STORM CELL CENTROIDS

ALGORITHM DESCRIPTION

NX-DR-Ø3-Ø37/Ø1

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

This algorithm identifies convective storm cells (or cells) by grouping cell segments (or segments) into components; computing the components' attributes; vertically correlating the components into cells; and computing the cells' attributes. A segment is a radial sequence of significant reflectivities; component is a two dimensional area of significant reflectivity; and a centroid is the mass weighted center of a three dimensional region of significant reflectivity. One large difference between this algorithm and the STORM CENTROIDS [ØØ5] algorithm is that instead of defining the volume of convective storms, this algorithm identifies the individual high reflectivity cores or cells within convective storms.

First, to identify cells, the algorithm combines radially overlapping and azimuthally adjacent radial segments (from the STORM CELL SEGMENTS [Ø36] algorithm) into two dimensional potential components. Since there are multiple reflectivity thresholds used to find segments, only segments found on the same elevation scan with the same specified reflectivity threshold are combined. A potential component which has at least a specified number of segments and areal extent becomes a component.

Next, a search is done for overlapping components of different reflectivity thresholds on the same elevation scan. If the center of a component found with a higher reflectivity threshold falls within the boundaries of another component, the component found with the higher reflectivity threshold is saved, and the other is discarded. In addition, the components on each elevation scan are sorted by decreasing mass.

Then the components are vertically correlated; when components are correlated, they are assigned to the same cell. The centers of mass of the components at adjacent elevation scans (starting at the lowest) are compared for proximity with respect to the x and y plane. For each component, the distance from the center of every component in the next highest elevation scan is compared until a component is found within a specified search radius. Since the components at each elevation scan are sorted by decreasing mass, the components with the largest masses will be compared first. If no match is found for a component, then the search radius is increased, and the comparison is done again. The comparison may be done up to three times with increasing search radii. If at least two components (on adjacent elevation scans) are vertically correlated, a cell is created, and its centroid and attributes are calculated.

If two cells' centroids are within spacial proximity, the cells are merged. To merge two cells, their centroids must be within a specified horizontal distance, and their bases and tops must be within a specified vertical and angular separation. When merging two cells, one cell's components are added to the other cell, and a new centroid is calculated.

The components (which compose the cells) are saved along with the following attributes: the elevation angle, mass weighted center (in

Cartesian (x and y) and polar coordinates (azimuth and range)), height (AGL), mass, maximum reflectivity, and reflectivity threshold. In addition, the following cell attributes are calculated: centroid (in Cartesian (x and y) and polar coordinates (azimuth and range)), height, maximum reflectivity, height of the maximum reflectivity, top, base, vertically integrated liquid (VIL), and number of components.

Next, to reduce the crowding, cells which are still within spacial proximity are deleted. If two cells are still within a specified horizontal distance and the difference in their cell depths is greater than a specified threshold, then the cell with the lesser Cell-based VIL is deleted.

Finally, the remaining cells are sorted by Cell-based VIL and secondly maximum reflectivity. The cells and components and their attributes are used as inputs to the HAIL CORE ALOFT [Ø35], STORM CELL TRACKING [Ø38], and STORM POSITION FORECAST [ØØ8] algorithms.

1.2 SOURCE

The STORM CELL CENTROIDs algorithm has been implemented as part of the Storm Cell Identification and Tracking (SCIT) algorithm by the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma (Johnson, 1994). The other parts of the SCIT algorithm are documented in the STORM CELL SEGMENTS [Ø35], STORM CELL TRACKING [Ø38], and STORM POSITION FORECAST [ØØ8](Version 26) algorithm descriptions.

REFERENCES

Johnson, J. T., 1994: Enhanced WSR-88D Storm Cell Identification and Tracking Algorithm - Final Documentation Report, NSSL, Norman, OK.

NEXRAD Algorithm Report, 1985: STORM CENTROID ALGORITHM DESCRIPTION [ØØ5/45], The NEXRAD Joint Systems Program Office (JSPO).

Witt, A., 1994: The NSSL Hail Detection Algorithm - Initial Documentation Report, NSSL, Norman, OK.

1.3 PROCESSING ENVIRONMENT

This algorithm is run each volume scan. For input, this algorithm requires segments from the STORM CELL SEGMENTS [Ø36] algorithm from each elevation scan. The STORM CELL CENTROIDS [Ø37] algorithm provides cell data to the HAIL CORE ALOFT [Ø35], STORM CELL TRACKING [Ø38], and STORM POSITION FORECAST [ØØ8] algorithms.

The algorithm's statistical performance was evaluated while running as part of the SCIT Algorithm. The SCIT algorithm identifies individual cells within a convective storm instead of the entire storm (Johnson, 1994).

