impact on the interpretation and configuration of radar products. Section 4 gives a brief description of capabilities of the IRIS System. Section 5 presents a discussion of timing issues influencing the number of radar products that can be generated on a routine basis. Section 6 presents recommendations for products. Implementation of recommended products falls into two categories. The first can be accomplished at the IRIS radar console in the Range Weather Office (RWO). The second would require software development and testing by the AMU, using IRIS programming features, before implementation in the operational environment.

2.0 Volume Scan Strategy

Radar reflectivity data from the WSR-74C is recorded on the IRIS System during the radar Volume-Scan Task, presently configured to make 360° sweeps at 12 selected elevation angles every 2.5 minutes. For each sweep data are recorded at 1° azimuth intervals, providing high resolution information in the horizontal dimension. Resolution in the vertical dimension is determined by the sequence of elevation angles.

Figure 1 shows a vertical cross-section of the beam coverage provided by the current WSR-74C volume-scan. Atmospheric refraction was accounted for by using the standard 4/3 earth-radius model (Rinehart 1997). The vertical scale has been truncated at 35 000 ft in order to emphasize the radar coverage pattern over the height interval where the 0°C and -20°C isotherms are usually found, from 10 400 to 27 600 ft. See Table 1 for more details. The vertical lines mark the horizontal range from the WSR-74C radar to Space Launch Complex 39B (SLC 39B) and SLC 17A, the farthest and closest active SLCs to the radar. The horizontal scale goes from zero to 60 nautical miles (nm), covering KSC/CCAFS and vicinity.

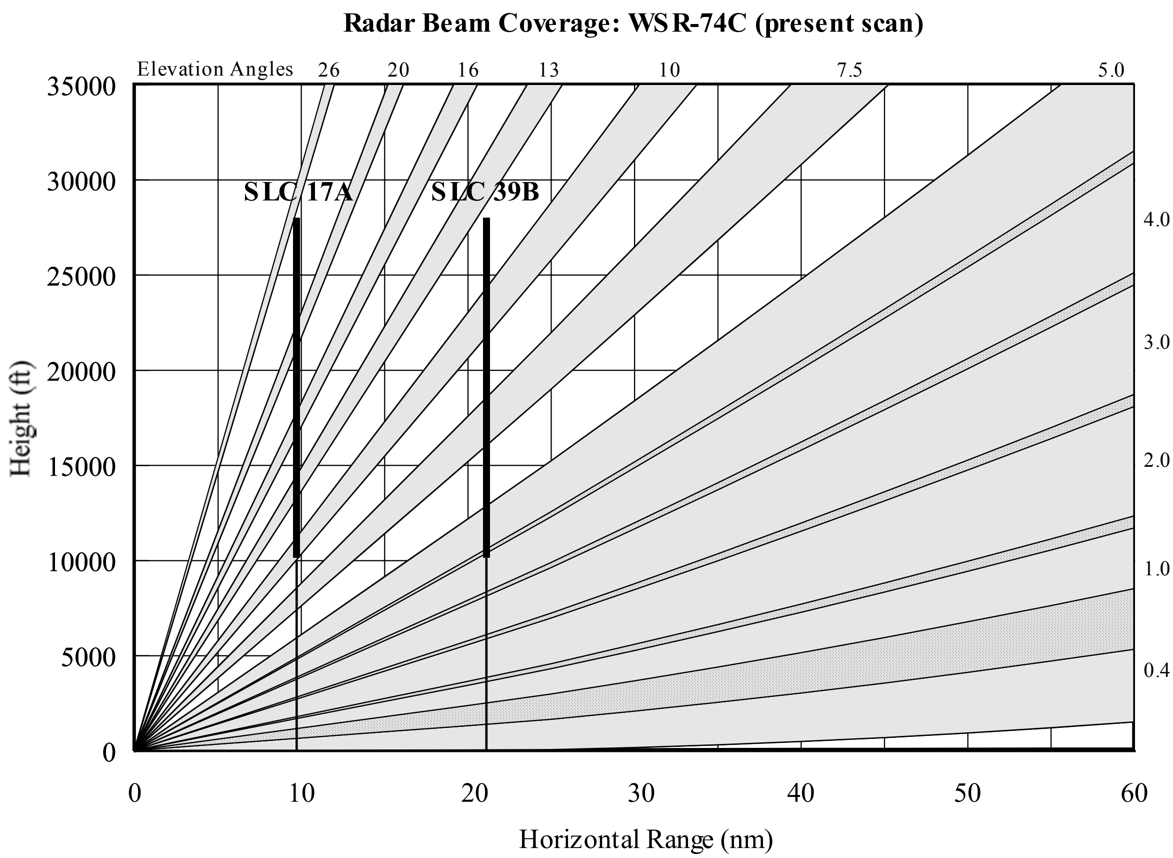

Figure 1. Vertical cross-section of beam coverage by the current WSR-74C volume-scan. A beamwidth of 1.1° was used. The stippled pattern indicates overlapping coverage by adjacent beams. The vertical lines indicate the locations of SLC 39B and SLC 17A relative to the radar. The lines are thickened between 10 400 ft and 27 600 ft to emphasize the layer where mixed phase processes and electrification are most likely to occur within clouds. The elevation angles are 0.4°, 1.0°, 2.0°, 3.0°, 4.0°, 5.0°, 7.5°, 10.0°, 13.0°, 16.0°, 20.0°, and 26.0°.

2.1 Gaps in Present Beam Coverage

The present scan sequence of the WSR-74C radar was examined to determine the scales of vertical gaps in coverage between the levels of the 0°C and -20°C isotherms, important altitudes for evaluating radar reflectivity and VIL structure within clouds. The gaps were determined between ranges of 3 nm to 60 nm from the radar, at altitudes between 10 000 ft and 25 000 ft and above the 5° elevation angle. These points approximate the domain where the accurate analysis of reflectivity structure is required to evaluate potentially hazardous weather conditions such as lightning and downbursts. Vertical gaps were defined as the spaces between the shaded beams in Fig. 1. Each beam is 1.1° in width. Therefore, the upper and lower boundaries of the shaded portions are a half beamwidth above and below the beam centers, respectively. This method of calculating gaps takes into account the width of the radar beam and its effect on detection of features that are near to, but not exactly on the beam center. The average vertical gap for the current scan sequence is 3190 ft. The radar may not detect features above the 5° elevation angle with a thickness less than this value. The largest gap is seen between the 5° and 7.5° elevation angles. This largest vertical gap increases from 2226 ft at an altitude of 10 000 ft to 5453 ft at an altitude of 25 000 ft.

