253 DUAL POLARIMETRIC QUALITY CONTROL FOR NASA'S GLOBAL PRECIPITATION MEASUREMENT (GPM) MISSION GROUND VALIDATION PROGRAM

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1. INTRODUCTION

The recent upgrade of the National Weather Service's Weather Surveillance Radar 88 Doppler (WSR-88D) radar network to dual polarization (DP) and the availability of research DP radars, such as NASA Polarimetric (NPOL) and Kwajalein Polarimetric (KPOL), allows NASA's GPM Ground Validation program (GPM-GV) to capture unique polarimetric data to foster improved understanding of precipitation microphysics, and provide essential input for development of precipitation retrieval algorithms. The quality control (QC) of these data sets is a critical first step in this process.

GPM-GV developed an algorithm based on Ryzhkov et al. 1998, that uses DP parameters to QC radar data (DPQC). QC algorithms based on DP parameters have been successful in the identification of non-precipitating echoes (Ryzhkov and Zrnic 1998; Zrnic and Ryzhkov 1999; Cifelli et al. 2002). A previous version of the DPQC algorithm was discussed in Marks et. al 2011. Updates to the algorithm include the ability to process WSR-88D data, improved data quality by only applying QC below the freezing level of the radar beam height, and the addition of modules that remove or apply thresholds to a sector. The algorithm is applied daily to twenty-five radars selected for evaluation of GPM (Fig. 1). Continuous operational DPQC is applied to Melbourne, FL (KMLB), Dover, DE (KDOX), Wakefield, VA (KAKQ), Newark, MD (NPOL) and KPOL. DPQC is applied during Tropical Rainfall Measuring Mission (TRMM) satellite overpasses to twenty-one WSR-88D radars situated in the southern United States. The radars are associated with the GPM-GV Validation Network (VN). DPQC was applied to NPOL data during the Midlatitude Continental Convective Clouds Experiment (MC3E – Jensen et al. 2010) and Iowa Flood Studies (IFloodS) field campaigns.

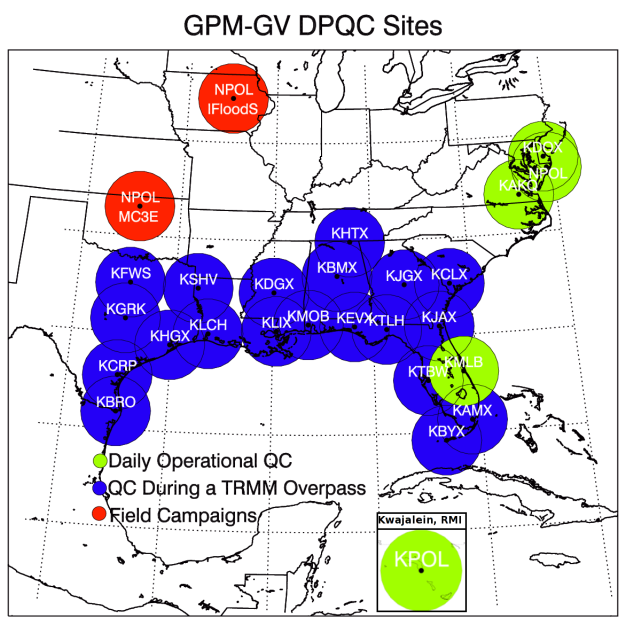

Fig 1. *Pictured are the twenty-five GPM-GV radar sites that use DPQC for quality control.*

This paper will review how the DPQC algorithm applies quality control to any radar structure using NASA's Radar Software Library (RSL) in the IDL programming language (RSL-in-IDL). An examination of the tunable DP parameter threshold

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modules, and which modules are best suited for the removal of ground clutter, sea clutter, biological targets, multiple trip echo, and anomalous propagation (AP) will be discussed. Finally, a discussion of additional modules that improve the QC product.

2. DPQC ALGORITHM

The goal of this effort was to develop a DPQC algorithm that is both modular and physically based. The modular functions and procedures were written using RSL so that the programs can easily be used with other polarimetric radars via passing of an RSL "radar" structure. DPQC can be applied to multiple scan types i.e. PPI, RHI, and PPS. RSL-in-IDL allows the user to easily view and manipulate the radar structure by volume, sweep, ray, and range. There are various fields within the radar structure (Table 1), and DPQC threshold modules are dependent on the values associated with these fields.

