DUAL POLARIMETRIC PREPROCESSOR
ALGORITHM DESCRIPTION
NX-DR-03-061/02

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1 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

1.1.1 Introduction

Raw (time series) radar data undergo processing at the Radar Data Acquisition (RDA) unit before being passed to the Radar Product Generator (RPG) in the form of base moments. In addition to the horizontally-polarized WSR-88D base moments (reflectivity, radial velocity, and spectrum width), a dual polarization RDA provides differential reflectivity corrected for noise (between horizontally and vertically polarized reflectivity), differential propagation phase shift (hereinafter called "differential phase"), and cross-polar (horizontal and vertical) correlation coefficient corrected for noise (hereinafter called "correlation coefficient corrected for noise"). Upon receipt at the RPG, base moments undergo processing by several RPG tasks, such as Process Base Data (i.e., pbd) and velocity dealiasing (i.e., veldeal). The output data from these tasks then go to dual polarization preprocessing. This document describes the preprocessing algorithm that is used to prepare base moments for use in the dual polarization analysis algorithms at the RPG. For convenience, the dealiasing of the differential phase is documented as a separate computation within this document and referenced in the processing sequence as the first computation within the algorithm. The computation for dealiasing differential phase may be easily ported outside this algorithm and execute as a separate RPG task prior to the preprocessor algorithm. The decision of either dealiasing of differential phase prior to this algorithm or as the first computation within this algorithm is an implementation issue left to the RPG software engineers.

The preprocessing outputs include smoothed and corrected dual polarimetric base moment data, signal-to-noise ratio, texture data, and (range-weighted) specific differential phase. Smoothing is a running average technique employing a specified number of sample bins for each feature. "Texture" is the spatial variability of feature field data, such as reflectivity or differential phase, where an increase in texture indicates a reduction in homogeneity of that feature field (Joe, 1991); texture could be described as the "choppiness" of the data. Preprocessing precedes data quality assessment, melting layer detection, radar echo identification, and precipitation estimation.

1.1.2 Horizontally-Polarized Reflectivity

Because it represents a summation of the droplet diameters within a sample volume, the horizontal reflectivity factor (Z) is very sensitive to particle size. Hence, the variance can be quite high in certain meteorological situations, such as convective storms. It is also very high in ground returns. In order to reduce the high variance of Z for some polarimetric algorithms, preprocessing averages Z along a radial using a three-gate running average. After undergoing smoothing, reflectivity is then corrected for attenuation in order to produce the final version of reflectivity ($Z^{(processed)}$). For simplicity in this document, Z can be assumed to always be the horizontally-polarized reflectivity unless specified otherwise. Also, reflectivity values have been adjusted for $Z^{(dBZ0)}$ at the RDA.

1.1.3 Differential Reflectivity corrected for noise

Differential reflectivity (Z_{DR}) is defined as ten times the logarithm of the ratio of the horizontal reflectivity factor over the vertical reflectivity factor. Because it is essentially a ratio of reflectivity factors, it is sensitive to hardware calibration errors. However, as stated by Brandes (2000), "The standard error of the Z_{DR} measurement, as indicated by gate-to-gate scatter among measurements along a radial is on the order of 0.2 to 0.3 dB. This error can be reduced to -0.1 dB by spatial averaging. Errors of this magnitude are important for rainfall estimation when Z_{DR} is small."

For the preprocessor, the RDA supplies differential reflectivity (Z_{DR}) that has been corrected for noise. Hereafter, $Z_{DR}^{(cor)}$ in this document will refer to differential reflectivity corrected for noise. $Z_{DR}^{(cor)}$ is used primarily for two purposes in the preprocessor. First it is smoothed using a five-gate spatial average for use in a conditional statement and is called $Z_{DR}^{(smoothed)}$. Second, $Z_{DR}^{(cor)}$ is corrected for horizontal attenuation and system calibration to create processed differential reflectivity ($Z_{DR}^{(processed)}$).

1.1.4 Horizontally-Polarized Radial Velocity

Mean horizontally-polarized radial velocity is used in the Hydrometeor Classification Algorithm in the determination of ground clutter. It is smoothed with a five-gate average filter. Whenever V is used in this document, it is assumed to be the horizontally-polarized radial velocity.

1.1.5 Correlation Coefficient corrected for noise

The correlation coefficient (ρ_{hv}) is a measure of the correlation between horizontal and vertical backscattered power from the scatterers in a given sample volume. At low signal-to-noise ratios, ρ_{hv} becomes questionable, so ρ_{hv} is corrected for noise at the RDA. It should be noted that ρ_{hv} is susceptible to contamination by ground returns (i.e., clutter) and by echoes from side lobes (Brandes, 2000).

For the preprocessor, the RDA supplies correlation coefficient (ρ_{hv}) corrected for noise. Hereafter, $\rho_{hv}^{(cor)}$ in this document will refer to correlation coefficient corrected for noise. $\rho_{hv}^{(cor)}$ is used primarily for use in a conditional statements and passes through the preprocessor without modification.

1.1.6 Total Differential Phase and Specific Differential Phase

Differential phase (Φ_{DP}) is a measure of the backscattering properties of targets when impacted by both horizontally-polarized and vertically-polarized radar waves. It is defined as the difference between the horizontal and vertical two-way phase angles (Φ_h - Φ_v). As described by Brandes (2000), "Backscattered signals return to the receiver with different accumulative phase (time) shifts depending on the hydrometeor size, shape, orientation, quantity, distance from the radar, and polarization state." The total differential phase is a combination of the propagative component and the backscatter differential phase component. Brandes points out that "the differential phase is sensitive to the water content of the medium."

Specific differential phase is derived from the total differential phase. It is the differential phase over a limited range increment. "It is insensitive to radar calibration, partial beam blockage, propagation effects, and system noise" (Brandes, 2000). "To reduce the error in estimates of K_{DP}, the Φ_{DP} measurements are filtered in range" (Brandes, 2000). Brandes et al. (2001) have documented negative K_{DP} values related to vertical gradients of precipitation.[1]

1.1.7 Sequence of Processing

The radar data are processed in the following sequence:

1. The unwrapped differential phase is computed (pending implementation of the algorithm in the RPG, this computation may reside as a separate RPG task outside the preprocessor algorithm).

2. Texture is computed for reflectivity and total differential phase by the following steps:
    a. Data are averaged.
    b. Residuals are computed from these averages.
    c. Standard deviations are computed from these residuals.

3. Differential reflectivity corrected for noise ($Z_{DR}^{(cor)}$), correlation coefficient corrected for noise ($\rho_{hv}^{(cor)}$), base reflectivity (Z), and mean Doppler velocity (V) are smoothed using a running average window (referred to as boxcar averaging).

4. Signal-to-noise ratio is computed.

[1] Hogan et al. (2002) claim that, when radar targets (such as ice crystals) are oriented vertically, as often occurs in lightning channels and in the updraft region of a thunderstorm, Φ_v can be greater than Φ_h, so the Φ_{DP} measurement can result in a negative K_{DP}; however, this condition would be short-lived.

5. Differential phase is smoothed using an average filter. Smoothed differential phase ($\Phi_{DP}^{(smoothed)}$) is computed for both 9-gate and 25-gate total differential phase.

6. Specific differential phase is computed using both short gate and long gate filtering.

7. Processed specific differential phase ($K_{DP}^{(processed)}$) is computed using either the specific differential phase short gate or specific differential phase long gate data based on a reflectivity limit test.

8. Base reflectivity (Z) and differential reflectivity corrected for noise ($Z_{DR}^{(cor)}$) are corrected for attenuation and adjusted for calibration changes.

1.1.8 Texture

Texture is the standard deviation of the residuals of 5-gate-averaged reflectivity or 9-gate-averaged unwrapped differential phase from their original values. As mentioned in the Introduction, texture is a measure of non-homogeneity, variability, small-scale fluctuations, or “choppiness.” For examples, high texture for either reflectivity or differential phase typically indicates ground returns, while low texture for these moments typically indicates meteorological returns (Schuur et al., 2003).

