Identifying Radar Non-meteorological Signal Using Modified Fuzzy-logic Algorithm with Objectively Derived Weighting Matrix

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Abstract

In order to utilize the radar data quantitatively, a fuzzy logic algorithm is developed to differentiate meteorological and non-meteorological signals (e.g., sea clutter, ground clutter and anomaly propagation) in this study. Rather than traditional approach using subjectively determined weighting for each radar variable (e.g., correlation coefficient, variance of PhiDP, ZHH, ZDR, etc.), a weighting matrix is obtained objectively for fuzzy logic algorithm to differentiate the characteristics of radar signals. This newly-designed method is applied to C-band dual-polarimetric radars in northern Taiwan. The results reveal that the modified fuzzy logic algorithm outperforms the threshold-based algorithm (i.e., correlation coefficient). Consequently, the radar-based QPE (Quantitative Precipitation Estimation) by new algorithm removing non-meteorological signals shows the comparable performance with that by fine-tuned, threshold-based algorithm.

Key word: Particle IDentification (PID), Fuzzy-logic Algorithm

1. Introduction

The radar measurement contains various errors and needs proper quality- control (QC) procedures before any further applications. Well quality-controlled radar data can improve its applications in quantitative precipitation estimation (QPE), weather analysis, flood warning, model input for forecasting and nowcasting, etc. For dual-polarimetric radar, the threshold-based method (cross-correlation coefficient, ρ_{HV}) is commonly used to identify non-meteorological signal. However, the threshold value is radar-dependent due to different manufactures and surrounding environments. Moreover, meteorological signal with low SNR (Signal-Noise Ratio) may have ρ_{HV} values less than 0.5 and the data will be removed incorrectly (FIG. 1).

Fuggy-logic algorithm has been proposed to identify meteorological and non-meteorological echo in numerous researches (Vivekanandan et al 1999; Cho et al. 2006; Gourley et al. 2007). The probability density function (PDF) of various radar variables for meteorological and non-meteorological signals are obtained from pre-selected training data. The fuzzy-logic algorithm utilizes these PDFs (also known as membership function, MF) with pre-determined weighting to differentiate meteorological and non-meteorological signals. Cho et al. (2006) further improve the fuzzy-logic algorithm by deriving the weightings from inverse overlapping area of two MFs. The larger overlapping MFs from given radar variable, the less capability of distinguishing meteorological and non-meteorological signals from that variable. And only two categories (i.e., meteorological and non-meteorological signals) are used in Cho et al. (2006). Furthermore, Gourley et al. (2007) averaged the MFs of ground clutter and clear air echo as non-meteorological signal and compare with meteorological signal. Gourley et al. (2007) suggests that a weighting array can be beneficial for further distinguishing meteorological and different non-meteorological signals.

In this study, a fuzzy-logic-based particle identification (PID) QC with weighting array is developed. Two types of non-meteorological signal (i.e., sea clutter and ground clutter) and meteorological signals can be identified by PID QC. In order to validate the performance of PID QC, QPE resulting from PID QC and threshold-based algorithm are compared.

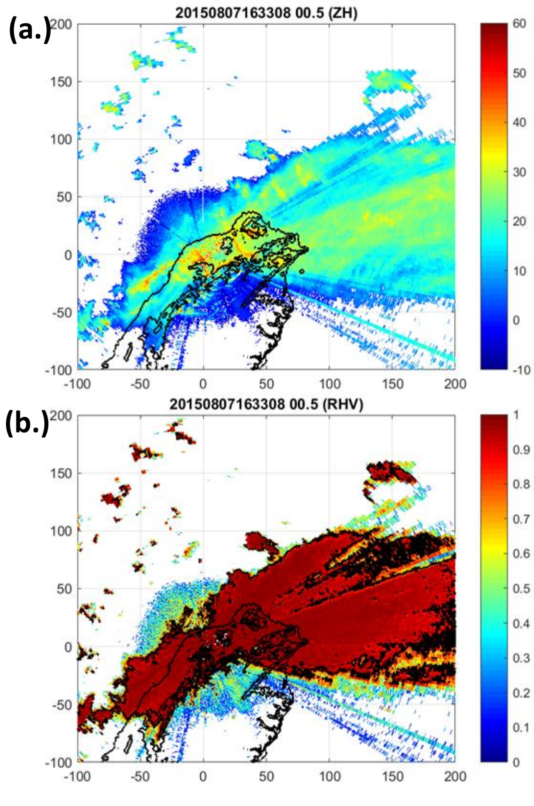

FIG. 1. (a.) Reflectivity Z_H and (b.) cross-correlation coefficient ρ_{HV} with the black contour where ρ_{HV} is larger than 0.85, regarded as meteorological signal.