A different approach to calculating gaps in radar coverage has been used by Brown et al. (2000a and 2000b) in their recent studies of the impact of radar volume scan strategies on severe storm algorithms. Their method calculates gaps between beam centers, where the radar detection capability is a maximum. The average vertical gap between beam centers for the present scan sequence, at altitudes between 10 000 ft and 25 000 ft, and above the 5° elevation angle, is 4924 ft. The largest gaps are again between the 5° and 7.5° elevation angles increasing from 3975 ft at an altitude of 10 000 ft to 9739 ft at an altitude of 25 000 ft.

The impact of a scan strategy on the visual appearance of radar products and the performance of radar algorithms is also affected by the spatial interpolation scheme used to fill data gaps and to smooth the reflectivity data, which is inherently noisy. IRIS allows the user to prescribe smoothing parameters. However, the interpolation algorithm is not given in the USER'S Manual. Recent research has been directed at developing improved interpolation schemes that account for the radar beamwidth (Henja and Michelson, 1999). While the ultimate test of a scan strategy is in how it affects products and algorithm performance (Trapp and Doswell 2000) that type of evaluation is beyond the scope of the present report.

The following sections describe alternative scan strategies that are designed to minimize beam gaps as defined by the center-to-center and half-beamwidth-to-half-beamwidth criteria. The characteristic that is common to both scan strategies described below is the requirement that vertical gaps are constant with range at a fixed altitude. What differs is whether the gaps are measured between beam centers, a conservative approach, or between the half-beamwidth points, recognizing that the radar can detect features that are off the beam axis.

2.2 Alternative Scan Strategies

In the following sections the number of elevation angles per volume scan has been fixed at 12. An increase in the number could be considered and the techniques described below applied to determine scan strategies. For example, the WSR-88D volume coverage pattern (VCP) 11 has 14 elevation angles between 0.5° and 19.5° with an average center-to-center gap of 2907 ft and an average half beamwidth gap of 1318 ft, using the same height and range intervals as above. One disadvantage of the VCP-11 scan for the WSR-74C is that the maximum elevation angle would pass over SLC-17A at an altitude of 21 000 ft, well below the altitude of the -20°C isotherm. Prior to the installation of the IRIS system the WSR-74C volume scan consisted of 24 elevation angles every 5 minutes, providing average gaps of 2907 ft (center-to-center) and 1318 ft (half beamwidth). This volume scan was designed to give constant vertical gaps between beam centers at a fixed altitude.

Trade-offs exist between spatial and temporal resolutions as finer spatial resolution requires more elevation angles, increasing the time interval between consecutive volume scans and decreasing the temporal resolution. Pulse repetition frequency, pulse length, number of samples and scan speed are also important considerations. These parameters are fixed at their present values for this report. The primary focus here is to describe objective criteria for determining the sequence of elevation angles and to graphically depict the resulting volume scans. This will facilitate the discussion and design of possible alternative scan strategies.

2.2.1 Center-to-Center Strategy

The volume scan depicted in Figure 2 is designed to have vertical gaps between beam centers that are constant with range from 0 to 60 nm, at a given altitude, following Brown et al. (2000b). Constraints were to retain 12 elevation angles, to keep the minimum and maximum elevation angle values at 0.4º and 26.0º, respectively, and to specify elevation angles to the nearest 0.1°. The IRIS software imposes the latter constraint in addition to requiring that the ratio of the highest-to-lowest elevation angles be greater than about 60. The average gap between beam centers, between 10 000 ft and 25 000 ft, and above the 5° elevation angle, is 4875 ft, a slight reduction from the current scan strategy. The average gap between half-beamwidths is 3043 ft, again a slight reduction from the current scan strategy. Compared to the present volume scan there is more overlap between beams at the lowest elevation angles, required to satisfy the criterion of having constant gaps between beam centers at a given altitude.

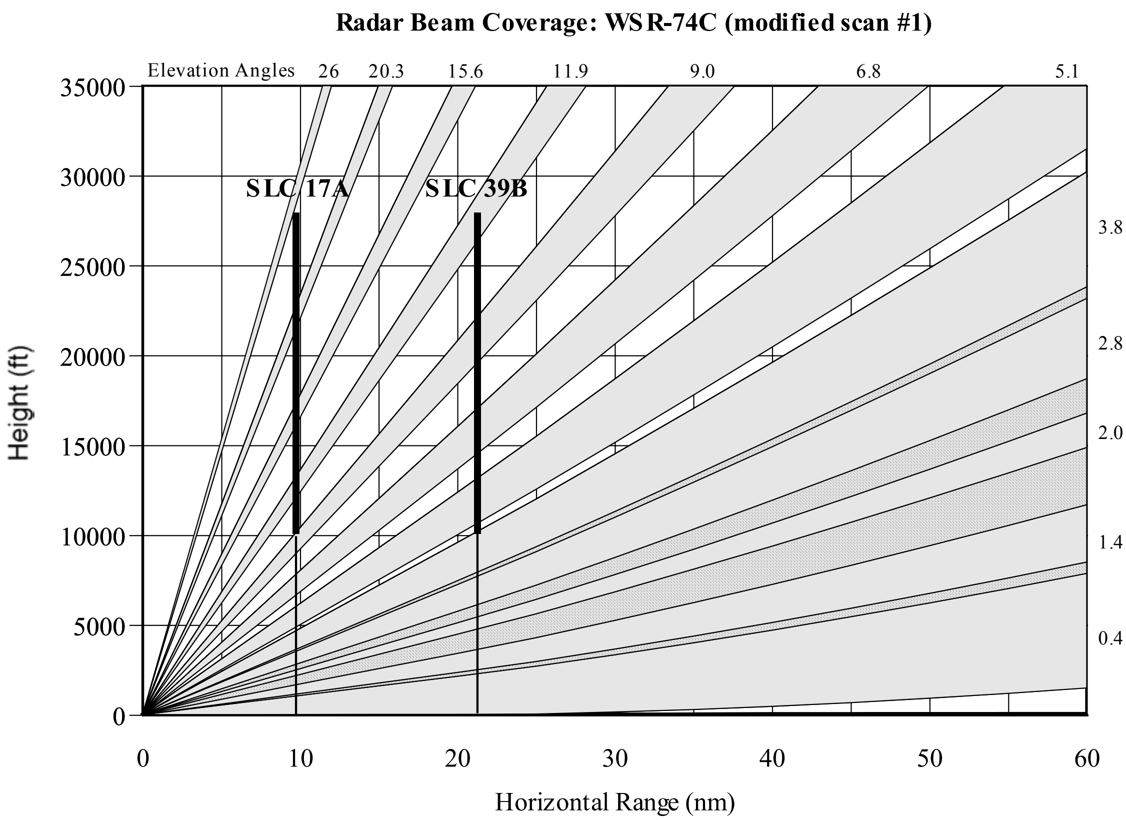

Figure 2. Vertical cross-section of beam coverage by a modified WSR-74C volume-scan using 12 elevation angles. The elevation angle sequence is designed to produce vertical gaps between beam centers that are constant with range at a fixed altitude. A beamwidth of 1.1° was used. The vertical lines indicate the locations of SLC 39B and SLC 17A relative to the radar. The line is thickened between 10 400 ft and 27 600 ft to emphasize the layer where mixed phase processes and electrification are most likely to occur within clouds. The elevation angles are 0.4°, 1.4°, 2.0°, 2.8°, 3.8°, 5.1°, 6.8°, 9.0°, 11.9°, 15.6°, 20.3°, and 26.0°.