1.1.9 Smoothing of Z, V, $\rho_{hv}^{(cor)}$, and $Z_{DR}^{(cor)}$

Smoothing of radial data is done using a type of running average. The number of sample bins for this running average is three for reflectivity (Z) and five for V, $\rho_{hv}^{(cor)}$, and $Z_{DR}^{(cor)}$.

1.1.10 Signal-to-Noise Calculation

Signal-to-noise ratio in the horizontal channel is computed from base reflectivity, the calibration constant (dBZ0), the atmospheric attenuation factor, and the slant range to each sample bin. The signal-to-noise ratio is given in units of decibels (the decibel value of the signal (dBZ) minus the decibel value of noise).

1.1.11 Smoothing of Differential Phase

Smoothed total differential phase ($\Phi_{DP}^{(smoothed)}$) is computed for both short 9-gate and long 25-gate total differential phase. The Φ_{DP} with 9-gate filtering is considered "lightly filtered," while the Φ_{DP} with 25-gate filtering is considered "heavily filtered."

1.1.12 Specific Differential Phase Calculation

By definition (Doviak and Zrnic, 1993), specific differential phase (K_{DP}) for one-way propagation is one half the difference between the differential phases at two range locations (r_1 and r_2):

$$K_{DP} = \frac{\Phi_{DP}(r_2) - \Phi_{DP}(r_1)}{2(r_2 - r_1)}$$

K_{DP} is computed for both short gate and long gate filtering using "a slope of a least squares fit for two range averaging intervals, corresponding to 9 and 25 successive gates (Ryzhkov et al., 2005). For any particular range gate, the lightly filtered (9 gates) estimate of K_{DP} is selected if $Z > 40$ dBZ, otherwise, the heavily filtered estimate (25 gates) is used. Thus, radial resolution of the K_{DP} estimate is about 6 km for relatively light rain ($R < 12$ mm h^{-1}) and about 2 km for more intense rain" (Ryzhkov, 2005).

There are several ways to compute the least squares fit. Ryzhkov uses the computation for K_{DP} (shown in Section 3.2.2) as follows:

$$K_{DP}^{(FLTLNG)}(i) = \frac{6 \sum_{j=-(HFLTLNG)}^{HFLTLNG} j\,(\Phi_{DP}^{(FLTLNG)}(i+j))}{\Delta r\,(FLTLNG)\,(FLTLNG-1)\,(FLTLNG+1)}$$

where FLTLNG stands for the filter length, Δr is the gate spacing, i is the range bin number, and j represents the position within the selected filter (or smoothing) window having filter length, FLTLNG (either 9 or 25 range bins). Note: this equation has been optimized to work with odd number of gates (i.e., 3, 5, 7, 9, etc. number of gates) and a more generic version using Linear Least Squares Estimation should be applied for even number of gates (i.e., 2,4,6,8, etc. number of gates).

A $K_{DP}^{(processed)}$ value is created for any particular range bin by selecting the lightly filtered (9 gate) $K_{DP}^{(9)}$ if the Z > reflectivity threshold (default 40 dBZ), otherwise, the heavily filtered (25 gate) $K_{DP}^{(25)}$ is used. The $K_{DP}^{(processed)}$ is the only specific differential phase output by this algorithm.

1.1.13 Corrections for Noise

Correlation coefficient and differential reflectivity undergo a correction for noise at the RDA. Note that the noise correction is needed because both correlation coefficient and differential reflectivity are negatively biased if the signal-to-noise ratio is less than 20 dB (Bringi and Chrandrasekar, 2001).

1.1.14 Correction for Attenuation and Adjustment for Calibration

The attenuation loss is computed using the relations ΔZ (dB) = 0.04 ($\Phi_{DP}^{(25)} - \Phi_{DP}^{(sys)}$) (degrees) and ΔZ_{DR} (dB) = 0.004 ($\Phi_{DP}^{(25)} - \Phi_{DP}^{(sys)}$) (degrees) (Ryzhkov and Zrnic, 1995). In other words, attenuation is due to the amount of water vapor in the atmosphere, as measured by the differential phase relative to an RDA-determined system differential phase ($\Phi_{DP}^{(sys)}$). Calibration changes also affect both reflectivity and differential reflectivity. Once the calibration adjustment is added to the change in reflectivity and differential reflectivity due to attenuation, the algorithm below refers to the resulting moments as “processed” reflectivity and differential reflectivity, respectively.

1.2 SOURCE

The dual polarimetric preprocessor was developed by members of the National Severe Storms Laboratory (NSSL) under Memoranda of Understanding with the National Weather Service (NWS) Office of Science and Technology (OS&T) and the Radar Operations Center (ROC).

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1.3 PROCESSING ENVIRONMENT

Dual polarimetric preprocessing is done in real time at the Radar Product Generator (RPG). Dealiasing of velocity (to rectify velocity ambiguity) is done prior to the dual polarimetric preprocessing described in this document. Dealiasing of differential phase (to rectify phase ambiguity) is include in this document for convenience, but is included as a single computation capable of being removed from the Preprocessor and performed elsewhere in the RPG.

1.4 VERSION INFORMATION

Version #	Date	Author	Changes
1.0	December 2006	Rich Murnan, Dan Berkowitz, John Krause, and Zhongqi ("Zack") Jing	Initial version (for Build 10 software)
2.0	October 2008	Rich Murnan, Dan Berkowitz, John Krause, and Zhongqi ("Zack") Jing	Changes made to accommodate QPE Echo Classification version (v. 2.0)
3.0	October 2009	Rich Murnan, John Krause and Zhongqi ("Zack") Jing	Modifications for unwrapping Φ_{DP}

2 INPUTS

2.1 IDENTIFICATION

Term	Definition
WRAPPED DIFFERENTIAL PHASE	$\Phi_{DP}^{WRAPPED}$ (deg) – the wrapped (aliased) difference in phase between the horizontally- and vertically- polarized pulses at a given range along the propagation path. $\Phi_{DP}^{WRAPPED}$ values range from 0.0 (deg) to 360.0 (deg) with a precision of 0.35 degrees.
ATMOS	Atmospheric attenuation factor (dB/km) supplied by the RDA. ATMOS values range from -0.02 to -0.002 with a precision of 0.001 dB.
CALIBRATION CONSTANT FOR REFLECTIVITY	$Z^{(dBZ0)}$ (dB) or also referred to as dBZØ – calibration adjustment for reflectivity provided by the RDA. The range is -99.0 dB to +99.0 dB.
CALIBRATION CONSTANT FOR DIFFERENTIAL REFLECTIVITY	$Z_{DR}^{(calb)}$ (dB) – calibration adjustment for differential reflectivity provided by the RDA. Values range from -7.8750 dB to +7.7500 dB.
CORRELATION COEFFICIENT CORRECTED FOR NOISE	$\rho_{hv}^{(cor)}$ – is a correlation between the backscattered power of the horizontally and vertically polarized echoes that has been corrected for noise at the RDA. The $\rho_{hv}^{(cor)}$ values range from 0.2 to 1.05 with a precision of 0.00333.

