CLUTTER REMOVAL

ALGORITHM DESCRIPTION

NX-DR-03-050/01

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Weather Surveillance Radar - 1988 Doppler (WSR-88D) Composite Reflectivity and low altitude Layer Composite Reflectivity products are occasionally contaminated by ground clutter, frequently caused by anomalous beam propagation (AP). The clutter contamination falsely indicates regions of heavy precipitation and can significantly reduce the accuracy and reliability of the Composite Reflectivity products, particularly for use in Air Traffic control.

The CLUTTER REMOVAL algorithm was designed to identify regions of ground clutter in real time using the radar base data (Reflectivity, Radial Velocity, and Spectrum Width), and to remove the clutter from the Composite Reflectivity and low level Layer Composite Reflectivity products.

The CLUTTER REMOVAL algorithm uses base data that has been registered, i.e. the Reflectivity data from the surveillance scan has been mapped to/aligned with the azimuths of the Doppler (Velocity and Spectrum Width) scan. This implies that each one-kilometer Reflectivity range gate is azimuthally associated with four 250-meter Doppler range gates.

The CLUTTER REMOVAL algorithm creates versions of the Composite Reflectivity and low level Layer Composite Reflectivity product with the clutter contamination removed using the following logic.

Note, since the purpose of the CLUTTER REMOVAL algorithm is to prevent high reflectivity ground clutter returns from contaminating Composite Reflectivity products and in order to speed up processing, Reflectivity data values below THRESHOLD (Minimum Reflectivity) are never considered to be Clutter.

The CLUTTER REMOVAL algorithm process can be divided into three distinct functions: <u>1) Clutter Identification</u>, <u>2) Clutter Extension</u>, and <u>3) Data Smoothing</u>.

<u>Clutter Identification function.</u> Because the Clutter Identification function is three dimensional and the resulting Reflectivity data is used to build Composite Reflectivity products, the logic of this function is integrated with compositing logic. Therefore, this function generates two vertically composited two dimensional polar Reflectivity arrays. These polar arrays contain the maximum uncontaminated Reflectivity value at each range and azimuth (whole degrees) from any tilt in the volume scan between the surface and the top sampling height (70,000 feet) for the Composite Reflectivity and between the surface and LAYER COMPOSITE (Low Level - Height) for the low level Layer Composite Reflectivity.

For the purpose of Clutter Identification, this algorithm assumes that AP induced ground clutter displays the following three distinguishing characteristics:

1. Radial Velocity values in clutter are near zero.
2. Spectrum Widths values in clutter are low.
3. Clutter is most common in low tilts near the radar.

Based on these characteristics, the Clutter Identification function defines four regions (Figure 1) at successively farther ranges and higher altitudes from the radar. Each region uses different “rules” to determine whether the Reflectivity data at that point is Clutter.

<u>Region 1</u> - OMIT ALL Reflectivity data. All Reflectivity data with values exceeding THRESHOLD (Minimum Reflectivity) are considered to be Clutter.

Region 1 extends outward from the radar to a distance THRESHOLD (Range - OMIT ALL) and upwards to an altitude THRESHOLD (Altitude - OMIT ALL) above the radar.

<u>Region 2</u> - ACCEPT IF Reflectivity data are determined to contain only Weather. Reflectivity data are considered to contain only Weather if at least one of the associated Doppler range gates has an absolute radial Velocity value greater than or equal to THRESHOLD (Velocity - Weather) or a Spectrum Width value greater than or equal to THRESHOLD (Spectrum Width - Weather) and no associated Doppler range gate has both an absolute radial Velocity value less than THRESHOLD (Velocity - Clutter) and a Spectrum Width value less than THRESHOLD (Spectrum Width - Clutter).

Region 2 extends outward from THRESHOLD (Range - OMIT ALL) to THRESHOLD (Range - ACCEPT IF) and includes all range gates from elevation angles less than or equal to THRESHOLD (Elevation Angle - ACCEPT IF) that are below the altitude THRESHOLD (Altitude - ACCEPT IF) above the radar.

