# Ground Clutter Suppression Algorithm for Dual-Polarization Weather Radar

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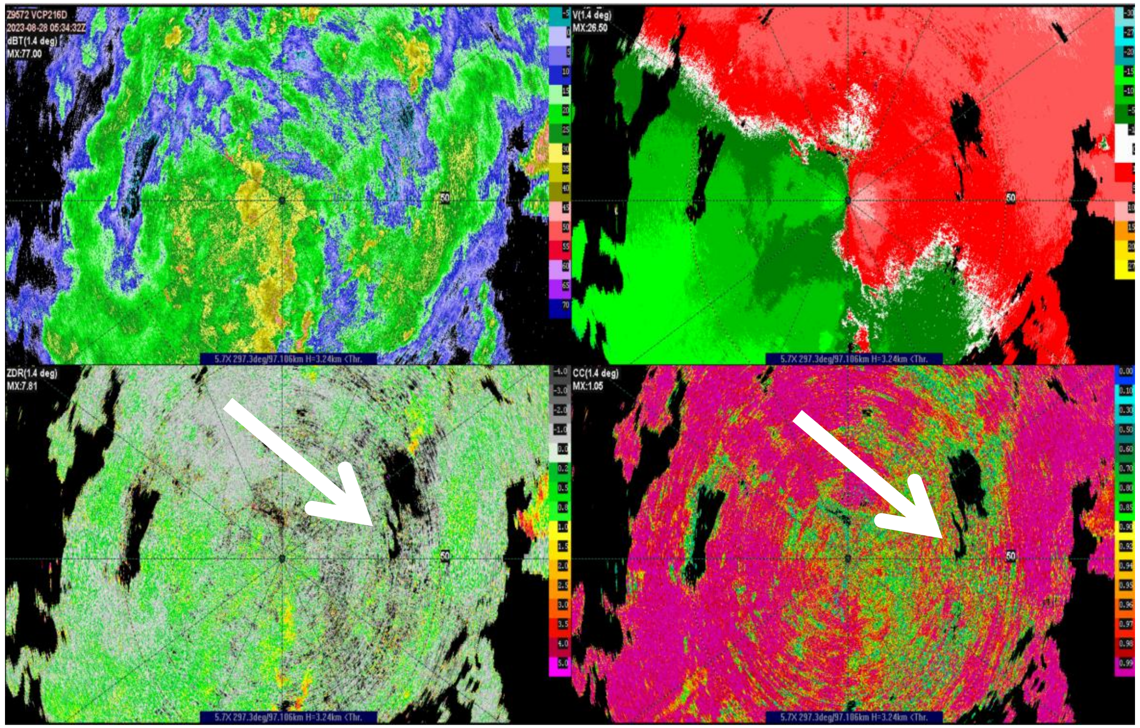
中国气象局气象探测中心
CMA Meteorological Observation Centre

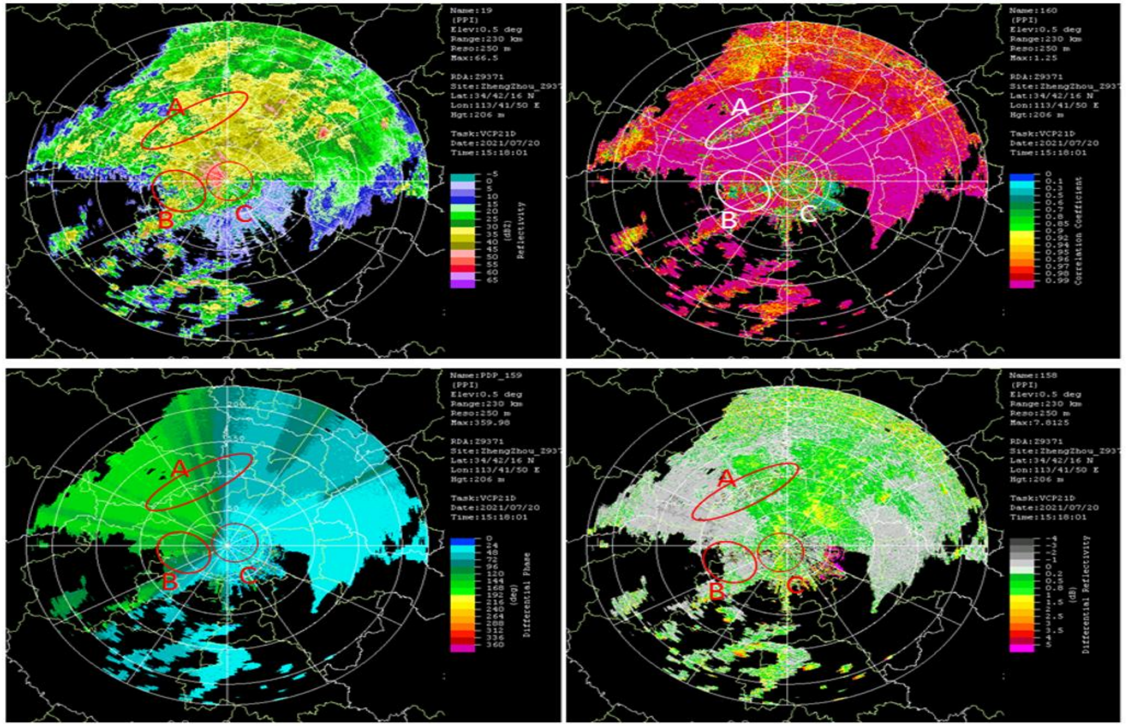
# Outline

# 1. Research Background and Motivation

Ground clutter severely degrades the data quality of China New Generation Weather Radar (CINRAD), especially its dual-polarization parameters.



HuZhou station in ZheJiang Province



ZhangZhou station in FuJian Province

# 1. Research Background and Motivation

The complete ground clutter suppression algorithm employed in operational radars comprises three sequential steps.

**1st: Identification**

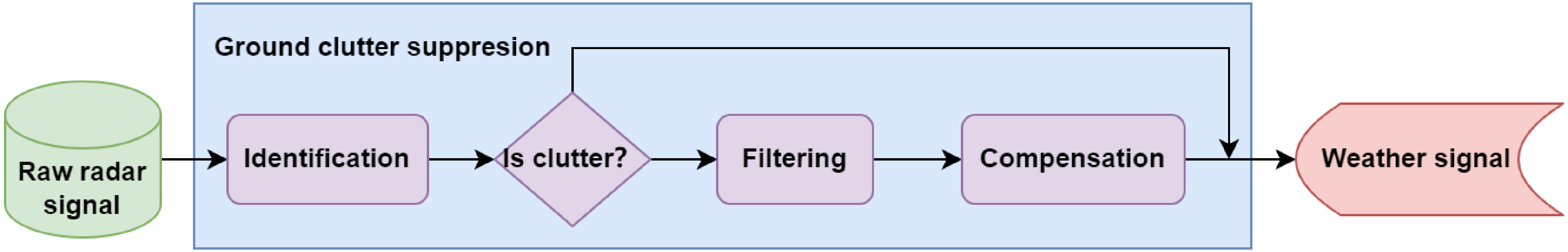
Identify regions contaminated by ground clutter to enable targeted suppression of clutter signals.

**2nd: Filtering**

Apply high-pass filtering to radar echoes containing ground clutter to eliminate near-zero frequency components.

**3rd: Compensation**

Fill the near-zero frequency spectrum with alternative spectral components to mitigate side-effects induced by filtering.