When the value of a gate falls outside one of the thresholds a missing data mask will be applied to

Field	Description
ZT (Sigmet)	Raw reflectivity [dBZ].
DZ (WSR-88D)	Level II reflectivity [dBZ].
CZ	Corrected reflectivity [dBZ]. Created by DPQC.
DR	Differential reflectivity [dB].
RH	Co-polar cross correlation.
PH	Differential phase [deg].
SD	Standard deviation of PH [deg]. Created by DPQC.
SQ	Signal quality index. Sigmet only.
KD	Specific differential phase [deg km^{-1}] Created by DPQC for WSR-88D.
VR	Radial velocity [m s^{-1}]

Table 1. *Fields of interest within the RSL "Radar" structure.*

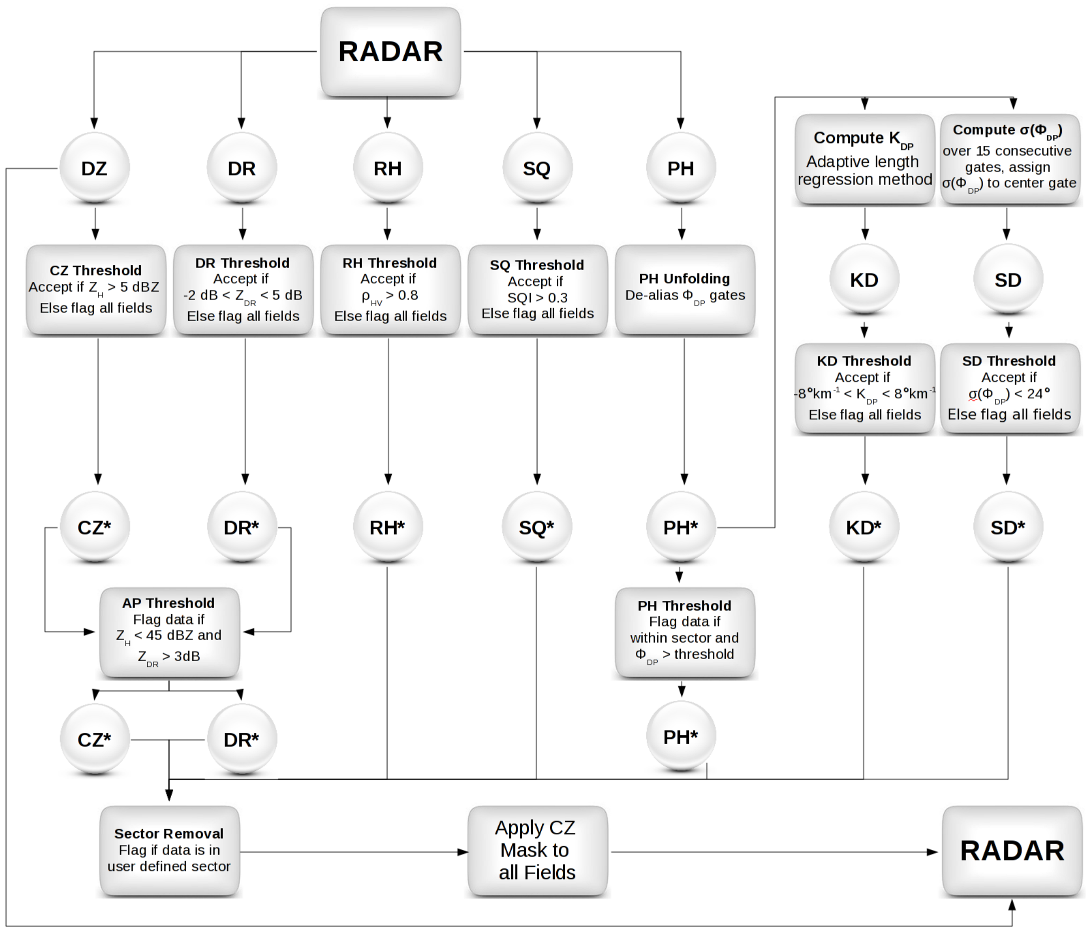
that specific gate for all fields. DP values commonly fall outside the established QC thresholds near the melting level, resulting in unwarranted data removal. To account for this problem, DPQC calculates the height of the radar beam and only applies QC below a user defined height or sounding retrieved height. In an operational environment hourly model soundings are used to estimate the melting level, and QC is applied to data 1-km below this level.

A function within DPQC determines if a differential phase (Φ_{DP}) gate is aliased. An aliased gate is identified when the absolute value of the phase difference between the consecutive gates exceeds 149° (Marks et al. 2011), and the gate is not considered to be noise or clutter. When an aliased PH gate is detected DPQC will correct the data by adding 180° to the aliased gate.