<u>Region 3</u> - REJECT only IF Reflectivity data are determined to contain Clutter. Reflectivity data is considered to contain Clutter if at least one associated Doppler range gate has both an absolute radial Velocity value less than THRESHOLD (Velocity - Clutter) and a Spectrum Width value less than THRESHOLD (Spectrum Width - Clutter).

Region 3 extends outward from THRESHOLD (Range - ACCEPT IF) to THRESHOLD (Range - REJECT IF) and includes all range gates from elevation angles below THRESHOLD (Elevation Angle - REJECT IF) that were not previously used in Region 1 or Region 2.

<u>Region 4</u> - ACCEPT ALL data. This region extends to the rest of the radar volume that is not included in either of the three

other regions. None of the data in Region 4 is considered Clutter.

Clutter Extension function. Range ambiguities and difficulties registering Reflectivity data (motion of echoes, etc.) will cause some Reflectivity range gates to not have valid associated Doppler data. If a Reflectivity range gate has no valid associated Doppler data it is impossible to test for Clutter using the logic stated in the paragraphs above. The Clutter Extension function provides a mechanism to radially extend clutter identification into areas without valid associated Doppler data. Clutter Extension is only performed if FLAG (Extend Clutter) is true and is only performed in Region 3 (REJECT IF).

Clutter Extension is performed radially outward, from Reflectivity data bins which have already been defined to contain Clutter, a distance not exceeding THRESHOLD (Extend - Range Gates). Clutter Extension defines each succeeding Reflectivity data bin to contain Clutter until the process encounters a Reflectivity data bin which is defined as containing only Weather (as defined in Region 2 - ACCEPT IF) or which has a Reflectivity value which differs by more than THRESHOLD (Extend - Reflectivity Difference) from the initial Reflectivity data bin value.

Data Smoothing function. Following the identification and removal of clutter, the resulting composite polar Reflectivity data arrays may appear “noisy” or may contain small regions of echoes that are not representative of the precipitation field. If the adaptable parameter FLAG (Filter Output Reflectivity) is set, a median filter is applied to improve the appearance of the Reflectivity data arrays.

The Median Filter domain is defined to be the individual bins of Reflectivity data extending in range +/- THRESHOLD (Filter - Number Range Gates) and +/- one azimuth if the center of the azimuth does not exceed THRESHOLD (Filter - Cross Range) distance from the center of the Range bin. Beyond the range at which the distance between adjacent azimuths exceed THRESHOLD (Filter - Cross Range), the filtering is applied only in range.

Each Reflectivity data value is replaced with the median of the Reflectivity values in the Median Filter domain.

Following the completion of these three CLUTTER REMOVAL Algorithm logical functions, the resulting composite polar Reflectivity data arrays are remapped onto a 4 X 4 kilometer (116 X 116 element) rectangular grid to build the Composite Reflectivity (Clutter Removed) and low level Layer Composite Reflectivity (Clutter Removed) products. The remapping is performed by assigning the maximum value from each polar array element in the 4 X 4 km grid to be the grid value.

1.2 SOURCE

The CLUTTER REMOVAL algorithm was developed for the Federal Aviation Administration (FAA) by the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL).

REFERENCES

Pace, D. J. *(not the actual author)* 1996 <u>MIT/LL algorithm description for AP mitigation.</u>

1.3 PROCESSING ENVIRONMENT

The CLUTTER REMOVAL processing will be performed using base data preliminary to the construction of the Composite Reflectivity (AP Removed) products.

2.0 INPUTS

2.1 IDENTIFICATION

LAYER COMPOSITE (Low Level - Height)	=	Maximum vertical extent of low level Layer Composite above sea level. Precise to 1 ft. Default 24,000 ft. Range 6,000 - 58,000 ft.
THRESHOLD (Minimum Reflectivity)	=	Minimum reflectivity limit below which no CLUTTER REMOVAL processing need be performed. Precise to 0.5 dBZ. Default 10.0 dBZ. Range 5.0 - 20.0 dBZ.
THRESHOLD (Altitude - OMIT ALL)	=	Altitude bounding the top of Region 1. Precise to 1 m. Default 1.0 km, Range 0.0 - 5.0 km.
THRESHOLD (Altitude - ACCEPT IF)	=	Altitude bounding the top of Region 2. Precise to 1 m. Default 3.0 km. Range 0.0 - 10.0 km.
THRESHOLD (Range - OMIT ALL)	=	Outer range bounding Region 1. Precise to 1 km. Default 45 km. Range 1 - 100 km.
THRESHOLD (Range - ACCEPT IF)	=	Outer range bounding region 2. Precise to 1 km. Default 103 km. Range 0 - 300 km.

