Computer Processing of Digital Radar Data Gathered during HIPLEX

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ABSTRACT

Digital radar data are being collected as part of the Bureau of Reclamation's High Plains Cooperative Program (HIPLEX). The radars used in this study are sensitive, narrow-beam, 5 cm wavelength systems which record echo data on computer compatible magnetic tape. The antenna scans continuously in a volume mode of 360° in azimuth and 12° in elevation. The time interval for a complete volume scan is approximately 5 min. An overview of the HIPLEX radar operational program and data flow from collection to analysis products is presented.

Computer programs to edit, correct, compress, process and archive the data have been developed and tested. Examples and descriptions of printed, microfiche and magnetic tape output are described. These include composite maximum reflectivity and echo top displays, an equivalent reflectivity file, and a case study summary file which contains location, area, volume, rain and motion information for cells that were identified and tracked. It is shown that the flow of digital radar data has a sufficient amount of human intervention to maintain quality control in an evolving computer environment.

1. Introduction

The purpose of this paper is to describe the High Plains Cooperative Program (HIPLEX) radar equipment, data management and analysis procedures. A primary intention is to provide an overview of the HIPLEX radar program and give a synopsis of the data flow from field collection to analysis products, describing in some detail the initial analysis and final processing outputs. The "composite B-scan," which is produced in order to delineate precipitation cells, is also discussed in detail.

HIPLEX is part of the Bureau of Reclamation's Project Skywater, which has the overall goal of developing an effective weather modification technology for precipitation management scientifically and socially acceptable to provide a portion of the nation's required fresh water. Miles City, Mont., Colby-Goodland, Kans., and Big Spring-Snyder, Tex., represent the northern, central and southern High Plains experimental areas, respectively.

An improved physical understanding of natural precipitation processes must precede the final design for testing procedures. Radar, being a remote sensor that produces measurements which provide good temporal and spatial coverage of cloud structures and precipitation over large areas, has been selected as one of the principal sensors for gathering information on precipitation processes caused by natural and augmenting mechanisms.

2. Equipment

The HIPLEX program acquired two 5 cm (C band) wavelength, 1° beam width radar systems with digital recording capability, which were located at Miles City, Mont., and Goodland, Kan. Each is housed in a separate semitrailer and both are equipped with a digital video integrator and processor (DVIP) similar in operation and accuracy to the DVIP designed and described by the National Severe Storms Laboratory (Sirmans and Doviak, 1973). The radars are capable of detecting minimum equivalent reflectivities (Z_e) of -10 dBZ at 25 km and $+$ 5 dBZ at 150 km. Table 1 summarizes the characteristics of the HIPLEX SWR-75 radars.

Digital recording capabilities for each system consist of two 9-track, 800 cpi, odd parity, computer compatible magnetic tape recorders with read-after-write recording. Two recorders per system permit tape changes to take place without loss of data. Each digital system has read capabilities which permit a field check of tapes before they are sent to the computer center for processing. This can give an early indication of some radar system problems which may occur. In addition, the HIPLEX radar system is designed so that aircraft positions are monitored on a remote PPI scope, which

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does not interfere with the monitoring and recording of the precipitation data.

3. Calibration and transfer function

Radar and digitizer calibrations are crucial to attaining useful data from the DVIP-produced numbers recorded on the magnetic tape. Electronic and sphere calibration procedures are used. Complete system calibration is performed on each of the radars at the beginning and end of each operational season. This calibration consists of a measurement of the effective antenna system gain and also incorporates a pre-, mid- and post-season antenna boresighting, elevation and azimuth error determinations and corrections using solar evaluations.

Digitizer calibrations to relate the recorded binary eight-bit number in each bin to a received power at the radar are made weekly. The DVIP is quite stable, usually not deviating by more than $\frac{2}{3}$ dB from one week to the next. The DVIP calibration consists basically of injecting RF test signals of specified power levels through the directional coupler into the receiver. For each DVIP level the test signal and corresponding digitizer response are recorded (dBm vs DVIP units). Later a polynominal regression analysis of these dBm/DVIP data is carried out to compute the coefficients of a third-order equation of the form

$$y=a+bx+cx^2+dx^3, \quad (1)$$

where x is the DVIP value and y the corresponding estimated dBm value.

Daily checks consist of measuring the pulse repetition frequency, average power, transmitter frequency, minimum discernable signal and checking three levels of the DVIP. If the DVIP varies by more than 1 dBm from the weekly calibration, a complete recalibration is performed.

An independent evaluation of the Miles City radar and calibration procedures was carried out by Smith (1977).

Recorded data are not range-corrected, but subsequent data processing introduces the correction. The 2.5 dBm log-averaging correction (Lhermitte and Kessler, 1965) and 0.2 dBm finite incremental truncation bias correction (Sirmans, 1972) are also made during the computer processing stage.

4. Data acquisition and flow

a. Data acquisition

Recording of data is accomplished in two modes of operation—surveillance and volume. While in the surveillance mode, one 5 min volume scan (360° in azimuth and 12° in elevation starting at 1° and going in steps of 1°) is taken on the hour and 30 min past the hour. The purpose of the surveillance mode is to detect echoes within 150 km, at which time recording of continuous, sequential, 5 min volume scans begins. The antenna azimuth sweep and elevation step sequence are automatically regulated. The sweep rate is controlled by the pulse repetition frequency (PRF) setting and number of pulse samples per averaged return (SA). For HIPLEX the PRF is set at 414 and the SA is set at 32 for a base elevation sweep and 16 for higher elevation sweeps. This translates to a sweep duration (one antenna rotation) of 34 s at 1° elevation and 17 s for the other elevations. The returned signals are digitized and linearly averaged over the range bin interval using rectangular integration techniques. Pulse-to-pulse averaging is initiated on the whole azimuth angle (e.g., 273.0°) and terminates after about 0.7° (e.g., 273.7°) in the 1° azimuth recording mode. Each $\frac{1}{2}$-km range bin value is determined by adding four $\frac{1}{8}$ km (in range) samples, dividing by 4, and repeating and accumulating until the number of samples specified by SA is fulfilled at which time the sum is divided by SA to produce the DVIP number.

Table 1. Characteristics of HIPLEX SWR-75 radars.