The Storm Cell Centroids algorithm was developed for use on a Weather Surveillance Radar - 1988 Doppler (WSR-88D). The SCIT algorithm was developed and tested on NSSL's Radar Analysis and Display Software (RADS) on a 32 bit UNIX based SUN Workstation which ingests live (wideband) or archived (Level II) radial data from a WSR-88D.

2.0 INPUTS

2.1 IDENTIFICATION

average DELTA AZIMUTH (Elevation)		The average angular width of the radials in the ELEVATION scan, in degrees.
AZIMUTH(Segment)	=	The azimuthal position of a CELL SEGMENT, in degrees.
BEAM WIDTH	=	The angular distance between half-power points on either side of the center of the radar beam, in degrees.
beginning RANGE (Segment)	=	The slant range to the beginning (the front of the first sample volume) of a CELL SEGMENT, in km.
CELL SEGMENT	=	A contiguous run of SAMPLE VOLUMES along a radial with reflectivity values above one of multiple reflectivity thresholds with the following attributes: AZIMUTH, beginning RANGE, ELEVATION angle, ending RANGE, MASS WEIGHTED LENGTH, MASS WEIGHTED LENGTH SQUARED, maximum REFLECTIVITY FACTOR, and THRESHOLD (Reflectivity).
ELEVATION	=	Angle of the elevation scan, in degrees.
ending RANGE (Segment)	=	The slant range to the end (the back of the last sample volume) of a CELL SEGMENT, in km.
MASS WEIGHTED LENGTH(Segment)	=	The mass density weighted length of a CELL SEGMENT, in kg/km^2.
MASS WEIGHTED LENGTH SQUARED(Segment)	=	The mass density weighted length squared of a CELL SEGMENT, in kg/km.
maximum REFLECTIVITY FACTOR(Segment)	=	The maximum (average) reflectivity factor of a CELL SEGMENT, in dBZe.
NUMBER OF SEGMENTS	=	The number of CELL SEGMENTS identified on each ELEVATION and THRESHOLD (Reflectivity).
RANGE SAMPLE SPACING	=	The difference in slant range between two adjacent SAMPLE VOLUMEs along a radial, i.e. the length of a SAMPLE VOLUME (1), in km.

THRESHOLD (Azimuthal Separation)	=	The maximum azimuthal separation required for assigning CELL SEGMENTS into the same COMPONENT (1.5), in degrees.
THRESHOLDS (Component Area)	=	A set of required minimum areas for a COMPONENT. There is an area threshold for each reflectivity threshold used to find CELL SEGMENTs (10), in km^2.
THRESHOLD (Depth Delete)	=	The maximum difference in the depths of two STORM CELLs required to delete one of the STORM CELLs (4), in km.
THRESHOLD (Elevation Merge)	=	The maximum difference in the elevation angles between the top of one STORM CELL and the bottom of another STORM CELL required to merge the STORM CELLs (3.0), in degrees.
THRESHOLD (Height Merge)	=	The maximum difference in the height between the top of one STORM CELL and the bottom of another STORM CELL required to merge the STORM CELLs (4), in km.
THRESHOLD (Horizontal Delete)	=	The maximum horizontal distance between two centroids required to delete one of the STORM CELLs (5), in km.
THRESHOLD (Horizontal Merge)	=	The maximum horizontal distance between two centroids required to merge the STORM CELLs (10), in km.
THRESHOLD (NUMBER OF SEGMENTS)	=	The minimum number of CELL SEGMENTs required in a COMPONENT (2).
THRESHOLDS (Reflectivity)	=	A set of minimum effective reflectivities used to find CELL SEGMENTs and COMPONENTs and ordered from largest to smallest (6Ø, 55, 5Ø, 45, 4Ø, 35, 3Ø), in dBZe. The reflectivity factors of the sample volumes in a CELL SEGMENT must meet or exceed the same THRESHOLD (Reflectivity). And only CELL SEGMENTs which have been found using the same THRESHOLD (Reflectivity) can be assigned to the same COMPONENT.

THRESHOLDS (Search Radii)	=	A set of distances away from a COMPONENT's mass weighted center which a search is made for another COMPONENT's mass weighted center on the next elevation scan with which to correlate (5, 7.5, 10), in km.
THRESHOLD (Segment Overlap)	=	The minimum slant range overlap required for assigning CELL SEGMENTs to the same component (1.95), in km.

2.2 ACQUISITION

The algorithm inputs CELL SEGMENTs from the STORM CELL SEGMENTS [Ø35] algorithm. For each CELL SEGMENT the following attributes are also input: the beginning RANGE, ending RANGE, maximum REFLECTIVITY FACTOR, MASS WEIGHTED LENGTH, MASS WEIGHTED LENGTH SQUARED, ELEVATION, and AZIMUTH. In addition, for each elevation, the STORM CELL SEGMENTS [Ø35] algorithm supplies the average DELTA AZIMUTH and the NUMBER OF SEGMENTs found with each reflectivity threshold.