THRESHOLD (Range - REJECT IF)	=	Outer range bounding region 3. Precise to 1 km. Default 230 km. Range 0 - 300 km.
THRESHOLD (Elevation Angle - ACCEPT IF)	=	Elevation angle bounding the top of region 2. Precise to 0.1 deg. Default 0.5 deg. Range 0.0 - 5.0 deg.
THRESHOLD (Elevation Angle - REJECT IF)	=	Elevation angle bounding the top of region 3. Precise to 0.1 degrees. Default 5.0 deg. Range 0.0 - 15.0 deg.
THRESHOLD (Velocity - Weather)	=	Lower limit in absolute value of Doppler velocity used to test for weather. Precise to 0.5 m/s. Default 1.0 m/s. Range 0.0 to 5.0 m/s.
THRESHOLD (Spectrum Width - Weather)	=	Lower limit in value of Spectrum Width used to test for weather. Precise to 0.5 m/s. Default 0.5 m/s. Range 0.0 - 5.0 m/s.
THRESHOLD (Velocity - Clutter)	=	Upper limit in absolute value of Doppler velocity used to test for clutter. Precise to 0.5 m/s. Default 1.0 m/s. Range 0.0 - 5.0 m/s.
THRESHOLD (Spectrum Width - Clutter)	=	Upper limit in value of Spectrum Width used to test for clutter. Precise to 0.5 m/s. Default 0.5 m/s. Range 0.0 - 5.0 m/s.
FLAG (Extend Clutter)	=	Determines whether to extend the CLUTTER identification into range ambiguous regions.
THRESHOLD (Extend - Range Gates)	=	Range limit for extending CLUTTER identification. Precise to 1 range gate. Default 4 gates. Range 0 - 20 gates.
THRESHOLD (Extend - Reflectivity Difference)	=	Maximum reflectivity difference allowed to extend CLUTTER identification. Precise to 0.5 dBZ. Default 10.0 dBZ. Range 0.0 - 30.0 dBZ.
FLAG (Filter Output Reflectivity)	=	Determines whether to filter output Reflectivity products.

THRESHOLD (Filter - Number Range Gates)	=	The number of range gates (+/-) to be used for filtering the output Reflectivity products. Precise to 1 range gate. Default 1 gate. Range 0 - 5 gates.
THRESHOLD (Filter - Cross Range)	=	The maximum distance between adjacent radials for azimuthally filtering output Reflectivity products. Defines the range limit of azimuthal filtering. Precise to 1 m. Default 2.0 km. Range 0.0 - 10.0 km.
Base Data	=	Individual radials containing Reflectivity and Doppler (Velocity and Spectrum Width) data.
Grid Size	=	Rectangular product grid size. Precise to 1 kilometer.

2.2 ACQUISITION

LAYER COMPOSITE (Low Level - Height), THRESHOLD (Minimum Reflectivity), THRESHOLD (Altitude - Region 1), THRESHOLD (Altitude - Region 2), THRESHOLD (Range - Region 1), THRESHOLD (Range - Region 2), THRESHOLD (Range - Region 3), THRESHOLD (Elevation angle - Region 2), THRESHOLD (Elevation angle - Region 3), THRESHOLD (Velocity - Region 2), THRESHOLD (Spectrum Width - Region 2), THRESHOLD (Velocity - Region 3), THRESHOLD (Spectrum Width - Region 3), FLAG (Extend Clutter), THRESHOLD (Extend - Range Gates), THRESHOLD (Extend - Reflectivity Difference), FLAG (Filter Output Reflectivity), THRESHOLD (Filter - Number Range Gates), and THRESHOLD (Filter - Cross Range) are adaptable parameters defined in the...file.