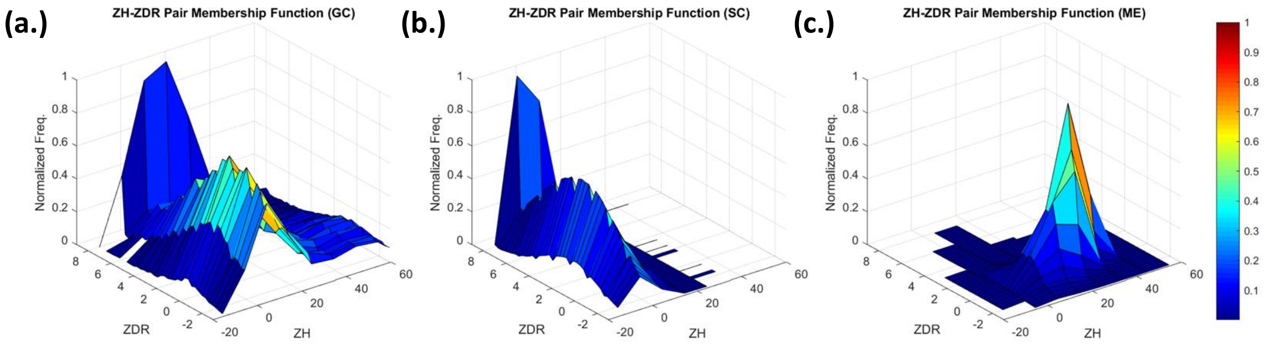

FIG. 2. Z_H-Z_{DR} pair distributions in (a.) ground clutter (GC), (b.) sea clutter (SC), and (c.) meteorological echo (ME) categories.

2. Methodology

At first, 2D-MFs of various radar measurements are established respectively. The number density functions are normalized by the maxima value in each category, namely ground clutter (GC), sea clutter (SC), and meteorological echo (ME). In this study, 10-pairs of variables are used in the PID QC. The first parameters, reflectivity and above ground height (hereafter know as AG) are coupled with the second parameters ρ_{HV}, differential reflectivity (Z_{DR}), and variance of ρ_{HV}, Z_{DR}, Z_H, and differential phase shift (ϕ_{DP}). FIG. 2 shows Z_H-Z_{DR} pair for example. It reveals pronounced different distribution in each category, with wider distribution of Z_{DR} and high Z_{DR} value (close to 8) in GC and SC, while smaller Z_H in SC. In ME, Z_{DR} has narrow distribution between -2 and 2 dB within Z_H interval 0 ~ 40 dBZ.

Three algorithms determining the weighting values are examined. The first algorithm is no weighting (NoW) test whose weighting is defined as unity. And the next is 1-D weighting (1DW), which is the inverse of the sum of all overlapping volume (2-D MFs) between each two MFs. When there is no overlapping volume or it is smaller than 0.01, the volume will be set as 0.01. The last, the array weighting (AW), every category has its own two weightings with respect to other two categories. The equation can be expressed as below,

$$\boldsymbol{score(i)} = \sum_{j=1}^{j=3} \sum_{k=1}^{k=10} \boldsymbol{MF_i^k} \times \boldsymbol{W_{i,j}^k}$$

where i and j represent category (GC, SC, ME) and k stands for 10 variable-pairs. For example, when we calculate the score of GC, MF of GC, MF_{GC}^k, is multiplied by weightings $W_{GC,SC}^k$ and $W_{GC,ME}^k$ individually. The pixel is identified as the category with the highest score. The details of weighting algorithms are summarized in TABLE 1.