The RANGE SAMPLE SPACING and BEAM WIDTH are radar system parameters. All other thresholds, coefficients, and exponents are supplied as adaptable parameters whose values have been based on theoretical and empirical studies (See Adaptable Parameter Table Appendix C) and are adjustable at the UCP.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM CELL CENTROIDS)

1.0  DO FOR ALL (ELEVATIONs)
     1.1  DO FOR ALL (THRESHOLDS (Reflectivity))
     1.1.1   DO FOR ALL (CELL SEGMENTS(Reflectivity
                Threshold) not yet assigned to a Potential
                Component(Reflectivity Threshold))
     1.1.1.1 DO WHILE (CELL SEGMENT(Reflectivity Threshold)
                   is not assigned to a Potential Component
                   (Reflectivity Threshold))
                   DO FOR ALL (CELL SEGMENTS(Reflectivity
                      Threshold) assigned to any Potential
                      Component(Reflectivity Threshold))
                      COMPUTE (SEGMENT RANGE OVERLAP)
                      COMPUTE (AZIMUTHAL SEPARATION)
                      IF ((AZIMUTHAL SEPARATION) is less than
                         or equal to THRESHOLD (Azimuthal Separation))
                         AND (SEGMENT RANGE OVERLAP is greater than or
                         equal to THRESHOLD (Segment Overlap))
                         THEN
                            COMPUTE (NUMBER OF SEGMENTS
                               (Component))
                            Assign the unassigned CELL SEGMENT
                               to the same Potential Component
                               (Reflectivity Threshold) as the assigned
                               CELL SEGMENT
                      ENDIF
                   END DO
                   COMPUTE (NUMBER OF SEGMENTS(Component))
                   Start a new Potential Component
                      (Reflectivity Threshold) and assign the CELL
                      SEGMENT to it
                END DO
             END DO
     1.1.2   DO FOR ALL (Potential Components(Reflectivity
                Threshold))
                COMPUTE (AREA(Component))
                IF ((AREA(Component) is greater than or equal
                   to THRESHOLD (Component Area)) AND (NUMBER OF
                   SEGMENTS(Component) is greater than or equal to
                   THRESHOLD (NUMBER OF SEGMENTS)))
                   THEN
                      Label Potential Component as a Component
                      Increment the NUMBER OF COMPONENTS
                         (Elevation)
                      DO FOR ALL (CELL SEGMENTS(Component))
                         COMPUTE (beginning RANGE(Component))
```

```
                COMPUTE (ending RANGE(Component))
                COMPUTE (beginning AZIMUTH(Component))
                COMPUTE (ending AZIMUTH(Component))
                COMPUTE (maximum REFLECTIVITY FACTOR
                   (Component))
             END DO
             COMPUTE (MASS(Component))
             COMPUTE (X-POSITION(Component))
             COMPUTE (Y-POSITION(Component))
             COMPUTE (RANGE(Component))
             COMPUTE (AZIMUTH(Component))
             COMPUTE (HEIGHT(Component))
       ENDIF
    END DO
1.1.3   IF (THRESHOLD (Reflectivity) is not the first))
       THEN
          DO FOR ALL (COMPONENTs(Reflectivity
             Threshold))
             DO WHILE (COMPONENT OVERLAP is false)
                DO FOR ALL (COMPONENTs at all previous
                   THRESHOLDs (Reflectivity))
                   COMPUTE (COMPONENT OVERLAP)
                END DO
             END DO
             IF (COMPONENT OVERLAP is true)
                THEN
                   Discard the COMPONENT with the
                      lesser THRESHOLD (Reflectivity)
                   Decrement the NUMBER OF COMPONENTS
                      (Elevation)
                   Reset COMPONENT OVERLAP to false
             END IF
          END DO
    END IF
 END DO
 Sort by MASS(Component)
END DO
2.0  DO FOR ALL (ELEVATIONs except the highest)
        DO FOR ALL (THRESHOLD (Search Radii))
           DO FOR ALL (COMPONENTs(ELEVATION))
              DO UNTIL (COMPONENT(ELEVATION) is correlated
                 with a COMPONENT(next ELEVATION))
                 DO FOR ALL (uncorrelated COMPONENTs(next
                    ELEVATION))
                    COMPUTE (COMPONENT DISTANCE DIFFERENCE)
                    IF (COMPONENT DISTANCE DIFFERENCE is
                       less than or equal to THRESHOLD (Search
                       Radius))
                       THEN
                          COMPUTE (NUMBER OF COMPONENTS(Storm
                             Cell))
```