Base Data radials (Reflectivity and Doppler data) are obtained from the Base Data processing routine.

3.0 PROCEDURE

3.1 ALGORITHM

BEGIN ALGORITHM (CLUTTER REMOVAL)

```
1  DO FOR ALL Tilts
     COMPUTE Range limits for Region 1 - OMIT ALL, Region 2 -
     ACCEPT IF, and Region 3 - REJECT IF.
     COMPUTE Range to top of Low altitude Layer
1.1  DO FOR ALL Azimuths
       READ Base Data
       COMPUTE Azimuth (Whole Degrees)
```

IDENTIFY CLUTTER

```
1.1.1     DO FOR ALL Ranges
1.1.1.1     IF (Range within Region 1)
              THEN
                SET FLAG (Reflectivity Bin - Range)) = Clutter
1.1.1.2     ELSE IF (Range within Region 2)
              THEN
                COMPUTE FLAG (Weather_Bin)
1.1.1.2.1       IF (FLAG (Weather_Bin) = False)
                  THEN
                    SET FLAG (Reflectivity Bin - Range)) =
                    Clutter
                END IF
1.1.1.3     ELSE IF (Range within Region 3)
              THEN
                COMPUTE FLAG (Clutter_Bin)
1.1.1.3.1       IF (FLAG (Clutter_Bin) = True)
                  THEN
                    SET FLAG (Reflectivity Bin - Range)) =
                    Clutter
                END IF
            END IF
          END DO
```

EXTEND CLUTTER

```
1.1.2     IF (FLAG (Extend Clutter) = True)
            THEN
1.1.2.1       DO FOR ALL Ranges within Region 3
1.1.2.2       IF (FLAG (Reflectivity Bin - Range) = Clutter)
                THEN
1.1.2.2.1         DO FOR ALL Extended Range Bins from (Range + 1)
                  to (Range + THRESHOLD (Extend Range Gates))
                    COMPUTE (Reflectivity Difference)
1.1.2.2.1.1         IF ((Reflectivity Difference) less than or
                    equal to (THRESHOLD (Extend Reflectivity
                    Difference))
                      THEN
                        COMPUTE (FLAG (Weather_Bin))
1.1.2.2.1.1.1           IF (FLAG (Weather_Bin) = False)
                          THEN
                            SET FLAG (Reflectivity Bin - Range)
                            = Clutter
                        END IF (FLAG (Weather_Bin))
                    END IF (Reflectivity Difference)
                  END DO (Range Bins)
              END IF (FLAG (Reflectivity Bin - Range))
            END DO (Ranges)
          END IF (FLAG (Extend Clutter))
```

BUILD COMPOSITE POLAR REFLECTIVITY DATA ARRAYS

```
1.1.3   DO FOR ALL Ranges
1.1.3.1   IF (FLAG (Reflectivity Bin (Range)) not equal to
          Clutter AND (Reflectivity data (Range) greater than
          Composite Reflectivity (Azimuth (Whole Degrees),
          Range))
            THEN
              SET Composite Reflectivity (Azimuth (Whole
              Degrees), Range) = Reflectivity data (Range)
          END IF
1.1.3.2   IF (FLAG (Reflectivity Bin (Range)) not equal to
          Clutter AND (Range less than or equal to Range to top
          of Low altitude Layer) AND (Reflectivity data (Range)
          greater than Layer Composite (Azimuth (Whole Degrees),
          Range))
            THEN
              SET Layer Composite (Azimuth (Whole Degrees),
              Range) = Reflectivity data (Range)
          END IF
        END DO (Ranges)
      END DO (Azimuths)
    END DO (Tilts)
```