Process of ground clutter suppression algorithm

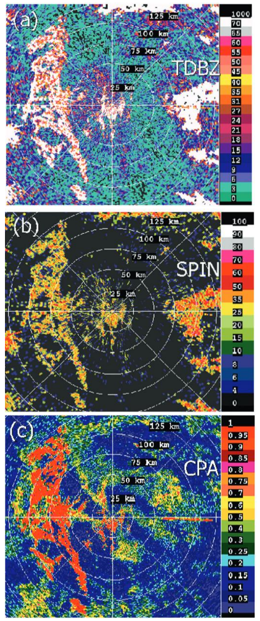
# Outline

1. Research Background and Motivation
2. Current Solutions in Operational Radar (CINRAD)
3. Improved Ground Clutter Suppression Algorithm
4. Performance Evaluation of the New Algorithm

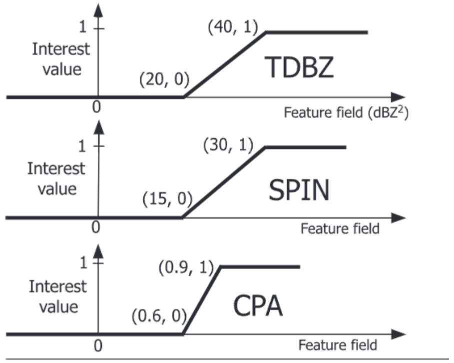
# 2. Current Solutions in operational radar (CINRAD)

- The CMD algorithm is used for ground clutter identification and outputs a clutter flag for each range bin.
- The GMAP algorithm only processes range bins that have been flagged as clutter, thereby reducing its impact on weather signals.

**CMD**



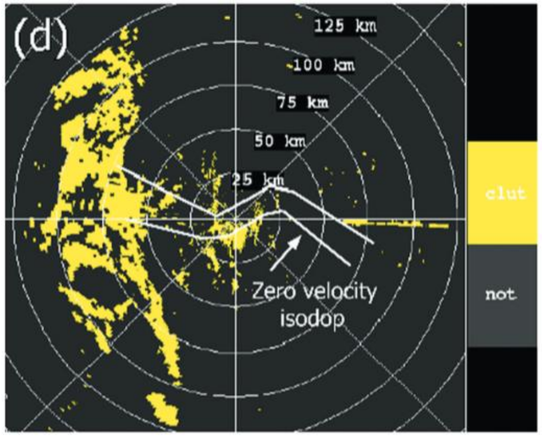

feature



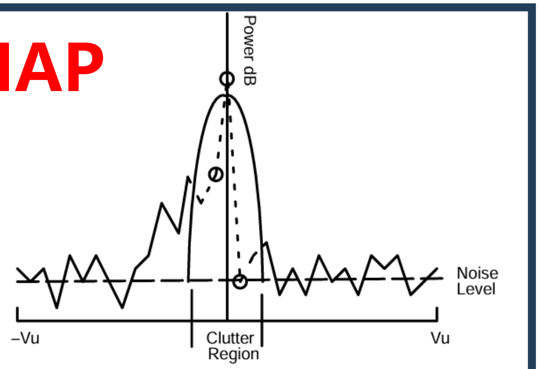

| Field | Weights |
|---|---|
| TDBZ | N/A |
| SPIN | N/A |
| MAX_TDBZ_SPIN | 1.0 |
| CPA | 1.01 |

fuzzy logic

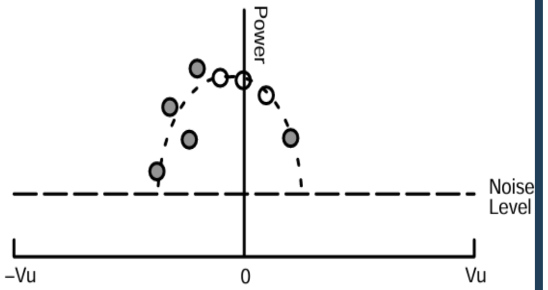
**GMAP**




clutter flag




Gaussian filtering




Gaussian interpolation

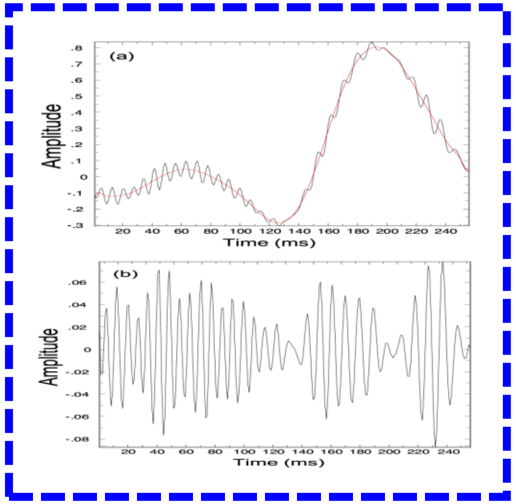
# 2.1 CMD (identification)

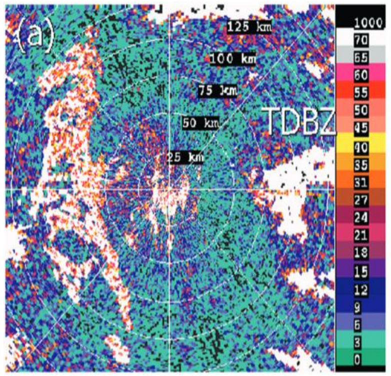
CMD（Clutter Mitigation Decision）method includes 2 steps:

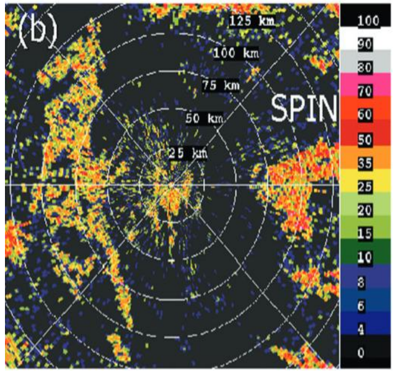
1st : Three features—CPA, TDBZ, and SPIN—are computed from IQ data. The latter two require reflectivity estimation first, and are then calculated based on the reflectivity.

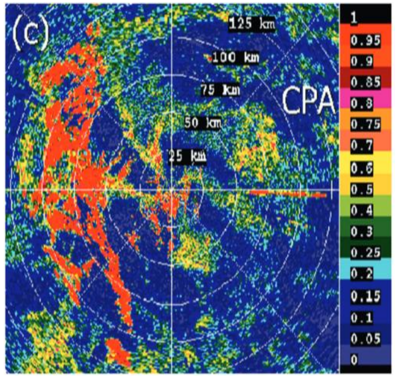
2nd :Fuzzy logic is used to integrate the three features, yielding a clutter probability for each range bin. This probability is then compared with a preset threshold (default 0.5) to determine the ground clutter flag.

I/Q data




$$\mathrm{TDBZ} = \left[\sum_{j}^{L}\sum_{i}^{M}(\mathrm{dBZ}_{i,j} - \mathrm{dBZ}_{i-1,j})^2\right] \Big/ N,$$

$$\mathrm{sign}\{X_i - X_{i-1}\} = -\mathrm{sign}\{X_{i+1} - X_i\},$$

$$\frac{|X_i - X_{i-1}| + |X_{i+1} - X_i|}{2} > \mathrm{spin\_thres},$$

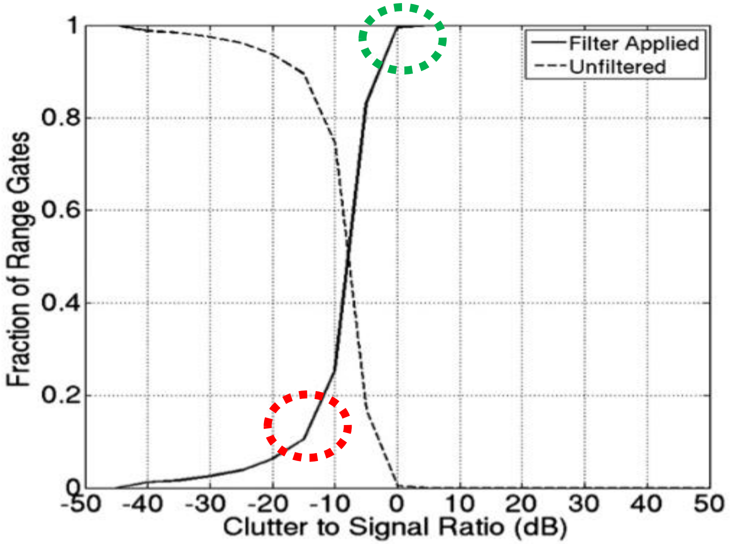
$$\mathrm{CPA} = \left|\sum_{i=1}^{N} x_i\right| \Big/ \left[\sum_{i=1}^{N} |x_i|\right].$$