The objectives of Brown et al. (2000b) in designing this type of scan sequence are to generate radar products whose errors are independent of range. They used simulation studies to show that the center-to-center scan strategy results in VIL errors that are uniform in range. Additional metrics for determining scan strategies could include minimization of volume or area-weighted gaps and errors, however, such metrics would be dominated by the range-squared dependence of area, resulting in the largest gaps and errors being closest to the radar. For example, gaps at 30 nm range would carry four times the weight of gaps at 15 nm range.

2.2.2 Beamwidth Strategy

The volume scan depicted in Figure 3 is designed to have vertical gaps between half beamwidths that are constant with range from 0 to 60 nm, at a given altitude. This method of calculating gaps takes into account the width of the radar beam and its effect on detection of features that are near to, but not exactly on the beam center. The average vertical gap at altitudes between 10 000 ft and 25 000 ft and above the 5° elevation angle has been reduced to 2020 ft, a 37% reduction from the present scan. In addition, the average gap between beam centers is 4216 ft, a 15% reduction from the present scan. The modified elevation angles are as follows: 0.4°, 1.8°, 3.2°, 4.8°, 6.6°, 8.6°, 10.9°, 13.4°, 16.1°, 19.1°, 22.4°, and 26.0°. The scan angles were determined by trial-and-error.

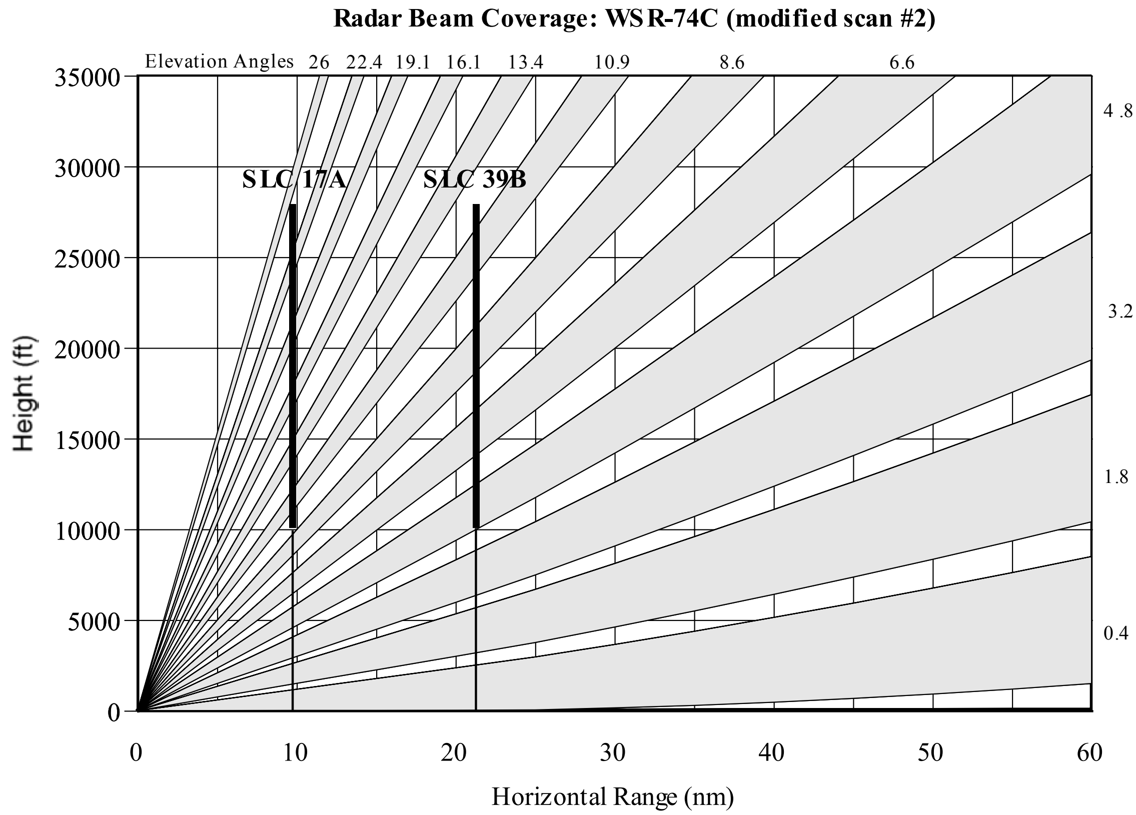

Figure 3. Vertical cross-section of beam coverage by a modified WSR-74C volume-scan using 12 elevation angles. The elevation angle sequence is designed to produce vertical gaps between half-beamwidths that are constant with range at a fixed altitude. A beamwidth of 1.1° was used. The vertical lines indicate the locations of SLC 39B and SLC 17A relative to the radar. The line is thickened between 10 400 ft and 27 600 ft to emphasize the layer where mixed phase processes and electrification are most likely to occur within clouds. The elevation angles are 0.4°, 1.8°, 3.2°, 4.8°, 6.6°, 8.6°, 10.9°, 13.4°, 16.1°, 19.1°, 22.4°, and 26.0°.

The beamwidth scan strategy above provides a higher density of observations above the 5° elevation angle, as compared to the center-to-center strategy shown in Fig. 2. This results in higher resolution data over the KSC/CCAFS complex. Constraints were to retain 12 elevation angles, to keep the minimum and maximum elevation angle values at 0.4º and 26.0º, respectively, and to specify elevation angles to the nearest 0.1°. The IRIS software imposes the latter constraint in addition to requiring that the ratio of the highest-to-lowest elevation angles be greater than about 60. If the factor-of-60 constraint could be overcome, one could attain even higher vertical resolution data over the KSC/CCAFS complex by increasing the elevations of the lowest scans, at the cost of missing shallow convective cells at farther ranges.

