PRECIPITATION PREPROCESSING

ALGORITHM DESCRIPTION

NX-DR-03-017/42

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The execution timing of the PRECIPITATION PREPROCESSING algorithm is controlled by the completion of a volume scan. The schedule for completion of volume scans containing data needed by this algorithm may depend on atmospheric conditions (see the Precipitation Detection Function and section 5.1 of this algorithm). When the Precipitation Detection Function indicates that no precipitation has occurred during the past hour, a volume scan containing at least the lowest two elevation angles specified by the ELEVATION/RANGE BOUNDARIES must be completed at least once every 10 minutes. At the completion of each of these volume scans during non-precipitation periods, this algorithm must be executed but it will not require any input data other than a precipitation detected flag (indicating no precipitation in the previous hour) obtained from the Precipitation Detection Function.

When the Precipitation Detection Function indicates that precipitation has been detected during the previous hour, this algorithm must be executed each volume scan. During these precipitation periods, the PRECIPITATION PREPROCESSING algorithm prepares reflectivity factor data for input to the PRECIPITATION RATE algorithm [018]. The PRECIPITATION RATE algorithm requires data from elevation scans composites to form a single HYBRID SCAN. The four scans are normally obtained during a sampling period not to exceed 2 minutes at a frequency of approximately one every 5 minutes. The elevation angles of the elevation scans used will depend on the local topography and clutter conditions at each site, but most often the four scans will be obtained from the lowest four elevation angles between approximately 0.5 and 3.5 degrees. These elevation angles must be separated by no more than 1.1 degrees. Under certain conditions, when precipitation amounts and areal extent are small (see Precipitation Detection Function and section 5.1 of this algorithm), the sampling period for the four scans may be increased from 2 to 4 minutes and the frequency may be reduced from once every 5 minutes to once every 10 minutes. Data from multiple tilt elevation angles are being included to:

- Assist in the further reduction of residual ground clutter, anomalous propagation, RF interference and spurious noise which may still exist following the preprocessing done earlier in the NEXRAD processing stream.

- Provide capability to construct a composite low altitude array from the lower elevation scans in order to obtain rainfall estimates from data obtained at a more nearly uniform altitude as a function of range.

- Enable the incorporation of techniques to minimize the problems associated with abnormal beam refractions and losses.

The azimuth and range limits for the sectors used to construct the hybrid from each of the four elevation scans (HYBRID SCAN SECTORS) are determined from relevant terrain data as defined in the WSR-88D CPCI-26 B-specifications. The sectors from the two lowest elevation angles used sometimes overlap in order to test the suitability of the lowest scan and for the bi-scan maximization outlined below.

After the data are assembled, isolated reflectivity values are eliminated and suspect reflectivity values are modified. Occultation corrections for both partial obscurations and complete obscurations (up to 2 degrees in azimuth) are also performed.

Each sample volume which potentially may be used in the HYBRID SCAN is first adjusted for any significant partial (up to 60%) occultations of the beam resulting from man-made or natural obstacles. The intent is to correct for the percentage of the two way beam intensity which is obscured from each volume. This is done by simply adding a predetermined value, based on individual site surveys, to the equivalent reflectivity factor at each sample volume which requires adjustment for these losses. The adjustment is applied in 1 dBZe steps and ranges from 1 to 4 dBZe, where the magnitude of the adjustment is proportional to the percent of the beam obscured.

Then, each sample volume is inspected to determine whether or not it is isolated. An isolated sample volume is defined as follows: 1) the equivalent reflectivity factor value is greater than a low minimum threshold and 2) less than two of the eight neighbors within the same elevation scan have equivalent reflectivity factor values greater than the minimum threshold. The equivalent reflectivity factor values of isolated sample volumes are then set to zero.

Sample volumes with a value greater than a maximum (outlier) threshold are assumed not to be valid. Each outlier will be replaced with an interpolated value (a simple average of the values of all eight neighbors in the same elevation scan) only if all eight neighbors have values below the outlier threshold. Otherwise, it is set to a low non-zero value (in order that the sample volume is still included in the area calculations of the area reduction test which follows). These changes are made in such a way that subsequent alterations of outliers are not affected by the changes to those previously identified.