Another function calculates the standard deviation of differential phase $\sigma(\Phi_{DP})$. The SD field is estimated by calculating the standard deviation of fifteen consecutive Φ_{DP} gates and applying that value to the center gate. A minimum of five gates must contain valid data to calculate $\sigma(\Phi_{DP})$, otherwise, the center gate is set to the missing data mask.

The RVP processor calculates specific differential phase (K_{DP}) for Sigmet radars (NPOL, KPOL). DPQC calculates K_{DP} from Φ_{DP} for WSR-88D radars using an adaptive length regression method. For light precipitation (less than 35 dBZ) twenty-five consecutive Φ_{DP} gates are used for the regression line. Moderate to heavy precipitation (greater than 35 dBZ) nine consecutive Φ_{DP} gates are used for the regression line. The resulting K_{DP} value is applied to the center gate.

The DPQC algorithm outputs the quality controlled radar structure into Universal Format (UF) for downstream product generation. Additional output includes plots of all quality controlled radar fields and a quality control parameter file detailing which modules were run and the thresholds used (Table 2).



* All fields are modified in each step to remove non-precipitating echo. Threshold values are default for WSR-88D radars.

Fig 2. *Flowchart depicting the DPQC algorithm.*

3. DPQC THRESHOLD MODULES

Each threshold module has its strengths for removing a certain type of non precipitating echo. Primary fields for QC threshold modules include ZT/DZ, RH, DR, σ(PH), KD, and SQ. A flow chart of the DPQC algorithm is presented in Fig. 2, and a description of each step follows. We will use a test case with abundant false echo, Fig. 3a shows a PPI DZ plot from KLIX (New Orleans, LA) on July 3, 2013 at 1433Z. QC height is set to 4.4 km, this allows QC to be applied out to 200 km for the 0.48° base sweep.

3.1 *Reflectivity (CZ) Threshold*

The first module DPQC executes is CZ threshold which removes very light echo that is usually associated with noise. QC height is not factored into its application. When a reflectivity gate is less than the threshold, the gate is flagged as missing. The default CZ threshold of 5 dBZ is applied to our test case, low reflectivity values were removed. The results are shown in the PPI CZ plot in Fig. 3b.

3.2 Co-polar Cross Correlation (RH) Threshold

The RH threshold is useful in distinguishing rain from non-rain. When a ρ_{HV} gate is less than the threshold, the gate is flagged as missing. Most likely values of ρ_{HV} for precipitation range from 0.9-1.0, however ice and large wet aggregates can have ρ_{HV} values below 0.9. For most non-precipitation echoes ρ_{HV} is rarely greater than 0.90 except for certain types of static ground clutter which can get as high as 0.99 (National 2013). To be cautious the default RH threshold is set to 0.8, thereby avoiding the removal of

QC Parameter File	
RH_Thresh_Test:	0.800000
Min dBZ:	5
Min Zdr:	-2
Max Zdr:	5
Min Kdp:	-8
Max Kdp:	8
Use_Sounding:	no
QC_Height:	4.40000 KM
DO_SQ_THRESH:	no
DO_AP_THRESH:	yes
--> AP_Zdr_THRESH:	3
--> AP_dBZ_THRESH:	45
DO_SD_THRESH:	yes
--> SD_THRESH:	24.00
DO_sector_wipeout:	yes
--> RH Sector:	1.20000
--> Start azimuth:	210
--> End azimuth:	25
--> Min range:	0.00000 KM
--> Max range:	200 KM
--> Wipeout applied to:	ALL sweeps
DO_ph_sector:	no
DO_Cone_of_Silence:	no
No_Precip:	no
BEGIN_TIME:	1433
END_TIME:	1433

Table 2. *The DPQC algorithm outputs a parameter file with information on which modules were applied and their associated parameters. The above table is a test case from KLIX (New Orleans, LA) on July 3, 2013 at 1433Z*

gates with precipitation echoes. A PPI plot of the RH field with low values of ρ_{HV} can be observed in Fig. 3c. Executing the module with the default threshold of 0.8 removes some false echo (Fig. 3d). When there is no precipitation DPQC applies an elevated RH threshold to remove all echo.