3.0 Variability of Atmospheric Temperatures

Natural and triggered lightning LCCs and shuttle FRs require monitoring of convective cloud characteristics at altitudes corresponding to the +5°C, -5°C, -10°C and -20°C isotherms. For example, LCCs prohibit a launch if the flight path will carry the vehicle within 10 nm of any cumulus cloud with its cloud top higher than the -20°C level. Similar LCC restrictions are referenced to cloud characteristics at the above temperature levels. Radar observations provide the primary means for determining the height of clouds and for monitoring their vertical structure. The height of the 0°C isotherm is also required for interpretation of VIL signatures associated with potentially hazardous weather. Therefore, proper interpretation of radar data requires knowledge of the atmospheric temperature structure. The vertical temperature profile is obtained from local temperature soundings, taken 2 or more times per day at the CCAFS Weather Station (KXMR; World Meteorological Organization Identifier 74794). A climatology of the monthly and annually averaged temperature profiles and their variability are available from the Edwards Air Force Base website (http://www.edwards.af.mil/weather/). Temperature statistics are available for each month. The period of record for the observations is January 1973 through December 1992.

3.1 Annual Variability

Table 1 lists the annual average altitude and variability of the height of the +10, +5, 0, -5, -10, -15 and -20°C isotherms. Isotherm levels and their variability were obtained by linear interpolation from temperature statistics provided at 1-km intervals.

Table 1. Annual average altitude and variability of selected temperatures at KXMR from Range Reference Atmosphere data.

Temperature (°C)	Height (ft)	Standard Dev. (σ; ft)	{Extremes +/- 2σ}	
			Low (ft)	High (ft)
+10	7737	2328	3081	12 393
+5	10 969	1831	7307	14 631
0	13 857	1727	10 403	17 311
-5	16 606	1729	13 148	20 064
-10	19 299	1666	15 967	22 631
-15	21 806	1695	18 416	25 196
-20	24 126	1757	20 612	27 640

As indicated in Table 1, the annual average altitudes of the +5°C, -10°C and -20°C are at 10 969 ft, 19 299 ft, and 24 126 ft, respectively. Therefore, maps of radar reflectivity patterns at the 10 000, 20 000, and 25 000 ft levels give the radar operator a quick look at cloud characteristics near the average height of the critical temperature levels, +5°C, -10°C and -20°C. However, the altitude of the critical temperature levels can vary considerably, as indicated by the standard deviations. For example, the average height of the +5°C isotherm is found at 10 969 ft and its standard deviation is 1831 ft. These statistics can be used to estimate that the +5°C isotherm is located between 7307 ft and 14 631 ft 95% of the time, assuming a normal distribution. Carrying the statistical analysis one step further, Table 2 lists the estimated probabilities that the +5°C isotherm will be found within 1000 ft intervals, from 7000 ft to 15 000 ft, and the estimated probability that it will be found within the 9000 ft interval from 6500 ft to 15 500 ft. Summation of the probabilities for nominal heights from 9000 ft to 11 000 ft indicates that a 10 000 ft reflectivity map is within 1500 ft of the +5°C isotherm only 52.5 % of the time. By assuming a lapse rate of -6C° per km a 1500 ft error in height translates to a temperature error of 2.7C°. Similar statistics can be computed for each isotherm.

Table 2. Estimated probability of finding the +5°C isotherm within 1000 ft height intervals. A normal distribution was assumed, using mean and standard deviation values from Table 1.

Nominal Height (ft)	Estimated Probability (%)	Interval (ft)
7000	2.2	≥6500 to <7500
8000	6.0	≥7500 to <8500
9000	12.2	≥8500 to <9500
10 000	18.8	≥9500 to <10 500
11 000	21.5	≥10 500 to <11 500
12 000	18.4	≥11 500 to <12 500
13 000	11.8	≥12 500 to <13 500
14 000	5.7	≥13 500 to <14 500
15 000	2.0	≥14 500 to <15 500
11 000	98.6	≥6500 to <15 500

3.1.1 Variability of the Height of the 0°C Isotherm

The degree of variability in atmospheric temperatures shown in Tables 1 and 2 suggests that radar products designed to convey information about cloud characteristics at specific temperatures could be improved by routine reconfiguration based on sounding data. The degree of variability in atmospheric temperatures indicated in Tables 1 and 2 can be more accurately characterized by dividing the year into warm (May, June, July, August, September; MJJAS) and cool (November December, January, February, March; NDJFM) seasons. April and October are considered to be transition months. Figure 4 shows the estimated probability distribution of the height of the 0°C isotherm for the warm and cool seasons.

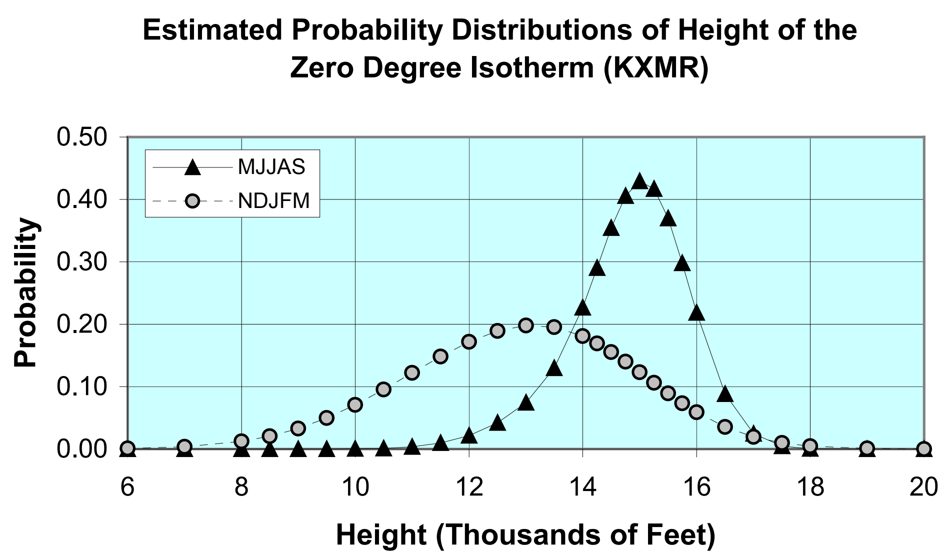

Figure 4. Estimated probability distributions of the height of the 0°C isotherm based on the climatology of soundings from KXMR. The period of record for the observations is January 1973 through December 1992. The estimated seasonal probability distributions during the warm (MJJAS) and cool (NDJFM) seasons were obtained by first using the long-term mean and standard deviation for each month to construct normal distributions. The estimated seasonal distributions were then constructed as composites of the monthly normal distributions.