After adjusting for any outliers, an occultation correction is applied to sample volumes which are completely (>60%) blocked. In this case, an interpolation must be performed using the values of the two closest sample volumes, on both sides, and at the same range and elevation, which are not also completely blocked. This is done only if 2 degrees or less in azimuth are completely blocked. When more than 2 degrees of azimuth are identified as being completely blocked at a particular elevation, no attempt is made to interpolate because of the large errors which would result. These changes are made in such a way that subsequent alterations of blocked sample volumes are not affected by the changes to those made previously.

The next function performed by the algorithm is to determine whether data from the lowest elevation scan will be used at all in building the HYBRID SCAN. The lowest scan data are used in building the HYBRID SCAN if any one of the following tests is passed:

- o The total echo area is less than a threshold for significant areal coverage. The total echo area consists of sample volumes from all sectors at the lowest elevation with values greater than a low minimum intensity threshold.

- o The area averaged reflectivity of significant echo areas from all sectors at the lowest elevation is less than a specified value.

- o The third test is based on the ratio of two values: The first value is the area covered by sample volumes with significant echoes from the lowest scan sectors which are not significant at the second lowest scan. ("Significant" echoes exceed a certain threshold). The second value is the total area of significant echoes from the lowest scan sectors. If the ratio of the first value to the second is below a certain threshold, then the lowest scan is considered acceptable.

The intent of these tests is to identify cases where the lowest elevation is significantly contaminated by residual ground clutter, anomalous propagation, RF interference or spurious noise, and to avoid using it in these cases.

The sectors are then used to construct the HYBRID SCAN. Within a specified minimum and maximum radar range, the maximum of values from the two lowest elevation scan sectors at each range and azimuth are used in the HYBRID SCAN. This procedure, known as bi-scan maximization, is applied in a certain range interval, outside of which the lowest tilt values are used. If the lowest elevation is deemed unusable, the second lowest is used for all these ranges and azimuths.

These values, combined with sectors from the two higher tilts, form the HYBRID SCAN. The HYBRID SCAN consists of 82,800 values on a 1 degree by 1 km polar grid from 1 to 230 km.

1.2 SOURCE

The PRECIPITATION PREPROCESSING algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm is based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as well as an in-depth analysis of ways with which weather radar data could be better used for hydrometeorological purposes.

REFERENCES

Ahnert, P.R., M.D. Hudlow, and E.R. Johnson, 1984: Validation of the "on-site" Precipitation Processing System for NEXRAD. Preprints, 22nd Radar Meteor Conf., AMS, Boston, Mass.

Ahnert, P.R., M.D. Hudlow, E.R. Johnson, D.R. Greene, and M.R. Dias, 1983: Proposed "on-site" precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf. , AMS, Boston, Mass.

Hudlow, M.R., D.R. Greene, P.R. Ahnert, W.F. Krajewski, T.R. Sivaramakrishnan, M.R. Dias, and E.R. Johnson, 1983: Proposed off-site precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf., AMS, Boston, Mass.

1.3 PROCESSING ENVIRONMENT

It is assumed that several preprocessing steps will be applied to the equivalent reflectivity factor data before the data are input to the PRECIPITATION PREPROCESSING algorithm (for example, clutter suppression). Care must be taken to ensure that these steps are accomplished without loss of data quality or quantitative accuracy.

Some of the important preprocessing steps expected before data are input to this algorithm include:

- Oxygen absorption correction [function of antenna elevation angle, range, height of antenna, and the assumed atmospheric state (probably the U.S. Standard Atmosphere)],

- Assignment of zero values to all reflectivities below a specified noise threshold.

- Signal processing in ground clutter areas as specified by clutter map to suppress ground clutter, as well as anomalous propagation possible, and other sources of interference (where possible, equivalent reflectivity factor values from these sources should be reduced to a level below 10 dBZe without degradation of the accuracy in the reflectivity estimates exceeding one, or at most, two dBZe), and

- Automatic calibration and quality control functions as desirable and feasible.