Peak transmitter power	250 kW
Pulse duration	2.0 μs
Antenna type	circular parabolic
Horizontal half-power beamwidth	0.9°
Vertical half-power beamwidth	1.0°
Effective system gain	43.7* dB
Wavelength	5.4 cm
Pulse repetition frequency	207/414 pps
Receiver noise	2 dB
Receiver	logarithmic
Receiver bandwidth	0.6 MHz
Receiver dynamic range	80 dB
System noise figure	<3 dB

* This figure incorporates all waveguide mismatch and similar losses beyond the directional couplers as well as radome loss.

A "blue-sky" elimination feature is wired into the radar hardware so that only records containing at least one radial with bin data above a preset threshold level are recorded. The first and last records of a constant elevation sweep are always recorded to maintain antenna sweep history.

b. Description of magnetic tape record

Each magnetic tape record (Fig. 1) consists of 22 frames of housekeeping information (date, time, radar settings, etc.) and four sets of 1) four frames of azimuth and elevation data, 2) 250 frames of averaged-echo range bin data, 3) three frames of project aircraft positions, and 4) three frames of automatic calibration data.

Housekeeping information includes a frame for operator's notes which are loaded via a special keyboard. This is primarily used to record pertinent information about project aircraft (i.e., locations, times, seeding, cloud penetrations, etc.). The range delay setting (switch selectable 0–99) is used to specify the range of the first data bin; scan mode indicates whether the

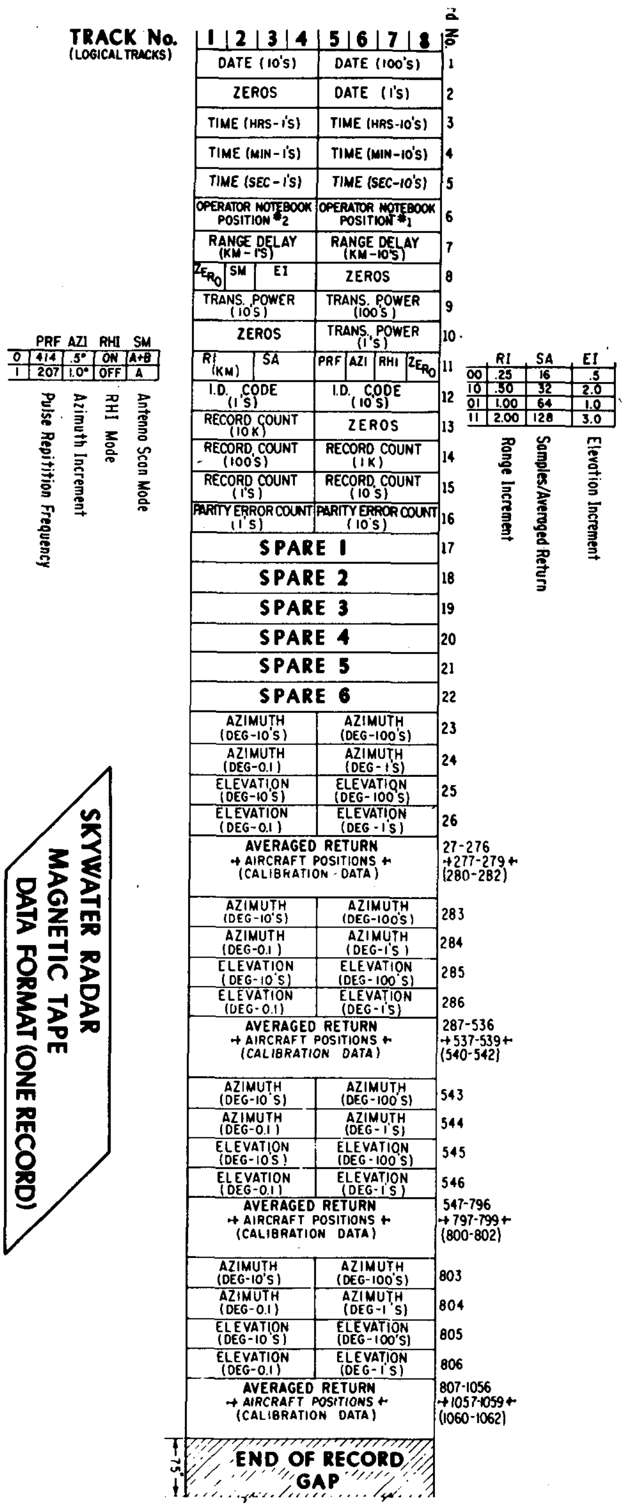


FIG. 1. Record format of SWR-75 digital radar data.

antenna is sweeping in a constant elevation mode (A mode) or a volume scan (A+B mode); range interval indicates the length (km) of each data bin, while the azimuth increment indicates its width (deg). Table 2 shows the settings used during HIPLEX.

Each range bin value contains the binary equivalent of a number up to 255 which is directly related to the average power received for the corresponding range and azimuth intervals. The standard deviations of intensity estimates are 1.05 and 1.48 dB for the base tilt and higher elevation sweeps, respectively. Odd numbers (one-bit on) only occur in those bins where project aircraft are located as detected by a separate IFF antenna. Bin positions 251–253 contain a number 0–250 which indicates the bin positions of project aircraft one through three, respectively. For instance, if bin position 252 contains the number 37, this means the project aircraft designated as number two has been detected by the IFF antenna to be located at bin position 37. This technique of recording aircraft positions allows the retention of reflectivity values also.

About 13 000 records can be recorded on a single tape which may cover a period of 1–12 h depending on the number of radials containing echo data.

5. Computer processing software

There are four clearly defined steps involved in the processing of the radar data. These are outlined in Fig. 2 and described separately later in this section. Most of the computer routines comprising these steps are written in FORTRAN IV. Briefly, the processing procedure consists of mailing the radar tapes containing radar data to the processing computer, deleting non-echo and clearly erroneous information, producing hard-copy printout and microfiche containing data and housekeeping information, and optimally compressing the raw data files. The analyst at this point notes the problems and generates corrections for input to an error-correction program, which produces composite maximum reflectivity and echo top B-scans (a range and azimuth display of all data contained in a 5 min volume scan), composite maximum reflectivity and echo top PPI's, and an optimally compressed, edited raw data file which is archived on 1600 cpi magnetic tape. The analyst inspects the composite B-scan for the desired contours and defines the area(s) for further analysis. Specification cards containing area location information are input to the final processing program which converts raw digital data to meteorological radar units (dBZ) and rainfall rates and amounts. Several distinct reports and data files are produced in the final processing steps. No adjustments are made to correct

TABLE 2. SWR-75 Radar settings during HIPLEX.