Term	Definition
DIFFERENTIAL PHASE	Φ_{DP} (deg) – the unwrapped difference in phase between the horizontally- and vertically-polarized pulses at a given range along the propagation path. Usually, Φ_{DP} will increase with range from the radar. The unwrapped Φ_{DP} values range from 0.0 (deg) to 1080 (deg) with a precision of 0.35 degrees.
DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE	$Z_{DR}^{(cor)}$ (dB) – a ratio of the reflected horizontal and vertical power returns that has been corrected for noise at the RDA. Specifically, $Z_{DR}^{(cor)}$ is a measure of the reflectivity-weighted mean axis ratio of the hydrometeors in a radar volume. $Z_{DR}^{(cor)}$ values range from -7.8750 dB to +7.9375 dB with a precision of 0.06 dB. $Z_{DR}^{(cor)}$ values have not been adjusted for $Z_{DR}^{(calb)}$ at the RDA.
INITIAL SYSTEM DIFFERENTIAL PHASE	$\Phi_{DP}^{(sys)}$ (deg) – a system bias between the vertical and horizontal polarized phases supplied by the RDA.
REFLECTIVITY	Z (dBZ) – the original RDA base reflectivity factor from horizontal polarization over a radar bin. Accuracy is defined by the accuracy of the base data. Currently, reflectivity values range from -32.0 dBZ to +94.5 dBZ, and the precision is 0.50 dBZ. Reflectivity values have been adjusted for $Z^{(dBZ0)}$ at the RDA.
SAMPLE VOLUME	A data sample volume along a radial whose (half power) dimensions are described by the azimuthal and vertical beam widths and the range sampling interval. These dimensions are approximately 1 degree in azimuthal and vertical width (perpendicular to the beam) and 250 meter in range (or length).
SLANT RANGE	R (km) – slant range to the center of a SAMPLE VOLUME.
SPECTRUM WIDTH	σ_{υ} (m s^{-1}) – a measure of the dispersion of velocities in a radar sample volume. The computation performed is the returned signal autocorrelation which is related to the velocity spectrum standard deviation.

Term	Definition
THRESHOLD (CORRELATION COEFFICIENT)	$\rho_{hv}^{(threshold)}$ – an adaptable parameter value set at the RPG. Default value is set to 0.9.
THRESHOLD (DIFFERENCE BOUNDARY DIFFERENTIAL PHASE)	An adaptable parameter value set at the RPG. Default value is set to 100.0.
THRESHOLD (REFLECTIVITY)	An adaptable parameter value set at the RPG. Default value is set to 40 dbZ.
THRESHOLD (DIFFERENCE BOUNDARY REFLECTIVITY)	An adaptable parameter value set at the RPG. Default value is set to 50.0.
THRESHOLD (SIGNAL TO NOISE FOR CORRELATION COEFFIECENT)	A value used at the RDA to determine valid data for ρ_{hv}. This value is supplied by the RDA. It has a range of -12.0 to +20.0 dB with a precision of 0.125 dB.
THRESHOLD (SIGNAL TO NOISE FOR DIFFERENTIAL REFLECTIVITY)	A value used at the RDA to determine valid data for Z_{DR}. This value is supplied by the RDA. It has a range of -12.0 to +20.0 dB with a precision of 0.125 dB.
VELOCITY	V_h (m/s) – the original ORDA base radial velocity from horizontal polarization over a radar bin. Accuracy is defined by the accuracy of the base data generated at the RDA. Radial velocity ranges from -63.5 m/s to +63.0 m/s with low (0.5 m/s) velocity increment and from -127.0 m/s to +126.0 m/s with high (1.0 m/s) velocity increment. Precision is 0.50 m/s at low increment and 1.00 m/s at high increment.

2.2 ACQUISITION

REFLECTIVITY, VELOCITY, SPECTRUM WIDTH, DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE, DIFFERENTIAL PHASE, and CORRELATION COEFFICIENT CORRECTED FOR NOISE have radial resolution of 0.250 km with total number of range bins depending on the VCP. The maximum range for all Angular resolution of the radar data is 0.5º from the RDA but a recombine routine at the RPG constructs a 1.0º angular resolution prior to the Preprocessor Algorithm.

3 PROCEDURE

3.1 ALGORITHM

BEGIN ALGORITHM (Dual Polarization Preprocessing)

DO FOR ALL (ELEVATIONs)
    DO FOR ALL (RADIALs)
        ASSIGN arrays populating REFLECTIVITY, VELOCITY, SPECTRUM WIDTH,
            DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE, WRAPPED DIFFERENTIAL PHASE, and
            CORRELATION COEFFICIENT CORRECTED FOR NOISE
        COMPUTE (Unwrapping (WRAPPED DIFFERENTIAL PHASE, DIFFERENTIAL PHASE, FILTER LENGTH = 30)
        COMPUTE (Average Filter (REFLECTIVITY, SMOOTHED REFLECTIVITY, FILTER LENGTH = 5))
        COMPUTE (Texture (REFLECTIVITY, SMOOTHED REFLECTIVITY, TEXTURE FOR REFLECTIVITY,
            THRESHOLD (DIFFERENCE BOUNDARY REFLECTIVITY), FILTER LENGTH = 5))
        COMPUTE (Average Filter (DIFFERENTIAL PHASE, SMOOTHED DIFFERENTIAL PHASE,
            FILTER LENGTH = 9))
        COMPUTE (Texture (DIFFERENTIAL PHASE, SMOOTHED DIFFERENTIAL PHASE, TEXTURE FOR
            DIFFERENTIAL PHASE, THRESHOLD (DIFFERENCE BOUNDARY DIFFERENTIAL PHASE),
            FILTER LENGTH = 9))
        COMPUTE (Average Filter (CORRELATION COEFFICIENT CORRECTED FOR NOISE, SMOOTHED
            CORRELATION COEFFICIENT, FILTER LENGTH = 5))
        COMPUTE (Average Filter (DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE, SMOOTHED
            DIFFERENTIAL REFLECTIVITY, FILTER LENGTH = 5))
        COMPUTE (Average Filter (VELOCITY, SMOOTHED VELOCITY, FILTER LENGTH = 5))
        COMPUTE (Average Filter (REFLECTIVITY, SMOOTHED REFLECTIVITY, FILTER LENGTH = 3))
        COMPUTE (SIGNAL TO NOISE RATIO)

```
COMPUTE (Meteo Data)
COMPUTE (Meteo Groups)
COMPUTE (Median (DIFFERENTIAL PHASE, MEDIAN DIFFERENTIAL PHASE, FILTER
        LENGTH = 5))
COMPUTE (Conditional Check (MEDIAN DIFFERENTIAL PHASE, METFLAG)
COMPUTE (Average Filter (MEDIAN DIFFERENTIAL PHASE, SMOOTHED MEDIAN DIFFERENTIAL
        PHASE, FILTER LENGTH = 9))
COMPUTE (Valid Meteo Groups (FILTER LENGTH = 9))
COMPUTE (Interpolate (SMOOTHED MEDIAN DIFFERENTIAL PHASE, DIFFERENTIAL PHASE
        SHORT GATE, FILTER LENGTH = 9))
COMPUTE (Average Filter (MEDIAN DIFFERENTIAL PHASE, SMOOTHED MEDIAN DIFFERENTIAL
        PHASE, FILTER LENGTH = 25))
COMPUTE (Valid Meteo Groups (FILTER LENGTH = 25))
COMPUTE (Interpolate (SMOOTHED MEDIAN DIFFERENTIAL PHASE, DIFFERENTIAL PHASE LONG
        GATE, FILTER LENGTH = 25))
COMPUTE (SPECIFIC DIFFERENTIAL PHASE SHORT GATE, FILTER LENGTH = 9)
COMPUTE (SPECIFIC DIFFERENTIAL PHASE LONG GATE, FILTER LENGTH = 25)

DO FOR ALL (SAMPLE VOLUMEs)
        IF (DIFFERENTIAL PHASE is equal to NO DATA)
                THEN
                SET HORIZONTAL ATTENUATION FOR REFLECTIVITY equal to 0
                SET HORIZONTAL ATTENUATION FOR DIFFERENTIAL REFLECTIVITY equal to 0
        ELSE
                COMPUTE (HORIZONTAL ATTENUATION FOR REFLECTIVITY)
                COMPUTE (HORIZONTAL ATTENUATION FOR DIFFERENTIAL REFLECTIVITY)
        ENDIF
        IF (SMOOTHED DIFFERENTIAL REFLECTIVITY is equal to NO DATA)
                THEN
                SET PROCESSED DIFFERENTIAL REFLECTIVITY equal to NO DATA
        ELSE
```

```
        COMPUTE (PROCESSED DIFFERENTIAL REFLECTIVITY)
    ENDIF
    IF (SMOOTHED REFLECTIVITY is equal to NO DATA)
        THEN
        SET PROCESSED REFLECTIVITY equal to NO DATA
    ELSE
        COMPUTE (PROCESSED REFLECTIVITY)
    ENDIF
END DO (SAMPLE VOLUMEs)

DO FOR ALL (SAMPLE VOLUMEs)
    IF (CORRELATION COEFFICIENT CORRECTD FOR NOISE is less than THRESHOLD (CORRELATION
    COEFFICIENT) OR CORRELATION COEFFICIENT CORRECTED FOR NOISE is equal to NO DATA)
        THEN
        SET (SPECIFIC DIFFERENTIAL PHASE SHORT GATE to NO DATA)
        SET (SPECIFIC DIFFERENTIAL PHASE LONG GATE to NO DATA)
    ENDIF
    SET PROCESSED SPECIFIC DIFFERENTIAL PHASE equal to SPECIFIC DIFFERENTIAL PHASE
        SHORT GATE
    IF PROCESSED REFLECTIVITY is less than or equal to THRESHOLD (REFLECTIVITY)
        THEN
        SET PROCESSED SPECIFIC DIFFERENTIAL PHASE equal to SPECIFIC DIFFERENTIAL
            PHASE LONG GATE
    END IF
    SET PROCESSED DIFFERENTIAL PHASE equal to DIFFERENTIAL PHASE LONG GATE
END DO (SAMPLE VOLUMEs)
WRITE (PROCESSED REFLECTIVITY)
WRITE (SMOOTHED VELOCITY)
WRITE (SPECTRUM WIDTH)
WRITE (PROCESSED DIFFERENTIAL REFLECTIVITY)
WRITE (PROCESSED DIFFERENTIAL PHASE)
```

```
        WRITE (CORRELATION COEFFICIENT CORRECTED FOR NOISE)
        WRITE (SIGNAL TO NOISE RATIO)
        WRITE (PROCESSED SPECIFIC DIFFERENTIAL PHASE)
        WRITE (TEXTURE FOR REFLECTIVITY)
        WRITE (TEXTURE FOR DIFFERENTIAL PHASE)
    END DO (RADIALs)
END DO (ELEVATIONs)
```