Furthermore, this algorithm assumes that the data being input have been converted to equivalent reflectivity factor data, hereafter referred to simply as reflectivity factor data, using the standard assumptions in the classical radar equation. In addition, it is assumed that corrections have been applied to adjust for any known biases and losses resulting from the signal processing, alterations in equipment calibration, dry radome attenuation (eventually, wet radome effects should be addressed in the preprocessing or within the PRECIPITATION PREPROCESSING or other PRECIPITATION algorithms themselves), and any other known losses.

If some of these effects are not taken into account, the information required to make adjustments should be made available for input to the PRECIPITATION PREPROCESSING or other PRECIPITATION algorithms, and the algorithms should be modified to make the required adjustments to the reflectivity data before using them.

The algorithm includes four quality control procedures (partial occultation correction, isolated sample volume check, outlier check, complete occultation correction) which must be done for each sample volume which potentially may be used in the HYBRID SCAN. These steps must be accomplished in such a way that the resultant effects on the data are identical to the result of doing each step, one at a time, for all sample volumes.

If the range or azimuth resolution of the base data exceeds the 1 km by 1 degree specified for the input to this algorithm, then two alternative strategies are available. The first strategy is simply to average the higher resolution data upstream in the processing from this algorithm. The averaging technique is important, as it will affect the bias in the averaged value. The ideal averaging scheme, for precipitation estimation purposes, is to convert the reflectivity factor data to rainfall rate (see the PRECIPITATION RATE [018] algorithm); then average all of the higher resolution sample volumes that fall within each of the specified 1 degree by 1 km cells, then perform the reverse conversion.

An acceptable alternative is to average in Z units, i.e., convert the logarithmic units (dBZe) to linear units (Ze), then average in linear units, then convert the linear units on the 1 km by 1 degree grid back to logarithmic units. Averaging directly in logarithmic units (dBZe) is not acceptable, nor is it acceptable to perform some operation other than averaging (e.g., taking the higher resolution sample volume closest to the center of the 1 km by 1 degree cell, or using an interpolation scheme to produce the best estimate at the center of the 1 degree by 1 km cell). NOTE: In discussing "the ideal averaging scheme for precipitation estimation purposes" this paragraph says that logarithmic units should not be used. The compute REFLECTIVITY (Area-Averaged) (see page 017-18) appears to contradict this guidance because it uses logarithmic units. There is no contradiction, however, because it is not used for precipitation estimation purposes. (REFLECTIVITY (Area-Averaged) is used as a test in a decision tree.) Since there is no contradiction and since the compute uses $DBZE_n$ (logarithmic units), it follows that $DBZE_n$ is preferred. ZE_n (linear units) may be substituted for $DBZE_n$ in this compute provided the threshold values for maximum AREA (Percent Reduction) and any other related site adaptable parameters are accordingly adjusted.

The second strategy is to defer the averaging process until after certain of the initial quality control steps are done. This averaging could be done at any point in the processing stream before the computation of the AREA (Lowest Elevation Echo) (Step 4.12 in the algorithm). The second strategy would certainly increase the computational burden for this algorithm. However, it might be useful if the quality control steps indicated in this algorithm (isolated sample volumes, outliers, and occultation corrections) duplicate those of other NEXRAD algorithms which require retention of the higher resolution data. If the second strategy is adopted, the averaging process must still comply with the criteria described above.

Especially for use in the higher level (regional/national) processing, it will be critical that certain file management information be appended to the basic rainfall data. This information will be required to identify certain characteristics about the data up to that point in the processing stream, and it will be used as part of the information for accomplishing more discriminating quality control functions at the higher level of processing.

2.0 INPUTS

2.1 IDENTIFICATION

TIME (Volume Scan)	=	Time at which a volume scan was completed. Precise to at least 1/1200 hour.
TIME (Stamp)	=	Time at which the Precipitation Detection Function was last executed. Precise to at least 1/1200 hour.
TIME (Last Precipitation Detected)	=	The time at which the Precipitation Detection Function last detected precipitation. Precise to at least 1/1200 hour.
SAMPLE VOLUME	=	A data sample volume whose dimensions are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).

NOTE: Within this algorithm the data SAMPLE VOLUME is treated as a horizontal projection (1 degree in azimuth by 1 km in range).