Range delay	25 km
Antenna scan mode	A+B (volume)
Elevation increment	1°
Range interval for data bins	0.5 km
Samples/averaged return	32 (1° el) 16 (>1° el)
PRF	414
Azimuth increment for data bins	1°

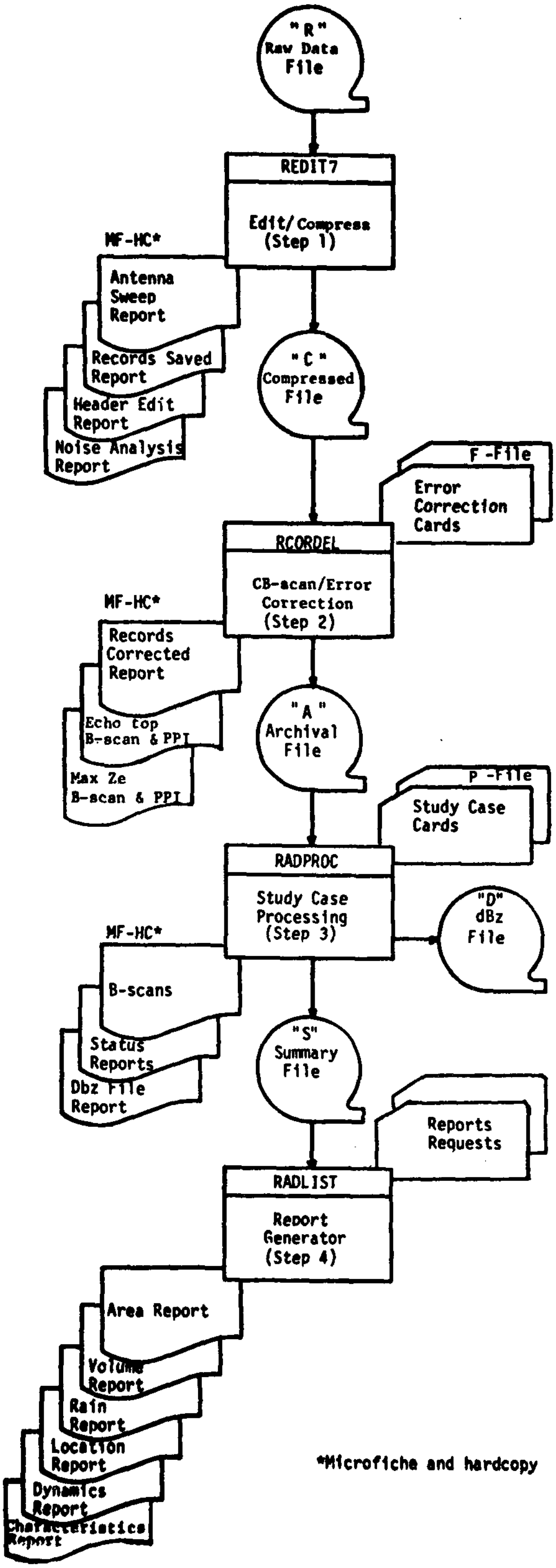


FIG. 2. Flow diagram of automatic data processing procedures for HIPLEX digital radar data.

data for attenuation and partial beam filling. Hildebrand (1978) calculated that storms with reflectivity maxima of less than about 50 dBZ are not seriously attenuated at 5 cm wavelengths, provided the storms are not too extensive.

a. Raw data edit

Original data can contain an assortment of errors: date and/or time may be set or incremented incorrectly; azimuth, elevation and record count may be erroneous; preset variables such as sampling mode, pulse repetition frequency and azimuth increment may have been reset by accident; and radar characteristics may change, signaling problems. When any of these conditions exist they are flagged and displayed in the header edit report. Radials are automatically deleted for reasons such as azimuth and elevation angles not being within accepted limits, azimuth skipping and noise in all header entries. A complete history of the antenna sweep sequence (elevations, times and azimuthal degrees swept) is another useful output from this step.

To conserve computer processing time, the "noise" or "lower threshold" level is saved in the compressed data file. This number is the result of searching 100 consecutive bins in a radial for a value which occurs in at least 55 bins, i.e., the modal value. The search begins with the first 100 recorded range bins. If a modal value is not found, the first 10 range bins are deleted from the 100-bin string and the next 10 bins (bins 101–110) are added. This procedure is continued until a modal value is gleaned from 100 consecutive bins of data, which may or may not contain echoes. It is highly improbable that a signal (echo) region could be involved in the computation of the modal value. During the search the minimum DVIP value is saved. It is subtracted from the modal value and the difference is then added to the modal value plus a guard value of 3 DVIP units, i.e., modal value + (modal value − minimum value) + 3 = "noise" or "lower threshold" DVIP value. Addition of the 3 DVIP units (1 dB) accounts for the small noise fluctuation of the radar system and adds reliability to the precipitation data because system noise is not as apt to be identified as returned echo data. Before a DVIP value is converted to meteorological units, it must be larger than the "lower threshold" DVIP value. This step, done at records 1, 5401, 8701 and 11501, also provides a check on the accuracy of the manually set threshold level of the "blue-sky" elimination feature in the hardware. The procedure described above was arrived at after inspection of data spanning two operational seasons. Nevertheless, even with the 1 dB guard value added on, the noise band occasionally extends slightly beyond the computed value. When this occurs an additional guard value of 2 or 3 DVIP units is added for subsequent processing when minimum threshold reflectivities are required.

TABLE 3. Contents of optimally compressed archive file.