```
                              IF (COMPONENT(ELEVATION) is not
                                 already correlated into a STORM CELL
                                 with other COMPONENTs)
                                 THEN
                                    Identify new STORM CELL
                                    Increment the NUMBER OF STORM
                                       CELLS
                              END IF
                              Correlate COMPONENT(next ELEVATION)
                                 with COMPONENT(ELEVATION)
                        END IF
                     END DO
                  END DO
               END DO
            END DO
     END DO
3.0  DO FOR ALL (STORM CELLs)
          COMPUTE (MASS(Storm Cell))
          COMPUTE (X-POSITION(Storm Cell))
          COMPUTE (Y-POSITION(Storm Cell))
          COMPUTE (BASE(Storm Cell))
          COMPUTE (TOP(Storm Cell))
     END DO
4.0  DO FOR ALL (STORM CELLs)
          DO FOR ALL (remaining STORM CELLs which have not
             been checked for mergers)
             COMPUTE (CENTROID DISTANCE DIFFERENCE)
             COMPUTE (ELEVATION DIFFERENCE)
             COMPUTE (HEIGHT DIFFERENCE)
             IF ((CENTROID DISTANCE DIFFERENCE is less
                than or equal to THRESHOLD (Horizontal Merge)) AND
                (ELEVATION DIFFERENCE is greater than zero) AND (HEIGHT
                DIFFERENCE is greater than zero) AND ((ELEVATION
                DIFFERENCE is less than or equal to THRESHOLD
                (Elevation Merge)) OR (HEIGHT DIFFERENCE is less than
                or equal to THRESHOLD (Height Merge))))
                THEN
                   Decrement the NUMBER OF STORM CELLS
                   Merge the STORM CELLS by moving the
                      COMPONENTs into one STORM CELL, adding the NUMBER
                      OF COMPONENTS(Storm Cell) from one STORM CELL to
                      the other STORM CELL, and deleting the other
                      STORM CELL.
             END IF
          END DO
          IF (STORM CELLS were Merged)
             THEN
                COMPUTE (MASS(Storm Cell))
                COMPUTE (X-POSITION(Storm Cell))
                COMPUTE (Y-POSITION(Storm Cell))
                COMPUTE (BASE(Storm Cell))
```

```
            COMPUTE (TOP(Storm Cell))
      END IF
      COMPUTE (RANGE(Storm Cell))
      COMPUTE (AZIMUTH(Storm Cell))
      COMPUTE (HEIGHT(Storm Cell))
      COMPUTE (VERTICALLY INTEGRATED LIQUID(Storm Cell))
      COMPUTE (DEPTH)
      DO FOR ALL (COMPONENTS(Storm Cell)
         COMPUTE (maximum REFLECTIVITY(Storm Cell))
         COMPUTE (HEIGHT maximum REFLECTIVITY(Storm
            Cell))
      END DO
   END DO
5.0   DO FOR ALL (STORM CELLs)
      DO WHILE (STORM CELL is not deleted)
         DO FOR ALL (remaining STORM CELLs which have not
            been checked for deletion)
            COMPUTE (CENTROID DISTANCE DIFFERENCE)
            IF (CENTROID DISTANCE DIFFERENCE is less than
               or equal to THRESHOLD (Horizontal Delete))
               THEN
                  Decrement the NUMBER OF STORM CELLS
                  Delete the STORM CELL and its COMPONENTS
                     with the smallest VERTICALLY INTEGRATED
                     LIQUID.
            END IF
            COMPUTE (DEPTH DIFFERENCE)
            IF ((CENTROID DISTANCE DIFFERENCE is less than
               or equal to twice the THRESHOLD (Horizontal Delete))
               AND (DEPTH DIFFERENCE is greater than THRESHOLD
               (Depth Delete)))
               THEN
                  Decrement the NUMBER OF STORM CELLS
                  Delete the STORM CELL and its COMPONENTS
                     with the smallest DEPTH.
            END IF
         END DO
      END DO
   END DO
6.0   DO FOR ALL (STORM CELLs)
      Sort by VERTICALLY INTEGRATED LIQUID(Storm Cell) -
         if two STORM CELLs have equal VERTICALLY INTEGRATED
         LIQUID(Storm Cell) then first select the STORM CELL with
         the greater maximum REFLECTIVITY(Storm Cell)
      WRITE (STORM CELLs)
      WRITE (X-POSITION(Storm Cell))
      WRITE (Y-POSITION(Storm Cell))
      WRITE (BASE(Storm Cell))
      WRITE (TOP(Storm Cell))
      WRITE (RANGE(Storm Cell))
      WRITE (AZIMUTH(Storm Cell))
```