ELEVATION	=	Elevation angle, in radians. Precise to at least .001 radians.
HYBRID SCAN SECTORS	=	The Hybrid Scan sectors as defined by the CPCI-26 software. This information includes the azimuth angle and range extents for each elevation angle used to build the Hybrid Scan.
REFLECTIVITY FACTOR	=	The effective radar reflectivity factor (DBZE) of a SAMPLE VOLUME, in dBZe.
OCCULTATION CODEs	=	Coded values for each SAMPLE VOLUME which are based on the percentage of the total (two way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.

Code	Occultation (%)
0	0 > 10, > 60[1]
1	11 > 29
2	30 > 43
3	44 > 55
4	56 > 60
5	> 60[2]

[1] SAMPLE VOLUME is part of a completely obscured region extending over more than 2 degrees in azimuth.

[2] SAMPLE VOLUME is part of a completely obscured region extending over no more than 2 degrees in azimuth.

minimum THRESHOLD	=	The minimum reflectivity factor (Reflectivity-1) considered to be non-zero in the test for isolated SAMPLE VOLUMEs, in dBZe.

maximum THRESHOLD	=	The maximum reflectivity factor (Reflectivity-1) which could be expected when precipitation is occurring, in dBZe.
REFLECTIVITY (Tilt Test)	=	Low reflectivity, approximately 0-10 dBZe.
RANGE (Tilt Test)	=	The inner and outer range boundaries between which the lowest and second lowest elevation reflectivity data are compared, in kilometers. This will be approximately 40 and 150 km.
minimum AREA (Echo)	=	The minimum area of precipitation echoes in the low tilt sectors and between the inner and outer RANGEs (Tilt Test) which must be exceeded in order to do the tilt test (600), in km^2.
minimum REFECTIVITY factor (Area-Averaged)	=	The area-averaged reflectivity factor for all SAMPLE VOLUMES in the lowest elevation sectors between the inner and outer RANGEs (Tilt Test), which must be exceed in order to do the tilt test (10.0), in dBZe. Precise to at least 0.1 dBZe.
maximum AREA (Percent Reduction)	=	The percentage of echo area in the lowest elevation sector and between the inner and outer RANGEs (Tilt Test) which is eliminated by going to the second lowest elevation, which when exceeded, flags the lowest elevation scan as being bad, in percent.
minimum RANGE (Bi-Scan)	=	Minimum range at which the bi-scan maximization procedure is applied, in kilometers.
maximum RANGE (Bi-Scan)	=	Maximum range at which the bi-scan maximization procedure is applied, in kilometers.
TIME (Elevation Scan)	=	The time at the beginning and end of each elevation scan.
PRECIPITATION STATUS MESSAGE	=	An alphanumeric message which includes the radar includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY (Precipitation), number of gages in data base, and time since last update to the gage data base.
CATEGORY(Precipitation)	=	The precipitation category currently in effect.

CATEGORY	MEANING
0	No precipitation detected during the past hour
1	Significant precipitation detected during the past hour
2	Light precipitation detected during the past hour

2.2 ACQUISITION

PRECIPITATION STATUS MESSAGE, CATEGORY(Precipitation), Time (Stamp), and TIME (Last Precipitation Detected) are obtained from a Precipitation Detection Function.

SAMPLE VOLUMEs, ELEVATIONs, TIMEs (Volume Scan) and TIMEs (Elevation Scan) are intrinsic system parameters and are acquired directly from the radar.

HYBRID SCAN SECTORS and OCCULTATION CODEs are unit adaptation parameters based on relevant terrain information. The values are determined off-line in CPCI-26 and are delivered as data files (HYSECTRS.DAT and HYOCCULT.DAT respectively) along with operational code.

REFLECTIVITY FACTOR (DBZE) data are acquired from the NEXRAD base data.

Minimum THRESHOLD (Reflectivity-1) and REFLECTIVITY (Tilt Test) are system adaptation parameters based on empirical/ theoretical studies.