3.3 Differential Reflectivity (DR) Threshold

DPQC continues with the DR threshold. Z_{DR} is an excellent identifier of ground clutter, AP, biological targets, and chaff. Typical values of Z_{DR} for precipitation range from 0 to 5 dB, however frozen precipitation can fall bellow 0 dB (National 2013). The DR threshold default values of -2.0 dB for the minimum and 5.0 dB for the maximum account for all types of precipitation. When a Z_{DR} gate is less than the minimum threshold or greater than the maximum threshold that gate will be flagged as missing. The PPI plot of DR in Fig. 3e is a great example of Z_{DR} identifying false echo where excessively high values are non-precipitating, most likely biological targets and AP. The defaults seem too conservative for the current case, so a smaller allowable range of -2.0 to 3.0 dB would in theory remove the false echo. In actuality this range would remove gates of real echo especially at higher elevations. Defaults are run on our test case and the data is noticeably cleaner (Fig. 3f).

3.4 *Standard Deviation of Phase (SD) Threshold*

The SD threshold is useful in the detection of AP, ground clutter, and multiple trip echo. Observations of $\sigma(\Phi_{DP})$ for GPM-GV radars revealed that within precipitation $\sigma(\Phi_{DP})$ is usually less than the default threshold of 24°. When a $\sigma(\Phi_{DP})$ gate is greater than the SD threshold the gate is flagged as missing. If SD could not be calculated then that gate is set to missing for all fields. This test is good for removing speckle close to the radar. A PPI plot of the SD field is shown in Fig. 4a. The revised PPI CZ field with SD threshold set to 24° is shown in Fig. 4b.

3.5 Specific Differential Phase (KD) Threshold

The KD threshold identifies extremely unrealistic values of K_{DP}. Realistic values for K_{DP} are approximately -1 to 7 deg km^{-1} (National 2013). K_{DP} is noisy as seen in the PPI KD plot in Fig. 4c, so thresholds are usually relaxed to avoid removing valid data. When a K_{DP} gate is less than the minimum