3.2 COMPUTATION

3.2.1 NOTATION

Term	Definition
AVER	The running average for DIFFERENCE data using a window of FILTER LENGTH in size
BEGBIN	Beginning bin location of "meteo" range interval to be interpolated.
BEGPHI	Beginning differential phase value of span of data to be interpolated.
c	Counter used to keep track of the number of valid data values.
counter	Counter used to keep track of the number of valid data values along the radial.
DIFFERENCE	Calculated array of the difference between smoothed and unsmoothed data.
DWRPINDEG	The truncated (WRPINDEG * 2) represented as an integer.
ENDBIN	Ending bin location of "meteo" range interval to be interpolated.
ENDPHI	Ending differential phase value of span of data to be interpolated.
FLTLNG	FILTER LENGTH takes on different values in the preprocessor. When used in the Average routine FILTER LENGTH is always selected as an odd number (i.e., 1,3,5,7,9 etc.). When used in the Unfolding routine, there is no restriction on the value of FILTER LENGTH (i.e., 30).
HFLTLNG	The truncated ((FLTLNG – 1) / 2) represented as an integer.
HWRPINDEG	The truncated (WRPINDEG / 2) represented as an integer.
i	Bin number, with a range of 0 to N.
j	Bin position within the window being used for filtering (i.e., smoothing).
k	Counter used in the median calculation to track the number of valid values in array UNSRTARR.
K_{DP}	Specific differential phase (degrees per km).
$K_{DP}^{(25)}$	SPECIFIC DIFFERENTIAL PHASE LONG GATE is K_{DP} after heavy (25-gate) filtering. Specifically, it is the slope of a least squares fit of 25 successive SAMPLE VOLUMEs of $\Phi_{DP}^{(25)}$.
$K_{DP}^{(9)}$	SPECIFIC DIFFERENTIAL PHASE SHORT GATE is K_{DP} after light (9-gate) filtering. Specifically, it is the slope of a least squares fit of 9 successive SAMPLE VOLUMEs of $\Phi_{DP}^{(9)}$.
$K_{DP}^{(processed)}$	PROCESSED SPECIFIC DIFFERENTIAL PHASE is created for any particular range bin by selecting the lightly filtered (9 gate) $K_{DP}^{(9)}$ if the Z > THRESHOLD(REFLECTIVITY) (i.e., default

Term	Definition
	of 40 dBZ), otherwise, the heavily filtered (25 gate) $K_{DP}^{(25)}$ is used.
m	Calculated from the value k/2, "m" is a truncated integer between the range of 1 to HFLTLNG.
MAXSTDEV	Maximum standard deviation used to determine when to update UNFMEDIAN. Standard deviation calculations resulting in a value below MAXSTDEV force UNFMEDIAN to be recalculated.
METFLAG	Meteorological data flag (0 = non-meteorological data, 1 = meteorological data)
METGPBX	Meteo group beginning index.
METGPEX	Meteo group ending index.
MGTOTAL	Meteo group total.
MGXSIZE	Meteo group index size.
MINSTART	Minimum number of SAMPLE VOLUMEs that must be processed before unfolding WRAPPED DIFFERENTIAL PHASE data. Default value is 100.
MINVALID	Minimum number of SAMPLE VOLUMEs containing a valid data value. Used when calculating the standard deviation as part of the Texture calculation. Default value equal to FLTLNG.
N	Index of the last SAMPLE VOLUME along the radial, first SAMPLE VOLUME indexed as 0.
NO DATA	A value selected based on the data array to signify unusable data. Unusable data includes range folded as well as data below threshold.
NUMVALID	Number of valid SAMPLE VOLUMEs containing weather before allowing unfolding to occur. Default value is 15.
R	Slant range to the center of a SAMPLE VOLUME, in km.
SAMPLE VOLUME (*i*)	Data from bin or SAMPLE VOLUME *i*, where the range of i is $0 \leq i \leq N$.
SNR	Signal-to-noise ratio (dB) in the horizontal channel.
SORTARR	Sorted array.
UNSRTARR	Array to be sorted.
UNWMEDIAN	Median value calculated throughout a radial during the unwrapping process. Default is set to $\Phi_{DP}^{(sys)}$ before processing each radial.
VMETGPBX	Valid meteo group beginning index.
VMETGPEX	Valid meteo group ending index.
VMGPNUM	Valid meteo group number (count).