Maximum THRESHOLD (Reflectivity-1), maximum AREA (Percent Reduction), minimum RANGE (Bi-Scan), and maximum RANGE (Bi-Scan) are seasonally dependent unit adaptation parameter values based on empirical/theoretical studies.

RANGEs (Tilt Test), minimum AREA (Echo), and minimum REFLECTIVITY (Area-Averaged) are unit adaptation parameters based on empirical/theoretical studies.

3.0 PROCEDURE

3.1 ALGORITHM

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BEGIN ALGORITHM (PRECIPITATION PREPROCESSING)

1.0  Clear FLAG (Zero Hybrid)

2.0  IF  (CATEGORY (Precipitation) indicates no precipitation during the past
         hour)
         THEN
            Set FLAG (Zero Hybrid)
         ELSE
            IF (Reflectivity data specified by HYBRID SCAN SECTORS not
            included in this volume scan)
               THEN
                  STOP (Restart after next volume scan is complete with the
                  PRECIPITATION PREPROCESSING algorithm)
            END IF
      END IF

3.0   WRITE (FLAG (Zero Hybrid))

4.0   IF (FLAG (Zero Hybrid) set)
      THEN
   4.1   Set average TIME (Scan) to TIME (Volume Scan)
   4.2   WRITE (average TIME (Scan))
      ELSE
   4.3   In the following steps, only include those SAMPLE VOLUMEs which are
         defined in HYBRID SCAN SECTORS.
   4.4   DO FOR ALL (Partially occulted SAMPLE VOLUMEs)
            COMPUTE (OCCULTATION (Partial Adjustment))
         END DO
   4.5   DO FOR ALL (SAMPLE VOLUMEs)
            IF (REFLECTIVITY FACTOR (DBZE) is greater than minimum THRESHOLD
               (Reflectivity-1)
            AND   the number of neighboring SAMPLE VOLUMEs greater than
                  minimum THRESHOLD (Reflectivity-1) is less than two)
            THEN  (Mark the SAMPLE VOLUME as isolated. Keep count of the
                  NUMBER (Isolated Sample Volumes)).
            END IF
         END DO
   4.6   WRITE (NUMBER (Isolated Sample Volumes))
   4.7   Replace the REFLECTIVITY FACTOR (DBZE) of isolated SAMPLE VOLUMEs
         with a value of 0 (lower limit of REFLECTIVITY FACTOR (DBZE))
   4.8   DO FOR ALL (SAMPLE VOLUMEs)
            IF (REFLECTIVITY FACTOR (DBZE) is greater than maximum THRESHOLD
               (Reflectivity-1))
            THEN  (Mark the SAMPLE VOLUME as an outlier)
               IF (All eight adjoining SAMPLE VOLUMEs are less than maximum
                  THRESHOLD (Reflectivity-1)AND all eight not previously
                  identified as an outlier)
               THEN
                  COMPUTE (REFLECTIVITY (Interpolated).  Replace REFLECTIVITY
                  FACTOR (DBZE) with REFLECTIVITY (Interpolated).  Keep count
                  of the NUMBER (Interpolated Outliers))
               ELSE  (Replace REFLECTIVITY FACTOR (DBZE) with REFLECTIVITY
                     (Tilt Test).  Keep count of the NUMBER (Replaced
                     Outliers))
               END IF
            END IF
         END DO
   4.9   WRITE (NUMBER (Interpolated Outliers))
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    4.10  WRITE (NUMBER (Replaced Outliers))
    4.11  DO FOR ALL (Completely occulted SAMPLE VOLUMEs)
             IF (Complete blockage extends over two degrees, or less, in
                azimuth)
             THEN
                COMPUTE (REFLECTIVITY (Complete Occultation))
             END IF
          END DO
    4.12  COMPUTE (AREA (Lowest Elevation Echo))
    4.13  IF (AREA (Lowest Elevation Echo) is greater than minimum AREA (Echo))
          THEN
             COMPUTE  (Reflectivity (Area-Averaged))
             IF (REFLECTIVITY (Area-Averaged) is greater than minimum
                REFLECTIVITY (Area-Averaged))
             THEN
                COMPUTE  (AREA (Percent Reduction))
                WRITE       (AREA (Percent Reduction))
                IF (AREA (Percent Reduction) is greater than maximum AREA
                   (Percent Reduction))
                THEN  (Do not use the lowest scan sectors.  Use the second
                      lowest scan sectors)
                ELSE
                   IF (RANGE (Slant) > min. RANGE (Bi-Scan) AND < max. RANGE
                      (Bi-Scan))
                   THEN  (Use the maximum reflectivity between the two
                         lowest elevation sections.  Keep count of the
                         number of  second tilt SAMPLE VOLUMEs selected)
                   ELSE
                            (Use only the lowest scan sectors.)
                   END IF
                END IF
             ELSE
                IF (RANGE (Slant) > min. RANGE (Bi-Scan) AND < max. RANGE
                   (Bi-Scan))
                THEN  (Use the maximum reflectivity between the two lowest
                      elevation sections.  Keep count of the number of
                      second tilt SAMPLE VOLUMEs selected)
                ELSE
                      (Use only the lowest scan sectors.)
                END IF
             END IF
          ELSE
             IF    (RANGE (Slant) > min. RANGE (Bi-Scan) AND    < max. RANGE
                   (Bi-Scan))
             THEN  (Use the maximum reflectivity between the two lowest
                   elevation sections.  Keep count of the number of second
                   tilt SAMPLE VOLUMEs selected)
             ELSE
                      (Use only the lowest scan sectors.)
             END IF
          END IF
    4.14  COMPUTE (RATIO (Bi-Scan))
    4.15  WRITE (RATIO (Bi-Scan))
    4.16  Assemble the HYBRID SCAN
    4.17  WRITE (HYBRID SCAN)
    4.18  COMPUTE (average TIME (Scan))
    4.19  WRITE (average TIME (Scan))
    END IF