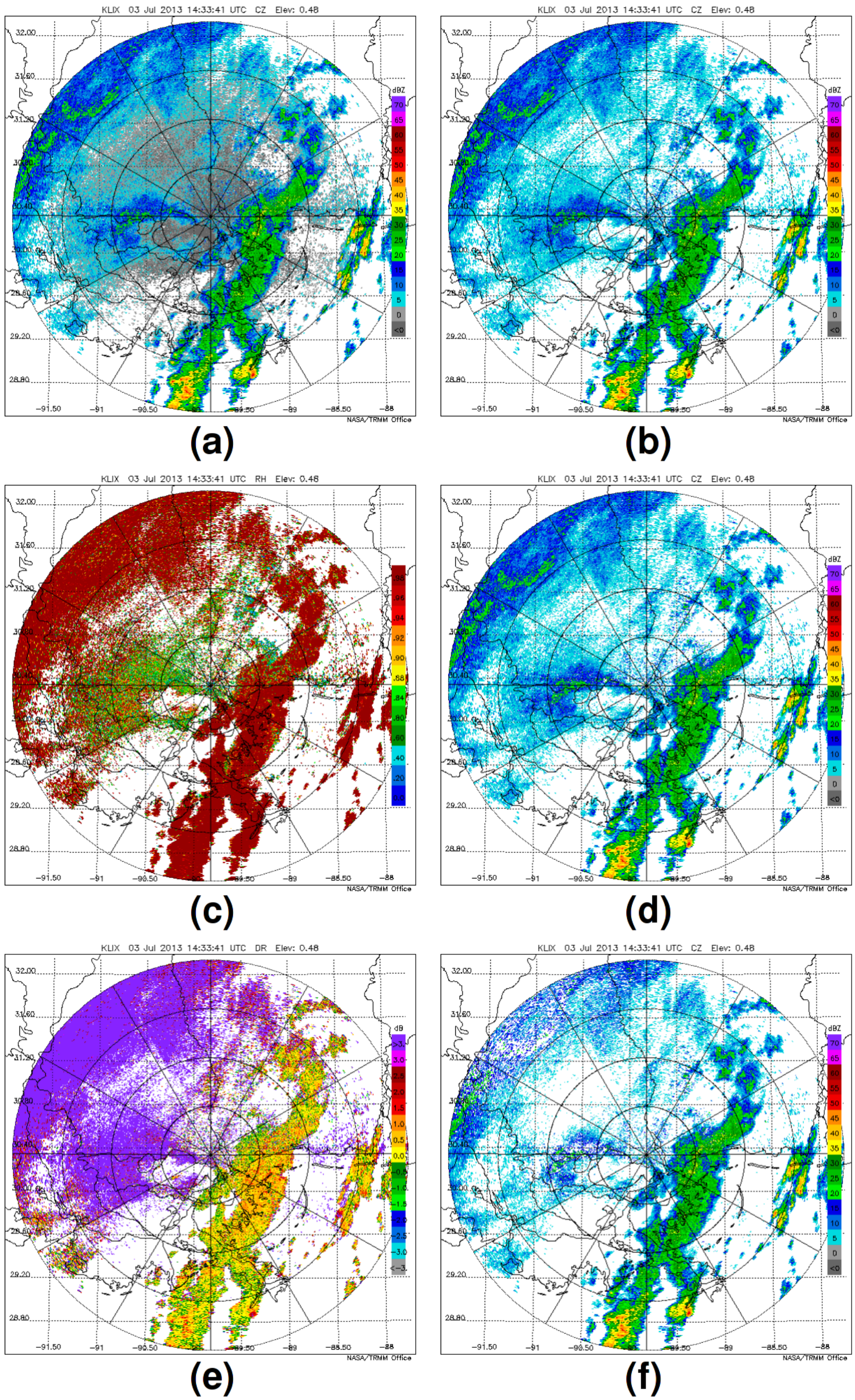


Fig 3. *Sequential 0.48° elevation PPI plots of a DPQC test case from KLIX (New Orleans, LA) on July 3, 2013 at 1433Z. When a gate fails a threshold test that gate will be masked as missing for all fields. (a) DZ field, (b) CZ field with a CZ threshold of 5 dBZ, (c) RH field, (d) CZ field with a RH threshold of 0.80, (e) DR field, and (f) CZ field with a DR threshold of -2 dB to 5 dB. Each threshold removes some false echo.*