Term	Definition
WRPINDEG	Fold in degrees used in the unfolding process. Default value is set to 360 degrees.
Z	Reflectivity factor (dBZ) for horizontal polarization.
$Z^{(processed)}$	Final processed Reflectivity factor smoothed, then corrected for noise plus horizontal attenuation.
$Z^{(smoothed)}$	Horizontal reflectivity smoothed by a running average technique of FILTER LENGTH gates.
$Z_{DR}^{(calb)}$	Calibration adjustment for differential reflectivity provided by the RDA.
$Z_{DR}^{(processed)}$	Final processed Differential Reflectivity (after smoothing and correcting for horizontal attenuation and system calibration).
$Z_{DR}^{(smoothed)}$	SMOOTHED DIFFERENTIAL REFLECTIVITY - differential reflectivity corrected for noise ($Z_{DR}^{(cor)}$) that is smoothed by a running average technique of FILTER LENGTH gates.
Δr	Range bin spacing (km).
ΔZ	Delta Reflectivity is the bias in base reflectivity due to horizontal attenuation. Specifically it is a measure of the reflectivity-weighted mean axis ratio of the hydrometeors in a radar volume.
ΔZ_{DR}	Delta Differential Reflectivity is the bias in differential reflectivity due to horizontal attenuation.
$\rho_{hv}^{(smoothed)}$	SMOOTHED CORRELATION COEFFICIENT - correlation coefficient corrected for noise ($\rho_{hv}^{(cor)}$) that is smoothed by a running average technique of FILTER LENGTH gates.
$\rho_{hv}^{(threshold)}$	THRESHOLD (CORRELATION COEFFICIENT) - an adaptable parameter value set at the RPG. Default value is set to 0.9.
Φ_{DP}	DIFFERENTIAL PHASE (degrees) that has been unwrapped.
$\Phi_{DP}^{(25)}$	DIFFERENTIAL PHASE LONG GATE is DIFFERENTIAL PHASE that has been unwrapped, smoothed by a 5-gate median filter, then a 25-gate running average filter, and finally interpolated between meteorological targets. The FILTER LENGTH of 25-gates is considered as “heavy” filtering.
$\Phi_{DP}^{(9)}$	DIFFERENTIAL PHASE SHORT GATE is DIFFERENTIAL PHASE that has been unwrapped, smoothed by a 5-gate median filter, then a 9-gate running average filter, and finally interpolated between meteorological targets. The FILTER LENGTH of 9-gates is considered as “light” filtering.
$\Phi_{DP}^{(processed)}$	PROCESSED DIFFERENTIAL PHASE is set equivalent to $\Phi_{DP}^{(25)}$ values and written as an output of the Preprocessor. $\Phi_{DP}^{(processed)}$ has a range from 0.0 to 1080.0 with a precision of at least 0.35 degree.
$\Phi_{DP}^{(sys)}$	A system bias between the vertical and horizontal polarized phases supplied by the RDA.

3.2.2 SYMBOLIC FORMULAS

<u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Calculate a smoothed version of the INPUT ARRAY using a running average window (referred to as boxcar averaging). The smoothed data is stored in the OUTPUT ARRAY.

Where,

1. the INPUT ARRAY is the original data array,
2. the OUTPUT ARRAY is the smoothed data array, and
3. FILTER LENGTH (i.e., FLTLNG) is the size of the running average window.

For SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

$$\mathrm{OUTPUT\,ARRAY}(i) = \frac{1}{c} \sum_{j=i-\mathrm{HFLTLNG}}^{i+\mathrm{HFLTLNG}} \mathrm{INPUT\,ARRAY}(j)$$

Where:

1. the summation of INPUT $\mathrm{ARRAY}_{(j)}$ does not include any INPUT $\mathrm{ARRAY}_{(j)}$ values equal to NO DATA,
2. the counter “c” represents the number of INPUT ARRAY values included in the summation,
3. when “c” = 0 after completing the summation (i.e., all INPUT ARRAY values included in the summation were equal to NO DATA), the OUTPUT ARRAY(i) = NO DATA , and
4. the (j) index used in the summation is constrained to the interval 0 (zero) through N.

<u>COMPUTE</u> (Average Filter (CORRELATION COEFICIENT CORRECTED FOR NOISE, SMOOTHED CORRELATION COEFICIENT, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the CORRELATION COEFFICIENT CORRECTED FOR NOISE array, and
2. OUTPUT ARRAY is equal to the SMOOTHED CORRELATION COEFFICIENT array.

<u>COMPUTE</u> (Average Filter (DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE, SMOOTHED DIFFERENTIAL REFLECTIVITY, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the DIFFERENTIAL REFLECTIVITY CORRECTED FOR NOISE array, and
2. OUTPUT ARRAY is equal to the SMOOTHED DIFFERENTIAL REFLECTIVITY array.

<u>COMPUTE</u> (Average Filter (VELOCITY, SMOOTHED VELOCITY, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the VELOCITY array, and
2. OUTPUT ARRAY is equal to the SMOOTHED VELOCITY array.

<u>COMPUTE</u> (Average Filter (REFLECTIVITY, SMOOTHED REFLECTIVITY, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the REFLECTIVITY array, and
2. OUTPUT ARRAY is equal to the SMOOTHED REFLECTIVITY array.

<u>COMPUTE</u> (Average Filter (DIFFERENTIAL PHASE, SMOOTHED DIFFERENTIAL PHASE, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the DIFFERENTIAL PHASE array, and
2. OUTPUT ARRAY is equal to the SMOOTHED DIFFERENTIAL PHASE array.

<u>COMPUTE</u> (Average Filter (MEDIAN DIFFERENTIAL PHASE, SMOOTHED MEDIAN DIFFERENTIAL PHASE, FILTER LENGTH))

Use <u>COMPUTE</u> (Average Filter (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the MEDIAN DIFFERENTIAL PHASE array, and
2. OUTPUT ARRAY is equal to the SMOOTHED MEDIAN DIFFERENTIAL PHASE array.

<u>COMPUTE</u> (Conditional Check (MEDIAN DIFFERENTIAL PHASE, METFLAG)

For those SAMPLE VOLUMEs where there are no meteorological targets (i.e. METFLAG(i) = 0), the MEDIAN DIFFERENTIAL PHASE(i) is set to NO DATA.

For all SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

<u>IF</u> (METFLAG (i) = 0)
    <u>THEN</u>
    <u>SET</u> MEDIAN DIFFERENTIAL PHASE (i) = NO DATA
<u>ENDIF</u>

<u>COMPUTE</u> (Texture (INPUT ARRAY, SMOOTHED INPUT ARRAY, OUTPUT ARRAY, THRESHOLD, FILTER LENGTH))

Calculate the texture by first calculating the difference between the original data array and a smoothed data array. Next the difference is squared and used in the standard deviation calculation, which is the basis for the texture calculation.

Where,

1. the INPUT ARRAY is the original data array,
2. the SMOOTHED INPUT_ARRAY is the smoothed data array,
3. the OUTPUT ARRAY is the calculated texture array,
4. the THRESHOLD is a data boundary check, and
5. FILTER LENGTH (i.e., FLTLNG) is the size of the running average window.

First, for all SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

IF (INPUT ARRAY (i) = NO DATA OR SMOOTHED INPUT ARRAY (i) = NO DATA)
THEN

$$\text{DIFFERENCE}(\,i\,) = \text{NO DATA}$$

ELSE

$$\text{DIFFERENCE}\ (\,i\,) = \text{INPUT ARRAY}\ (\,i\,) - \text{SMOOTHED INPUT ARRAY}\ (\,i\,)$$

IF (DIFFERENCE (i) > THRESHOLD OR DIFFERENCE (i) < - THRESHOLD)
THEN

$$\text{DIFFERENCE}(\,i\,) = \text{NO DATA}$$

ENDIF
ENDIF

For the next series of calculations, the following apply:

1. calculate the summation for AVER such that it excludes any DIFFERENCE values equal to NO DATA,
2. calculate the summation for OUTPUT ARRAY (i) such that it excludes any DIFFERENCE values equal to NO DATA,
3. the counter “c” represents the number of DIFFERENCE values included in the summation of AVER or OUTPUT ARRAY(i),
4. HFLTLNG is the truncated ((FLTLNG – 1) / 2) represented as an integer, and
5. the (j) index used in the summations is constrained to the interval 0 through N.

