Reply to Referee 4

We appreciate the reviewer provided these important comments help us improving our manuscript. We'd like to address these comments as following.

1. ZDR is a moment that needs to be calibrated. How stable is the ZDR calibration with time for the C-band you are using. Usually one attempts to be within +/- 0.2 dB. Do you use birdbath scans to calibrate ZDR?

Response: Thank you for the reviewer pointing this out. We totally agree with the reviewer that calibration plays a critical role in radar data processing and weather radar applications. A bias within 0.2 dB is the basic requirement on the ZDR field. In the current work, we directly used the data provided by the radar engineers from Central Weather Bureau of Taiwan, and no further calibration was applied on the Z_{DR} field. We believed the quality of data is good, and the calibration bias of ZDR should be within the reasonable range based on following two reasons:

1.) This radar belongs to Weather Wing of the Chinese Air Force (CAF), and the data became available to the Central Weather Bureau (CWB) since 2009. Currently, RCMK is one of the operational radars in the radar network, and its data are used in the real-time quantitative precipitation estimation (QPE) and forecasting (QPF). The quality of the radar data is closely examined by the engineers from CAF and CWB. Therefore, we believe this radar is well maintained and calibrated.
2.) Same data sets (such as: 08/06/2009 ~ 08/09/2009) from this radar were also examined in few QPE papers (e.g., Wang et al. 2013, 2014). In order to achieve less than 10% bias in QPE products, the bias (including mis-calibration and attenuation) of reflectivity, and differential reflectivity should be within 1 dBZ, and 0.1 dB, respectively. Based on the QPE results estimated from this radar using different combinations of polarimetric radar variables, we believe the bias of Z and ZDR should be within a reasonable range.

On the other hand, following the reviewer's suggestion, we did the sensitivity analysis on the ZDR field. In this analysis, the observed ZDR field was manually adjusted by a factor of -0.2 dB, -0.1 dB, 0.1 dB, and 0.2 dB, respectively. The separation index was recalculated with the "biased" Z_{DR} field. The performances from proposed approach and using separation index only were analyzed with the "biased" fields. Please refer to the reply to comment 2 for more details related to this test.

2. How sensitive is the separation index (eq2) to a ZDR bias? You assume implicitly a perfect radar (hardware wise), where only attenuation corrections need to be applied (if necessary). I wonder how sensitive your method is to some radar hardware influences or issues. Or can you rule out any influence from radar hardware? A discussion is needed here.

Response: First, we do appreciate the reviewer pointing this out. We did not include sensitivity analysis in the original manuscript. We believe such analysis is very useful to guide readers to evaluate and apply this algorithm.

To address this concern, we did the sensitivity test through simulation and real data validation. In the simulation part, the separation index *i* was calculated with four distinct *Z* values: 10 dBZ, 20 dBZ, 30 dBZ, and 40 dBZ. For each *Z*, *ZDR* changes between -0.5 dB to 2 dB, which is used to simulate the bias on ZDR field. The simulation results could be found from revised manuscript in section 3.3.

In the real case validation, we did the following test:

1.) After correcting the Z_{DR} field from attenuation, we manually added ΔZ_{DR} values (as the designed bias) on the corrected Z_{DR} field. The ΔZ_{DR} values are: -0.2 dB, -0.1 dB, 0 dB, 0.1 dB, and 0.2 dB, and the "biased" Z_{DR}: are calculated as:

$$Z_{DR}^{b} = Z_{DR} + \Delta Z_{DR}$$

where Z_{DR}^{b} indicates biased Z_{DR}.

2.) Calculate the separation index (i^{b}) with Z_{DR}^{b}. Evaluate the impacts of ΔZ_{DR} on performances of BAL^{0} and $BAL^{-0.5}$ on cases 08/30/2011 and typhoon case (08/06/2009~ 08/09/2009).
3.) With Z_{DR}^{b} and i^{b} as the inputs to the proposed SVM approach, Evaluate the impacts of ΔZ_{DR} on performances of SVM approach on cases 08/30/2011 and typhoon case (08/06/2009~ 08/09/2009).