# 2.1 CMD (identification)

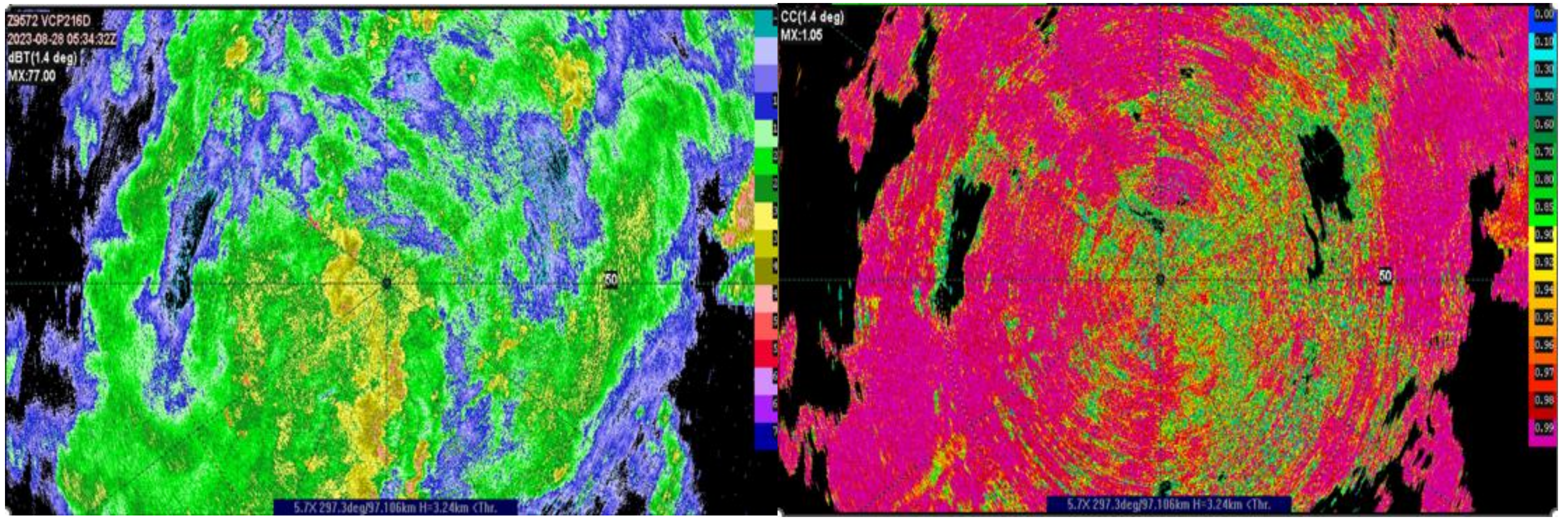
The CMD algorithm demonstrates limited recognition performance under low Clutter-to-Signal Ratios (CSR), significantly degrading dual-polarization parameter quality.

Key research findings indicate:

- CSR ≤ 0 dB: Required for high-quality reflectivity (least sensitive).
- CSR ≤ -15 dB: Required for high-quality correlation coefficients (most sensitive).
- Other parameters: Exhibit sensitivity levels falling between these two extremes.




Identification Rate vs. CSR

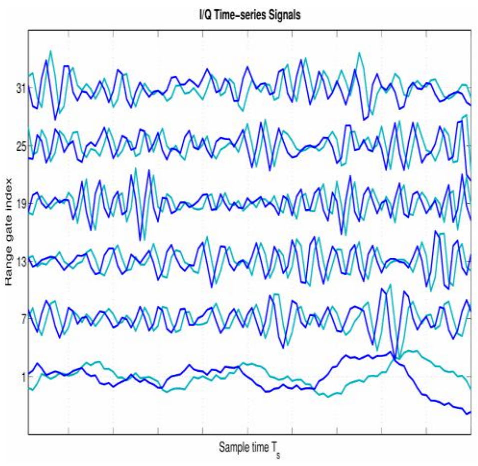



Degraded Quality of Dual-Polarization Parameters at Low CSR

# 2.2 GMAP (filtering and compensation)

GMAP (Gaussian Model Adaptive Processing) method  includes three steps:

- Perform power spectral estimation on the I/Q data of flagged range bins.
- Remove clutter by applying Gaussian fitting to the near-zero frequency components.
- Utilize surrounding signals for secondary Gaussian fitting to compensate the near-zero frequency weather signals.

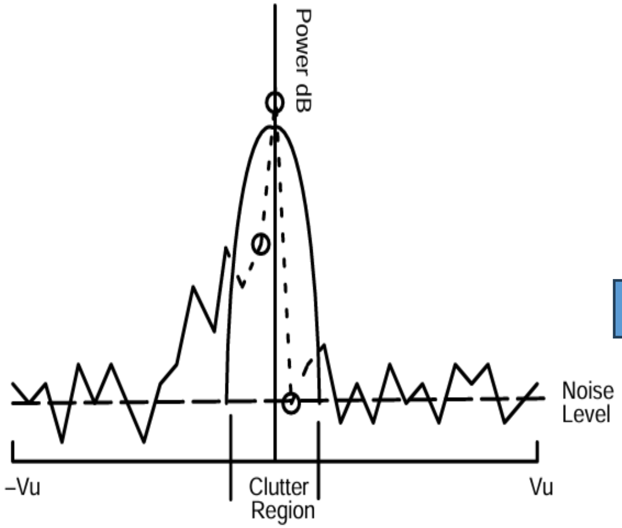



Raw I/Q Data

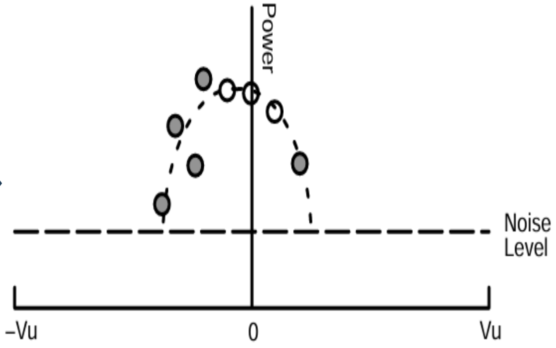
$$Z(k) = \sum_{m=0}^{M-1} V(m) e^{-j2\pi mk/M},$$