During the warm season the height of the freezing level is less variable, with a mean near 15 000 feet and a standard deviation of about 1000 ft. During the cool season the mean is near 13 000 ft and the standard deviation is about 2000 ft. These statistics suggest that products sensitive to the height of the 0°C isotherm may have to be reconfigured more often during the cool season than the warm season.

3.1.2 Variability of the Height of the –20°C Isotherm

Figure 5 shows estimated probability distributions of the height of the -20°C isotherm during the warm and cool seasons. The distributions are similar to those of the 0°C isotherm, only shifted 10 000 ft higher. During the warm season the -20°C isotherm has a mean height near 25 500 ft and a standard deviation of about 1000 ft. During the cool season the mean is near 23 000 ft and the standard deviation is approximately 1500 ft.

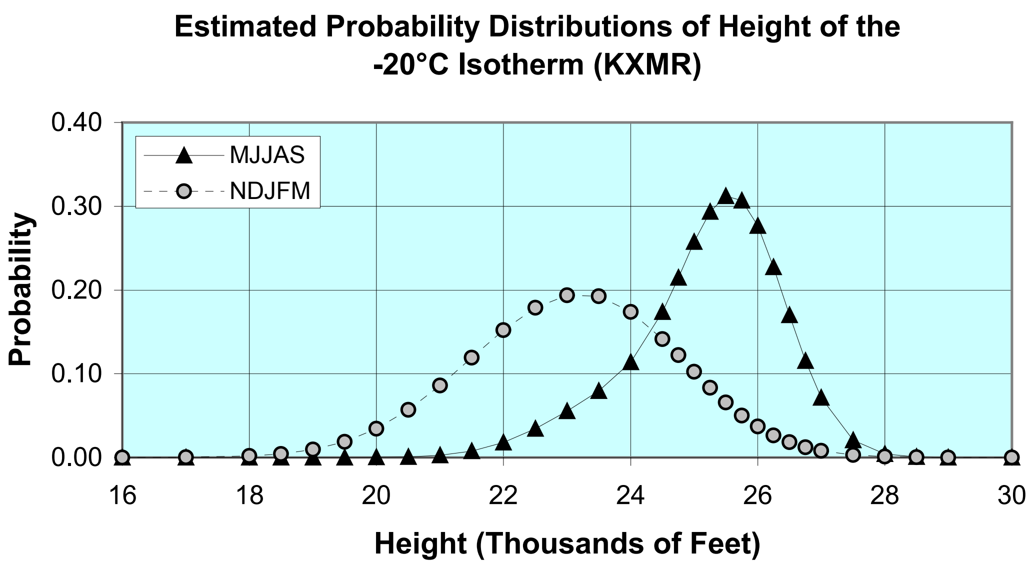

Figure 5. Estimated probability distributions of the height of the -20°C isotherm based on the climatology of soundings from KXMR. The period of record for the observations is January 1973 through December 1992. The estimated seasonal probability distributions during the warm (MJJAS) and cool (NDJFM) seasons were obtained by first using the long-term mean and standard deviation for each month to construct normal distributions. The estimated seasonal distributions were then constructed as composites of the monthly normal distributions.

From Fig. 5 it is evident that the nature of the annual variability in the height of the -20°C isotherm is more accurately portrayed when the statistics are computed separately for the warm and cool seasons. This is also true for all the levels shown in Table 1. The following sections provide tables of statistics for the warm and cool seasons as computed from the Range Reference Atmosphere data.

3.2 Warm Season Variability

Tables 3 and 4 list the average altitude and variability of the height of the +10, +5, 0, -5, -10, -15 and -20°C isotherms during the warm season when deep convection is frequently observed. Isotherm levels and their variability were obtained by linear interpolation from monthly temperature statistics provided at 1-km intervals. Seasonal statistics were then composited from the monthly statistics.

During the warm season (Table 3) the average standard deviation for all temperature levels is 1060 ft, and is within 5% of that value at all levels listed. In comparison to the annual average variability, which is larger and strongly dependent on temperature, this height variability is consistent with the tropical conditions that prevail during the warm season, with a lack of mid-latitude frontal activity. A similar clustering of the temperature variability at fixed altitudes is evident in the climatological data.

Table 3. Average altitude and variability of selected temperatures at KXMR during the warm season (MJJAS) from Range Reference Atmosphere data.

Temperature (°C)	Height (ft)	Standard Dev. (σ; ft)	Extremes +/- 2σ	
			Low (ft)	High (ft)
+10	9047	1099	6849	11 244
+5	11 957	1019	9920	13 994
0	14 814	1035	12 744	16 884
-5	17 653	1056	15 540	19 765
-10	20 395	1041	18 313	22 476
-15	22 952	1077	20 797	25 107
-20	25 382	1095	23 192	27 572

The height of the +5°C isotherm is found near 12 000 ft on average during the warm season, 1000 ft above its annual average height. Summation of the probabilities for nominal heights from 9000 ft to 11 000 ft from Table 4 indicates that a 10 000 ft reflectivity map is within 1500 ft of the +5°C isotherm only 32.7 % of the time. It is estimated that the +5°C isotherm is found between 10 500 ft and 13 500 ft with 85.9% probability during the warm season.

Table 4. Estimated probability of finding the +5°C isotherm within 1000 ft height intervals during the warm season (MJJAS). A normal distribution was assumed, using mean and standard deviation values from Table3.

Nominal Height (ft)	Estimated Probability (%)	Interval (ft)
7000	0.0	≥6500 to <7500
8000	0.0	≥7500 to <8500
9000	0.8	≥8500 to <9500
10 000	6.8	≥9500 to <10 500
11 000	25.1	≥10 500 to <11 500
12 000	37.6	≥11 500 to <12 500
13 000	23.2	≥12 500 to <13 500
14 000	5.9	≥13 500 to <14 500
15 000	0.6	≥14 500 to <15 500
11 000	100.0	≥6500 to <15 500

3.3 Cool Season Variability

During the cool season (NDJFM; Table 5) the standard deviation averages 2015 ft and is a strong function of temperature. The increase in standard deviation with increasing temperature and decreasing altitude is due to transient mid-latitude frontal systems whose strength and associated temperature contrasts are stronger near the surface.

Table 5. Average altitude and variability of selected temperatures at KXMR during the cool season (NDJFM) from Range Reference Atmosphere data.