For each SAMPLE VOLUME (i) of $0 \le i \le N$:

$$\text{AVER} = \frac{1}{c} \sum_{j=i-\text{HFLTLNG}}^{i+\text{HFLTLNG}} \text{DIFFERENCE}(j)$$

IF (c < MINVALID OR c = 0)
THEN

$$\text{OUTPUT ARRAY}(i) = \text{NO DATA}$$

ELSE

$$\text{OUTPUT ARRAY}(i) = \left[\frac{1}{(c-1)} \sum_{j=i-\text{HFLTLNG}}^{i+\text{HFLTLNG}} (\text{DIFFERENCE}(j) - \text{AVER})^2 \right]^{1/2}$$

ENDIF

COMPUTE (Texture (REFLECTIVITY, SMOOTHED REFLECTIVITY, TEXTURE FOR REFLECTIVITY, THRESHOLD (DIFFERENCE BOUNDARY REFLECTIVITY), FILTER LENGTH))

Use COMPUTE (Texture (INPUT ARRAY, SMOOTHED INPUT ARRAY, OUTPUT ARRAY, THRESHOLD, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the REFLECTIVITY array,
2. SMOOTHED INPUT ARRAY is equal to the SMOOTHED REFLECTIVITY array,
3. OUTPUT ARRAY is equal to the TEXTURE FOR REFLECTIVITY array, and
4. THRESHOLD is equal to THRESHOLD (DIFFERENCE BOUNDARY REFLECTIVITY).

COMPUTE (Texture (DIFFERENTIAL PHASE, SMOOTHED DIFFERENTIAL PHASE, TEXTURE FOR DIFFERENTIAL PHASE, THRESHOLD (DIFFERENCE BOUNDARY DIFFERENTIAL PHASE), FILTER LENGTH))

Use COMPUTE (Texture (INPUT ARRAY, SMOOTHED INPUT ARRAY, OUTPUT ARRAY, THRESHOLD, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the DIFFERENTIAL PHASE array,
2. SMOOTHED INPUT ARRAY is equal to the SMOOTHED DIFFERENTIAL PHASE array,
3. OUTPUT ARRAY is equal to the TEXTURE FOR DIFFERENTIAL PHASE array, and
4. THRESHOLD is equal to THRESHOLD (DIFFERENCE BOUNDARY DIFFERENTIAL PHASE).

COMPUTE (SIGNAL TO NOISE RATIO)

Calculate the signal-to-noise ratio for the horizontal channel (SNR).

Where,

1. SNR (i) = NO DATA when $Z^{(smoothed)}(i)$ = NO DATA, and
2. ATMOS is delivered from the RDA as a negative value.

For SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

$$SNR_h\ (i) = Z^{(smoothed)}\ (i) - 20\log(R(i)) + (ATMOS * R(i)) - Z^{(dBZ0)}$$

COMPUTE (Meteo Data)

Identify SAMPLE VOLUMEs as meteorological targets using METFLAG (i) = 1.

For all SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

IF ($\rho_{hv}^{(smoothed)}(i) < \rho_{hv}^{(threshold)}$ OR $\rho_{hv}^{(smoothed)}(i)$ = NO DATA OR Φ_{DP} (i) = NO DATA)
THEN
METFLAG (i) = 0
ELSE
METFLAG (i) = 1
ENDIF

COMPUTE (Meteo Groups)

Identify consecutive clusters of METFLAG = 1 by recording the beginning SAMPLE VOLUME index, the size of the Meteo Group cluster, and the ending SAMPLE VOLUME index.

For the following computation, the initial value for:

1. METFLAG (0) is equal to 1,
2. METGPBX (0) is equal to 0 (zero),
3. MGTOTAL is equal to 0 (zero), and
4. index “j” is equal to 0 (zero).

For all SAMPLE VOLUMEs (i) of 1 ≤ i ≤ N:

```
IF (METFLAG (i-1) = 0 AND METFLAG (i) = 1)
        THEN
        SET METGPBX (j) = i
        SET MGTOTAL = j
ELSEIF (METFLAG (i-1) = 1 AND METFLAG (i) = 0)
        THEN
        SET METGPEX (j) = i – 1
        SET MGXSIZE (j) = METGPEX (j) – METGPBX (j) +1
        SET j = j + 1
ENDIF
```

When all SAMPLE VOLUMEs (i) are complete, there should be an equal number of METGPBX and METGPEX identified. If this is not the case, add the final METGPEX and calculate MGXSIZE:

METGPEX (j) = N
MGXSIZE (j) = METGPEX (j) – METGPBX (j) +1

Note: For a radial where no meteorological targets exist, the above computation will result in one Meteo Group being defined with values of METGPBX (0) = 0, METGPEX (0) = 0, MGXSIZE (0) = 1, and MGTOTAL = 0.

COMPUTE (Median (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Calculate the median for the INPUT ARRAY and store the result in the OUTPUT ARRAY. The process involves:

1. generating an array called UNSRTARR (unsorted array) containing a group of valid INPUT ARRAY values within a FILTER LENGTH (i.e., FLTLNG) window centered about the SAMPLE VOLUME (i),
2. sorting the UNSRTARR array into an array called SORTARR, and
3. copying the midpoint value from the array SORTARR and storing in OUTPUT ARRAY (i).

For the calculation of UNSTRARR the following apply:

1. k is a counter representing the number of valid INPUT ARRAY(j) values included in the UNSRTARR (k),
2. the UNSRTARR (k) does not include any INPUT ARRAY(j) values equal to NO DATA,
3. HFLTLNG is the truncated ((FLTLNG – 1) / 2) represented as an integer, and
4. the (j) index is constrained to the interval 0 (zero) through N.

For all SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

$$\mathrm{UNSRTARR(k)}\Big|_{k=0}^{\mathrm{FTRLNG\text{-}1}} = \mathrm{INPUTARRAY(j)}\Big|_{j=i\text{-}\mathrm{HFLTLNG}}^{i+\mathrm{HFLTLNG}}$$

IF (k = 0)
THEN
SET OUTPUT ARRAY (i) = NO DATA
ELSE
SORT (UNSRTARR (k) into a new array called SORTARR (k))
SET m = k / 2
SET OUTPUT ARRAY (i) = SORTARR (m)
ENDIF

COMPUTE (Median (DIFFERENTIAL PHASE, MEDIAN DIFFERENTIAL PHASE, FILTER LENGTH = 5))

Use COMPUTE (Median (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the DIFFERENTIAL PHASE array, and
2. OUTPUT ARRAY is equal to the MEDIAN DIFFERENTIAL PHASE array.

<u>COMPUTE</u> (Valid Meteo Groups (FILTER LENGTH))

Identify the beginning and ending indexes of Meteo Group clusters with a size greater than or equal to FILTER LENGTH.

For the following computation, the initial value for:

1. index "k" is equal to 0 (zero), and
2. VMGPNUM is equal to 0 (zero).

For all MGXSIZE (j) of $0 \leq j \leq$ MGTOTAL,

<u>IF</u> (MGXSIZE (j) ≥ FLTLNG)
<u>THEN</u>
<u>SET</u> VMETGPBX (k) = METGPBX (j)
<u>SET</u> VMETGPEX (k) = METGPEX (j)
<u>SET</u> VMGPNUM = VMGPNUM + 1
<u>SET</u> k = k +1
<u>ENDIF</u>

<u>COMPUTE</u> (HORIZONTAL ATTENUATION FOR REFLECTIVITY)

For the specific SAMPLE VOLUME (i),

$$\Delta Z\ (i) = 0.04\ (\Phi_{DP}{}^{(25)}(i) - \Phi_{DP}{}^{(sys)})$$

<u>COMPUTE</u> (HORIZONTAL ATTENUATION FOR DIFFERENTIAL REFLECTIVITY)

For the specific SAMPLE VOLUME (i),

$$\Delta Z_{DR}(i) = 0.004\,(\Phi_{DP}^{(25)}(i) - \Phi_{DP}^{(sys)})$$

<u>COMPUTE</u> (Interpolate (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Between Valid Meteo Group clusters, an interpolation method is used to change INPUT ARRAY values outside and at the beginning and ending of each Valid Meteo Group cluster. The interpolation method starts by identifying the range of SAMPLE VOLUMEs that exist between the Valid Meteo Group clusters, then expands this range by HFLTLNG into the Valid Meteo Group clusters at each end of this interpolation range. Straight line interpolation occurs over the identified SAMPLE VOLUME range. If there are no Valid Meteo Group clusters defined for the radial, the OUTPUT ARRAY is set to a constant ($\Phi_{DP}^{(sys)}$).