$$s\hat{S}(k) = \frac{|Z(k)|^2}{M},$$

Power Spectrum Estimation



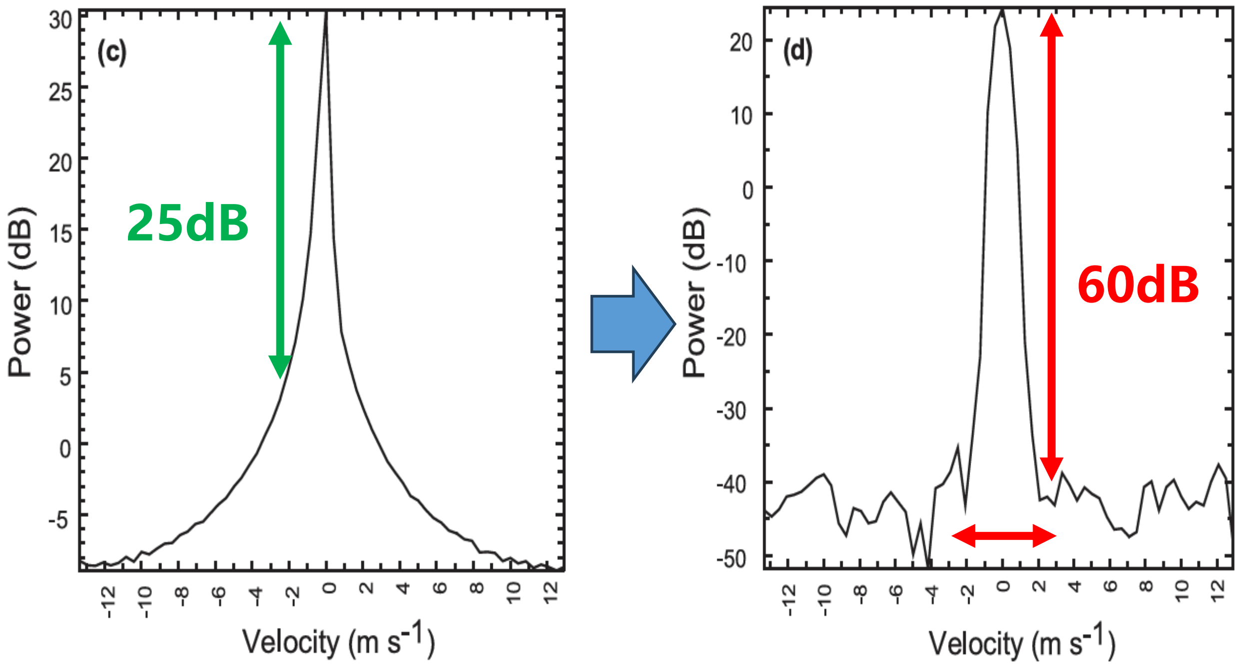

Clutter Removal



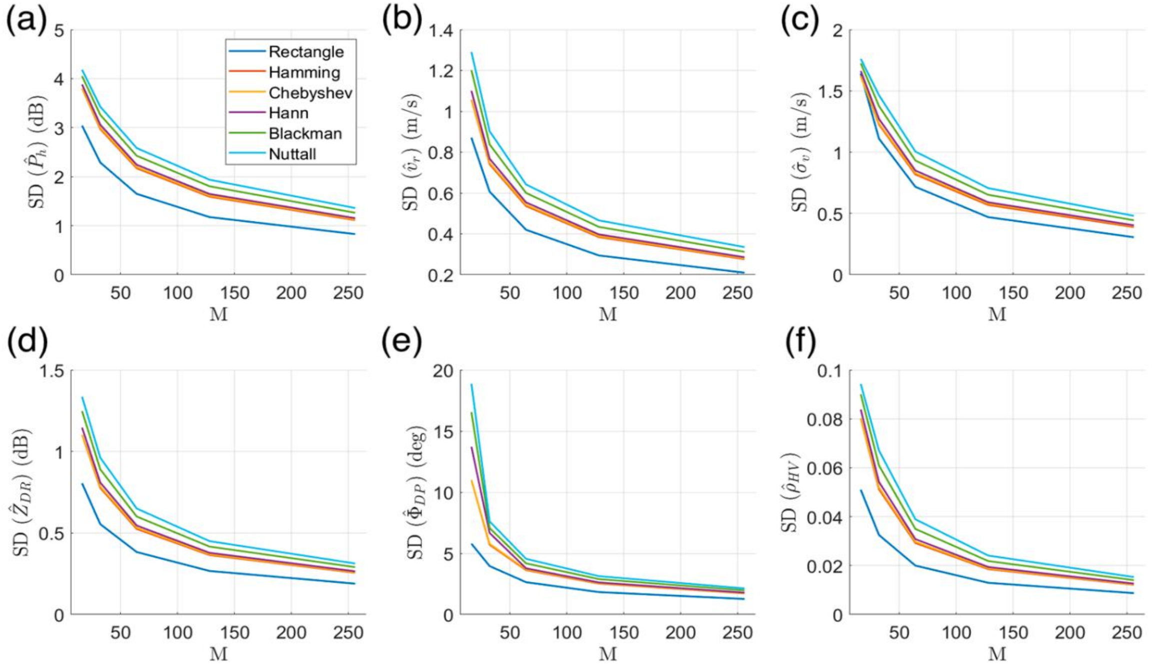

Signal Restoration

# 2.2 GMAP (filtering and compensation)

For the GMAP method, prior to power spectrum estimation, the I/Q data is windowed to mitigate spectral leakage, which inherently introduces a loss of sampling information.




Power Spectrum Before and After Windowing




Standard Deviation of Parameter Estimation Before and After Windowing

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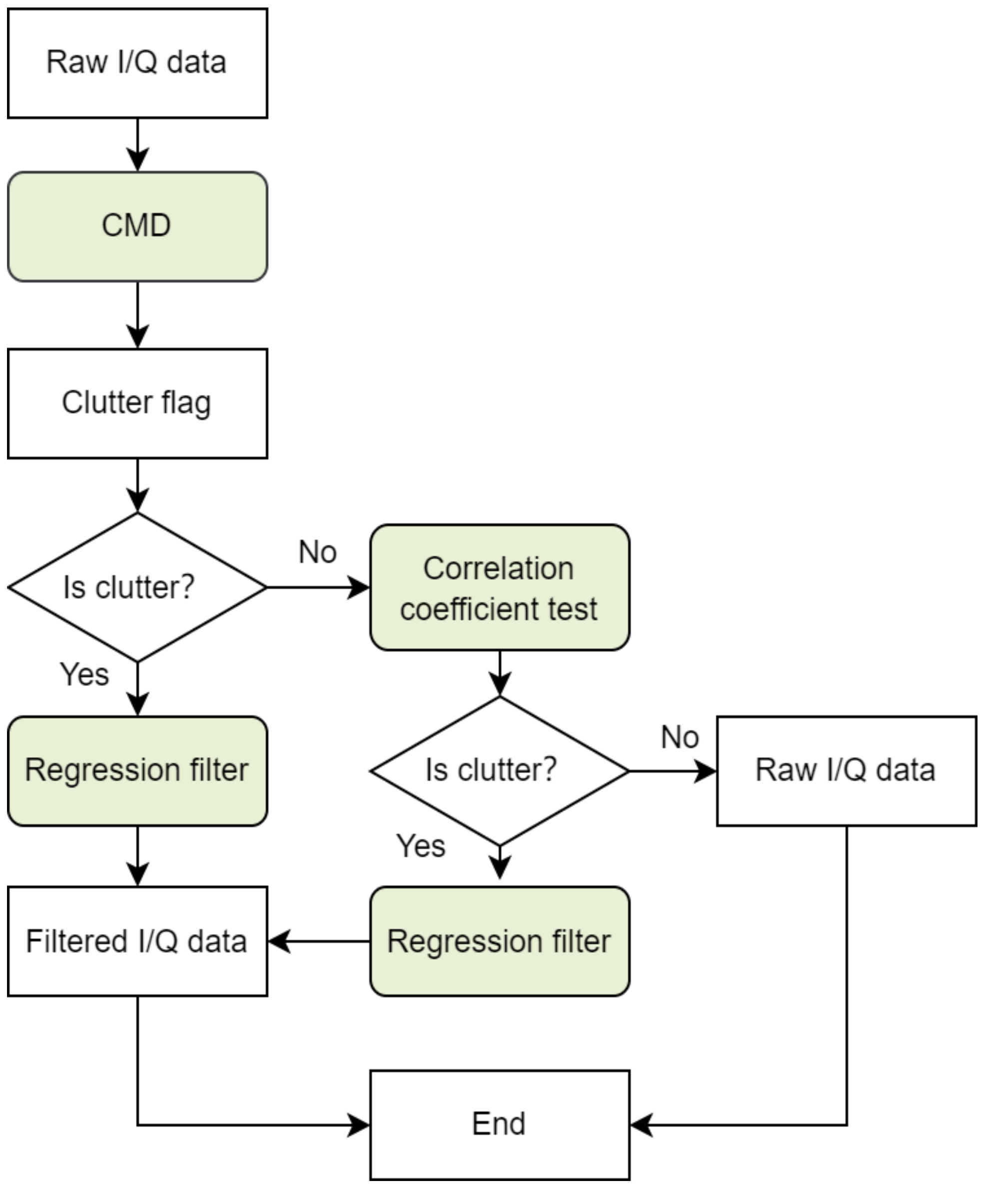
3. Improved Ground Clutter Suppression Algorithm
4. Performance Evaluation of the New Algorithm