SMOOTH REFLECTIVITY DATA

```
2  IF (FLAG (Filter Output) = True)
     THEN
       COMPUTE (Range to THRESHOLD (Filter - Cross Range)
2.1    DO FOR ALL Ranges from 1 + (THRESHOLD (Filter - Number
       Range Gates) to maximum Range - THRESHOLD (Filter -
       Number Range Gates)
2.1.1    DO FOR ALL Azimuths (Whole Degrees)
           COMPUTE Composite Reflectivity Median (Azimuth
           (Whole Degrees), Range)
           COMPUTE Layer Composite Median (Azimuth (Whole
           Degrees), Range)
         END DO
       END DO
2.2    DO FOR ALL Ranges from 1 + (THRESHOLD (Filter - Number
       Range Gates) to maximum Range - THRESHOLD (Filter -
       Number Range Gates)
2.2.1    DO FOR ALL Azimuths (Whole Degrees)
           REPLACE Composite Reflectivity (Azimuth (Whole
           Degrees), Range) with Composite Reflectivity Median
           (Azimuth (Whole Degrees), Range)
           REPLACE Layer Composite (Azimuth (Whole Degrees),
           Range) with Layer Composite Median (Azimuth (Whole
           Degrees), Range)
         END DO
       END DO
   END IF
```

REMAP POLAR ARRAYS TO RECTANGULAR GRIDS

```
3  DO FOR ALL Azimuths (Whole Degrees)
3.1  DO FOR ALL Ranges
       COMPUTE Rectangular Grid coordinates (X, Y)
3.1.1  IF (Composite Reflectivity (Azimuth (Whole Degrees),
       Range) greater than Composite Reflectivity Grid (X, Y)
          THEN
             SET Composite Reflectivity Grid (X, Y) = Composite
             Reflectivity (Azimuth (Whole Degrees), Range))
       END IF
3.1.2  IF (Layer Composite (Azimuth (Whole Degrees), Range)
       greater than Layer Composite Grid (X, Y)
          THEN
             SET Layer Composite Grid (X, Y) = Layer Composite
             (Azimuth (Whole Degrees), Range))
       END IF
     END DO
  END DO

END ALGORITHM  (CLUTTER REMOVAL)
```

3.2 COMPUTATION

3.2.1 NOTATION

R_{LL} = Range to top of Low altitude Layer. In kilometers.

Ht_{LL} = LAYER COMPOSITE (Low Level - Height). In meters.

Ht_R = Height (MSL) of radar. In meters.

ER_E = Effective Earth radius (1.21 * 6371 km). In tenths of a kilometer.

N = Elevation angle. In tenths of a degree.

R_{min} = Range - THRESHOLD (Extend Range Gates). In kilometers.

R_{max} = Range + THRESHOLD (Extend Range Gates). In kilometers.

2_W = Azimuth (Whole Degrees).

Note: Precision will be units specified unless otherwise stated

3.2.2 SYMBOLIC FORMULAS

<u>COMPUTE</u> Range Limits

For Region 1 - OMIT ALL.
   Minimum Range = 1 kilometers
   Maximum Range = THRESHOLD (Range - OMIT ALL)

For Region 2 - ACCEPT IF
Minimum Range = THRESHOLD (Range - OMIT ALL)
Maximum Range = THRESHOLD (Range - ACCEPT IF)

For Region 3 - REJECT IF
Minimum Range = THRESHOLD (Range - ACCEPT IF)
Maximum Range = THRESHOLD (Range - REJECT IF)

<u>COMPUTE</u> Range to top of Low altitude Layer

$$R_{LL} = ER_E \times \left(\sqrt{(\sin f \times \sin f) + \left((Ht_{LL} - Ht_R) \times \frac{2}{ER_E} \right)} - \sin f \right)$$

Where:

R_{LL} = Range to top of Low altitude Layer
Ht_{LL} = LAYER COMPOSITE (Low Level - Height)
Ht_R = Height (MSL) of radar
ER_E = Effective Earth radius (1.21 * 6371 km)
N = Elevation angle

Note, this logic is based on the RPG B5 Specifications, section 3.2.3.2.3 <u>Meteorological Algorithms</u>.

