STORM POSITION FORECAST

ALGORITHM DESCRIPTION

NX-DR-03-008/27

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of the STORM POSITION FORECAST algorithm is to predict the future centroid locations of storms (or storm cells) based on a history of the their movement. The first volume scan a storm is detected, it is considered ‘new’, and no prediction of movement is made. After the first volume scan a storm is detected, it is considered a ‘continuing storm’, and a forecast movement is computed based on a linear least squares extrapolation of the storm's previous positions. The linear least squares fits are for both X-position versus time and Y-position versus time. This process is continued for each consecutive volume scan that a storm is tracked.

Forecast positions are computed in equal time steps for each continuing storm. The number of forecast positions computed for a storm depends on the scaled forecast error and a permissible error. The scaled forecast error is the accuracy of the forecast from the previous volume scan for the storm, or forecast error, scaled by the ratio of a user specified error interval over the time between volume scans. The permissible error is a user specified allowable error scaled by the error interval over the length (in time) of the forecast. Basically, the poorer a forecast was for a cell for the past volume scan, the fewer the number of forecast positions. Each volume scan a vector-average storm motion is computed from all the continuing storms, and this average storm motion is assigned to any new storms.

1.2 SOURCE

The STORM POSITION FORECAST algorithm has been implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachusetts. Version 27 is based on the Storm Cell Identification and Tracking (SCIT) algorithm implemented by the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-TR-80- 0316, Air Force Geophysics Lab., Hanscom AFB, Mass. 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 POSITION FORECAST algorithm is the final step in the storm identification and movement prediction process. It utilizes information output by the STORM CELL TRACKING [Ø38] and the STORM CELL CENTROIDS [Ø37] algorithms. Therefore, it cannot be applied until the completion of that analysis, which requires a complete volume scan of data.

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

ALLOWABLE ERROR	=	The maximum acceptable error in the track of a STORM CELL allowed for the minimum forecast interval, in km (20).
CORRELATION (Table)	=	A data set used to keep track of the positions of correlated STORM CELLs.
DEFAULT SPEED	=	A user-supplied speed at which storm cells are expected to move, in km/hr.
DEFAULT DIRECTION	=	A user-supplied direction from which storm cells are expected to move, in degrees.
ERROR INTERVAL	=	The amount of time upon which the ALLOWABLE ERROR was based, in hours (0.25).
FORECAST INTERVAL	=	A set of time intervals for which STORM CELL positions may be projected into the future, in hours (0.25).
STORM CELLs	=	A three-dimensional region composed of components characterized by reflectivity values above a given threshold (or set of thresholds).
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.
TIME (Scan)	=	The beginning time of a volume scan, in hours.

2.2 ACQUISITION

CORRELATION (Table) is acquired from the STORM CELL TRACKING [Ø38] algorithm.

ALLOWABLE ERRORs, ERROR INTERVAL, THRESHOLD (minimum SPEED), FORECAST INTERVALs, DEFAULT SPEED, and DEFAULT DIRECTION are adaptable parameters.

STORM CELLs and their X-POSITION(Storm Cell) and Y-POSITION(Storm Cell) are obtained from a storm cell isolation algorithm such as the STORM CELL CENTROID [Ø37] algorithm.

TIME (Scan) is acquired by direct measurement from a Doppler radar.

3.0 PROCEDURE

3.1 ALGORITHM

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BEGIN ALGORITHM (STORM POSITION FORECAST)