Parameter	Units
Site location	
Year	calendar
Date	Julian
Time	h, min, s
Antenna azimuth	deg
Antenna elevation	deg
Maximum and minimum antenna elevation of recorded data	deg
Aircraft locations	km
Range delay	km
Range interval	km
Azimuthal recording mode	code
Elevation recording mode	code
Sampling average	code
Pulse repetition frequency	code
Antenna scan mode	code
Noise level	DVIP
Reflectivity values	DVIP

The compressed file created during this step contains only data for bins which exceed the computed noise level. This results in a significant size reduction which is most convenient for long-term storage. In fact, when archived on 1600 cpi magnetic tape, a space reduction of 10:1 occurs when compared with the raw data. The contents of this optimally compressed archive file are listed in Table 3.

b. *Error correction and B-scan compositing*

This step provides the analyst his first glimpse of processed data. Inputs are the raw, compressed data on disk and a file describing the corrections to housekeeping data. As the error correction functions are performed, a single B-scan and PPI, representing all data from all sweeps taken within a 5 min volume scan, is composited.

Since the composite B-scan is a tool to be used for delineating cloud complexes, identifying mergers and characterizing precipitation, the maximum equivalent reflectivity (Z_e) factor between two horizontally and vertically adjacent bin values is displayed. The printed characters represent the maximum radar reflectivities which occurred at any given range-azimuth location during a volume scan. B-scan and PPI formats are also used to display echo tops for each volume scan.

This step also accumulates the number of data points (bins) from each elevation angle in the volume scan which exceed the noise and reflectivity thresholds requested, computes the number of points contributed at each elevation, and prints a summary at the end of each composite. A sample of a portion of a composite B-scan and a sample of a composite PPI are shown in Figs. 3 and 4, respectively.

The file produced by this step is the Archival File which is a corrected version of the optimally compressed file generated during the edit phase. This file is recorded on magnetic tape, containing the three-dimensional information at its basic recorded resolution. About 10 files can be recorded on one tape which is then duplicated (for backup purposes) and permanently stored in the Bureau of Reclamation tape library. After about a year the raw data tapes are degaussed, cleaned, verified, and used again at the field sites.

Location and identification of echo cells are accomplished with the composite B-scans. Presently only 20 dBZ and greater reflectivities are being displayed. Extreme flexibility exists for the manner in which a cell is defined. A "cell" can be defined minimally as a single range bin, or for all range bins recorded. One technique being used to identify cells for an extensive study is described below.

Cells are identified if they lie between 25 and 150 km. If a cell touches the inner or outer range boundary it must extend at least 20 km into the area of concern, or have at least one separate peak of 30 dBZ or greater.

Naming of the cell entity is done at this time. The objective rules for the 10 position (AAAABCDEFG) identification are as follows:

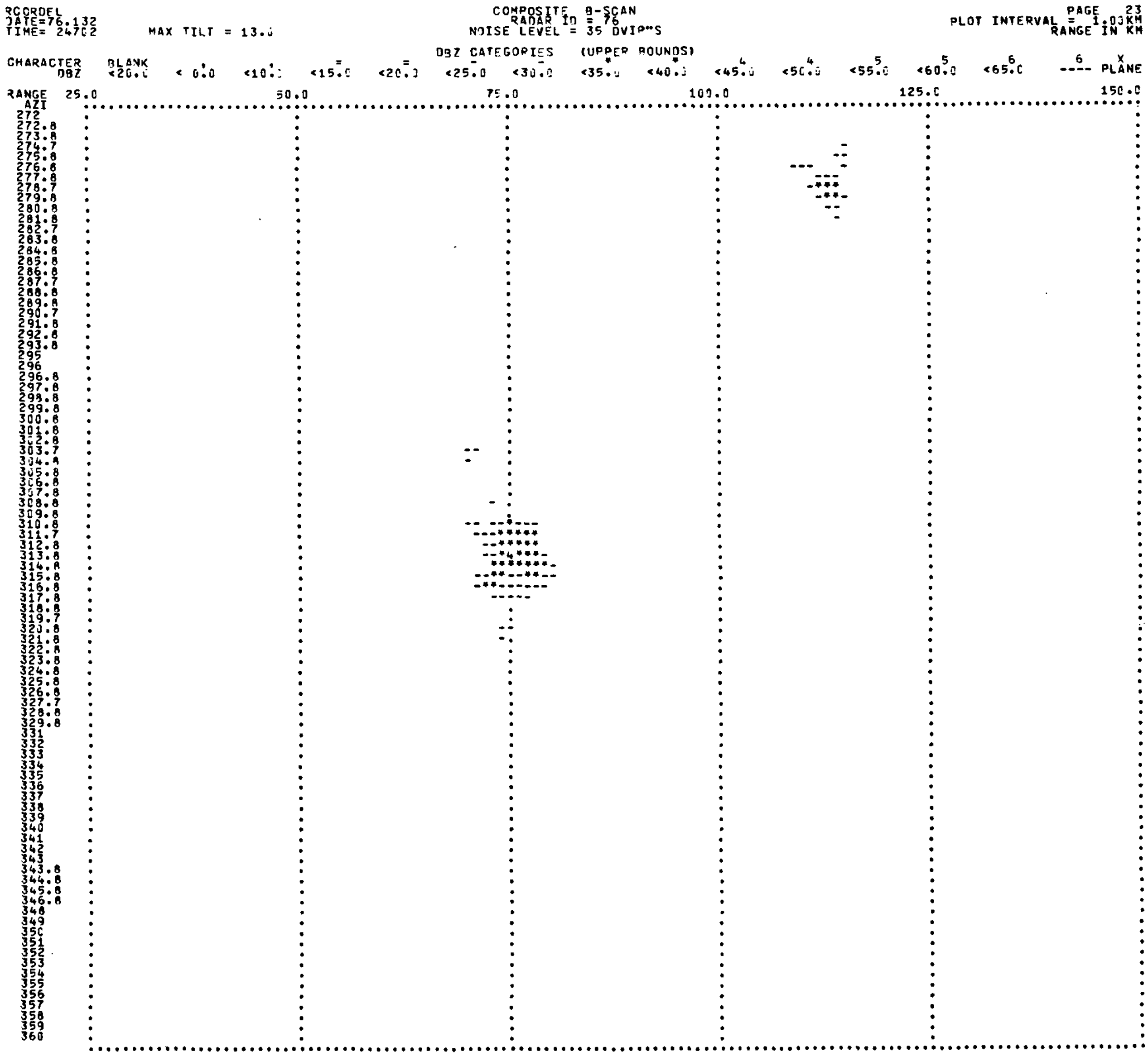
1. AAAA: 4-position cell number from 1 to 9999
2. B: number of peak reflectivity values between 30 and 39.9 dBZ
3. C: number of peak reflectivity values between 40 and 49.9 dBZ
4. D: number of peak reflectivity values greater than 49.9 dBZ
5. E: cell origin and seeding status code according to the following table:

	First Echo	Split	Pre-existing
No seed	N	Z	V
AGI seed	A	X	T
Hygroscopic seed	H	Y	U

6. F: boundary code to indicate whether or not the echo entity is a complete echo
7. G: number of cells that have merged into the system.

