STORM CELL TRACKING

ALGORITHM DESCRIPTION

NX-DR-Ø3-Ø38/Ø1

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The STORM CELL TRACKING algorithm monitors the movement of storm cells by matching storms found in the current volume scan to the storm cells from the previous volume scan in time and space, through the use of a correlation table. The storm cells are matched as follows. Starting with the most intense cell (i.e. largest cell-based VIL value) in the current volume scan, the centroid position is compared to the projected centroid positions of cells from the previous volume scan. A cell's projected centroid position is it's forecasted position for the current volume scan. The cell from the previous volume scan which is correlated is the cell with a projected centroid located within an adaptable range which is closest to the current cell. When a cell is correlated, it is considered the same cell and assigned the same storm cell ID. Then the next most intense cell in the current volume scan is compared to all uncorrelated cells in the previous volume scan, and so on until all cells in the current volume scan are processed. Once a cell from the previous volume scan is correlated, it is not compared to any more cells in the current volume scan. If no projected centroid positions are within the adaptable range of a cell's centroid position, the cell remains uncorrelated and is assigned a new storm cell ID. If more than a specified amount of time has passed between subsequent volume scans, then no matching is done, and all storm cells in the current volume scan are considered new. The centroid positions used are in a Cartesian coordinate system with the radar at the origin, and where the X-axis denotes east-west directions and the Y-axis denotes north-south directions.

1.2 SOURCE

This 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 [Ø36], STORM CELL CENTROIDS [Ø37], and the STORM POSITION FORECAST [ØØ8] algorithm descriptions. The tracking portion of the SCIT was adapted from the STORM TRACKING [ØØ4] algorithm implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachusetts.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-T-80-0316, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

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

1.3 PROCESSING ENVIRONMENT

The STORM CELL TRACKING algorithm is run each volume scan as part of a storm cell movement prediction process. This algorithm needs data from a storm cell identification process giving locations of identified storm cells over a known period of time. An algorithm for such a process is described in the STORM CELL CENTROIDS [Ø37] algorithm description. To complete the prediction process, the STORM POSITION FORECAST [ØØ8] algorithm must be used.

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 Tracking algorithm was developed for use on the 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

CORRELATION (Speed)	=	Speed used to compute the CORRELATION (Distance), in km/hr.
CORRELATION (Table)	=	A data set used to keep track of the positions of correlated STORM CELLS.
DIRECTION (Storm Cell)	=	The direction from which a STORM CELL is moving, in degrees. Precise to 10^{-4} deg.
ID	=	A unique label from a circular list assigned to a STORM CELL throughout it's existence.
SPEED (Storm Cell)	=	Speed of a STORM CELL, in km/hr. Precise to 10^{-4} km/hr.
STORM CELL	=	A three-dimensional region composed of COMPONENTs characterized by reflectivity values above a given threshold, ordered by cell-based VIL .
TIME (Maximum)	=	The maximum allowed TIME BETWEEN VOLUME scans (20), in minutes. Storm Correlation between the current and previous volume scans is not performed if the scan separation exceeds this value.
TIME (Scan)	=	The beginning time of a volume scan, in hours. Precise to 1/3600 hr.
X-POSITION(Storm Cell)	=	X-coordinate of the centroid (or center of mass weighted volume) of a STORM CELL, in km. Precise to 10^{-4} km.
Y-POSITION(Storm Cell)	=	Y-coordinate of the centroid (or center of mass weighted volume) of a STORM CELL, in km. Precise to 10^{-4} km.

2.2 ACQUISITION

CORRELATION (Speed) is a constant based on empirical and theoretical studies of storm movements and is an adaptable threshold.

CORRELATION (Table) is an internal table used to keep track of the positions of correlated STORM CELLs.

IDs are a set of unique labels from an internal circular list.

Time (Scan) is acquired by means of direct measurements conducted at the beginning of volume scans of the radar.

Time (Maximum) is an adaptable threshold.

STORM CELLs, X-POSITION(Storm Cell), and Y-POSITION(Storm Cell) are acquired after the STORM CELLs are isolated based on reflectivity data obtained by a weather radar. The details of isolating storms are described under a separate algorithm description called STORM CELL CENTROIDS [Ø37].