More details about simulation and real data validation could be found in section 3.2 in the revised manuscript. In the revised manuscript, only the case from 08/30/2011 is provided. The results from 2009 are provided as below:

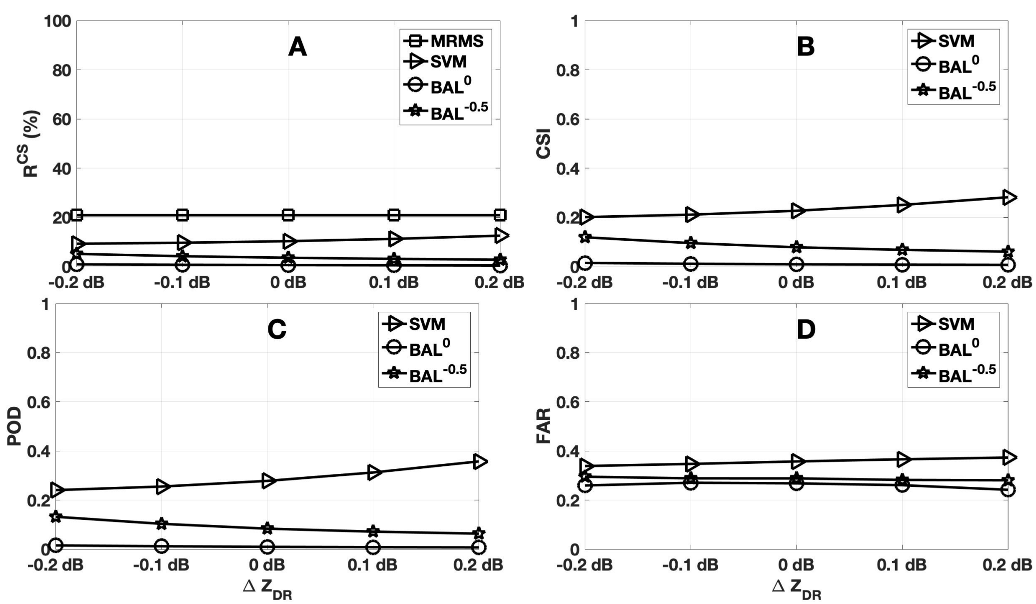

Figure 1. 96-hour averaged R^{CS}(A), CSI(B), POD(C), and FAR(D) from 6~9 August 2009. The results from BAL with threshold T_0 = -0.5, BAL with threshold T_0 = 0, SVM, and MRMS are indicated with symbols of pentagram, circle, triangle, and square, respectively.

Are the radome effects an issue (especially for the typhoon case you present; is it possible that part of the somewhat unusual ZDR pattern in Fig. 10 may be attributed to such a source?)

Response: Yes, we agree with the reviewer. The wet radome could be a possible issue for radar variables such as Z and Z_{DR}. In the revised manuscript, we added following discussion:

Line 280 Other reasons such as wet radome may also contribute to the Z and Z_{DR} issues.

L164, can you motivate why using such a large rhohv (> 0.98) as a criterion? You seem to throw away a lot of data e.g., if you have mixed phase precipitation with hail. Is there no hail in Taiwan? How much of the data are not considered? What happens if you observe rhohv < 0.98. How is the performance degrading if you have data ranges present that where considered for training. Those rangebins cannot be classified, since you trained the data for only specific ranges? Explain what consequence this choice of threshold has, how sensitive your results are, and before that, how the training results are dependent on this choice. Did you make sensitivity studies?

Response: We'd like to address the reviewer's concern from following few different aspects:

1.) In the manuscript, we use 0.98 as the threshold of RhoHV only in the training data selection. As reported by Kumjian (2013), pure rain generally produces very high of RhoHV (> 0.98) observed by WSR-88D. Such value (0.98) also suggested by Ryzhkov and Zrnic (2004) as the RhoHV field from majority of pure rain in C-band. Such large RhoHV was also suggested in hydrometeor classifications (e.g., Liu and Chandrasekar 2000; Park et al. 2009). For example, Park et al. (2009) suggested that RhoHVs for light/moderate rain, and heavy rain are 0.97 and 0.95, respectively. The precipitation may be classified as the mixed rain and hail if RhoHV is below 0.9. Following these pioneering works, we choose 0.98 as the threshold of RhoHV in the training data selection.