 END ALGORITHM  (PRECIPITATION PREPROCESSING)
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3.2 COMPUTATION

3.2.1 NOTATION

OC	=	OCCULTATION CODEs, coded values for each SAMPLE VOLUME which are based on the percentage of the total (two-way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.
OCP	=	OCCULTATION (Partial Adjustment), an additive adjustment for beam occultation, in dBZe.
NIO	=	NUMBER (Interpolated Outliers), number of SAMPLE VOLUMEs for which the REFLECTIVITY (Interpolated) was computed.
NIS	=	NUMBER (Isolated SAMPLE VOLUMEs), number of SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD (Reflectivity-1) but are surrounded by less than two SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD (Reflectivity-1).
NRO	=	NUMBER (Replaced Outliers), number of outliers which have at least one neighbor which is also an outlier and whose REFLECTIVITY FACTOR(DBZE) is replaced with the REFLECTIVITY (Tilt Test).
DBZE	=	REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. A precision of at least 1 dBZe and a dynamic range of at least 0 to 71 dBZe are required.
ZEI	=	REFLECTIVITY (Interpolated), the average of all eight neighboring SAMPLE VOLUME reflectivities, in dBZe.
ZCO	=	REFLECTIVITY (Complete Occultation), the average of the reflectivity factor values at the same range on either side of a completely occulted SAMPLE VOLUME, in dBZe.
RS	=	RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 0.1 km.
ALE	=	AREA (Lowest Elevation Echo), echo area including those SAMPLE VOLUMEs with a reflectivity factor greater than the REFLECTIVITY (Tilt Test) from the lowest elevation sectors and between the inner and outer RANGEs (Tilt Test), in km^2.
FZH	=	FLAG (Zero Hybrid), a set or cleared flag indicating, if set, that no precipitation exists in the current scan.
ASV	=	AREA (Sample Volume), the area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km^2, in km^2.
AEmin	=	Minimum AREA (Echo), the minimum area of precipitation echoes in the low tilt sectors between the inner and outer RANGEs (Tilt Test) which must be exceeded in order to do the tilt test, in km^2.
ZAVlow	=	REFLECTIVITY (Area-Averaged), the area-averaged reflectivity factor for all SAMPLE VOLUMEs from the lowest elevation sector between the inner and outer RANGEs (Tilt Test) with reflectivity factor greater than or equal to the REFLECTIVITY (Tilt Test), in dBZe. Precise to 0.1 dBZe.