3. Results

a. PID performance

FIG. 3 shows the comparisons of QC results among three experiments and the traditional, threshold-based method where the black contour means ρ_{HV} larger than 0.85, regarded as meteorological signal. It shows that the values of ρ_{HV} are less than 0.85 near the edge of the rain band, due to low SNR with weak Z_H. Nevertheless, these meteorological signals are removed by the threshold-based method. On the contrary, more reasonable results are found in fuzzy-logic algorithm using NoW and 1DW. Furthermore, the AW outperforms NoW and 1DW by obtaining more meteorological signals. Three of them keep more meteorological information in low ρ_{HV} area while AW results in the less incorrect categorized percentage calculated by percentage of GC identified in sea area and SC in terrain area.

b. QPE performance

The performances of QPE are consequently used to evaluate the PID QC results. Three cases (12 hours in total) observed by NCU C-band dual-polarimetric radar are selected. These cases include three different types of precipitation system, that is meiyu (2015/06/05), afternoon convection (2014/08/19), and cold-front (2015/02/24). The removal of non-meteorological signal process in QC procedure is done according to PID QC and find-tuned threshold-based method separately. The other QC processes include attenuation correction and wet radome correction. Subsequently, the rainfall is estimated in the polar coordinate, with corresponding rain-type rainfall relationship. Here we use three different estimators to calculate the rainfall, that is single estimator $R - Z_H$ and hybrid estimators $R - K_{DP} / R - Z_H$ and $R - (K_{DP}, Z_{DR}) / R - Z_H$, which generally has the best performance. At last, PPI polar coordinate will be interpolated into Cartesian coordinate and use the lowest effective CAPPI data as the final product (Chen et al. 2017).

The QPE results validated by 97 gauges from three cases are shown in FIG. 4. Overall, new PID QC method indicates the comparable performances with slightly lower NRMSE and NMB when compared to fine-tuned threshold-based method.

TABLE 1. Three experiments are undertaken to examine different weightings used in fuzzy-logic algorithm. There are no weighting (NoW), 1-D weighting (1DW) and array weighting (AW) test. Formulas and incorrect categorized percentage are also listed.

Weighting	Formula	Incorrect categorized percentage
NoW	$W^k = 1$	19.92%
1DW	$W^k = \frac{1}{V^k}$, where $V^k = V^k_{GC,SC} + V^k_{GC,ME} + V^k_{SC,ME}$ …	21.07%
AW	$W^k_{GC,SC} = \frac{1}{V^k_{GC,SC}}$; $W^k_{GC,ME} = \frac{1}{V^k_{GC,ME}}$; $W^j_{SC,ME} = \frac{1}{V^k_{SC,ME}}$ …	12.55%