   In the revised manuscript, we added the reference paper on Line 186.

2.) The threshold of 0.98 for RhoHV is only applied in the training data selection. Such aggressive threshold can assure the training data from pure precipitation, and not smeared by clutter (including ground clutter, sea clutter, biological scatter), AP, and possible ice phase precipitation. When we test the algorithm with precipitation events, the threshold for RhoHV is selected as 0.90. Any pixel (gate) with RhoHV below than 0.9 is classified as non-precipitation echo. Any pixel with RhoHV above 0.9 is treated as pure rain, and the same support vector obtained from training data is applied.

3.) The separation index (*i*) was derived from two drop size distribution (DSD) parameters N_w and D_0. Therefore, it only validates at liquid phase precipitation (stratiform and convective types) as suggested by (Bringi et al. 2009). For other phase precipitation, such as mixed hail and rain, its performance is not well studied (Bringi et al. 2009). Other hydrometeor classification schemes are suggested for such scenario (Bringi et al. 2009). In this work, the separation index also plays an important role in the SVM approach, therefore, we limited the application of the proposed approach only within pure water phase precipitation. We have not tested it on the mixed phase precipitation with hail. In the revised manuscript, we emphasized this limitation at Line 344.

4.) The goal of this work is to propose a prototype algorithm, and this manuscript focuses on describing this algorithm. We are working on further analyzing this approach including deriving the new separation index for S-band radar (WSR-88D), validating its long-term performance, including more variables (such as reflectivity texture), including multiple elevation angles. Sensitivity test for different training data definitely is also included in this work. We plan to report further findings in the upcoming papers.

L166, what is exactly a "data set"? A range bin with all the moments you use satisfying the criteria for Z, RhoHV? Would be helpful to the reader who is not so familiar with this method.

Response: We appreciate the reviewer pointing this out. A "set" means a set of data from one radar gate (defined as azimuthal angle and range). Be more specific, a set of training data means a vector of $[Z(a,r)\ Z_{DR}(a,r)\ i(a,r); d(a,r)]$. Where "*a*" indicates azimuthal angle, "*r*" indicates range; "d" is the desired response with "1" represents convective, and "-1" represents stratiform.

Line 188: A total of 17281 sets of data (15144 sets of stratiform, and 2137 sets of convective) are used in the training process. In this work, one data set is defined as the variables from a single gate in terms of range and azimuthal angle. Be more specific, a collection of training data means a vector of [$Z(a, r)$ $Z_{DR}(a, r)$ $i(a, r)$ $d(a, r)$], where *a* and *r* indicate azimuthal angle and range, respectively. The variable *d* is the ground truth (with 1 and -1 represents convective and stratiform), i.e., the desired response in the training process.

L234: the intrinsic ZDR for stratiform precipitation: isn't it something around 0.2 dB, Or is this different in Taiwan?

Response: Yes, the reviewer is correct. The ZDR values we provided in the manuscript is not accurate. The ZDR values mentioned in the manuscript are within the black circle in the following figure (Fig. 7 in the original manuscript). If we examine carefully, especially for those gates with Z around 30 dBZ, the ZDR values are around 0.2 dB, instead of 0 dB.