# 3. Improved Ground Clutter Suppression Algorithm

To address the limitations of the current CMD+GMAP combination scheme, an improved ground clutter suppression algorithm is proposed based on a survey of recent research. The steps are as follows:

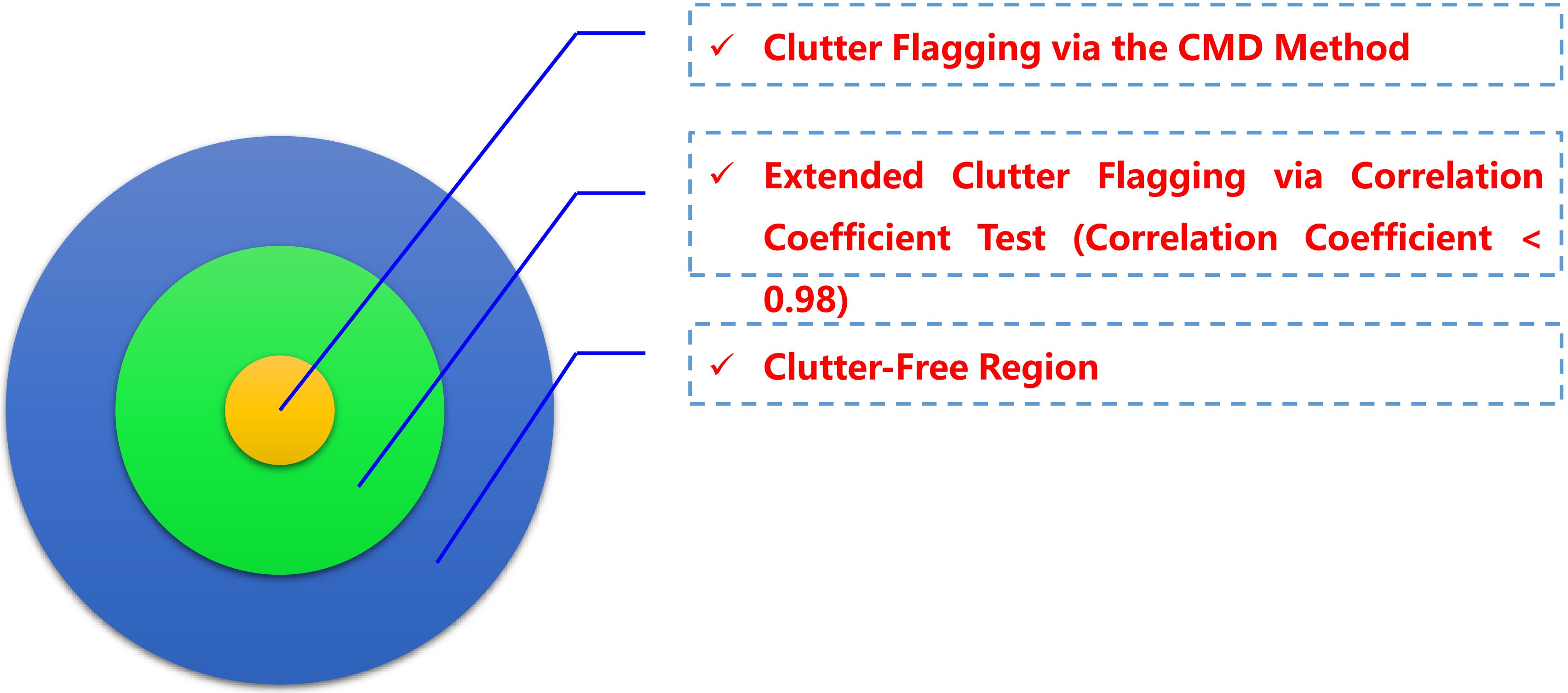
1st : apply the CMD method for initial ground clutter identification, followed by regression filtering for clutter removal and compensation.

2nd : test the remaining range bins (not flagged by CMD) using the correlation coefficient, and classify those that pass the test as ground clutter.



# 3.1 Correlation coefficient test (identification)

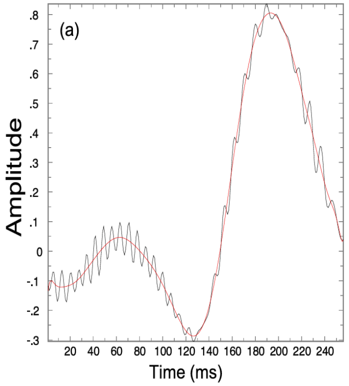
A correlation coefficient test was introduced to improve recognition performance under low clutter-to-signal ratio conditions, where the CMD method alone is inadequate. The first step of this test is to expand the clutter flags, i.e., any range bin with a correlation coefficient below 0.98 is regarded as potential ground clutter.



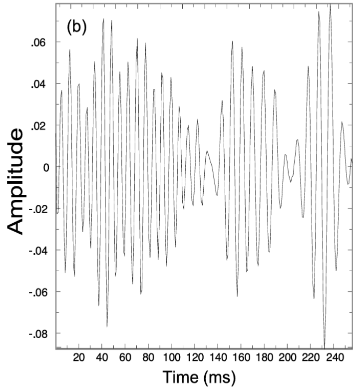
# 3.1 Correlation coefficient test (identification)

Among all radar parameters, the correlation coefficient is the most sensitive indicator of clutter. By quantifying the improvement in this parameter before and after filtering, the algorithm determines whether the signal is clutter characterized by a low clutter-to-signal ratio.

Pre-filtering




Post-filtering




$$\hat{\rho}_{\mathrm{hv}} = \frac{\left|\hat{C}_{\mathrm{hv}}(0)\right|}{\sqrt{\hat{P}_{\mathrm{h}}\hat{P}_{\mathrm{v}}}}.$$

$$\hat{C}_{\mathrm{hv}}(n) = \frac{1}{M-n}\sum_{m=1}^{M-n} V_{\mathrm{h}}^{*}(m+n)V_{\mathrm{v}}(m),$$

$$\hat{P}_{\mathrm{h,v}} = \hat{R}_{\mathrm{h,v}}(0) = \frac{1}{M}\sum_{m=1}^{M}\left|V_{\mathrm{h,v}}(m)\right|^{2}.$$

Parameter Estimation

$$\rho_{HV}^{uflt}$$

$$\rho_{HV}^{filt}$$

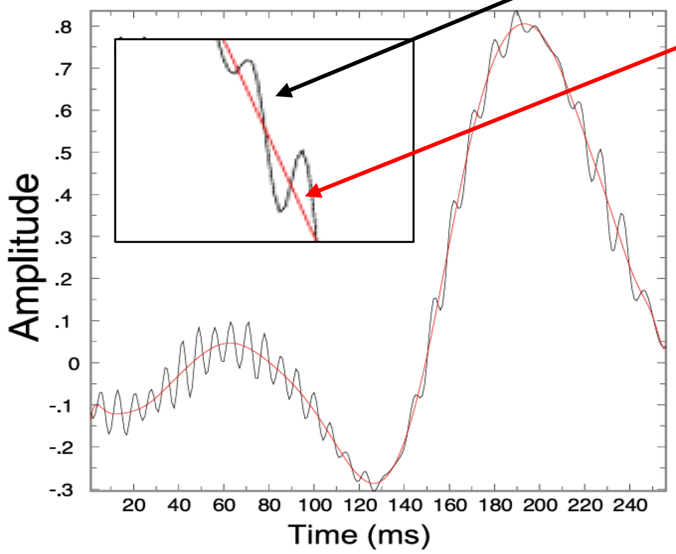
$$\mathcal{F} = \frac{1-\rho_{HV}^{uflt}}{1-\rho_{HV}^{filt}} > 4$$