```
            WRITE (HEIGHT(Storm Cell))
            WRITE (VERTICALLY INTEGRATED LIQUID(Storm Cell))
            WRITE (maximum REFLECTIVITY(Storm Cell))
            WRITE (HEIGHT maximum REFLECTIVITY(Storm Cell))
            WRITE (NUMBER OF COMPONENTS(Storm Cell))
            DO FOR ALL (COMPONENTS(Storm Cell)
               WRITE (COMPONENTs)
               WRITE (maximum REFLECTIVITY FACTOR(Component))
               WRITE (HEIGHT(Component))
               WRITE (ELEVATION(Component))
               WRITE (X-POSITION(Component))
               WRITE (Y-POSITION(Component))
               WRITE (RANGE(Component))
               WRITE (AZIMUTH(Component))
            END DO
        END DO
        WRITE (NUMBER OF STORM CELLS)

    END ALGORITHM (STORM CELL CENTROIDS)
```

3.2 COMPUTATION

3.2.1 NOTATION

A	=	The AREA(Component), the area of a COMPONENT, in km^2.
AC	=	The AZIMUTH(Component), the azimuth of the mass weighted center of a COMPONENT, in degrees.
ACbeg	=	The beginning AZIMUTH(Component), the most counterclockwise extent of a COMPONENT, in degrees.
ACend	=	The ending AZIMUTH(Component), the most clockwise extent of a COMPONENT, in degrees.
AS	=	The AZIMUTH(Storm Cell), the azimuth of the centroid (or mass weighted center) of a STORM CELL, in degrees.
AZ_SEP	=	The AZIMUTHAL SEPARATION, the angular difference between a CELL SEGMENT assigned to a Potential Component and an unassigned CELL SEGMENT, in degrees.
BASE	=	The BASE(Storm Cell), the HEIGHT of the lowest COMPONENT in a STORM CELL, in km.
BW	=	The BEAM WIDTH, the angular distance between half-power points on either side of the center of the radar beam (1.0), in degrees.
CSAZ	=	The AZIMUTH(Segment) of a CELL SEGMENT assigned to a Potential Component, in degrees.
CSRbeg	=	The beginning RANGE(Segment) of a CELL SEGMENT assigned to a Potential Component, in km.
CSRend	=	The ending RANGE(Segment) of a CELL SEGMENT assigned to a Potential Component, in km.
DBZECmax	=	The maximum REFLECTIVITY FACTOR(Component), the maximum reflectivity factor in a COMPONENT, in dBZe.
DBZESmax	=	The maximum REFLECTIVITY FACTOR(Segment), the maximum (average) reflectivity factor in a segment assigned to a COMPONENT, in dBZe.
DD	=	The DEPTH DIFFERENCE, the magnitude of the difference in the depths of two STORM CELLs from TOP to BASE, in km.

DD_C	=	The COMPONENT DISTANCE DIFFERENCE, the horizontal distance between the mass weighted centers of two COMPONENTs, in km.
DD_SC	=	The CENTROID DISTANCE DIFFERENCE, the horizontal distance between the centroids (or mass weighted centers) of two STORM CELLs, in km.
DELAZavg	=	The average DELTA AZIMUTH, the average difference in horizontal azimuthal position of the adjacent radials on the ELEVATION scan, in degrees.
DP	=	The DEPTH, the difference in height from TOP to BASE of a STORM CELL, in km.
ED	=	The ELEVATION DIFFERENCE, the difference in ELEVATION angle between the top of one STORM CELL and the base of another STORM CELL, in degrees.
EL	=	The elevation angle of an ELEVATION scan, in degrees.
H_Zmax	=	The HEIGHT maximum REFLECTIVITY(Storm Cell), the height above ground (of the mass weighted center) of the maximum maximum REFLECTIVITY FACTOR(Component) in the STORM CELL, in km.
HC	=	The HEIGHT(Component), the height above ground (of the mass weighted center) of a COMPONENT, in km.
HD	=	The HEIGHT DIFFERENCE, the difference in height between the TOP of one STORM CELL and the BASE of another STORM CELL, in km.
HSC	=	The HEIGHT(Storm Cell), the height above ground of a centroid (or the mass weighted center) of a STORM CELL, in km.
i	=	An index for the ELEVATION scans in a volume scan.
IR	=	The index of refraction, or the factor by which Earth's radius is multiplied to account for the refraction of the radar beam in a standard atmosphere (1.21).
j	=	An index for CELL SEGMENTS within a COMPONENT; for each COMPONENT this index goes from 1 to the NUMBER OF SEGMENTS(Component).
k	=	An index for COMPONENTs; for each STORM CELL the index goes from 1 to the NUMBER OF COMPONENTS(Storm Cell).

m = An index for STORM CELLs.

MC = The MASS(Component), the mass weighted area of a COMPONENT, in gigagrams/km.

MWL = The MASS WEIGHTED LENGTH(Segment), the mass density weighted length of a CELL SEGMENT, in kg/km^2.

MWLS = The MASS WEIGHTED LENGTH SQUARED(Segment), the mass density weighted length squared of a SEGMENT, in kg/km.

MSV = The MASS(Storm Cell), the mass weighted volume of a STORM CELL, in gigagrams.

NS = The NUMBER OF SEGMENTS(Component), the number of CELL SEGMENTS assigned to each COMPONENT.

NSC = The NUMBER OF COMPONENTS(Storm Cell), the number of COMPONENTs assigned to each STORM CELL.

PI = A mathematical constant (3.1416), unitless.

r = An index for COMPONENTs at any previous (or higher) THRESHOLD (Reflectivity).

RC = The RANGE(Component), the slant range of the mass weighted center of a COMPONENT, in km.

RCbeg = The beginning RANGE(Component), the (flat earth projected) range of the closest part of a COMPONENT (to the radar), in km.

RCend = The ending RANGE(Component), the slant range of the farthest part of a COMPONENT (from the radar), in km.

RE = The radius of the Earth (6371), in km.

RO = The SEGMENT RANGE OVERLAP, the slant range overlap of two CELL SEGMENTs, in km.

RS = The RANGE(Storm Cell), the (flat earth projected) range of the centroid (or mass weighted center) of a STORM CELL, in km.

RSbeg = The beginning RANGE(Segment), the RANGE(Slant) to the front (closest to the radar) of the first sample volume of a CELL SEGMENT, in km.

RSend	=	The ending RANGE(Segment), the RANGE(Slant) to the back of the last sample volume of a CELL SEGMENT, in km.
s	=	An index for COMPONENTs of the same THRESHOLD (Reflectivity).
SAZ	=	The AZIMUTH(Segment), the azimuth of an unassigned CELL SEGMENT, in degrees.
SVL	=	The RANGE SAMPLE SPACING, the length (in slant range) of a SAMPLE VOLUME, in km.
TOP	=	The TOP(Storm Cell), the HEIGHT of the highest COMPONENT in a STORM CELL, in km.
VIL	=	The VERTICALLY INTEGRATED LIQUID(Storm Cell), the VIL of a STORM CELL as defined by its COMPONENTs' maximum REFLECTIVITY FACTORs, in kg/m^2.
XC	=	The X-POSITION(Component), the (flat earth projected) x-coordinate of the mass weighted center of a COMPONENT, in km.
XSC	=	The X-POSITION(Storm Cell), the (flat earth projected) x-coordinate of the centroid (or mass weighted center) of a STORM CELL, in km.
YC	=	The Y-POSITION(Component), the (flat earth projected) y-coordinate of the mass weighted center of a COMPONENT, in km.
YSC	=	The Y-POSITION(Storm Cell), the (flat earth projected) y-coordinate of the centroid (or mass weighted center) of a STORM CELL, in km.
Zmax	=	The maximum REFLECTIVITY(Storm Cell), the maximum maximum REFLECTIVITY FACTOR (Component) of the COMPONENTs in a STORM CELL, in km.

3.2.2 SYMBOLIC FORMULAS

<u>COMPUTE</u> (SEGMENT RANGE OVERLAP)