1.0         (Set SPEED (Mean) equal to DEFAULT SPEED)
2.0         (Set DIRECTION (Mean) equal to DEFAULT DIRECTION)
3.0         COMPUTE (DEFAULT X-SPEED)
4.0         COMPUTE (DEFAULT Y-SPEED)
5.0         (Set AVERAGE X-SPEED equal to DEFAULT X-SPEED)
6.0         (Set AVERAGE Y-SPEED equal to DEFAULT Y-SPEED)
7.0         DO FOR ALL (STORM CELLs at current time)
7.1               (Identify the Number of (current and past) Storm Cell Positions)
7.2               IF (Number of Storm Cell Positions is greater than one)
                    THEN
7.2.1                 COMPUTE (X-SPEED(Storm Cell))
7.2.2                 COMPUTE (Y-SPEED(Storm Cell))
7.2.3                 (Label Storm Cell as type Continuing)
7.2.4                 (Increment the Number of Continuing Storm Cells)
                  ELSE
7.2.5                 (Label STORM CELL as type New)
                  END IF
            END DO
8.0         DO FOR ALL (STORM CELLs at current time)
8.1               IF (STORM CELL type Continuing)
                    THEN
8.1.1             COMPUTE (FORECAST ERROR)
8.1.2                 COMPUTE (mean FORECAST ERROR)
8.1.3             WRITE (FORECAST ERROR)
8.1.4             WRITE (mean FORECAST ERROR)
8.1.5             COMPUTE (scaled FORECAST ERROR)
8.1.6             DO FOR ALL (FORECAST INTERVALs)
8.1.6.1                 COMPUTE (PERMISSIBLE ERROR)
8.1.6.2                 IF (scaled FORECAST ERROR is less than
                          PERMISSIBLE ERROR for this particular FORECAST
                           INTERVAL)
                          THEN
8.1.6.2.1                    COMPUTE (forecasted X-POSITION(Storm Cell))
8.1.6.2.2                    COMPUTE (forecasted Y-POSITION(Storm Cell))
                        END IF
8.1.6.3                 WRITE (forecasted X-POSITION(Storm Cell))
8.1.6.4                 WRITE (forecasted Y-POSITION(Storm Cell))
                    END DO
                  END IF
            END DO
9.0         IF (Number (STORM CELL type Continuing) greater than or equal to one)
              THEN
9.1               DO FOR ALL (STORM CELLS at current time)
9.1.1                 IF (STORM CELL type Continuing)
                        THEN
9.1.1.1                   COMPUTE (SPEED(Storm Cell))
9.1.1.2                   COMPUTE (DIRECTION(Storm Cell))
                      END IF
                  END DO
9.2               COMPUTE (AVERAGE X-SPEED)
9.3               COMPUTE (AVERAGE Y-SPEED)
9.4               COMPUTE (SPEED (Mean))
9.5               COMPUTE (DIRECTION (Mean))
            END IF
10.0        DO FOR ALL (STORM CELLS at current time)
10.1              IF (STORM CELL type New)
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                    THEN
10.1.1                (Set AVERAGE X-SPEED to (Storm Cell))
10.1.2                (Set AVERAGE Y-SPEED to (Storm Cell))
10.1.3                (Set SPEED (MEAN) to (Storm Cell))
10.1.4                (Set DIRECTION (MEAN) to (Storm Cell))
                  END IF
10.2              WRITE (SPEED(Storm Cell))
10.3              WRITE (DIRECTION(Storm Cell))
10.4              WRITE (X-SPEED(Storm Cell))
10.5              WRITE (Y-SPEED(Storm Cell))
            END DO

END ALGORITHM (STORM POSITION FORECAST)
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3.2 COMPUTATION

3.2.1 NOTATION

AER = ALLOWABLE ERROR, the maximum error in the track of a STORM CELL allowed during the ERROR INTERVAL, in km. Precise to 10^{-4} km.

DIRdef = DEFAULT DIRECTION, the operator-supplied default DIRECTION (Storm Cell) from which STORM CELLS are moving in degrees. Precise to .05 degrees.

DMN = DIRECTION (Mean), the vector average DIRECTION(Storm Cell) from which STORM CELLs are moving, in radians. Precise to 10^{-3} radians.

DRC = DIRECTION (Radar Coordinates), the operator-supplied direction towards which STORM CELLS are moving in radians.

DS = DIRECTION(Storm Cell), direction from which a STORM CELL is moving, in radians. Precise to 10^{-3} radians.

EI = ERROR INTERVAL, the amount of time upon which the ALLOWABLE ERROR was based, in hours. Precise to 1/3600 hr.

FE = FORECAST ERROR, the departure of the current STORM CELL position from the position forecasted for that STORM CELL at the previous time, in km. Precise to 10^{-4} km.