SPEED (Storm Cell) and DIRECTION (Storm Cell) are acquired from STORM POSITION FORECAST [ØØ8] from past volume scans. If a STORM CELL is continuing, i.e., it has been tracked for two or more volume scans, STORM POSITION FORECAST computes a unique speed and direction for that STORM CELL. Otherwise, if the STORM CELL was identified as "new", STORM POSITION FORECAST gives that STORM CELL a vector-averaged speed and direction computed from the other continuing STORM CELLS. In the event there are no continuing STORM CELLS, the STORM POSITION FORECAST algorithm gives new STORM CELLs an operator-supplied default speed and direction.

3.0 PROCEDURE

3.1 ALGORITHM

```
      BEGIN ALGORITHM (STORM CELL TRACKING)

1.0         COMPUTE (TIME (Scan) difference)
1.1         IF (TIME (Scan) difference greater than TIME (Maximum))
              THEN
1.1.1           SET the number of STORM CELLs at the previous time
                  to zero
            END IF
2.0         COMPUTE (CORRELATION (Distance))
3.0         DO FOR ALL (STORM CELLs at the previous time)
3.1           COMPUTE (BEST X-Position)
3.2           COMPUTE (BEST Y-Position)
            END DO
4.0         DO FOR ALL (STORM CELLs at the current time)
4.1           DO FOR ALL (STORM CELLs from the previous time)
4.1.1           IF (STORM CELL from previous time has not already been correlated)
                  THEN
4.1.2               COMPUTE (DIFFERENCE (Best Position))
4.1.3               IF (DIFFERENCE (Best Position) is less than the
                       CORRELATION (Distance))
                       THEN
4.1.3.1                   IF (Smallest DIFFERENCE (Best Position))
                             THEN
4.1.3.2                         Identify as same STORM CELL from
                                previous TIME in CORRELATION(Table)
4.1.3.2.2                       Assign the same ID
                          END IF
                    END IF
                END IF
              END DO
4.2           IF (STORM CELL from current time is not correlated with a STORM CELL
                from previous time)
                THEN
4.2.1             Assign ID from the top of the list of IDs
              END IF
            END DO
5.0         DO FOR ALL (STORM CELLS from the previous time)
5.1           IF (Not correlated with a STORM CELL from current time)
                THEN
5.1.1             Return ID to the bottom of the list of IDs
              END IF
            END DO
6.0         WRITE (CORRELATION (Table))
7.0         WRITE IDs

      END ALGORITHM (STORM TRACKING)
```

3.2 COMPUTATION

3.2.1 NOTATION

BPD	=	DIFFERENCE (Best Position), the distance between the best position and the current position of the STORM CELL, in km. Precise to 10^{-4} km.
BXP	=	BEST X-POSITION, the projected X-position of a cell from the previous volume scan, in km. Precise to 10^{-4} km.
BXS	=	BEST X-SPEED, the SPEED in the X-direction of a cell from the previous volume scan, in km/hr. Precise to 10^{-4} km/hr.
BYP	=	BEST Y-POSITION, the projected Y-position of a cell from the previous volume scan, in km. Precise to 10^{-4} km.
BYS	=	BEST Y-SPEED, the SPEED in the Y-direction of a cell from the previous volume scan, in km. Precise to 10^{-4} km/hr.
CD	=	CORRELATION (Distance), the maximum DIFFERENCE (Best Position) allowed to determine if a current STORM CELL is the same as a STORM CELL from the previous volume scan, in km. Precise to 10^{-4} km.
CS	=	CORRELATION (Speed), the speed used to compute the CORRELATION (Distance), in km/hr. Precise to 10^{-4} km/hr.
DBP	=	DIRECTION (Best Position), the direction towards which a STORM CELL is moving, in degrees. Precise to 10^{-4} degrees.
DIR	=	DIRECTION (Storm Cell), the direction from which a STORM CELL is moving in degrees. Precise to 10^{-4} degrees.
SPD	=	SPEED (Storm Cell), the speed at which at STORM CELL is moving in km/hr. Precise to 10^{-4} km/hr
TScur	=	TIME (Scan) current, the time of the current (or most recent) volume scan, in hours. Precise to 1/3600 hr.
TSdif	=	TIME (Scan) difference, time difference between the current and previous volume scans, in hours. Precise to 1/3600 hr.
TSpre	=	TIME (Scan) previous, the time of the previous volume scan, in hours. Precise to 1/3600 hr.
XCcur	=	Current X-POSITION(Storm Cell), the X-coordinate (of the centroid) of a STORM CELL from the current volume scan, in km. Precise to 10^{-4} km.