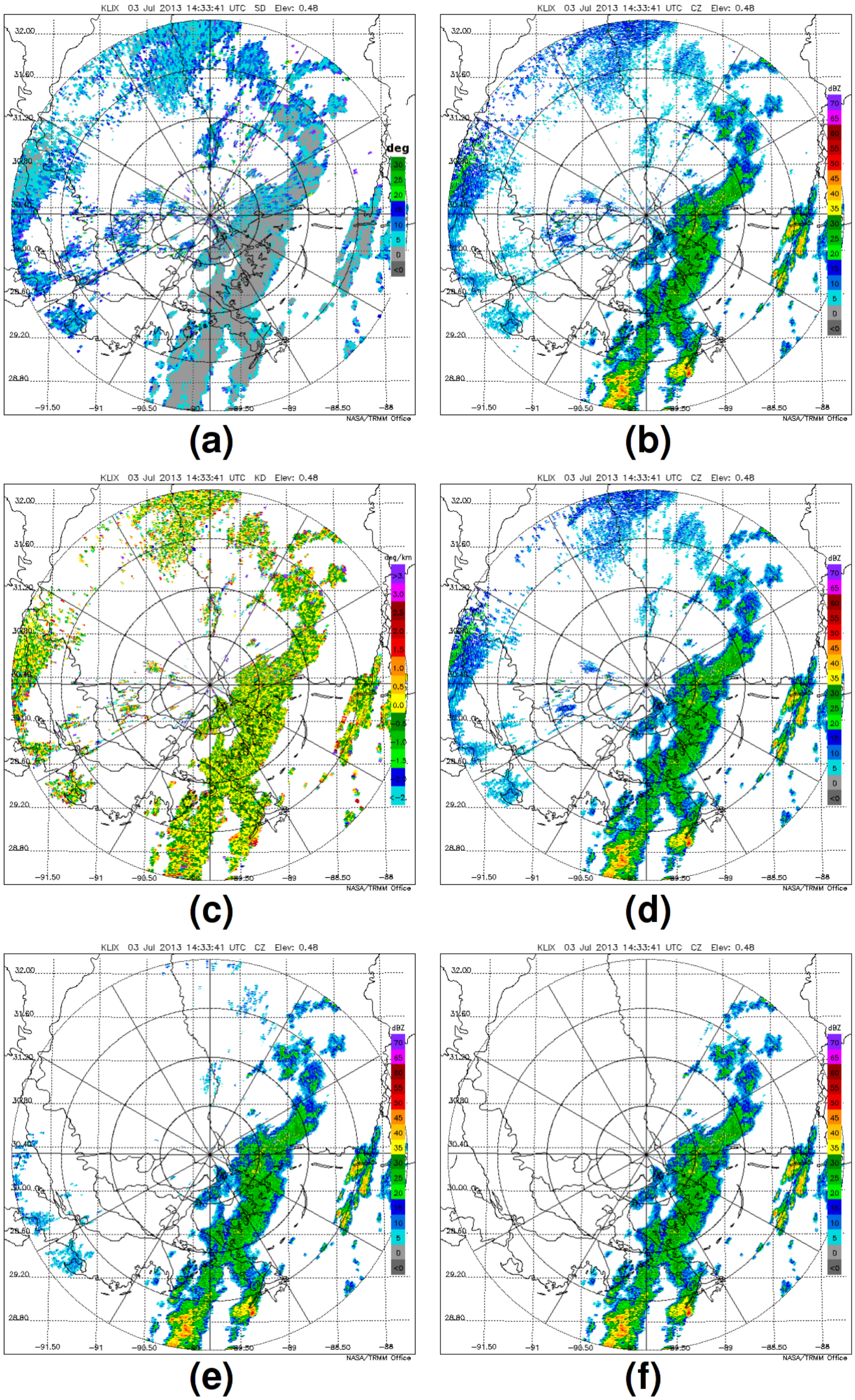


Fig 4. *A continuation from fig. 3 of the sequential plots from our test case. (a) SD field, (b) CZ field with a SD threshold of 24°, (c) KD field, (d) CZ field with a KD threshold of -8 to 8* deg km^{-1}, (e) *CZ field with a AP reflectivity threshold of 45 dBZ and a AP Z_{DR} threshold of 3 dB, (f) CZ field with the sector between azimuths 210-25° from 0-200 km range set to missing. QC complete, case is free of false echo.*

threshold or greater than the maximum threshold that gate will be flagged as missing. When gates of K_{DP} can not be calculated, those gates are flagged as missing for all fields. Similar to SD threshold this test will remove speckle. The test case is run with the default thresholds of -8 deg km^{-1} for the minimum and 8 deg km^{-1} for the maximum, and additional false echo is removed (Fig. 4d).

3.6 Anomalous Propagation (AP) Threshold

The DPQC code can be modified with additional modules that improve the operational QC product. These include an AP threshold module, a sector removal module, and a PH sector threshold module.

AP threshold is a unique module created to target AP. Observation of reflectivity and Z_{DR} values within AP indicates that some AP shows high Z_{DR} (Fig. 3e) and a moderate to low reflectivity (Fig. 3a). When a Z_{DR} gate is greater than the AP Z_{DR} threshold and the corresponding reflectivity gate is less than the AP reflectivity threshold that gate is flagged as missing. Users have to be cautious, AP threshold can produce a false positive result. For this case we will use AP threshold with the default values, 45 dBZ for the AP reflectivity threshold and 3 dB for the AP Z_{DR} threshold. AP threshold removed large areas of false echo to the north and west (Fig. 4e).

3.7 Sector Removal

After applying all the threshold modules the case still has false echo. A module was created for scenarios like this allowing the user to define a sector and flag it as missing based on azimuth, range, and sweep. In Fig. 4F, a PPI CZ plot, the sector between the 210-25° azimuths from 0-200 km range for all sweeps was set to missing. QC for the case is now finished and the resulting data is predominantly free of false echo.

3.8 Signal Quality Index (SQI) Threshold

SQI threshold can be used when the SQ field is available. SQI is useful in removing multiple trip echo due to inherent low coherency. When a SQI gate is less than the threshold that gate is flagged as missing. A PPI reflectivity plot depicts a multiple trip echo case from NPOL on May 20, 2013 at 0957Z during IFloodS (Fig. 5a). Multiple trip echo is embedded within real echo between the 120-150° azimuths. Setting the SQI threshold to 0.5 results in the removal of the multiple trip echo (Fig. 5b). When available this is a very useful tool in the QC process. Users must be cautious when using SQI threshold as it can remove precipitation when multiple trip echo is embedded.

3.9 Using Differential Phase (PH) to Quality Control

Occasionally Φ_{DP} can be used to remove radial spikes and other false echoes. A module was developed to allow the user to target a sector and apply a PH threshold. Similar to the sector removal module the user supplies the start and end azimuths, the minimum and maximum range, and a PH threshold. When a Φ_{DP} gate is greater than the PH threshold and within the sector the gate will be flagged as missing. The PPI PH plot in Fig 6a from KBMX (Birmingham, AL) on August 8, 2013 at 1901Z shows a radial spike to the south. A PH threshold of 80° is applied to the sector between the 150-180° azimuths from 50-200 km range. The radial spike is now removed, as seen in the CZ PPI plot in Fig. 6b.