<u>COMPUTE</u> Azimuth (Whole Degrees)

Azimuth (Whole Degrees)	=	Nearest whole integer of Base Data Azimuth

<u>COMPUTE</u> FLAG (Weather_Bin)

FLAG (Weather_Bin)	=	True <u>IF</u> both the following statements are true:

1) At least one of the four Doppler data (Range) bins contains a velocity value greater than or equal to THRESHOLD (Velocity - Weather) <u>OR</u> a spectrum width value greater than or equal to THRESHOLD (Spectrum Width - Weather)

2) None of the four Doppler data (Range) bins contains both a velocity value less than THRESHOLD (Velocity - Clutter) <u>AND</u> a spectrum width value less than THRESHOLD (Spectrum Width - Clutter)

<u>COMPUTE</u> FLAG (Clutter_Bin)

FLAG (Clutter_Bin)	=	True IF at least one of the four Doppler data (Range) bins contains both a velocity value less than THRESHOLD (Velocity - Clutter) AND a spectrum width value less than THRESHOLD (Spectrum Width - Clutter)

COMPUTE Reflectivity Difference

Reflectivity Difference	=	Absolute Value (Reflectivity data (Range) - Reflectivity data (Extended Range))

COMPUTE Range to THRESHOLD (Filter - Cross Range)

Range to THRESHOLD (Filter - Cross Range)	=	THRESHOLD (Filter - Cross Range) divided by the sine of 1 degree.

COMPUTE Composite Reflectivity Median (Azimuth (Whole Degrees), Range)

Composite Reflectivity Median	=	Median value of an Array of Composite Reflectivity values centered at (Azimuth (Whole Degrees), Range).

The Median value is computed as follows:

1) The Array is defined:

```
DO FOR ALL Ranges = R_min to R_max
   IF (Range less than or equal to Range to THRESHOLD
   (Filter - Cross Range)
      THEN
         DO FOR AzAngle = 2_w - 1 to 2_w + 1
            ASSIGN value of Composite Reflectivity
            (AzAngle, Range) to Array
         END DO
   ELSE
      ASSIGN value of Composite Reflectivity (2_w, Range)
      to Array
   END IF
END DO
```

Where:
R_{min} = Range - THRESHOLD (Extend Range Gates)
R_{max} = Range + THRESHOLD (Extend Range Gates)
2_w = Azimuth (Whole Degrees)

2) The Array is sorted by Reflectivity data value.

3) The Median value is defined to be the middle value of the sorted Array.

<u>COMPUTE</u> Layer Reflectivity Median (Azimuth (Whole Degrees, Range))

Layer Reflectivity Median	=	Median value of an Array of Layer Reflectivity values centered at Azimuth (Whole Degrees, Range). The Median value is computed as described in the three steps in the previous <u>COMPUTE</u>, except using the Layer Reflectivity (Az, Range) values.

<u>COMPUTE</u> Rectangular Grid coordinates (X, Y)

$$X = Range \times \sin q_W / Grid\_Size$$

and

$$Y = Range \times \cos q_W / Grid\_Size$$

Where;

2_W = Azimuth (Whole Degrees)

X and Y are integers where:

X is positive for Azimuth > 0 and Azimuth < 180 degrees and

Y is negative for Azimuth > 90 and Azimuth < 270 degrees.

4.0 OUTPUTS

4.1 IDENTIFICATION

The Composite Reflectivity Grid and Layer Composite Grid are output as products.

4.2 DISTRIBUTION

To Principal User Processors (PUPs) and other users.

5.0 INFERENCES

5.1 LIMITATIONS

The techniques used in this algorithm to identify Clutter contamination are rudimentary and may be based on assumptions of range and Doppler data characteristics that do not accurately or precisely identify Clutter contamination. It is possible that valid precipitation echoes may be removed and that regions of the resulting Reflectivity data fields may be contaminated by residual Clutter.

The products generated by this algorithm were designed primarily for use Air Traffic Control personnel.

5.2 FUTURE DEVELOPMENTS

Enhanced Clutter identification techniques are expected to become operational in the near future based on work at the National Center for Atmospheric Research (among others). These should be applied to improve the Composite Reflectivity products.

It is expected that the WSR-88D will be modified to produce polarimetric radar data within the next several years. Polarimetric data offers significantly improved capability to remove Clutter contamination from weather radar data.