XCpre = Previous X-POSITION(Storm Cell), the X-coordinate (of the centroid) of a STORM CELL from the previous volume scan, in km. Precise to 10^{-4} km.

YCcur = Current Y-POSITION(Storm Cell), the Y-coordinate (of the centroid) of a STORM CELL from the current volume scan, in km. Precise to 10^{-4} km.

YCpre = Previous Y-POSITION(Storm Cell), the Y-coordinate (of the centroid) of a STORM CELL from the previous volume scan, in km. Precise to 10^{-4} km.

Note: Precision is to the units unless otherwise specified.

Note: The NOTATION SECTION was alphabetized as per Algorithm Report Documentation Standards.

3.2.2 SYMBOLIC FORMULAS

<u>COMPUTE</u> (TIME (Scan) difference)

$TSdif = (TScur - TSpre)$

<u>COMPUTE</u> (CORRELATION (Distance))

$CD = (TSdif)\ (CS)$

<u>COMPUTE</u> (BEST X-POSITION)

$BXP = XCpre + (BXS)\ (TSdif)$

where BXS is computed from SPEED (Storm Cell) and DIRECTION (Storm Cell),

$BXS = (SPD) \sin (DBP)$

where,

$DBP = DIR - 180°$

<u>IF</u> $(DBP.LT.0)$, $DBP = DBP + 360°$

<u>COMPUTE</u> (BEST Y-POSITION)

$BYP = YCpre + (BYS)\ (TSdif)$

where BYS is computed from SPEED (Storm Cell) and DIRECTION (Storm Cell),

$BYS = (SPD) \cos (DBP)$

where,

$DBP = DIR - 180°$

IF $(DBP.LT.0)$ $DBP = DBP + 360°$

<u>COMPUTE</u> (DIFFERENCE (Best Position))

$BPD = [(BPDX)\ (BPDX) + (BPDY)\ (BPDY)]^{1/2}$

where,

$BPDX = |\ XCcur - BXP\ |$

and

$BPDY = |\ YCcur - BYP|$

4.0 OUTPUTS

4.1 IDENTIFICATION

The outputs of this algorithm are storm cell IDs and the CORRELATION (Table). IDs are a set of unique labels from an internal circular list for STORM CELLs. CORRELATION (Table) is a data set which allows the algorithm to track the same STORM CELL through a series of past volume scans. It consists of a list of indices and storm cell positions.

For example, during the first volume scan, a STORM CELL is identified and is given an index. During subsequent volume scans, other STORM CELLs are identified and ranked by index. The CORRELATION (Table) is used to cross reference these newly defined STORM CELLs with those tracked from the previous volume scan. By continuing this process, the same STORM CELL can be tracked through up to 13 (adaptable) volume scans.

4.2 DISTRIBUTION

The output of this algorithm is for use by the STORM POSITION FORECAST [ØØ8] algorithm. In addition, the outputs may be combined along with those from the forecast algorithm and formatted for display.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm performs best with isolated storm cells having consistent motions. Therefore, this algorithm's effectiveness could be reduced by very erratic storm motion, rapid storm evolution, and splits or mergers especially if storm cells are in close proximity. If cells are moving quite differently in different parts of the radar domain, tracking may be difficult, since new cells are assigned the average storm motion. Also, if cells quickly change their motion, algorithm performance will be reduced. Tracking will also be difficult, if cells are developing, growing, or decaying rapidly. And cell mergers and splits will reduce algorithm performance. In addition, if the TIME (Scan) difference is large, algorithm preformance will be degraded. Although algorithm failures due to these circumstances are uncommon, the actual frequency of such an occurrence is unknown.

The algorithm tracks the movement of individual cells; the algorithm was not designed to track lines or areas of storms.