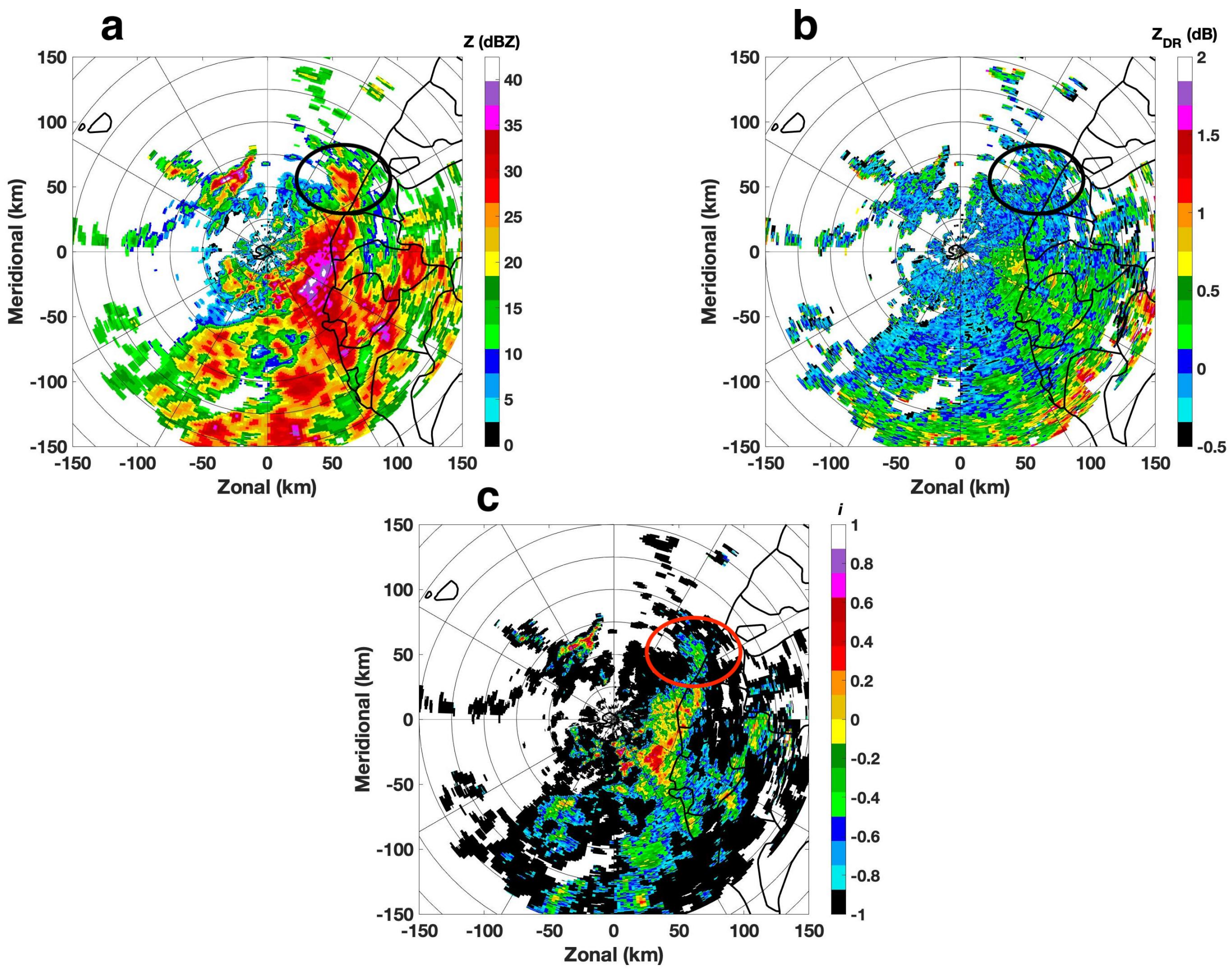

Fig 10: ZDR looks biased to me… There seem sector based (az, range) biases for 270 -> 90^{o}… you mention this in l250 ff, but Z looks relatively reasonable here.

Response: We agree with the reviewer. In this sector, ZDR looks over corrected from attenuation, but Z looks relatively better. One hypothesis is both coefficients α and β used in the linear PhiDP are need be adjusted based on the DSD and DSR features. Comparing to α, β is more sensitive to the impact of DSD and DSR.

Reference:

Kumjian, M. R., 2013: Principles and applications of dual-polarization weather radar. Part I: Description of the polarimetric radar variables. *J. Operational Meteor.,* **1** (19), 226-242, doi: http://dx.doi.org/10.15191/nwajom.2013.0119.

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Park, H, A. V. Ryzhkov, D. S. Zrnic, and K.-E. Kim, 2009: The hydrometeor classification algorithm for the polarimetric WSR-88D: description and application to an MCS. *Weather and Forecasting*, **24**, 730-748.

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