Whenever a number is required, as in positions B, C, D and G, characters 0–9 and A–Z may be used. For example, 0032E73ZN4 would identify a study case as cell number 32, 14 peaks between 30 and 39.9 dBZ, 7 peaks between 40 and 49.9 dBZ, 3 peaks greater than 49.9 dBZ, the unseeded cell originated through a split of another cell, it is a complete cell entity, and 4 cells have merged into this one cell system thus far.

This method of identification allows for a significant amount of cell description at the same time as making it adaptable to automatic echo identification and tracking, which has been developed following the processes being described. The option for manually identifying and tracking cells will continue.



Tilt (deg)	Bins above noise level	dBZ's above threshold	dBZ's replaced	New dBZ's found	Percent of total dBZ's above threshold
1.0	1707	198	198	198	40.0
2.0	1347	78	44	21	15.8
3.0	1015	100	50	24	20.2
4.0	687	85	19	9	17.2
5.0	395	32	3	1	6.5
6.0	334	2	1	1	0.4
7.0	246	0	0	0	0.0
8.0	52	0	0	0	0.0
9.0	18	0	0	0	0.0
10.0	14	0	0	0	0.0
11.0	3	0	0	0	0.0
12.0	0	0	0	0	0.0
13.0	0	0	0	0	0.0

FIG. 3. Sample of a portion of composite B-scan printout for 0247 GMT 11 May 1976.

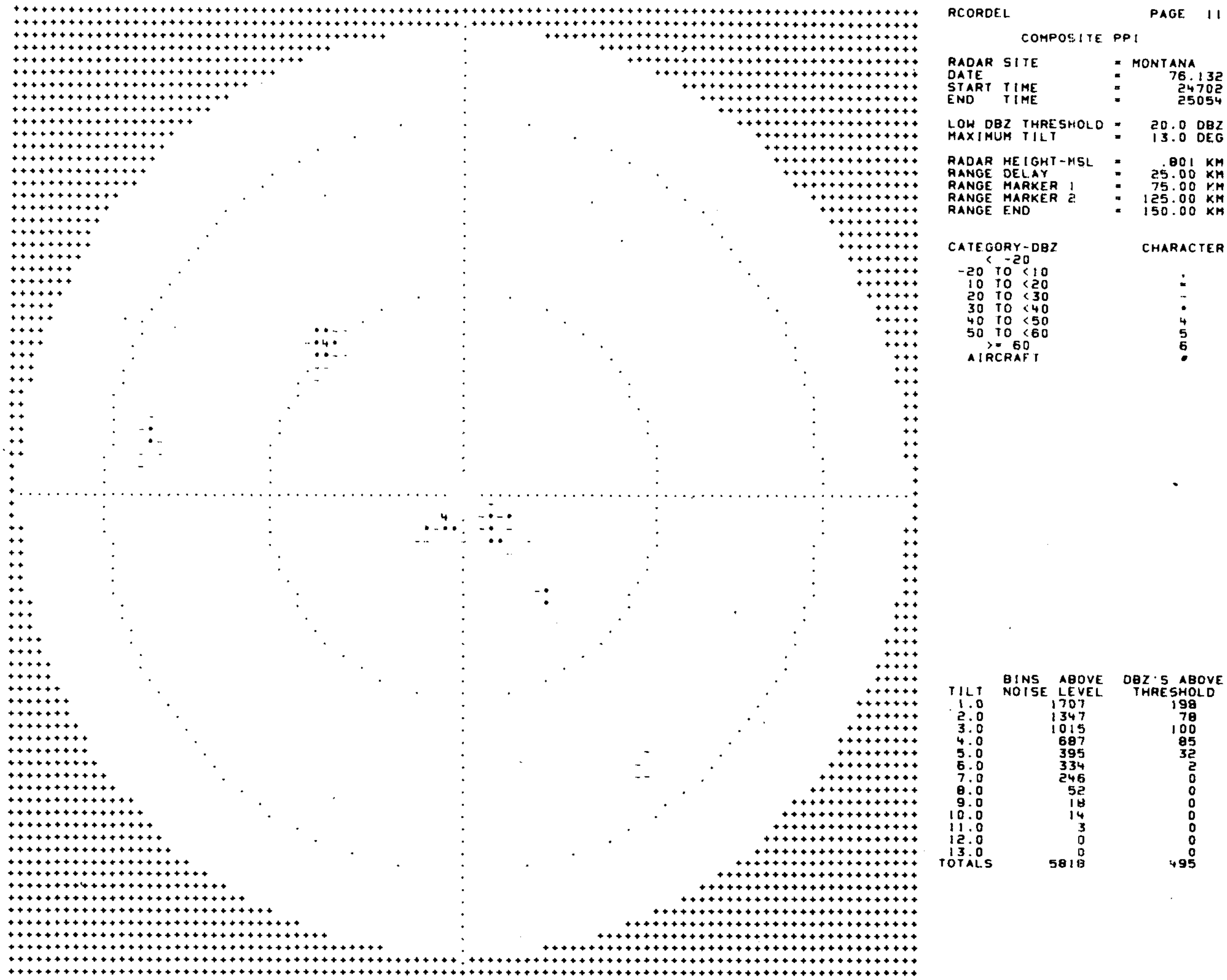


FIG. 4. Composite PPI for 0247 GMT 11 May 1976.

c. Data conversion and processing (program RADPROC)

At this stage of processing, the radar data are still in their original DVIP units. A modified version of the Probert-Jones (1962) radar equation is used to convert the DVIP value to meteorological units. Errors due to high reflectivity gradients are not considered although they could be appreciable in some instances.