```
IF (RSbeg ≥ CSRbeg)
  THEN
    R1 = RSbeg
ELSE
    R1 = CSRbeg
END IF

IF (RSend ≤ CSRend)
  THEN
    R2 = RSend
ELSE
    R2 = CSRend
END IF

RO = R2 - R1
```

<u>COMPUTE</u> (AZIMUTHAL SEPARATION)

AZ_SEP = ABS(SAZ - CSAZ),

if AZ_SEP > 180, then AZ_SEP = 360 - AZ_SEP

where ABS is the absolute value function

<u>COMPUTE</u> (NUMBER OF SEGMENTS(Component))

$NS_k = NS_k + 1$

if k is a new COMPONENT, $NS_k = 1$

<u>COMPUTE</u> (AREA(Component))

$$A_k = \sum_j \left[PI[(RSend_j)^2 - (RSbeg_j)^2]*DELAZavg_i/360 \right]$$

<u>COMPUTE</u> (beginning RANGE(Component))

$RCbeg_k = RSbeg_j$ if $RSbeg_j < RCbeg_k$

COMPUTE (ending RANGE(Component))

$RCend_k = RSend_j$ if $RSend_j > RCend_k$

COMPUTE (beginning AZIMUTH(Component))

$ACbeg_k = SAZ_j$ if $SAZ_j < ACbeg_k$

If the component crosses zero degrees, $ACbeg_k$ is the azimuth of the most counter-clockwise segment.

COMPUTE (ending AZIMUTH(Component))

$ACend_k = SAZ_j$ if $SAZ_j > ACend_k$

If the component crosses zero degrees, $ACend_k$ is the azimuth of the most clockwise segment.

COMPUTE (maximum REFLECTIVITY FACTOR(Component))

$DBZECmax_k = DBZESmax_j$ if $DBZESmax_j > DBZECmax_k$

COMPUTE (MASS(Component))

$$MC_k = \left[\sum_j (MWL_j)(SVL)(DELAZavg_i)(PI/180)\right] / 10^6$$

COMPUTE (X-POSITION(Component))

$$XC_k = \left[\sum_j SIN(CSAZ_j)(MWLS_j)(SVL)(DELAZavg_i)COS(EL)(PI/180)\right] / MC_k$$

where SIN and COS are the sine and cosine functions

COMPUTE (Y-POSITION(Component))

$$YC_k = \left[\sum_j COS(CSAZ_j)(MWLS_j)(SVL)(DELAZavg_i)COS(EL)(PI/180)\right] / MC_k$$

where COS is cosine function

COMPUTE (RANGE(Component))

$RC = (XC^2 + YC^2)^{½}$

COMPUTE (AZIMUTH(Component))

AC = ATAN2(XC,YC)(180/PI)

where ATAN2 is the arctangent function

if AC < 0, AC = AC + 360

COMPUTE (HEIGHT(Component))

$HC_k = SIN(EL_k)(RC) + RC^2/(2(IR)(RE))$

where SIN is the sine function

COMPUTE (COMPONENT OVERLAP)