Temperature (°C)	Height (ft)	Standard Dev. (σ; ft)	{Extremes +/- 2σ}	
			Low (ft)	High (ft)
+10	5891	3029	< 0	11 949
+5	9769	2407	4954	14 584
0	12 863	1987	8888	16 838
-5	15 602	1816	11 971	19 234
-10	18 202	1695	14 812	21 591
-15	20 667	1597	17 473	23 860
-20	23 040	1576	19 888	26 192

The height of the +5°C isotherm is found near 10 000 ft on average during the cool season, 1000 ft below its annual average height. Summation of the probabilities for nominal heights from 9000 ft to 11 000 ft from Table 6 indicates that a 10 000 ft reflectivity map is within 1500 ft of the +5°C isotherm only 46.4 % of the time. It is estimated that the +5°C isotherm is found between 6500 ft and 13 500 ft with 85.2% probability during the cool season. This 7000 ft interval compares with only a 3000 ft interval during the warm season, for approximately the same probability of occurrence.

Table 6. Estimated probability of finding the +5°C isotherm within 1000 ft height intervals during the cool season (NDJFM). A normal distribution was assumed, using mean and standard deviation values from Table 5.

Nominal Height (ft)	Estimated Probability (%)	Interval (ft)
4000	0.9	≥3500 to <4500
5000	2.5	≥4500 to <5500
6000	4.8	≥5500 to <6500
7000	8.6	≥6500 to <7500
8000	12.6	≥7500 to <8500
9000	15.6	≥8500 to <9500
10 000	16.4	≥9500 to <10 500
11 000	14.4	≥10 500 to <11 500
12 000	10.8	≥11 500 to <12 500
13 000	6.8	≥12 500 to <13 500
14 000	3.6	≥13 500 to <14 500
15 000	1.6	≥14 500 to <15 500
11 000	98.6	≥3500 to <15 500

4.0 The IRIS System

The IRIS System provides the user the means to specify tasks performed by the WSR-74C weather radar located at PAFB, to control the generation and display of meteorological products within the RWO in the Range Operations Control Center (ROCC), to change the configuration of meteorological products in real-time, and to create customized products. IRIS was upgraded from Version 6.12 to 7.05 in late December 1999.

4.1 Current Capabilities

The IRIS System provides the radar operator with the capability of selecting pre-configured radar tasks that control the volume scan sequence. At the present time the volume scan shown in Figure 1 (on Page 2) is run continuously every 2.5-minutes.

The IRIS System provides two methods of interrogating the reflectivity database. In the first, products selected by the radar operator are automatically generated and analyzed for significant weather. The products are displayed in Quick Look Windows (QLW) on the radar display system. Automatically generated warnings are also displayed. In the second method, the radar operator interactively uses the Graphical User Interface (GUI) tools on the QLW to examine selected weather features in detail. The two methods, automatic and manual, are used concurrently.

Table 7 lists the 11 types of meteorological products that can be currently generated automatically from radar reflectivity data by the Product Generator. Products are listed in their order of priority, assigned to each type by the 45 WS using the IRIS SETUP utility, to govern the production schedule. Detailed explanations of each product are contained in the SIGMET IRIS/Open™ User's Manual, Section 7. Brief explanations of each product type are given below Table 7.

Table 7. SIGMET IRIS/Open™ Meteorological Products

#	Acronym	Full Name	Priority
1	WARN	Warning/Centroid	80
2	TRACK	Track/Forecast	80
3	VIL	Vertically Integrated Liquid	70
4	CAPPI	Constant Altitude Plan Position Indicator	60
5	XSECT	Vertical Cross Section	60
6	MAX	Maximum Reflectivity	50
7	TOPS	Echo Tops	20
8	PPI	Plan Position Indicator	20
9	RAIN1	Hourly Rain Accumulation	20
10	RAINN	N-Hour Rain Accumulation	20
11	RHI	Range Height Indicator	20

Brief explanations of products follow below.

- WARN automatically looks at other products to detect significant weather and to issue warnings when protected areas are threatened. An example would be radar reflectivity values exceeding 45 decibels (dBZ) in the altitude layer between the 5 and 8 km levels. As soon as the product required for WARN is generated the warning analysis is performed. IRIS warnings are shown on the radar display system to alert the radar operator to potentially hazardous weather.

- TRACK automatically tracks features in other products with specified characteristics over a user-defined time interval and forecasts their future positions. TRACK can also generate warnings for protected areas based on the forecast. An important caveat is that complex patterns of evolving and propagating convective systems can produce features that are beyond the capability of the TRACK product to accurately diagnose and track.

- VIL maps vertically integrated liquid, where the vertical extent of integration is prescribed in the appropriate Configuration File.

- CAPPI provides the radar operator with a quick look at reflectivity patterns at fixed altitudes. The radar operator can configure and schedule a new CAPPI product at any desired altitude within a few minutes. An important caveat regarding the IRIS System is that all altitudes must be specified to the nearest 0.1 km (328 ft). The CAPPI product includes a 3D option, containing CAPPIs at N evenly spaced intervals, where N, the lowest altitude and the highest altitude are prescribed by the user.

- XSECT provides vertical cross sections by interpolation of the volume scan data. This provides the radar operator the ability to closely examine the vertical structure of any selected feature.

- MAX gives a map view of the maximum reflectivity found over each geographic location within a specified vertical interval. Composite vertical cross sections, taken across the image in the east-west and north-south directions, provide the operator with a quick look product for determining the strength and location of deep convective storms.

- TOPS gives the tops of echoes in kilometers (km) at various reflectivity thresholds. Thresholds of 10 dBZ, 18 dBZ and 30 dBZ are used to indicate opaque cloud, precipitation and storm tops, respectively.

- PPI is produced immediately after the radar completes the scan for the specified elevation angle. The lowest PPIs can provide information on low-level wind discontinuities.

- RAIN1 and RAINN give rainfall for one hour and N-hours respectively.

- RHI, or Range-Height Indicator, provides a vertical cross section along a user-selected azimuth. RHI is rarely used, as it requires a vertical sweep of the antenna, interrupting the standard volume scan task being run every 2.5-minutes.

The QLW is used to display products and to examine them interactively. Detailed descriptions of QLW functions are given in Section 9 of the IRIS/Open™ User's Manual. GUI tools on the QLW give the operator control over display features such as colors, overlays and range rings. In addition, the QLW has five tools that are routinely used by the radar operator to examine radar products in detail. Brief descriptions of these five GUI tools are given below.

- Animation Tool – Provides control of animation parameters such as speed and pause.

- Cursor Tool – Provides range and bearing of user selected data point relative to a reference point. Latitude and longitude of the reference can be selected from a pre-defined list or interactively defined by the user.

- Track/Annotate Tool – Provides interactive tracking, annotation and forecasting of storm movement. Includes closest-approach-distance and time of arrival for a user specified location.

- Forecast Tool – Shows a forecast position of the current weather features. At present the user inputs a specified speed, direction and forecast time, shifting the entire image forward in time. Future SIGMET upgrades are expected to provide a Forecast Product that automatically computes an average speed and direction based on the current and previous image.