First, a copy of the INPUT ARRAY values is moved into the OUTPUT ARRAY before beginning the interpolation process:

$$\text{OUTPUT ARRAY (i)}\Big|_{i=0}^{N} = \text{INPUT ARRAY (i)}$$

Next, the interpolation method is executed:

<u>IF</u> (VMGPNUM = 0)
    <u>THEN</u>

$$\text{OUTPUTARRAY(i)}\Big|_{i=0}^{N} = \Phi_{DP}^{(sys)}$$

<u>ELSE</u>
    <u>DO FOR ALL</u> Valid Meteo Groups (j) of $0 \le j \le$ VMGPNUM
        <u>IF</u> (j = 0)
            <u>THEN</u>
            <u>SET</u> BEGBIN = 0
            <u>SET</u> ENDBIN = (VMETGPBX (j) + HFLTLNG)
            <u>SET</u> BEGPHIDP = $\Phi_{DP}^{(sys)}$
            <u>SET</u> ENDPHIDP = INPUT ARRAY (ENDBIN)

```
ELSEIF (j = VMGPNUM)
        SET BEGBIN = (VMETGPEX (j) - HFLTLNG)
        SET ENDBIN = N
        SET BEGPHIDP =  INPUT ARRAY (BEGBIN)
        SET ENDPHIDP =  INPUT ARRAY (BEGBIN)
ELSE
        SET BEGBIN = (VMETGPEX ( j ) - HFLTLNG)
        SET ENDBIN = (VMETGPBX ( j + 1 )  + HFLTLNG)
        SET BEGPHIDP = INPUT ARRAY (BEGBIN)
        SET ENDPHIDP = INPUT ARRAY (ENDBIN)
ENDIF
```

$$\mathrm{SLOPE} = \frac{\mathrm{ENDPHIDP} - \mathrm{BEGPHIDP}}{\mathrm{ENDBIN} - \mathrm{BEGBIN}}$$

$$\mathrm{OUTPUT\ ARRAY\ (i)}\Big|_{\mathrm{i = BEGBIN}}^{\mathrm{ENDBIN}} = \mathrm{SLOPE} * (\mathrm{i} - \mathrm{BEGBIN}) + \mathrm{BEGPHIDP}$$

```
        ENDDO
ENDIF
```

COMPUTE (Interpolate (SMOOTHED MEDIAN DIFFERENTIAL PHASE, DIFFERENTIAL PHASE SHORT GATE, FILTER LENGTH = 9))

Use COMPUTE (Interpolate (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the SMOOTHED MEDIAN DIFFERENTIAL PHASE array,
2. OUTPUT ARRAY is equal to the DIFFERENTIAL PHASE SHORT GATE array.

COMPUTE (Interpolate (SMOOTHED MEDIAN DIFFERENTIAL PHASE, DIFFERENTIAL PHASE LONG GATE, FILTER LENGTH = 25))

Use COMPUTE (Interpolate (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the SMOOTHED MEDIAN DIFFERENTIAL PHASE array,
2. OUTPUT ARRAY is equal to the DIFFERENTIAL PHASE SHORT GATE array.

<u>COMPUTE</u> (SPECIFIC DIFFERENTIAL PHASE SHORT GATE, FILTER LENGTH)

For the calculation of $K_{DP}^{(9)}$ the following apply:

1. the (i + j) index used in the summation is constrained to the interval 0 (zero) through N.

For all SAMPLE VOLUMES (i) , calculate $K_{DP}^{(9)}$ (i) using the equation:

$$K_{DP}^{(9)}(i) = \frac{6 \sum_{j=-(HFLTLNG)}^{HFLTLNG} j\,(\Phi_{DP}^{(9)}(i+j))}{\Delta r\,(FLTLNG)\,(FLTLNG-1)\,(FLTLNG+1)}$$

Note: this equation only works for odd number of SAMPLE VOLUMES (i.e., 3, 5, 7, 9, etc. number of SAMPLE VOLUMES in the summation) and a more generic version using Linear Least Squares Estimation should be applied when the number of gates are not odd (i.e., 2,4,6,8, etc. number of SAMPLE VOLUMES in the summation).

<u>COMPUTE</u> (SPECIFIC DIFFERENTIAL PHASE LONG GATE, FILTER LENGTH)

For the calculation of $K_{DP}^{(25)}$ the following apply:

1. the (i + j) index used in the summation is constrained to the interval 0 (zero) through N.

For all SAMPLE VOLUMES (i), calculate $K_{DP}^{(25)}$ using the equation:

$$K_{DP}^{(25)}(i) = \frac{6 \sum_{j=-(HFLTLNG)}^{HFLTLNG} j\,(\Phi_{DP}^{(25)}(i+j))}{\Delta r\,(FLTLNG)\,(FLTLNG-1)\,(FLTLNG+1)}$$

Note: this equation only works for odd number of SAMPLE VOLUMES (i.e., 3, 5, 7, 9, etc. number of SAMPLE VOLUMES in the summation) and a more generic version using Linear Least Squares Estimation should be applied when the number of gates are not odd (i.e., 2,4,6,8, etc. number of SAMPLE VOLUMES in the summation).

<u>COMPUTE</u> (PROCESSED DIFFERENTIAL REFLECTIVITY)

For the specific SAMPLE VOLUME (i),

$$Z_{DR}^{(processed)}(i) = Z_{DR}^{(cor)}(i) + \Delta Z_{DR}(i) + Z_{DR}^{(calb)}$$

<u>COMPUTE</u> (PROCESSED REFLECTIVITY)

For the specific SAMPLE VOLUME (i),

$$Z^{(processed)}(i) = Z^{(smoothed)}(i) + \Delta Z(i)$$

<u>COMPUTE</u> (Unwrapping (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Unwrap the wrapped (aliased) radial contained in INPUT ARRAY and store the results in OUTPUT ARRAY.

Where,

1. the INPUT ARRAY is the original data array,
2. the OUTPUT ARRAY is the unwrapped array, and
3. FILTER LENGTH (i.e., FLTLNG) is the filter length used as part of the UNWMEDIAN calculation.

For the computation, the following apply:

1. the UNSRTARR (k) does not include any INPUT ARRAY(j) values equal to NO DATA;
2. the UNSRTARR (k) includes only INPUT ARRAY(j) values where the $\rho_{hv}^{(cor)}$ value at SAMPLE VOLUME(j) is greater then or equal to $\rho_{hv}^{(threshold)}$;
3. the counter "c" represents the number of valid UNSRTARR(k) values that are included in the summation of AVER or STDDEV;
4. the (j) index used in the UNSTRARR calculation is constrained to the interval 0 (zero) through N; and
5. OUTPUT ARRAY (i) = NO DATA, when INPUT ARRAY (i) = NO DATA.

To start the computation, the process begins by setting several variables before processing each radial:

1. UNWMEDIAN is set to $\Phi_{DP}^{(sys)}$;
2. counter is set to 0 (zero);
3. MAXSTDEV is set to WRPINDEG/3.0 ;
4. HWRPINDEG is set to WRPINDEG/2.0; and
5. DWRPINDEG is set to WRPINDEG*2.0.