Correlation Coefficient Test

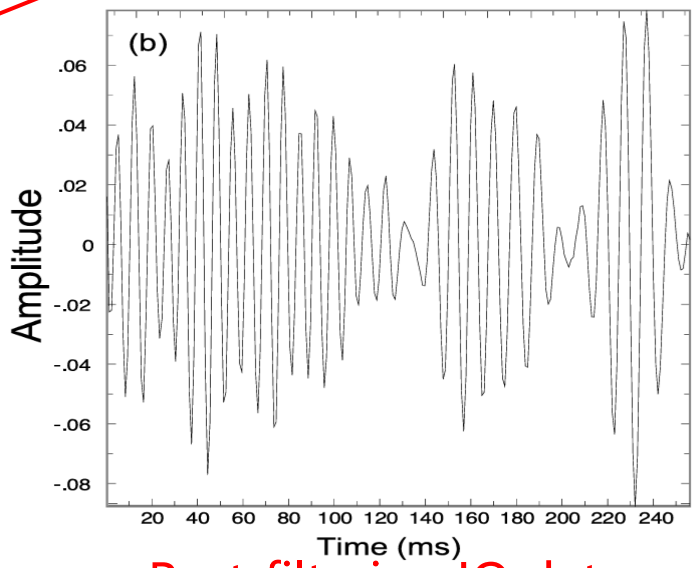
# 3.2 regression filter (filtering and compensation)

Unlike traditional methods (e.g., GMAP), regression filters eliminate the need for data windowing. They utilize Forsythe orthogonal polynomials to fit the low-frequency components of the I/Q signal, effectively removing these components to achieve clutter filtering.

$$r_i = x_i - \sum_{j=0}^{n} \alpha_j P_j(x_i),$$

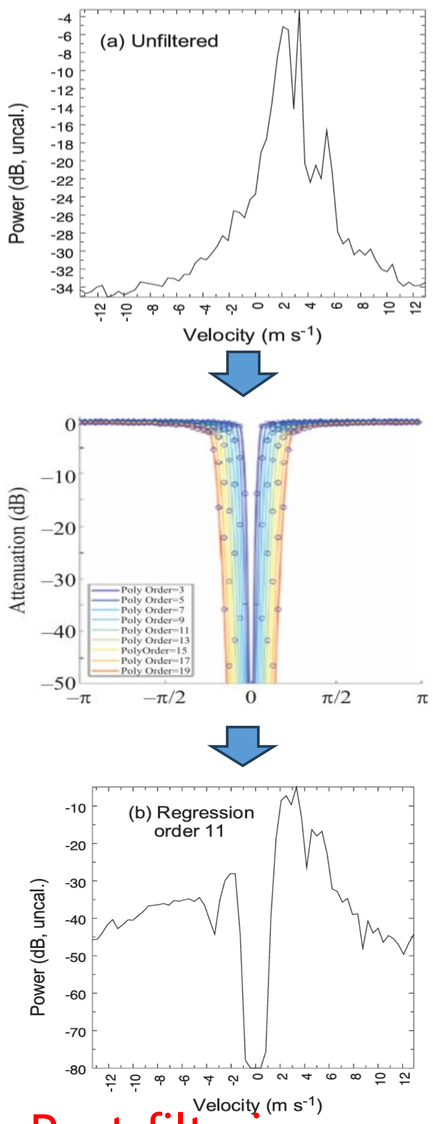


Pre-filtering IQ data



Post-filtering IQ data

Pre-filtering spectrum



Post-filtering spectrum

# 3.2 regression filter (filtering and compensation)

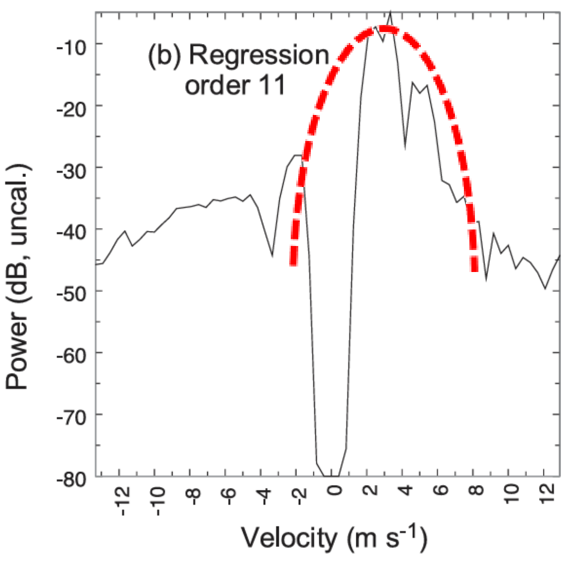
The filtered power spectrum is repaired through Gaussian iterative fitting of the components near zero frequency. Compared with the GMAP method, this approach not only effectively filters out the clutter component but also eliminates spectral leakage caused by windowing.

$$\widehat{F}(i) = \frac{\zeta}{\sqrt{2\pi}s} e^{(i-a)^2/2s^2}$$

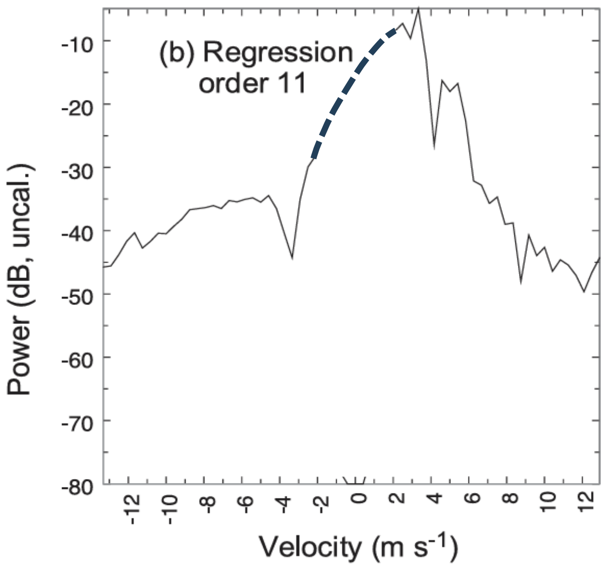
$$\zeta = \sum_{-M-L}^{M+L} F(i)$$

$$a = \left[\sum_{-M-L}^{M+L} i \cdot F(i)\right] / \zeta$$

$$s = \left\{\left[\sum_{-M-L}^{M+L} F(i)(i-a)^2\right] / \zeta\right\}^{\sqrt{0.5}}.$$