- Cross-section Tool – Provides a vertical cross-section display of reflectivity structure for user selected features. The mouse is used to draw a line segment across features of interest on mapped products such as CAPPIs.
- Product Output Options Tool – Allows user to select any level of 3D CAPPI for immediate display.

During manual operations the radar operator visually inspects radar products on the radar display system and uses the GUI tools to determine the structure and propagation characteristics of selected features such as convective cells, anvils and convective debris clouds. Attributes of the various products have been specified in Configuration Files prepared by the 45 WS to meet operational requirements. The Product Scheduler, controlled by the radar operator, commands the product Generator to create selected configured products. Output from the Product Generator is sent to the radar display system. In addition, the radar operator can configure new products in real-time and add them to the Product Scheduler for production and display. The radar operator determines the suite of products to be generated and displayed based on mission requirements and current weather conditions.

The radar operator can select an appropriate suite of products from approximately 130 products configured by the 45 WS on the RWO IRIS System. The radar operator usually selects about 40 products on the Product Scheduler on a daily basis. A subset of those 40 is chosen to run continuously and the remaining products are put on standby, available for production when required.

The IRIS Product Generator automatically analyzes the products and reflectivity database, searching for features with characteristics that have been preset in Product Configuration Files. IRIS warnings are automatically posted on the radar display system when storm features attain prescribed characteristics. For example, the presence or forecast propagation of a feature with VIL values exceeding a critical level into a protected area can trigger a warning, alerting the radar operator to the presence of potentially hazardous weather conditions. One limitation of the forecast functions is that they do not forecast changes in intensity, only changes in position.

4.2 Potential Capabilities

Potential capabilities of the IRIS System can be realized by the User Product Insert (UPI) feature and/or installation of upgraded IRIS software. The UPI feature is designed to allow the user to create special-purpose products, to write applications that accept data generated by IRIS, and to write new interfaces to IRIS. In addition, SIGMET Inc. develops periodic upgrades to IRIS, in an effort to continuously improve the system for their customers.

4.2.1 User Product Insert

The IRIS Programmer's Manual describes programming functions for expanding the capabilities of the product generation and display system and creating special purpose products. The UPI feature is described in Section 2 of the Programmer's Manual. Potential expanded capabilities such as a cell trends type product are discussed in Section 6.

4.2.2 Future Upgrades

A forecast (FCAST) Product is described in the User's Manual (page 7-30). However, the FCAST Product is not currently available for configuration on either of the RWO or AMU IRIS systems. If available, the FCAST Product would automatically determine a single speed and direction of motion for the entire radar image, based on a statistical comparison of sequential images for a user-selected product. Future IRIS upgrades are expected to include a vector field-of-motion and forecast intensity changes, variable across the radar image. The Quick Look Window (QLW), described above, provides a Forecast function, based on a user supplied speed and direction of motion.

A composite (COMP) Product described in the User's Manual (page 7-21) is also not currently available. The product would allow compositing of IRIS products from other radar sites. The product could be generated remotely or locally, using raw data from another radar ingested into the IRIS System. IRIS provides source code examples to customers who want to re-format non-IRIS data and insert it directly into the IRIS system for product generation.

5.0 Timing Issues

The production rate impacts the number of products that can be selected by the radar operator for routine generation. The radar volume scan task, programmed to be completed every 150 seconds, updates the reflectivity database during that time. For optimal utilization of the radar data the cycle of product generation and manual analysis should also be completed within 150 seconds. For example, during November 1999 there were 26 products being run by IRIS/Open™ Version 6.12 on the RWO system. The run-time for the 26 products was 80 seconds during clear weather and 100 seconds with scattered echoes. WARN and VIL products were generated first, within 15 seconds after the completion of the volume-scan, while TOPS products were generated last in accordance with the product scheduling priorities. In late January, after the upgrade to Version 7.05, the number of products routinely run on the RWO system had been reduced to 18 and took about 105 seconds with widely scattered echoes. A comparison of the product suites being run during the November and January runs indicated that they contained a similar balance of VIL, WARN, MAX, CAPPI and TOPS products. This preliminary investigation of run times indicates that the new Version 7.05 software package averages 5.8 seconds per product, about 50% slower than version 6.12, which averaged 3.8 seconds per product.

On the basis of the product generation rates above, the current processor will likely produce about 25 products within the required 150 seconds, given widely scattered echoes. It can be expected that generation rate will be slower during periods of dense echo coverage. This limitation must be kept in mind when scheduling and recommending new products. In the operational environment, the radar operator will select the product suite being generated based on mission requirements, prevailing weather conditions and the ability of the processor to stay on schedule. The 45 WS is evaluating a hardware upgrade of the RWO IRIS workstation, intended to increase the processing speed, at the time of this writing.

6.0 Recommendations for Products

The existing reservoir of 130 products configured by the 45 WS provides the radar operator with a comprehensive array of information required for evaluation of LCC, shuttle FR, and daily operational forecasts. The following recommendations for additional products, based on discussions with the 45 WS (W. Roeder and C. Pinder) and SMG (R. Lafosse) personnel, are designed to accomplish two goals. One is to provide the radar operator with additional tools for analysis and forecasting of potentially severe weather. The second is to fine-tune temperature sensitive products to day-to-day variations in the atmospheric temperature profile.

The first 7 products in Table 8 can be implemented at the IRIS radar console in the RWO by use of GUI tools. The remaining 10 recommended products would require development and testing using the UPI capability mentioned in Section 4.2 before implementation. Some operational applications of new products might require studies to generate forecaster guidance.

Table 8. Additional products recommended for the RWO IRIS Product Generator.

Product	Implementation	Usage
0ºC ≥ VIL > -20ºC	Graphical User Interface*	Lightning Forecast/Downburst
0ºC ≥ VIL > -10ºC	Graphical User Interface*	Lightning Forecast
-10ºC ≥ VIL > -20ºC	Graphical User Interface*	Lightning Forecast
MAX above level of -10ºC	Graphical User Interface*	LCC
CAPPI at +5ºC	Graphical User Interface*	LCC/Flight Rules
CAPPI at -10ºC	Graphical User Interface*	LCC/Flight Rules
CAPPI at -20ºC	Graphical User Interface*	LCC/Flight Rules
VIL/Storm Top	User Product Insert	Downburst/Wind Gust Potential
VIL/Echo Top	User Product Insert	Downburst/Wind Gust Potential
Height/Max dBZ	User Product Insert	Downburst/Wind Gust Potential
Cell based VIL	User Product Insert	Downburst
Cell Trends (see next 5 entries)		
Height of MAX dBZ	User Product Insert	Downburst/Hail
Cell based VIL	User Product Insert	Downburst/Hail
Maximum dBZ	User Product Insert	Lightning/Downburst/Hail
Cell Top	User Product Insert	Lightning/Downburst
Core aspect ratio	User Product Insert	Downburst/Hail
Alarms for downburst & hail	User Product Insert	Downburst/Hail
Rain coverage within 20 nm of SLF (Shuttle Landing Facility)	User Product Insert	Flight Rules

*For temperature sensitive products, it may be possible to automatically reconfigure the products, based on input from the latest temperature sounding. This would require a UPI programming effort.