APR = AREA (Percent Reduction), the percentage echo area from the lowest elevation sectors and between the inner and outer RANGEs (Tilt Test) which is eliminated by going to the second lowest elevation.

ASL = AREA (Second Elevation Echo), the echo area which satisfies the requirements of AREA (Lowest Elevation Echo) at the lowest elevation but not at the second lowest elevation, in km^2.

BIR = RATIO (Bi-Scan), the ratio of the number of SAMPLE VOLUMEs with reflectivity > REFLECTIVITY (Tilt Test) used from the second lowest elevation scan to the number of SAMPLE VOLUMEs with reflectivity > REFLECTIVITY (Tilt Test) at either the first or second elevation scans within the range interval for the Bi-Scan maximization procedure.

HS = HYBRID SCAN, reflectivity factor data on a 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least l dBZe and dynamic range of at least 0 to 71 dBZe are required.

TESbeg = beginning TIME (Elevation Scan), time at which the beginning of an elevation scan was started. A precision of at least 1/1200 hour and an accuracy of 1/120 hour are required.

TESend = ending TIME (Elevation Scan), the time at which the end of a elevation scan occurred. A precision of at least 1/1200 and an accuracy of 1/120 hour are required.

Tsavg = average TIME (Scan), the average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

j = INDEX (Azimuth), the index for AZIMUTH.

PI# = PI, a mathematical constant (3.1416), unitless.

Note: Precision will be units specified unless otherwise stated

3.2.2 SYMBOLIC FORMULAS

(OCCULTATION (Partial Adjustment))

$DBZE = DBZE_{meas} + OCP\ (OC)$

where;

OCP (dBZe)	OC (code)
0	0
1	1
2	2
3	3
4	4
0	5

COMPUTE (REFLECTIVITY (Interpolated))

$$ZEI = 10 \log \frac{\sum_{n=1}^{8} 10^{DBZE_n / 10}}{8}$$

where;

sum is over all 8 neighboring sample volumes at the same elevation.

COMPUTE (REFLECTIVITY (Complete Occultation))

$$ZCO = 10 \log \frac{10^{DBZE_{j-1}/10} + 10^{DBZE_{j+1}/10}}{2}$$

where;

$DBZE_{j-1}$ and $DBZE_{j+1}$ are the reflectivity values at the same range on either side of the completely (>60%) occulted area.

Note: This subscription assumes that the azimuthal resolution is one degree. If the azimuthal resolution is less than one degree the two nearest (in azimuth) SAMPLE VOLUMEs at the same range, which are not themselves completely occulted, should be used.

COMPUTE (AREA (Lowest Elevation Echo))

$$ALE = \sum_{n} ASV_n$$

where;

sum is over all n sample volumes from the lowest scan sectors and between the inner and outer RANGEs (Tilt Test) whose REFLECTIVITY FACTOR (DBZE) is greater than or equal to REFLECTIVITY (Tilt Test).

and,

$$ASVn = \frac{2B(RS_n)}{360} \times 1\ km$$

Note: This assumes azimuthal resolution of 1 degree and range resolution of 1 km.

COMPUTE (REFLECTIVITY (Area-Averaged))

$$ZAVlow = \sum_n \frac{(ASV_n)(DBZE_n)}{ALE}$$

where;

ASVn is defined above and is summed under the same conditions as above.

COMPUTE (AREA (Percent Reduction))

$$APR = \frac{ASL}{ALE}(100)$$

where;

ALE is defined above,

and;

$$ASL = \sum_n ASV_n$$

sum is over all n sample volumes from the lowest scan sectors and between the inner and outer RANGEs (Tilt Test) whose REFLECTIVITY FACTOR (DBZE) at the lowest scan is greater than or equal to the REFLECTIVITY (Tilt Test) and whose REFLECTIVITY FACTOR (DBZE) at the second lowest scan is less than the REFLECTIVITY (Tilt Test).