Gaussian Fitting

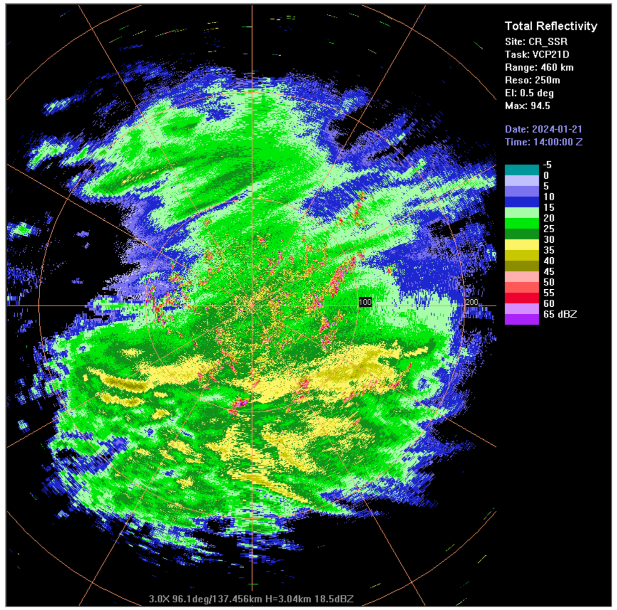



Restored Spectrum

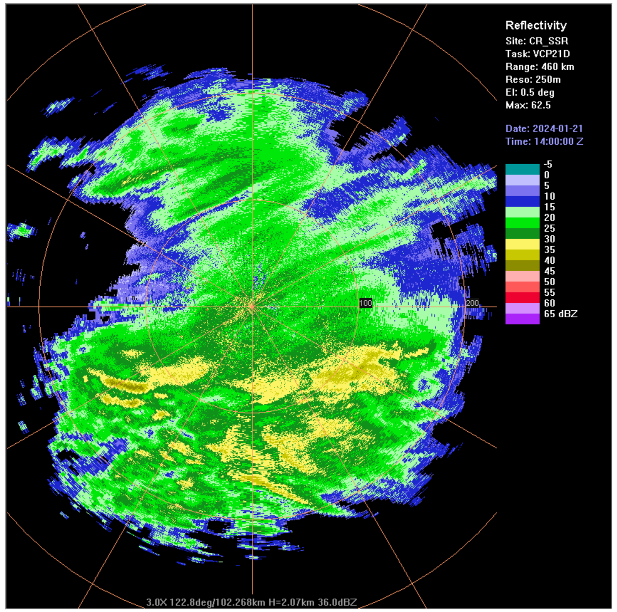
# Outline

# 4. Performance Evaluation of the New Algorithm

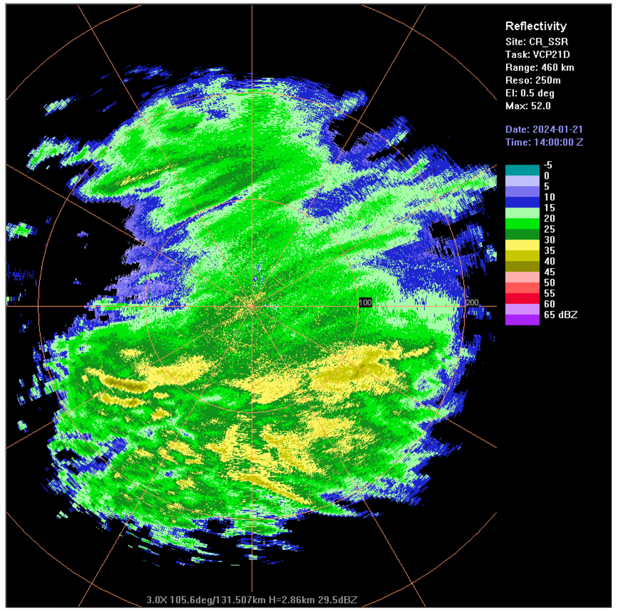
A qualitative demonstration of the algorithm's performance is presented firstly. A snowfall event observed on January 21, 2024, by the Changsha S-band dual-polarization weather radar is selected as the case study. From the reflectivity fields, there is no discernible difference before and after the algorithm improvement; both versions effectively suppress the negative impact of ground clutter to an invisible level.




**Raw**



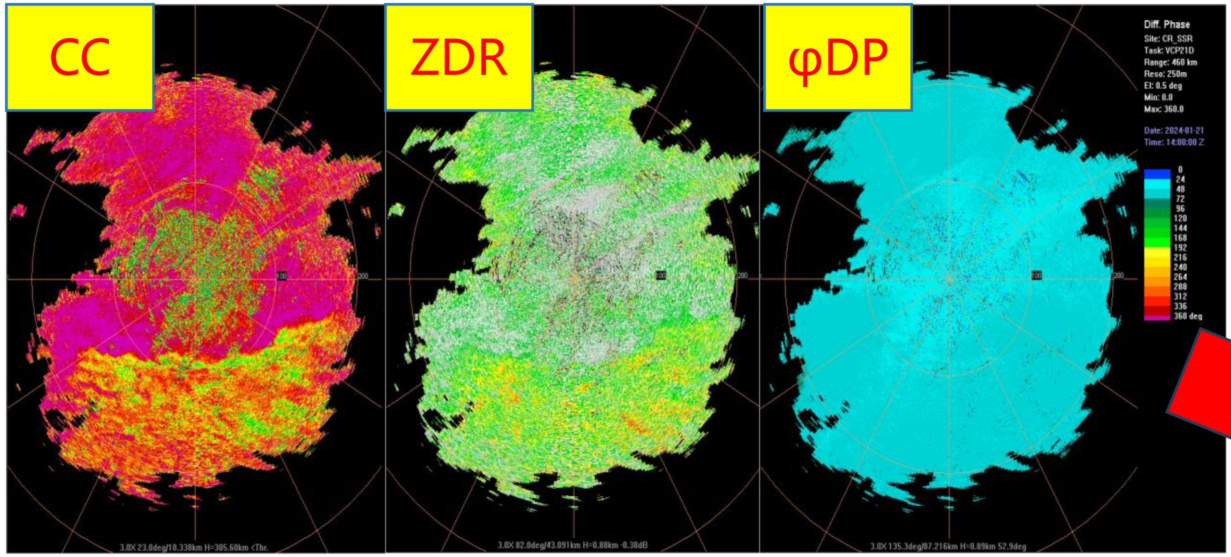

**Operational**




**Proposed**

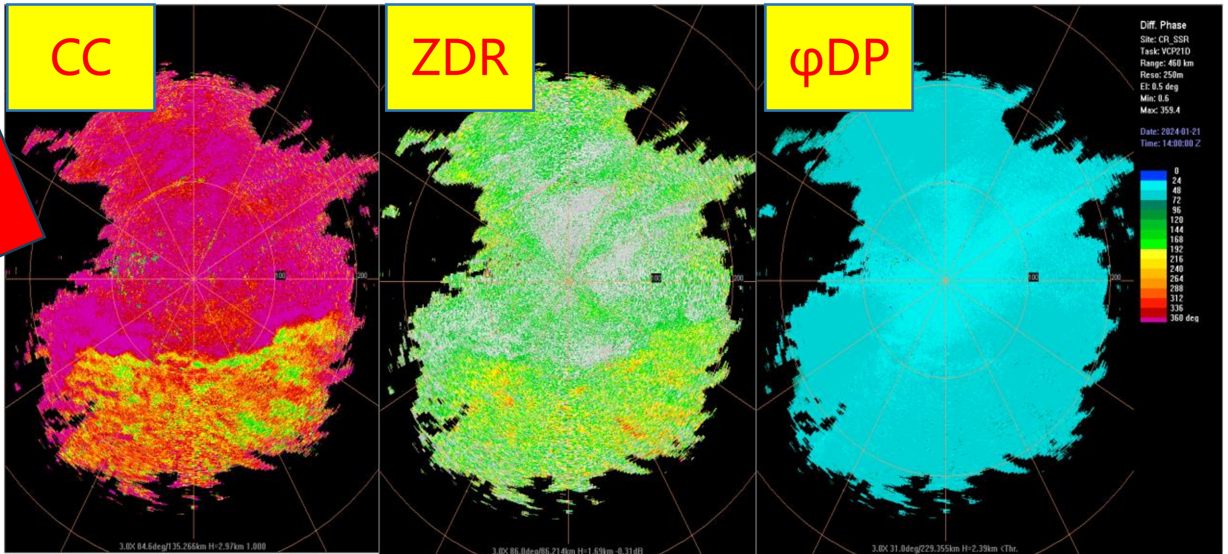
# 4. Performance Evaluation of the New Algorithm

From the perspective of dual-polarization parameters, data quality for the correlation coefficient, differential reflectivity, and differential phase was severely degraded before the algorithm improvement. After the improvement, these parameters recovered notably, exhibiting typical characteristics of meteorological echoes, e.g., high correlation coefficient, and smooth transitions in differential reflectivity and differential phase.