Brief explanations of recommended products follow below.

- VIL between 0°C and -20°C levels: High values of VIL between the 0°C and -20°C isotherms (≥5mm) is correlated with cloud electrification and the potential for triggered lightning, in-cloud lightning, cloud-to-cloud and cloud-to-ground lightning. Rapid decreases in VIL can signify the onset of a downburst.
- Layered VIL: By dividing the VIL into two layers, some differentiation between high layers associated with active convection (-10°C ≥ VIL > -20°C) and lower layers (0°C ≥ VIL > -10°C) associated with decaying anvils can be realized.
- MAX above -10°C level: Persistence (hang time) of high dBZ values is associated with lightning ("Pinder Principles").
- CAPPI at +5°C level: Provides information for interpretation of Lightning LCC and Flight Rules.
- CAPPI at -10°C level: Provides information for interpretation of Lightning LCC and Flight Rules.
- CAPPI at -20°C level: Provides information for interpretation of Lightning LCC and Flight Rules.

- VIL/Storm Top: Provides guidance on wind gust potential associated with downbursts.
- VIL/Echo Top: VIL density provides guidance on wind gust potential associated with downbursts.
- Height/Max dBZ: Provides guidance on wind gust potential associated with downbursts.
- Cell based VIL: Convective cells are occasionally tilted in Florida. Cell based VIL integrates the liquid through the center of the cell, giving a more accurate representation of cell strength and downburst potential.
- Cell Trends:
    - Height of Maximum dBZ:
        - Rapid decrease is a precursor of a downburst.
        - Rapid increase is a precursor of hail.
    - Cell based VIL:
        - Rapid decrease is a precursor of a downburst.
        - Rapid increase is a precursor of hail.
    - Maximum dBZ: Persistence of high values at levels < -10°C is a precursor of lightning. Rapid decrease in the height of the maximum is a precursor for downbursts. A rapid increase is a precursor for hail.
    - Cell top: Maximum height has a secondary correlation to the first CG lightning stroke. Rapid decrease is a possible precursor for downbursts.
    - Core aspect ratio: Rapid increase indicates a strong updraft and hail potential. Rapid decrease is a possible precursor for downbursts.

    Note: A WSR-74C cell trends display may also be useful for detecting the potential for tornado-genesis in central Florida within convective cells that interact with sea breeze or outflow boundaries, when used in conjunction with WSR-88D Doppler products such as storm rotational velocity (Michaels, 2000).
- Alarms for downburst and hail: IRIS automatic warnings.
- Rain Coverage within 20 nm of SLF: Less than 10 % coverage allows Return to Launch Site (RTLS) under certain conditions.

The cell trends product indicated in Table 8 would be modeled after the WSR-88D cell trends product, a four-panel display (see Wheeler 1998). Because the time required for generating a cell trends-type product on IRIS is presently unknown, it may be prudent to consider two panel displays, with the option of selecting one or the other. A minimum requirement for implementation of a given suite of products is that they can be generated and interpreted during the database refresh cycle, currently every 2.5-minutes.

The IRIS Product generator in use within the RWO is a state-of-the-art system, allowing a wide range of flexibility for production and display of radar products, derived from the WSR-74C reflectivity observations. IRIS allows reconfiguration of standard products in real-time by utilization of GUI driven configuration menus. In addition, IRIS is an “open architecture” system, with provisions for addition of customized products by utilization of the UPI feature. The UPI feature requires use of an IRIS specific programming language, described in the IRIS Programmer’s Manual, in addition to the C programming language.

7.0 References

Brown, R. A., J. M. Janish, and V. T. Wood, 2000a: Impact of WSR-88D Scanning Strategies on Severe Storm Algorithms. *Wea. Forecasting*, **15**, 90 – 102.

Brown, R. A., V. T. Wood, and D. Sirmans, 2000b: Improved WSR-88D Scanning Strategies for Convective Storms. *Wea. Forecasting*, **15**, 208 - 220.

Gremillion, M. S., and R. E. Orville, 1999: Thunderstorm Characteristics of Cloud-to-Ground Lightning at the Kennedy Space Center, Florida: A Study of Lightning Initiation Signatures as Indicated by the WSR-88D. *Wea. Forecasting*, **14**, 640 – 649.

Henja, A., and D. B. Michelson, 1999: Improved Polar to Cartesian Radar Data Transformations. Poster paper P2-28 at the *29th Conference on Radar Meteorology*, Montreal, Canada, Amer. Met. Soc.

IRIS/Open™ User's Manual, 1999: SIGMET Inc.

Lambert, W. C., and M. M. Wheeler, 1997: Final Report on the AMU NEXRAD Exploitation Task. NASA Contractor Rep. CR-203009, 45 pp.

Michaels, J. L, 2000: Pulse-cellular Tornado-genesis. Abstract submitted to the 20th Conference on Severe Local Storms, Orlando, FL, Amer. Met. Soc.

Pinder, C. S., 1992: The Pinder Principles, *Local Forecast Guidance Tool*, 45th Weather Squadron, 4 pp.

Pinder, C. S., 1998: IRIS VIL Lightning Forecasting Rules-of-Thumb. 45th Weather Squadron, 2 pp.

Rinehart, R. E., 1997: Radar for Meteorologists. *Rinehart Publications*, Grand Forks, 428 pp.

Roeder, W. P. and C. S. Pinder, 1998: Lightning Forecasting Empirical Techniques for Central Florida in Support of America's Space Program. Preprints, *16th Conf. On Weather Analysis, and Forecasting*, Phoenix, AZ, Amer. Met. Soc., 475 – 477.

Trapp, R. J., and C. H Doswell III, 2000: Radar Objective Analysis. *J. Atmos. Oceanic. Tech.*, **17**, 105 – 120.

Wheeler, M., 1998: WSR-88D Cell Trends Final Report. NASA Contractor Rep. CR-207-904, 36 pp.

NOTICE

Mention of a copyrighted, trademarked or proprietary product, service, or document does not constitute endorsement thereof by the author, ENSCO, Inc., the AMU, the National Aeronautics and Space Administration, or the United States Government. Any such mention is solely to inform the reader of the resources used to conduct the work reported herein.