4. SUMMARY

The DPQC algorithm is being used to quality control dual polarimetric radar data from twenty five radars for the GPM-GV program. The algorithm uses threshold modules based on DP parameters to determine if an echo is precipitating. If one of the DPQC thresholds fail for a given gate then the missing data mask is applied to all fields for that gate.

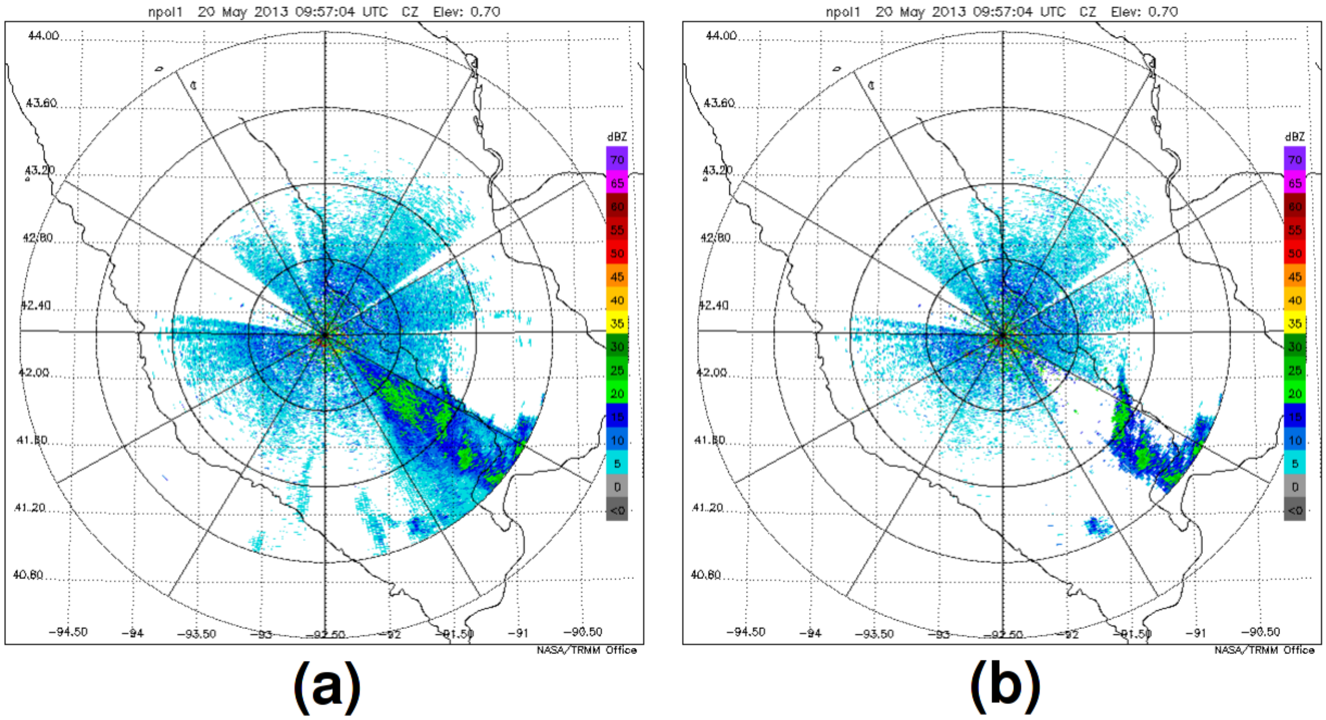


Fig 5. *Corresponding 0.48° elevation PPI plots of CZ field from NPOL on May 20, 2013 at 0957Z during IFloodS. (a) Multiple trip echo is embedded within real echo between the 120-150° azimuths. (b) An SQI threshold of 0.5 is applied, multiple trip echo is now removed.*