For each 360° sweep and volume scan, study cases are summarized in report form and on magnetic tape files. A B-scan optionally output on microfiche displays the measured radar intensity using a 14-character alphanumeric code representing 14 levels of 5 dBZ each, ranging from less than 5 to greater than 65 dBZ. In addition, a variable length record file containing reflectivity data is written on magnetic tape, and on microfiche as an option. A report of internal program information is also supplied with every run of the program. Whenever tables need to be recomputed due to changes in switch settings of the radar, a message is written to inform the user.

In addition to the four reports generated by the edit program, the one report and four displays produced by the composite B-scan and error correction program, RADPROC has the option to produce two reports, two magnetic tape files, and one display. A B-scan display, Z_e report and status report can be generated directly from RADPROC. The two magnetic tape files are described below.

1) COMPRESSED Z_e FILE

The purpose of this file is to supply the user community with equivalent reflectivity (Z_e) data already edited and preprocessed in an easily accessible, compressed form.

This file has variable length records containing the information shown in Table 4. Data are compressed for optimum utilization of tape. Bin information consists of the location of the first and last data bin. A B-scan may be reconstructed from this file even though each record contains only bin information defined for a particular study case. Its most probable uses are for areal precipitation analysis and precipitation formation and evolution studies which also use aircraft data and numerical and conceptual model results. Analysis programs have already been written which access this file and create time-height, vertical cross-section, multilevel constant-altitude PPI, three-dimensional representations, and total precipitation "footprints" of individual precipitating cells that have been identified.

2) Case study summary file

This file contains location, area, volume, rain and motion information for cells that were identified and tracked. The reports described later are generated from this file which contains fixed length records. Table 5 presents the radar echo information contained in the Case Study Summary File.

A general information record contains the radar location and Z-R relationships used for the rainfall computations. A volume summary record, following the general information record, is written, for every 5 min volume scan for every cloud entity. Since the 360° sweep at a constant antenna tilt is a basic sampling entity, an area summary record is generated summarizing case study areal data for each antenna elevation angle which contains echo information. A morphology record, written whenever a split, merger or termination takes place, precedes the volume summary record and follows the general information record.

d. Report generation (RADLIST)

Six reports are created by the report generator program from the case study summary file. Fig. 5 shows an example of each report for a cell that appears on the composite B-scan of Fig. 3.

A case study area report relates echo intensity and area for each case study. Data are presented in square kilometers by date, time, and tilt for the total area covered by the case and normally from 20 dBZ to 65 dBZ, in 5 dBZ increments. No accumulation is done for Z_e categories below the lowest level requested. The area totals are cumulative to the lowest specified Z_e category.

Table 4. Contents of compressed Z_e file.

Parameter	Units
Site location	
Case identification	
Date	year, day
Time	h, min, s
Antenna elevation	deg
Antenna azimuth	deg
Range gate interval	km
Azimuth step	deg
Elevation step	deg
Range start and end	km
Reflectivity values	dBZ

Table 5. Contents of the fixed length case study summary file.

Parameter	Units
Case identification	
Date	year, day
Time	h, min, s
Tilt	deg
Volume	km^3
Area	km^2
Centroid, echo-top and maximum Z_e range	km
Centroid, echo-top and maximum Z_e azimuth	deg
Centroid, echo-top and maximum Z_e height	km
Radar maximum tilt angle	deg
Cloud base height	km
Average and maximum Z_e	dBZ
Volume of 14 reflectivity categories	km^3
Area of 14 reflectivity categories	km^2
Average and maximum rainfall rates	mm h^{-1}
M-P rain flux	km^3 (5 min)$^{-1}$
Z-R relationships (2)	
Location and height of radar	km

The case study location report identifies several characteristics about a radar cloud. In addition to cloud base height (km), area (km^2) and cloud volume (km^3) for every case and associated volume scan, the report lists range (km), azimuth (degrees from true north of the radar) and height (km) of centroid, echo top, and maximum Z_e, average and maximum Z_e, and maximum tilt for the case.

Centroid calculations are done in the Cartesian coordinate system, assuming the Z_e value exists in the center of the originally recorded range bin. Each bin volume is weighted with the Z_e contained in it and they are all accumulated for the specific study case.

Height of the centroid is calculated using volumetric data of the study case. It is computed using the formula as developed by Greene (1971) and assumes an equivalent earth radius of 6370 km.

Echo top and maximum Z_e value, range, azimuth and height are determined employing the same technique as used for the centroid range, azimuth and height calculations.

Since its first application to meteorology, radar has been used to observe the formation, growth, dissipation and movement of echo areas. Radar echo movement as determined by the centroid of the area is a convenient method of describing the propagation and translation of the echo. The cloud dynamics report lists the results of the motion calculations.

Echo motion calculations are done in the rectangular (X,Y) coordinate system after conversion from the B-scan (r,θ) system. Rate of change is determined by calculating the amount of time in seconds from the beginning of one volume scan to the beginning of the next volume scan, and it is presented for the following:

1. Horizontal and vertical centroid motion
2. Height change of cloud top and maximum Z_e

RADLIST CASE ID = 0007 MONTANA CASE STUDY AREA REPORT PAGE 13

DATE	TIME	TILT	TOTAL AREA	AREA IN EACH DBZ CATEGORY IN SQUARE KILOMETERS =>-20.	=> 0.0	=>10.0	=>15.0	=>20.0	=>25.0	=>30.0	=>35.0	=>40.0	=>45.0	=>50.0	=>55.0	=>60.0	=>65.0
76.132	23248	2.1	7.106	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	23305	3.2	5.372	0.0	0.0	0.0	0.0	5.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	23725	1.1	6.091	0.0	0.0	0.0	0.0	6.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	23748	2.1	12.065	0.0	0.0	0.0	0.0	12.1	7.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	23805	3.1	9.043	0.0	0.0	0.0	0.0	9.0	7.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24225	1.1	16.109	0.0	0.0	0.0	0.0	16.1	10.0	6.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24248	2.1	14.977	0.0	0.0	0.0	0.0	15.0	7.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24305	3.1	9.979	0.0	0.0	0.0	0.0	10.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24322	4.1	1.001	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24726	1.1	25.853	0.0	0.0	0.0	0.0	25.9	9.9	5.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24748	2.1	17.750	0.0	0.0	0.0	0.0	17.7	6.9	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24805	3.1	14.381	0.0	0.0	0.0	0.0	14.9	4.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24823	4.1	1.972	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25226	1.1	37.320	0.0	0.0	0.0	0.0	37.3	14.8	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25248	2.1	30.009	0.0	0.0	0.0	0.0	30.0	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25305	3.1	14.523	0.0	0.0	0.0	0.0	14.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25323	4.1	2.952	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25726	1.1	43.614	0.0	0.0	0.0	0.0	43.6	21.4	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25748	2.1	34.248	0.0	0.0	0.0	0.0	34.2	4.7	.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25805	3.1	13.090	0.0	0.0	0.0	0.0	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	30226	1.1	48.466	0.0	0.0	0.0	0.0	48.5	13.2	3.7	.9	0.0	0.0	0.0	0.0	0.0	0.0
76.132	30248	2.1	25.988	0.0	0.0	0.0	0.0	26.0	6.5	.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	30305	3.2	6.499	0.0	0.0	0.0	0.0	6.5	3.7	.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0

RADLIST CASE ID = 0007 MONTANA CASE STUDY LOCATION REPORT RADAR HEIGHT = .801 KM MSL PAGE 7

DATE	TIME	TOTAL VOLUME KM ** 3	CLOUD BASE AREA KM ** 2	CLOUD BASE HEIGHT KM MSL	CENTROID RANGE KM	CENTROID AZIMUTH DEGREES	CENTROID HEIGHT KM MSL	ECHO TOP RANGE KM	ECHO TOP AZIMUTH DEGREES	ECHO TOP HEIGHT KM MSL	MAXIMUM DBZ MAX DBZ	MAXIMUM DBZ RANGE KM	MAXIMUM DBZ AZIMUTH DEGREES	MAXIMUM DBZ HEIGHT KM MSL	AVERAGE DBZ DBZ	AVERAGE Z DBZ	MAX TILT
76.132	23202	7.9	0.0	5.8	116.3	274.6	6.8	115.8	273.8	8.1	25.7	115.8	274.7	8.0	22.1	22.4	13.0
76.132	23702	17.4	6.1	3.8	115.4	276.1	6.1	116.3	275.9	7.9	33.7	115.3	275.9	5.8	25.0	28.2	13.0
76.132	24202	26.8	16.1	3.8	114.8	277.6	5.5	114.8	277.8	9.8	39.6	114.8	277.8	3.8	26.5	30.1	13.0
76.132	24702	38.1	25.9	3.6	113.6	278.5	5.4	113.3	278.8	9.6	36.2	113.3	278.7	3.7	24.9	27.3	13.0
76.132	25202	52.6	37.3	3.6	111.8	279.6	5.1	113.3	281.8	9.6	33.9	113.8	280.8	3.7	24.2	26.0	13.0
76.132	25702	55.5	43.6	3.5	109.8	280.4	4.8	112.3	282.7	7.6	34.4	111.3	281.7	3.7	23.8	25.2	13.0
76.132	30202	48.5	48.5	3.4	107.8	282.4	4.5	107.3	280.8	7.5	35.0	107.3	280.7	3.5	23.7	25.3	13.0

RADLIST CASE ID = 0007 MONTANA CASE STUDY CLOUD DYNAMICS REPORT PAGE 7

DATE	TIME	CENTROID MOTION HORIZ M/SEC	CENTROID MOTION DIRECT DEGREE	CENTROID MOTION VERT M/SEC	CLOUD TOP HEIGHT CHANGE M / SEC	MAXIMUM DBZ HEIGHT CHANGE M / SEC	MAXIMUM DBZ CHANGE RATE DBZ / MIN	AVERAGE DBZ CHANGE RATE DBZ / MIN	CLOUD BASE GROWTH RATE KM**2 / MIN	CLOUD VOLUME GROWTH RATE KM**3 / MIN
76.132	23702	10.76	20.5	-2.39	-.79	-7.48	1.60	.78	1.218	1.915
76.132	24202	10.21	19.7	-2.07	6.32	-6.75	1.19	.09	2.004	1.876
76.132	24702	7.27	41.2	-.17	-.42	-.16	-.69	-.31	1.949	2.265
76.132	25202	9.06	50.2	-.87	0.00	.05	-.46	-.14	2.293	2.899
76.132	25702	8.42	61.0	-1.24	-6.79	-.27	.09	-.07	1.259	.564
76.132	30202	14.22	39.0	-1.03	-.49	-.43	.14	-.03	.970	-1.385

RADLIST CASE ID = 0007 MONTANA CASE STUDY VOLUME REPORT PAGE 7

DATE	TIME	TOTAL VOLUME	VOLUME IN EACH DBZ CATEGORY IN CUBIC KILOMETERS =>-20.	=> 0.0	=>10.0	=>15.0	=>20.0	=>25.0	=>30.0	=>35.0	=>40.0	=>45.0	=>50.0	=>55.0	=>60.0	=>65.0
76.132	23202	7.868	0.0	0.0	0.0	0.0	7.9	.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	23702	17.444	0.0	0.0	0.0	0.0	17.4	3.7	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24202	26.825	0.0	0.0	0.0	0.0	25.8	13.4	5.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0
76.132	24702	38.149	0.0	0.0	0.0	0.0	38.1	13.7	5.0	.6	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25202	52.642	0.0	0.0	0.0	0.0	52.6	15.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	25702	55.460	0.0	0.0	0.0	0.0	55.5	16.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.132	30202	48.533	0.0	0.0	0.0	0.0	48.5	14.0	3.3	.6	0.0	0.0	0.0	0.0	0.0	0.0