FEmean = mean FORECAST ERROR, the average FORECAST ERROR of a STORM CELL (refers to a single STORM CELL over its entire life-time), in km. Precise to 10^{-4} km.

FEsca = scaled FORECAST ERROR, the departure of the current STORM CELL position from the position forecasted for the STORM CELL at the previous time adjusted by the ratio of the ERROR INTERVAL to the time between volumes, in km. Precise to 10^{-4} km.

FI = FORECAST INTERVAL, a set of time intervals for which storm cell positions may be projected into the future, in hours. Precise to 1/3600 hr.

i = The Number of Continuing Storm Cells in the Correlation Table (for the current volume scan).

n = The Number of (current and past) Storm Cell Positions (in the Correlation Table) for a storm cell.

PE = PERMISSIBLE ERROR, the maximum error allowed in the forecast of a STORM CELL for each forecast interval, in km. Precise to 10^{-4} km.

SPDdef = DEFAULT SPEED, the operator-supplied default SPEED(Storm Cell) at which STORM CELLS are moving in km/hr. Precise to .36 km/hr.

SPM = SPEED (Mean), the vector average SPEED(Storm Cell) which STORM CELLs are moving, in km/hr. Precise to .36 km/hr.

SS = SPEED(Storm Cell), speed of a STORM CELL, in km/hr. Precise to .36 km/hr.

TS = TIME (Scan), the beginning time of a volume scan, in hours. Precise to 1/3600 hr.

TSavg = average TIME (Scan), the average of all TIMEs (Scan) in forecast period, in hrs. Precise to 1/3600 hr.

TScur = current TIME (Scan), the current scan time, in hours. Precise to 1/3600 hr.

XC = X-POSITION(Storm Cell), the x-coordinate of the centroid (or center of mass weighted volume) of a STORM CELL, in km. Precise to 10^{-4} km.

XCavg = average X-POSITION(Storm Cell), the average STORM CELL position in the X-direction, in km. Precise to 10^{-4} km.

XCcur = current X-POSITION(Storm Cell), the current STORM CELL position in the X-direction, in km. Precise to 10^{-4} km.

XCfor = forecasted X-POSITION(Storm Cell), the forecasted STORM CELL position in the X-direction, in km. Precise to 10^{-4} km.

XCpre = previous X-POSITIONN(Storm Cell), the previous STORM CELL position in the X-direction, in km. Precise to 10^{-4} km.

XS = X-SPEED (Storm Cell), the speed of a STORM CELL in the X-direction, in km/hr. Precise to .36 km/hr.

XSavg = AVERGE X-SPEED, the vector average motion in the X-direction of all the STORM CELLs in the Correlation Table, in km/hr. Precise to .36 km/hr.

XSpre = previous X-SPEED (Storm Cell), the previous speed of a STORM CELL in the X-direction, in km/hr. Precise to .36 km/hr.

YC = Y-POSITION(Storm Cell), the y-coordinate of the centroid (or center of mass weighted volume) of a STORM CELL, in km. Precise to 10^{-4} km.

YCavg = average Y-POSITION(Storm Cell), average STORM CELL position in the Y-direction , in km. Precise to 10^{-4} km.

YCcur = current Y-POSITION(Storm Cell), the current STORM CELL position in the Y-direction , in km. Precise to 10^{-4} km.

YCfor = forecasted Y-POSITION(Storm Cell), forecasted STORM CELL position in the Y-direction, in km. Precise to 10^{-4} km.

YCpre = previous Y-POSITION(Storm Cell), the previous STORM CELL position in the Y-direction, in km. Precise to 10^{-4} km.

YS = Y-SPEED(Storm Cell), the speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

YSavg = AVERGE Y-SPEED, the vector average motion in the Y-direction of all the STORM CELLs in the Correlation Table, in km/hr. Precise to .36 km/hr.

YSpre = previous Y-SPEED(Storm Cell), the previous speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

Note: Precision is to the units specified unless otherwise stated.