Operational

Proposed



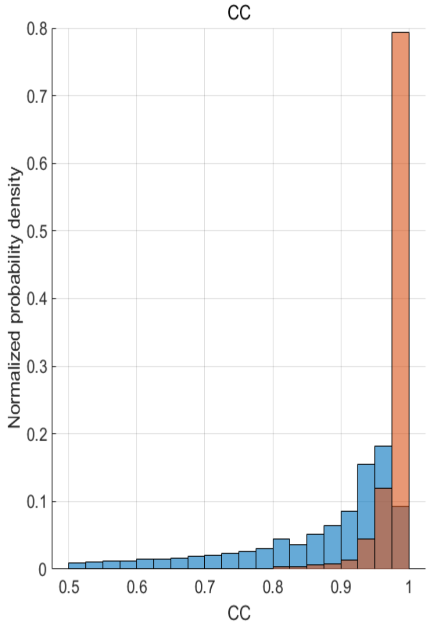
# 4. Performance Evaluation of the New Algorithm

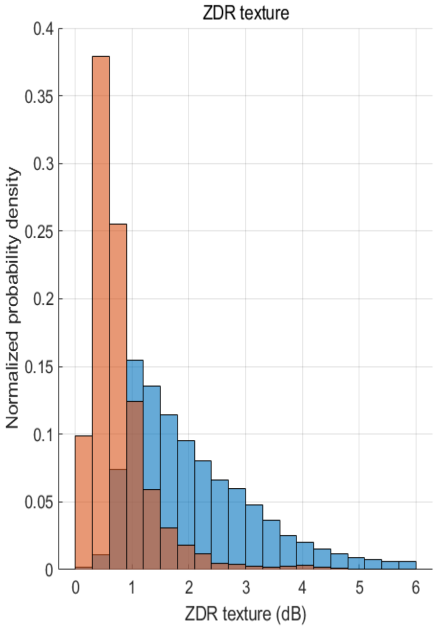
Eight representative precipitation events are selected for quantitative evaluation of the algorithm. The methodology is as follows:

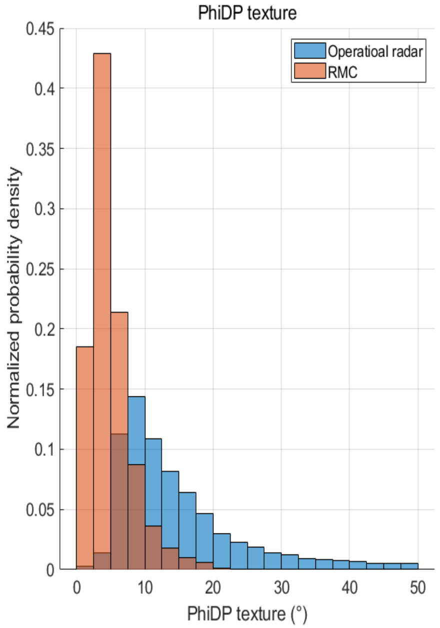
① Extract the correlation coefficient (CC), differential reflectivity texture (Tzdr), and differential phase texture (Tphi) within a 100 km range of the radar;

② Count the number of range bins that simultaneously satisfy CC > 0.98, Tzdr < 1.2, and Tphi < 10;

③ Calculate their ratio to the total number of valid range bins, and this metric is defined as the High-quality Polarization data Ratio (HPR).



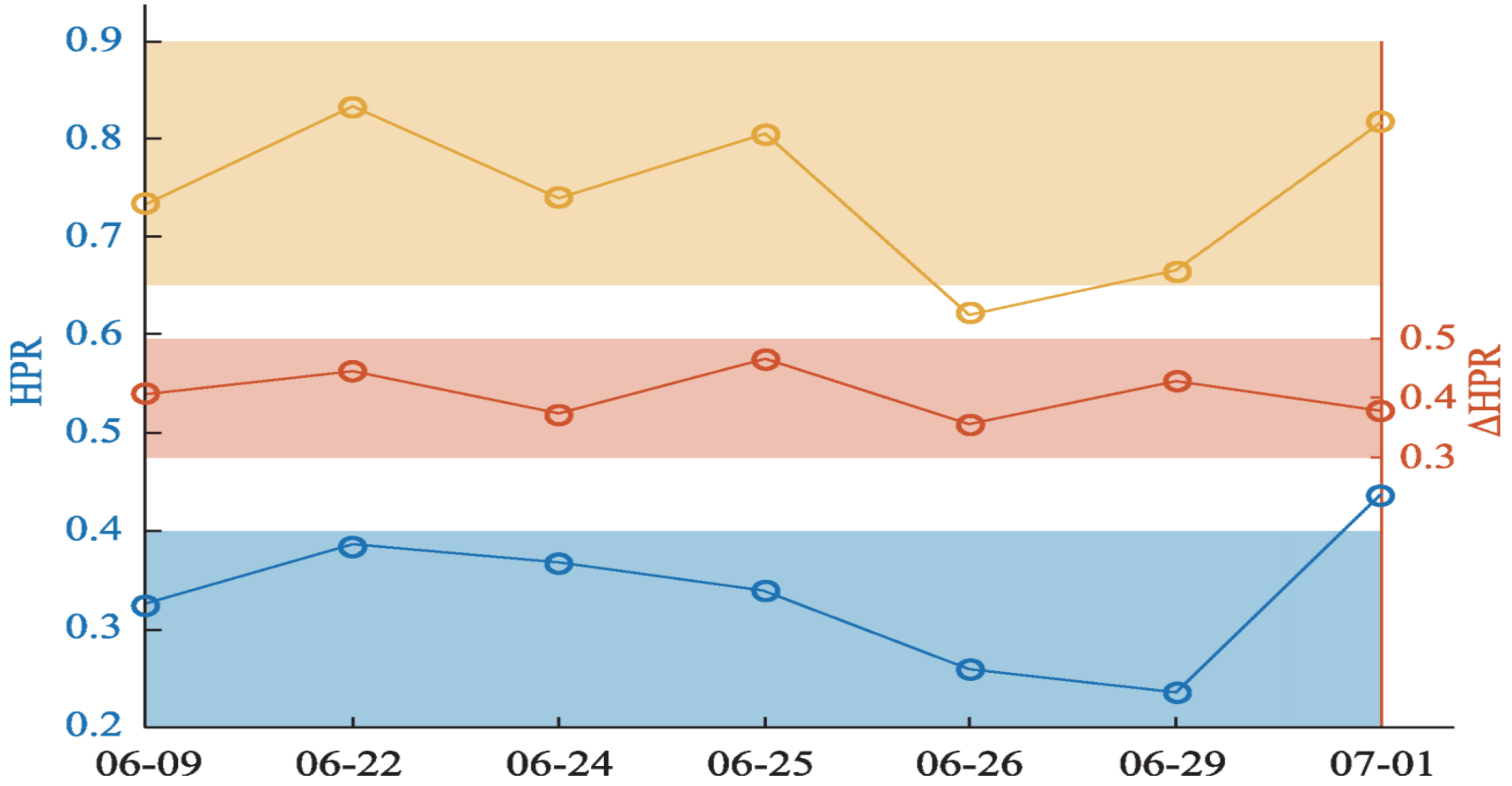




| Index | Station | Time (UTC) |
|---|---|---|
| 1 | Changsha | 21:00, Jun 9, 2024 |
| 2 | | 06:00, Jun 17, 2024 |
| 3 | | 01:00, Jun 22, 2024 |
| 4 | | 07:00, Jun 24, 2024 |
| 5 | | 06:00, Jun 25, 2024 |
| 6 | | 23:00, Jun 26, 2024 |
| 7 | | 05:00, Jun 29, 2024 |
| 8 | | 18:00, Jul 1, 2024 |

# 4. Performance Evaluation of the New Algorithm

Statistical results show that the HPR of the operational algorithm is generally below 0.4, while that of the proposed algorithm is generally above 0.65. The difference between them is approximately 0.4, indicating that the proposed algorithm improves the proportion of high-quality polarization data within a 100 km radar range by about 40% compared to the operational algorithm.



# Thank you！