RADLIST CASE ID = 0007 MONTANA CASE STUDY RAIN REPORT PAGE 7

DATE	TIME	CLOUD BASE AREA KM ** 2	MARSHALL - PALMER Z = 200.0 R ** 1.60 AVE RATE MM / HR	MAX RATE MM / HR	RAIN VOLUME HA-CM/5 MIN	RAIN VOLUME ACRE-FT/5 MIN	S DAKOTA SCHOOL OF MINES Z = 155.0 R ** 1.88 AVE RATE MM / HR	MAX RATE MM / HR	RAIN VOLUME HA-CM/5 MIN	RAIN VOLUME ACRE-FT/5 MIN
76.132	23202	0.000	0.000	0.000	0.000	0.00000	0.000	0.000	0.000	0.00000
76.132	23702	6.031	1.071	2.172	5.434	.44057	1.199	2.216	6.089	.49360
76.132	24202	16.109	3.288	10.910	44.138	3.57835	3.007	8.753	40.371	3.27296
76.132	24702	25.953	1.910	6.555	41.154	3.33643	1.918	5.747	41.328	3.35053
76.132	25202	37.320	1.737	4.786	54.010	4.37866	1.781	4.341	55.396	4.49101
76.132	25702	43.614	1.567	5.123	56.959	4.61773	1.654	4.599	60.116	4.87369
76.132	30202	48.466	1.274	5.649	51.467	4.17253	1.378	4.999	55.673	4.51352
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
76.132	42702	.933	.842	.842	.697	.05647	.989	.989	.818	.06635
TOTALS					457.737	37.10930			485.017	39.32096
AVERAGE		16.865								

CLOUD LIFE TIME = 2: 0: 5

RADLIST CASE ID = 0007 MONTANA CASE STUDY CHARACTERISTICS REPORT PAGE 7

DATE	TIME	NUMBER OF REFLECTIVITY PEAKS 30-39.9 DBZ	40-49.9 DBZ	=>50 DBZ	CELL ORIGIN	SEED STATUS	TOUCHING GROUND CLUTTER OR BOUNDARIES	NUMBER OF CELLS MERGED IN	LONGITUDE DEG MIN	LATITUDE DEG MIN	AREA KM*2	RADIUS KM
76.132	23202	0	0	0	FIRST ECHO	NONE	NO	0	107 24.9	46 29.8	0.00	0.0
76.132	23702	1	0	0	FIRST ECHO	NONE	NO	0	107 24.1	46 31.4	6.09	1.4
76.132	24202	1	0	0	FIRST ECHO	NONE	NO	0	107 23.3	46 33.0	16.11	2.3
76.132	24702	1	0	0	FIRST ECHO	NONE	NO	0	107 22.2	46 33.9	25.85	2.9
76.132	25202	1	0	0	FIRST ECHO	NONE	NO	0	107 20.6	46 34.8	37.32	3.4
76.132	25702	0	0	0	FIRST ECHO	NONE	NO	0	107 18.9	46 35.5	43.61	3.7
76.132	30202	0	0	0	FIRST ECHO	NONE	NO	0	107 16.9	46 37.2	48.47	3.9

FIG. 5. Composited example of reports produced by RADLIST.

3. Rate of change of maximum and average Z_e per minute

4. Growth rate of cloud base and cloud volume in square kilometers and cubic kilometers per minute, respectively.

The volume report has the same format as the area report discussed earlier. Data are displayed in cubic kilometers for each Z_e category for a complete volume scan. If a 360° sweep has been skipped by the radar for some reason, the volume is computed without the sweep. The analyst must be aware of the output of the edit and/or area reports before evaluating the volume information. Calculations assume a constant elevation step throughout a volume scan.

Volume scans up to at least 12° in elevation are taken every 5 min. Hopefully, a complete set of cloud top and areal data is obtained simultaneously. This mode of data gathering allows cloud-top measurements at 25 km of ~6.1 km, which is less than expected cloud tops, but it is a reasonable compromise for the data desired.

The rain report normally provides radar estimated rainfall information computed using the Marshall-Palmer (M-P), $Z=200R^{1.6}$ (Marshall and Palmer, 1948), and the North Dakota Pilot Project (NDPP), $Z=155R^{1.88}$ (Smith *et al.*, 1975), relationships. Other *Z-R* relationships can easily replace these if desired. Total rain volume, average cloud base area and cloud lifetime are tabulated for each case.

Along with date and time, the cloud-base area (km^2) is displayed, followed by the values computed for average and maximum rainfall rate (mm h^{-1}) and rain volume (ha-cm and acre-ft per 5 min) for the M-P and NDPP relationships.

Cloud-base area is computed by accumulating all the bin areas containing rainfall which extend from approximately 30–150 km at 1° elevation and from approximately 25–29.9 km at 2° elevation. Cloud-base height (km) is input by the analyst and the program calculates the appropriate elevation-range pairs. Total rain volume, average cloud-base area and cloud lifetime are tabulated for each case.

The characteristics report is generated by a program which decodes the 10 characters of each cell and lists the number of reflectivity peaks, cell origin, seeding status, echo data quality and mergers with other cells. The latitude and longitude location is also printed, as is the cloud base area (km^2) and equivalent circle area radius (km).

6. Concluding remarks

HIPLEX radar systems are capable of generating one 2400 ft, 800 cpi magnetic tape every hour. With this large amount of data, a concerted effort has been made to eliminate unreliable and insignificant echo data so as to decrease the size of the data set and make only useful radar data available to the HIPLEX scientists and the scientific community. Very real considerations were the type of computer and the amount of computer time available to the HIPLEX program. With these in mind, a processing system was designed to integrate manual and computer techniques where they were most efficient and effective. Manual intervention remains a very integral part of the computerized system to maintain quality. The system is automated to the extent where digital radar tapes from the two C band radar systems can be analyzed within several months of the end of the operational season.

Two magnetic tape files of great interest to the research scientist are the Z_e and Case Study Summary File for detailed precipitation and climatological analyses, respectively. With a fairly straightforward technique, the Z_e file may be used to generate "footprints" for hourly, daily, monthly and seasonal precipitation. Reflectivity gradients, raingage comparison, attenuation, *Z-R*, areal and hourly rainfall studies are only a matter of accessing the appropriate Z_e files.

For a climatology of convective clouds, the Case Study Summary File contains sufficient information to describe sizes and their frequency, regions and times of occurrence, life cycles, rainfall and reflectivity frequency distributions for each definable cloud complex of the HIPLEX program.

Although no significant changes are expected to be made to algorithms, methods to decrease processing time (manual and machine) are being investigated. An automated cell identification and tracking scheme are currently being implemented.

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