COMPUTE (RATIO (Bi-Scan))

$$BIR = \frac{\text{number of sample volumes used from the second lowest scan with reflectivity > REFL. (Tilt Test)}}{\text{number of sample volumes within the minimum and maximum RANGE (Bi-Scan) that had reflectivity > REFL. (Tilt Test) at either the first or second lowest scans}}$$

NOTE: BIR = 1 whenever BI-SCAN procedure is not used because of a high AREA (Percent Reduction).

COMPUTE (average TIME (Scan))

where;

sum is over the TIMEs (Elevation Scan) of the four elevation scans used in this algorithm.

4.0 OUTPUTS

4.1 IDENTIFICATION

The HYBRID SCAN, a 1 degree by 1 km resolution scan set of reflectivity factor values (from 1 to 230 km) composited from four elevation scans is output by this algorithm unless no precipitation has occurred during the past hour.

NUMBER (Isolated Sample Volumes), NUMBER (Interpolated Outliers), NUMBER (Replaced Outliers), AREA (Percent Reduction), average TIME (Scan), and RATIO (Bi-Scan) are included in SUPPLEMENTAL DATA.

Average TIME (Scan) and FLAG (Zero Hybrid) are output by this algorithm.

4.2 DISTRIBUTION

The HYBRID SCAN and FLAG (Zero Hybrid) are intended to be input to the PRECIPITATION RATE [018] algorithm. The Hybrid Scan is also to be used directly in the generation of both PUP-displayable products, and digital products intended for applications external to the NEXRAD system.

SUPPLEMENTAL DATA will be input to the PRECIPITATION PRODUCTS [021] algorithm.

Average TIME (Scan) is intended to be input to the PRECIPITATION RATE [018] and PRECIPITATION ACCUMULATION [019] as the time of the HYBRID SCAN and subsequent RATE SCAN, respectively.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm does not account for:

- frozen hydrometer effects, including bright band phenomena
- errors in signal averaging due to strong reflectivity gradients (within the reflectivity sample volumes)
- wet radome attenuation
- intervening rainfall attenuation

If any scan mode in the NEXRAD system fails to meet the requirements of Table 1, the NEXRAD site may completely fail to recognize precipitation occurrence. In addition, if any scan mode does not meet the requirements of Table 1, there can be no assurance that the category of precipitation (0, 1, or 2) as assigned by the Precipitation Detection Function (NTR-Appendix D) is representative of current conditions. This is important since the category determines whether or not the more stringent scan mode requirements in table 2 (Category 1) or table 3 (Category 2) must be met by the current scan mode. Failure to meet the requirements of Table l at all times, Table 2 when the precipitation category is 1, and Table 3 when the precipitation category is 2, will seriously degrade the performance of the Precipitation Processing Subsystem and result in the generation of unreliable products.

Table 1. Minimal Scan Mode Requirements

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	2 km or less
Azimuthal Coverage	360°
Azimuthal Resolution	2° or less
Tilts and Repetition	Lowest 2 tilts required by Precipitation Processing Subsystem (see PRECIPITATION PREPROCESSING algorithm) at least every 10 minutes. All 4 tilts required by Precipitation Processing Subsystem at least every 30 minutes.

Table 2. Minimal Scan Mode Requirements -- Maximum Accuracy Precipitation (Category 1)

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	1 km or even fraction of 1 km (e.g., 1/2, 1/3, 1/4, ...)
Azimuthal coverage	360°
Azimuthal Resolution	1°
Tilts and Repetition	Lowest 4 tilts required by Precipitation Processing Subsystem (see PRECIPITATION PREPROCESSING algorithm), contiguous, sequentially acquired over 2 minutes or less, repeated approximately every 5 minutes.

Table 3. Minimal Scan Mode Requirements -- Degraded Accuracy Precipitation (Category 2)

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	1 km or even fraction of 1 km (e.g., 1/2, 1/3, 1/4, ...)
Azimuthal Coverage	360°
Azimuthal Resolution	1°

Tilts and Repetition	Lowest 4 tilts required by Precipitation Processing Subsystem (see PRECIPITATION PREPROCESSING algorithm), contiguous, sequentially acquired over 4 minutes or less, repeated at least every 10 minutes.

5.2 FUTURE DEVELOPMENTS

Adaptation parameter values will be "fine tuned" using actual NEXRAD data.