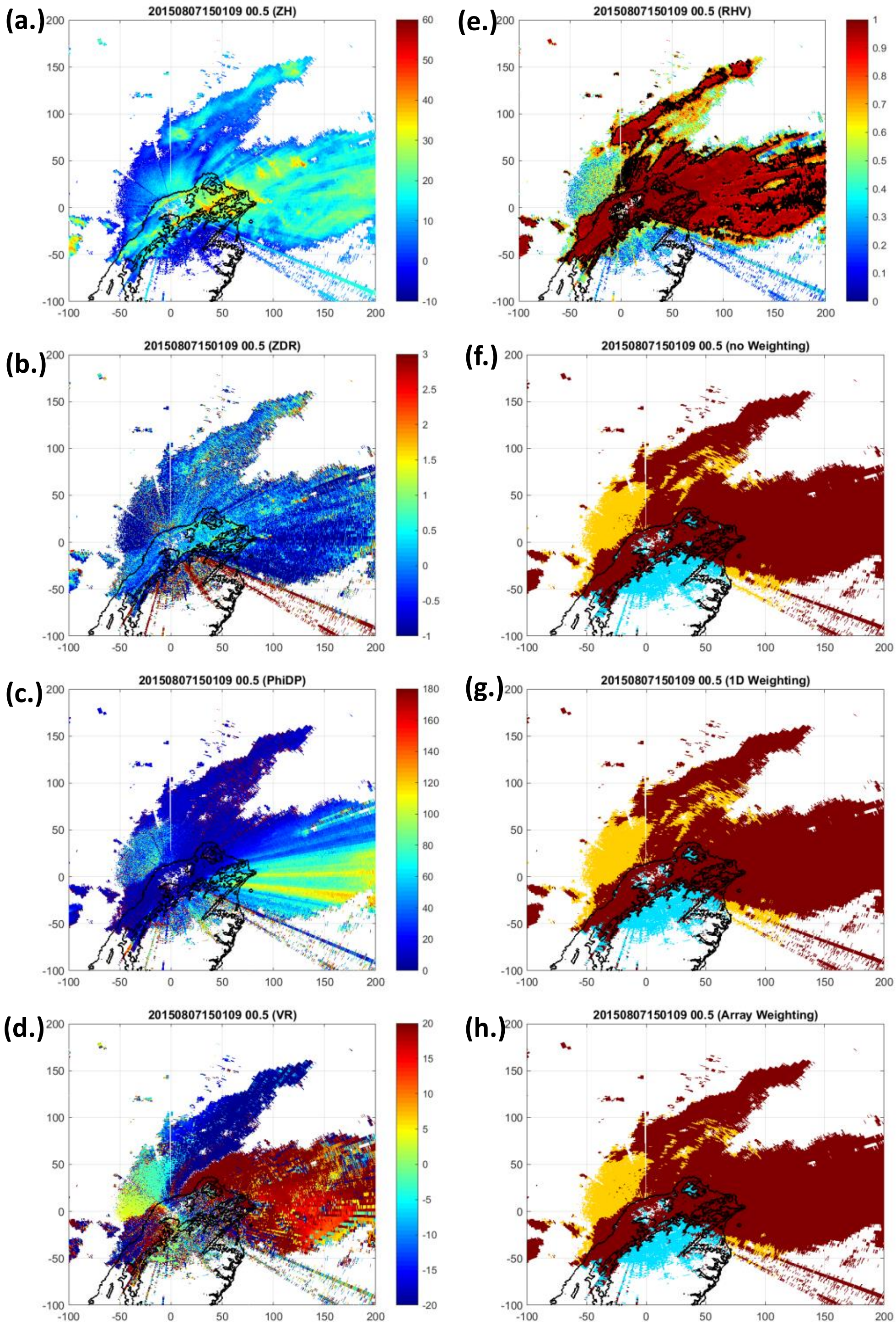

FIG. 3. The radar observational variables (a.) Z_H, (b.) Z_{DR}, (c.) ϕ_{DP}, (d.) Doppler velocity V_R, (e.) ρ_{HV} and PID results from different weighting algorithms (f.) NoW, (g.) 1DW, and (h.) AW, with blue color representing for GC, yellow for SC and brown for ME.

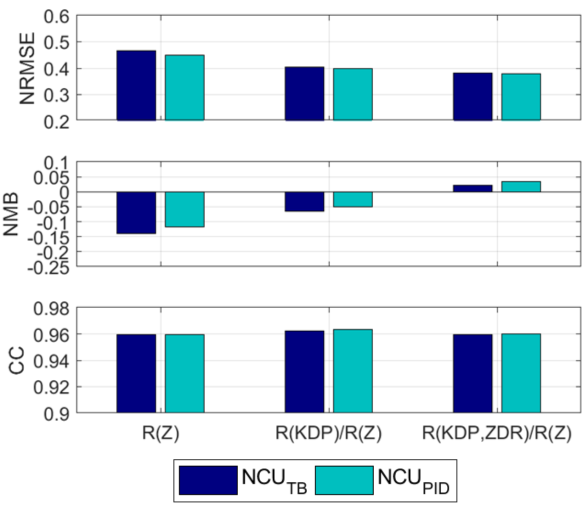

FIG. 4. QPE score comparisons from different QC processes to remove non-meteorological signal. Dark blue is the score by threshold-based method and light one by PID QC.

4. Conclusion

In the fuzzy-logic algorithm, each radar's MFs can be trained accordingly to adapt their own characteristics of different categorized signal. Compared to traditional threshold-based method, PID QC results by AW keep more meteorological information and improve the incorrect categorized percentage with respect to NoW and 1DW test. QPE results by PID QC method show comparable performance to those by threshold-based ones.

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