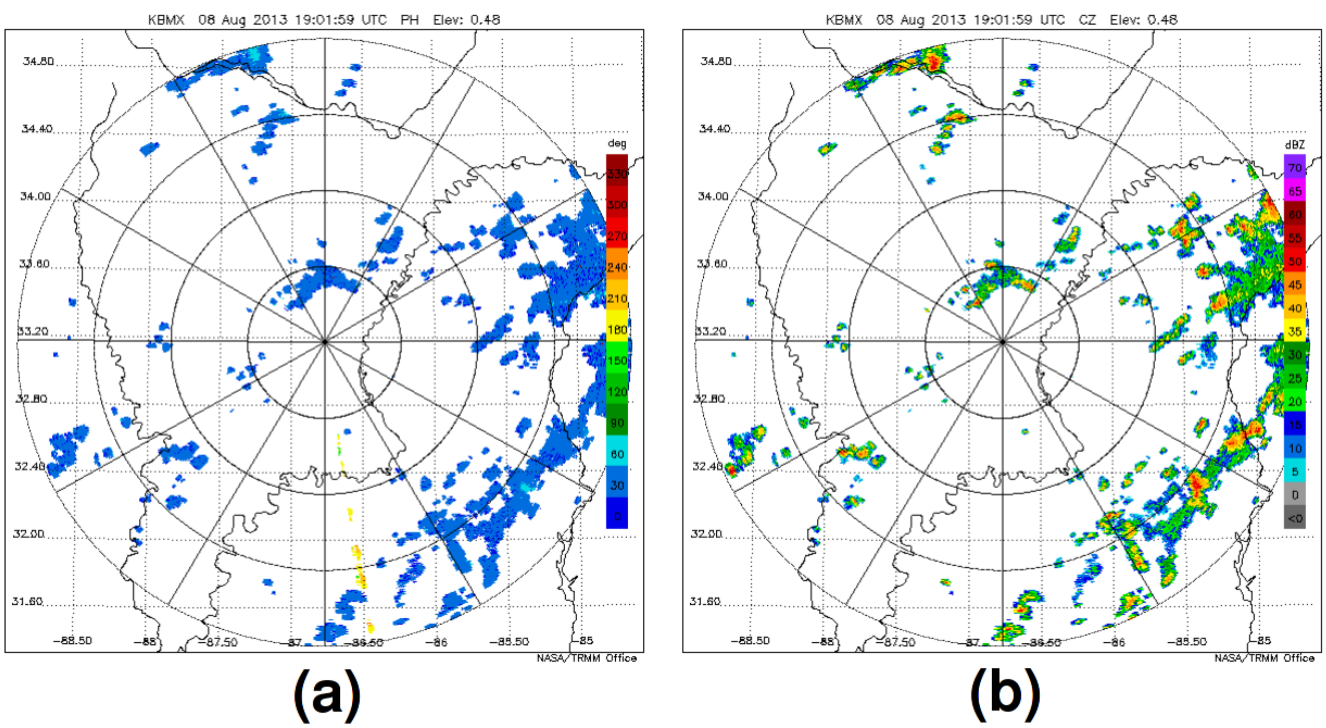


Fig 6. *Corresponding 0.48° elevation PPI plots from KBMX (Birmingham, AL) on August 8, 2013 at 1901Z. (a) PH field with radial spike evident to the south. (b) CZ field with a PH threshold of 80° applied to the sector between azimuths 150-180° from the 50-200 km range. The radial spike is now removed.*

Recent updates to the algorithm include the ability to process WSR-88D data. An improved method of applying QC, the freezing level is determined and QC is only applied below this level using radar beam height. This method of applying QC has greatly increased data quality. Additional modules were developed that remove or apply thresholds to a sector, insuring the best final product.

The DPQC algorithm, using default thresholds, is applied daily to all GPM-GV sites producing a nearly clean radar product. The default data is reviewed daily and additional adjustments are made to produce the highest quality radar product. Final output includes QC plots, QC UF, and a parameter file detailing which modules were run and their corresponding thresholds (Table 2).

Future developments for DPQC include a conversion of the IDL code to C for greatly decreased processing time. When future data issues arise the DPQC algorithm will be updated with code changes or additional modules. DPQC will be used for all future GPM-GV radar sites and field experiments.

The QCed DP data will allow improved understanding of precipitation microphysics, and provide essential input for development of precipitation retrieval algorithms. The resulting data will prove essential for calibration of the core GPM satellite and for development of physically based passive microwave radiometer algorithms.

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6. ALGORITHM AVAILABILITY AND CONTACTS

To obtain the DPQC algorithm, or for questions and comments, please contact,

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Information on NASA's Radar Software Library (RSL) and the programming language RSL_in_IDL can be found on the PMM Ground Validation Office web site: http://trmm-fc.gsfc.nasa.gov/trmm_gv/software/software.html

7. ACKNOWLEDGMENTS

Dr. Walt Petersen (NASA/WFF); Dr. Mathew Schwaller, Dr. Arthur Hou, and Dr. Scott Braun (NASA/GSFC); PMM-GV Office Support: Bart Kelley, Jianxin Wang, and David Makofski