For all SAMPLE VOLUMEs (i) of $0 \leq i \leq N$:

INITIALIZE UNSRTARR = 0
INITIALIZE UNWRAP = 0

IF ($\rho_{hv}^{(cor)}$ (i) $\geq \rho_{hv}^{(threshold)}$ AND $\rho_{hv}^{(cor)}$ (i) $\neq$ NO DATA)
THEN
SET counter = counter + 1
ENDIF

$$\text{UNSRTARR (k)}\Big|_{k=0}^{\text{FLTLNG}-1} = \text{INPUT ARRAY (j)}\Big|_{j=i-\text{HFLTLNG}}^{i+\text{HFLTLNG}}$$

SET c = number of valid values stored in UNSRTARR(k)

```
IF (c > HFLTLNG)
        THEN
```

$$\text{AVER} = \frac{1}{c}\sum_{k=0}^{c-1}\text{UNSRTARR}(k)$$

$$\text{STDDEV} = \left[\frac{1}{(c-1)}\sum_{k=0}^{c-1}(\text{UNSRTARR}(k) - \text{AVER})^2\right]^{1/2}$$

```
        IF (STDDEV < MAXSTDEV)
                THEN
                SORT (UNSRTARR (k) into a new array called SORTARR (k))
                SET m = FLOOR (c / 2)
                SET UNWMEDIAN = SORTARR (m)
        ENDIF
ENDIF

SET A = ABS (UNWMEDIAN – INPUT ARRAY(i))
IF (i ≥ MINSTART AND A ≥ HWRPINDEG AND counter > NUMVALID)
        THEN
        SET B = ABS (UNWMEDIAN – (INPUT ARRAY(i) + WRPINDEG))
        SET C = ABS (UNWMEDIAN – (INPUT ARRAY(i) + DWRPINDEG))
        IF (A > B)
                THEN
                SET UNWRAP = 1
        ENDIF
        IF (B > C)
                THEN
                SET UNWRAP = 2
        ENDIFENDIF
```

```
IF (UNWRAP = 1)
        THEN
        SET OUTPUT ARRAY(i) = INPUT ARRAY(i) + WRPINDEG
ELSEIF (UNWRAP = 2)
        THEN
        SET OUTPUT ARRAY(i) = INPUT ARRAY(i) + DWRPINDEG
ELSE
        SET OUTPUT ARRAY(i) = INPUT ARRAY(i)
ENDIF
```

COMPUTE (Unwrapping (WRAPPED DIFFERENTIAL PHASE, DIFFERENTIAL PHASE, FILTER LENGTH))

Use COMPUTE (Unwrapping (INPUT ARRAY, OUTPUT ARRAY, FILTER LENGTH))

Where,

1. INPUT ARRAY is equal to the WRAPPED DIFFERENTIAL PHASE array,
2. OUTPUT ARRAY is equal to the DIFFERENTIAL PHASE array, and
3. FILTER LENGTH (i.e., FLTLNG) is the filter length used as part of the unwrapping process.

4 OUTPUTS

4.1 IDENTIFICATION

Term	**Definition**
CORRELATION COEFFICIENT CORRECTED FOR NOISE	$\rho_{hv}^{(cor)}$ – is the original CORRELATION COEFFICIENT CORRECTED FOR NOISE that is provided by the RDA. $\rho_{hv}^{(cor)}$ values range from 0.2 to 1.05 with a precision of at least 0.00333. Values are stored within 16 bits and all 16 bits are used.
PROCESSED DIFFERENTIAL PHASE	$\Phi_{DP}^{(processed)}$ (deg) – is set equivalent to $\Phi_{DP}^{(25)}$ values which range from 0.0 to 1080.0 with a precision of at least 0.35 degree. Values are stored within 16 bits and all 16 bits are used.
PROCESSED DIFFERENTIAL REFLECTIVITY	$Z_{DR}^{(processed)}$ (dB) – the differential reflectivity factor from the horizontal polarization over a radar bin that has been corrected for noise at the RDA, then adjusted for calibration, and corrected for horizontal attenuation. Accuracy is defined by the accuracy of the base data. Values range from (-8.0) dB to +8.0 dB, and the precision is 0.06 dB.
PROCESSED REFLECTIVITY	$Z^{(processed)}$ (dBZ) – the original reflectivity factor from the horizontal polarization over a radar bin that has been adjusted for calibration (at the RDA), then smoothed (FILTER LENGTH = 3) and corrected for horizontal attenuation. Accuracy is defined by the accuracy of the base data. Reflectivity values range from (-32.0) dBZ to +94.5 dBZ, and the precision is 0.50 dBZ.
PROCESSED SPECIFIC DIFFERENTIAL PHASE	$K_{DP}^{(processed)}$ (deg km^{-1}) - is the combination of both SPECIFIC DIFFERENTIAL PHASE SHORT GATE and SPECIFIC DIFFERENTIAL PHASE LONG GATE data. SPECIFIC DIFFERENTIAL PHASE LONG GATE is used only for SAMPLE VOLUMEs where the PROCESSED REFLECTIVITY is less than or equal to THRESHOLD (REFLECTIVITY). Values range from -2.05 to +10.60 degrees/km with a precision of at least 0.05 degrees/km.* Values are stored within 16 bits and all 16 bits are used.

Term	Definition
SIGNAL TO NOISE RATIO	SNR (dB) – derived value representing the ratio of signal to noise in the horizontal channel. SNR values range from -12.0 to +110 dB with a precision of 0.5 dB.
SMOOTHED VELOCITY	$V^{(smoothed)}$ (m/s) – the original ORDA base radial velocity from horizontal polarization over a radar bin, smoothed using a 5 point running average. Accuracy is defined by the accuracy of the base data generated at the RDA. Radial velocity ranges from -63.5 m/s to +63.0 m/s with low (0.5 m/s) velocity increment and from -127.0 m/s to +126.0 m/s with high (1.0 m/s) velocity increment. Precision is 0.50 m/s at low increment and 1.00 m/s at high increment.
SPECTRUM WIDTH	σ_υ (m s^{-1}) – a measure of the dispersion of velocities in a radar sample volume. The computation performed is the returned signal autocorrelation which is related to the velocity spectrum standard deviation. Values range from -63.5 m/s to +63.0 m/s, and the precision is 0.50 m/s.
TEXTURE FOR DIFFERENTIAL PHASE	$SD(\Phi_{DP})$ – is a derived value based on standard deviation calculation using a 9-gate smoothed field of DIFFERENTIAL PHASE. Values range from 0 to 100 degrees with a precision of 0.4 degrees.*
TEXTURE FOR REFLECTIVITY	SD(Z) – is a derived value based on standard deviation calculation using a 5-gate smoothed field of REFLECTIVITY. Values range from 0 to 30 dBZ with a precision of 0.12 dBZ.*

* Two data levels have been reserved for "no data" and range folded data. Therefore, the precision is based on 2^{15} data levels.

4.2 DISTRIBUTION

The outputs can be displayed for subjective assessment. However, the primary value of preprocessing output is as input to dual polarimetric algorithms, such as the Hydrometeor Classification Algorithm (HCA) and the Dual Polarimetric Quantitative Precipitation Estimation (QPE) algorithm.

5 INFERENCES

5.1 STRENGTHS AND LIMITATIONS

a. Preprocessing enables better (i.e., less noisy) data to be used in algorithms (such as the HCA and QPE) that create dual polarization products.
b. As range increases, the beam width increases, which results in degraded polarimetric measurements.
c. Non-uniform beam filling, particularly at great ranges, can limit the quality of polarimetric measurements.
d. Regions having a strong vertical gradient of precipitation within a storm may cause negative K_{DP} values, which can limit K_{DP} usefulness.
e. Other limitations may be discovered after dual polarimetric radars have collected data in a variety of weather conditions (such as mixed precipitation, ground returns, and biological returns).

5.2 FUTURE DEVELOPMENTS

a. Thresholds may be optimized based on experience in a variety of weather conditions.
b. Smoothing parameters (i.e., the number of range bins used to smooth data) may need to be optimized depending upon performance of the data in dual polarimetric algorithms.
c. Depending upon data compression and bandwidth limitations, the precision levels may change for some products.