```
IF ((ACs ≥ ACbegr) and (ACs ≤ ACendr) and
      (RCs ≥ RCbegr) and (RCs ≤ RCendr))
      THEN
           COMPONENT OVERLAP is true
ELSE IF (ACbegr > ACendr)(i.e. COMPONENT crosses zero degrees)
      THEN
           IF ((ACs ≥ ACbegr) or (ACs ≤ ACendr) and
                (RCs ≥ RCbegr) and (RCs ≤ RCendr))
                THEN
                   COMPONENT OVERLAP is true
           END IF
END IF
```

where r is an index for COMPONENTs at the current THRESHOLD (Reflectivity) and s is an index for COMPONENTs at any previous (or higher) THRESHOLD(Reflectivity)

COMPUTE (COMPONENT DISTANCE DIFFERENCE)

$DD\_C = [(XC_i - XC_{i+1})^2 + (YC_i - YC_{i+1})^2]^{½}$

COMPUTE (NUMBER OF COMPONENTS(Storm Cell))

$NSC_m = NSC_m + 1$

if m is a new STORM CELL, then $NSC_m = 2$

COMPUTE (MASS(Storm Cell))

$$MSV_m = \sum_k (MC_k)(DCH_k)$$

where DCH is defined as

```
IF (k = 1)
     THEN
          IF (i = 1)
             THEN
                DCH_k = (HC_k+1 + HC_k)/2
          ELSE
                DCH_k = ABS(HC_k+1 - HC_k)
          END IF
ELSE IF (k = NSC)
          DCH_k = ABS(HC_k - HC_k-1)
ELSE
          DCH_k = ABS((HC_k+1 - HC_k-1)/2)
END IF
```

COMPUTE (X-POSITION(Storm Cell))

$$XSC_m = \left[\sum_k (XC_k)(MC_k)(DCH_k)\right]/MSV_m$$

where DCH is defined above

COMPUTE (Y-POSITION(Storm Cell))

$$YSC_m = \left[\sum_k (YC_k)(MC_k)(DCH_k)\right]/MSV_m$$

where DCH is defined above

COMPUTE (BASE(Storm Cell))

$BASE_m = HC_1$

where 1 is the index of the first (or lowest) COMPONENT

COMPUTE (TOP(Storm Cell))

$TOP_m = HC_k$

where k is the index of the last (or highest) COMPONENT

If COMPONENT k is from the highest elevation angle in the volume scan, label TOP as unknown.

COMPUTE (CENTROID DISTANCE DIFFERENCE)

$DD\_SC = [(XSC_m - XSC_{m+1})^2 + (YSC_m - YSC_{m+1})^2]^{½}$

COMPUTE (ELEVATION DIFFERENCE)

IF ($EL_{m,1} > EL_{n,k}$)
THEN
$ED = EL_{m,1} - EL_{n,k}$
ELSE
$ED = EL_{n,1} - EL_{m,k}$
END IF

where m and n are indices of STORM CELLs, k is the index of the highest COMPONENT in a STORM CELL, and the first (or lowest) COMPONENT is COMPONENT 1

COMPUTE (HEIGHT DIFFERENCE)

IF ($BASE_m > TOP_n$)
THEN
$HD = BASE_m - TOP_n$
ELSE
$HD = BASE_n - TOP_m$
END IF

where m and n are indices of STORM CELLs

COMPUTE (RANGE(Storm Cell))

$RS = (XSC^2 + YSC^2)^{½}$

COMPUTE (AZIMUTH(Storm Cell))

AS = ATAN2(XSC,YSC)(180/PI)

where ATAN2 is the arctangent function

if AS < 0, AS = AS + 360

COMPUTE (HEIGHT(Storm Cell))

$$HSC_m = \left[\sum_k (HC_k)(MC_k)(DCH_k)\right]/MSV_m$$

where DCH is defined above

COMPUTE (VERTICALLY INTEGRATED LIQUID(Storm Cell))

$$VIL_m = \sum_k [(LW_k)(DB_k)$$

where DB is defined as