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

3.2.2 SYMBOLIC FORMULAS

COMPUTE (DEFAULT X-SPEED)

XSdef = (SPDdef) sin(DRC)

where

DRC = (DIRdef - 180°) (B/180°)

COMPUTE (DEFAULT Y-SPEED)

YSdef = (SPDdef) cos(DRC)

where

DRC = (DIRdef - 180°) (B/180°)

COMPUTE (X-SPEED(Storm Cell))

$$XS = [\sum_{n} (XC_n - XCavg)(TS_n - TSavg)]/[\sum_{n} (TS_n - TSavg)^2]$$

where n is the number of entries in the Correlation Table for a particular storm cell.

COMPUTE (Y-SPEED(Storm Cell))

$$YS = [\sum_{n} (YC_n - YCavg)(TS_n - TSavg)]/[\sum_{n} (TS_n - TSavg)^2]$$

where n is the number of entries in the Correlation Table for a particular storm cell.

COMPUTE (FORECAST ERROR)

$FE = [(XE - XCcur)^2 + (YE - YCcur)^2]^{0.5}$

where;

$XE = (XSpre)(TScur - TSpre) + XCpre$

$YE = (YSpre)(TScur - TSpre) + YCpre$

COMPUTE (mean FORECAST ERROR)

$$FEmean = \sum_{n} FE_n/n$$

Note: n under the summation refers to a single storm cell over its entire life-time.

COMPUTE (Scaled FORECAST ERROR)

$FEsca = (FE)\ (EI)/(TScur - TSpre)$

COMPUTE (PERMISSIBLE ERROR)

$PE = (AER)[(EI)/(FI)]$

COMPUTE (forecasted X-POSITION(Storm Cell))

$XCfor = XCcur + (XS)(FI)$

COMPUTE (forecasted Y-POSITION(Storm Cell))

$YCfor = YCcur + (YS)(FI)$

COMPUTE (SPEED(Storm Cell))

$SS = (XS^2 + YS^2)^{0.5}$

COMPUTE (DIRECTION(Storm Cell))

$DS = \tan^{-1}(XS/YS) + B$

COMPUTE (AVERAGE X-SPEED)

$$XSavg = \left(\sum_{i} XS_i\right)/i$$

where i is the number of continuing storm cells in the Correlation Table

COMPUTE (AVERAGE Y-SPEED)

$$YSavg = \left(\sum_{i} YS_i\right)/i$$

where i is the number of continuing storm cells in the Correlation Table

COMPUTE (SPEED (Mean))

$$SPM = ((XSavg)^2 + (YSavg)^2)^{0.5}$$

COMPUTE (DIRECTION (Mean))

$$DMN = (\tan^{-1}(XSavg/YSavg)) + B$$

4.0 OUTPUTS

4.1 IDENTIFICATION

Every volume scan, for each storm cell, the following values are output: DIRECTION(Storm Cell), SPEED(Storm Cell), X-SPEED(Storm Cell), Y-SPEED(Storm Cell), forecasted X-POSITIONs(Storm Cell), forecasted Y-POSITIONs(Storm Cell), FORECAST ERROR, and mean FORECAST ERROR. In addition, each volume scan, the SPEED (Mean) and DIRECTION (Mean) (the vector average speed and direction of all continuing STORM CELLs in the Correlation Table) are output.

4.2 DISTRIBUTION

All of the outputs from this algorithm can be used by product generation algorithms which will output information concerning expected storm cell movement. Additionally, X-SPEED(Storm Cell), X-DIRECTION(Storm Cell), Y-SPEED(Storm Cell), and Y-DIRECTION(Storm Cell) are intended for input to the STORM CELL TRACKING [Ø38] algorithm and Weak Echo Region and Storm Relative Velocity (Map and Region) products. SPEED (Mean) and DIRECTION (Mean) are also output once per volume scan to the Weak Echo Region and Storm Relative Velocity products.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm averages actual changes in cell movement and erratic movement due to centroid shifting which occurs in some storm cells. The forecast track is always a straight line. Because several volume scans are used for the forecast, a sudden shift in a centroid location will be damped out until the new track becomes established. The accuracy of the forecasted movement provided by this algorithm is limited by the accuracy of the tracking algorithm. For example, if the STORM CELL TRACKING [Ø38] algorithm inaccurately matches storm cells between volume scans, then the forecasted movement of those cells will also be inaccurate.