```
IF (ELk is lowest in the volume scan)
     THEN
          DB = (RCk)[TAN((ELk + ELk + 1)/2)] +
                 (RCk)^2/[2(IR)(RE)(COS((ELk + ELk + 1)/2)^2]
ELSE IF (ELk is highest in the volume scan)
          DB = (RCk)[TAN(ELk + BW/2) - TAN(ELk - 1)]/2
ELSE
          DB = (RCk)[TAN(ELk + 1) - TAN(ELk - 1)]/2
END IF
```

where TAN is the tangent function,

and LW is defined as

$LW_k = (0.00344)(LZE)^{(4/7)}$

where LZE is defined as

```
LZ = DBZECmaxk
IF (DBZECmaxk > 56)
     THEN
        LZ = 56
END IF
LZE = 10^(LZ/10)
```

COMPUTE (DEPTH)

DP = TOP - BASE

COMPUTE (maximum REFLECTIVITY(Storm Cell))

$Zmax = DBZECmax_k$ if $DBZECmax_k \geq Zmax$

COMPUTE (HEIGHT maximum REFLECTIVITY(Storm Cell))

$H\_Zmax = HC_k$ when $Zmax = DBZECmax_k$ at the highest COMPONENT

COMPUTE (DEPTH DIFFERENCE)

$DD = ABS[DP_m - DP_n]$

where ABS is the absolute value function

4.0 OUTPUTS

4.1 IDENTIFICATION

The output of this algorithm is STORM CELLs, their attributes, their COMPONENTs, their COMPONENTs' attributes, and the NUMBER OF STORM CELLs. For each STORM CELL, the algorithm outputs the following attributes: X-POSITION, Y-POSITION, BASE, TOP, RANGE, AZIMUTH, HEIGHT, VERTICALLY INTEGRATED LIQUID, maximum REFLECTIVITY, HEIGHT maximum REFLECTIVITY, and NUMBER OF COMPONENTS. For each COMPONENT the algorithm outputs the following attributes: maximum REFLECTIVITY FACTOR, HEIGHT, ELEVATION, X-POSITION, Y-POSITION, RANGE, and AZIMUTH.

4.2 DISTRIBUTION

The outputs of this algorithm are inputs to the HAIL CORE ALOFT [Ø35], STORM CELL TRACKING [Ø38], and STORM POSITION FORECAST [ØØ8](Version 26) algorithms. In addition, the outputs may be formatted for display.

5.0 INFERENCES

5.1 LIMITATIONS

At long ranges, only the lowest elevation scans of a volume scan will contain components. For example, at 120 nmi, the bottom of radar beam at 0.5 degree is already above 10 kft (AGL). Components must be found on at least two consecutive elevation scans to be considered a storm cell. Storm cells at long ranges may not have enough vertical extent to be detected at even two elevation scans, and, therefore, will not be identified.

If the STORM CELL SEGMENTS [Ø36] algorithm is contaminated with non-meteorological targets (e.g. anomalous propagation or clutter), this may lead to falsely identified storm cells or parts of storm cells.

Rarely problems may arise in the vertical correlation process which will lead to improper identification of cells and/or computation of their attributes. When several cells are clustered closely together, the algorithm may combine separate components on an elevation scan into one component. Also, the algorithm may either falsely split a cell into two or more cells or combine a group of cells into one cell.

The cell merging and deletion processes attempts to decrease the cluttered nature of cells. But deletion and merging of cells may decrease the performance of downstream algorithms using cell and component data.

Alternatively (as studied and developed by NSSL), this algorithm uses the Severe Hail Index (SHI) from the HAIL CORE ALOFT [Ø35] algorithm (instead of Cell-based VIL) to sort cells and in the cell deletion process (which reduces crowding).

5.2 FUTURE DEVELOPMENTS

Adaptable parameter studies should be done to optimize performance for different meteorological conditions and geographical locations. The ultimate goal is to optimize the algorithm for each climatological region and each storm type.

A technique has been developed to allow cells at long ranges to be defined from only one component. Currently a cell must be composed of at least two components on adjacent elevation scans. The intent of this requirement is to filter shallow areas of significant reflectivity which may be ground clutter or caused by anomalous propagation. This technique applies the premise that components at long ranges are fairly high in altitude; have significant vertical (beam) depth; and, therefore, are most likely are storm cells.

A major addition to the algorithm will be a predictive capability which will forecast the change in intensity of storm cells. In order to accomplish this, a mechanism must be developed to automatically provide outside sources of data (other than radar), e.g. satellite, sounding, and model data, in a timely manner to the algorithm.