Mitigation of sea clutter and other non-stationary echoes based on general purpose polarimetric echo identification

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1. Introduction

Quality aspects of weather radar data are often a limiting factor in operational applications. Initially, radar echoes are strongly contaminated by signals other than precipitation. Ground clutter mitigation by Doppler radar is a classic example of substantial automated improvement in radar data quality. There are several other echo sources, at land and at sea, that remain in radar data after suppression of static ground echo. General and site specific knowledge may help identifying them in interactive analyses, for restoring the observations usefulness and for moderating their impacts. Automated radar products prefer more stringent quality of the data input. Continued improvements in data quality considerations are thus called for.

Polarimetric weather radar has an enhanced capability of echo identification. This capability is well suited to data quality considerations, such as mitigation of non-meteorological echoes. It builds on the accumulated common knowledge of polarimetric echo identification, compiled into automated decision methods (Straka and Zrnic 1993, Liu and Chandrasekar 2000, Lim et al. 2005, Park et al 2008). Given that automated fuzzy methods are made operationally available as part of real-time signal processing, such as HydroClass™ (Keränen et al 2007), the identification capability can be utilized at the gate level, promptly. Being a gate level functionality, it is robust to choices of scanning strategy.

The hypothesis of bulk precipitation can be tested against the one of non-meteorological signal by using a continuous smooth metric called the polarimetric meteorological index (PMI), derived from corresponding fuzzy rule strengths. The moment data is flagged and can be removed, bin-by-bin, when PMI is below a configurable threshold (thresholded, for short), accordingly. This greatly simplifies down stream data applications. It is available simultaneously with the Doppler clutter filtering which is optimized to mitigate significant stationary ground echo. Their combination allows high suppression of stationary and non-stationary non-meteorological echoes.

We report here on implementation of such a tool set and typical use cases. Data quality is considered in cases of significant sea-clutter and other non-stationary non-precipitation echoes that pass through Doppler filtering.

2. Implementation of the polarimetric quality index

In our case the polarimetric quality index is chosen to utilize the classification outcomes of the HydroClass™ pre-classifier modeled from the field tested method of the JPOLE campaign (Ryzhkov et al, 2005). The JPOLE method originally considered data in view of three categories: 1) precipitation, 2) bio-scatter, 3) ground clutter/anomalous propagation. Application to a broad variety of radar data has revealed that the method is suitable for separating precipitation from many kinds of echoes of non-meteorological origin, at varied site conditions, climates, and radar wave lengths with minor tuning of parameters.

This generality is not accidental. It is based on using the micro-physical characteristics of precipitation: relatively high co-polar correlation and relatively smooth radial behavior of co-polar differential phase and of echo power, accompanied with specific relations between reflectivity (Z_h) and differential reflectivity (Z_{dr}). The signals of varied non-meteorological origins may have wildly different characteristics but share the following: they exhibit no propagation effects, their co-polar correlation and signal power match with precipitation accidentally. As net outcome the chosen classifier performs well beyond its original context: locally significant bio-scatter and ground echo. Other polarimetric quality considerations for exclusive identification of precipitation utilize similar principles; see (Wang and Chandrasekar, 2009). To reiterate, the methods primarily perform due their consistency with general principles.

2.1 Interpretation of fuzzy rule strengths as the polarimetric quality index for precipitation

The rule strength sets (RS) of the fuzzy approach can be combined into a smooth continuous quality index, PMI. An empirical transformation is convenient of the type

$$PMI = 1 - 1 / [\, 1 + RS(\text{"meteorological signal"}) / \max\{ RS(\text{"other"}) \} \,] \qquad (1)$$

where RS("meteorological signal") is the rule strength for 'precipitation' and RS("other") refer to the class hypotheses of non-meteorological origin. Alternatively, a choice of likelihood ratio for statistical rigor can be considered

$$\text{PMI} = \text{RS}(\text{"meteorological signal"}) / \Sigma\{\text{RS}_i\} \qquad (2)$$

where the sum of rule strength is made over all classes in the hypothesis set. Both relations lead to PMI values in the range (0, 1), while the empirical one appears occupying the range more optimally. The empirical value PMI=0.5 coincides with the JPOLE maximum rule strength inference for 'precipitation'. The primary objective of the construction is to select for 'precipitation', while in principle the construction can be rotated to favor any of the classes in the underlying classifier - to filter the radar data for 'bio scatter', for example.

2.2 PMI as a part of common radar data quality considerations

Quality considerations of modern Doppler signal processing are a viable model to implement PMI. As a general rule, the gate data from relevant echoes are stored. Data are set null when no signal (noise). Data of unambiguously fake origin (e.g. static ground clutter, second range echo) are either filtered (signal recovered) or set null (thresholded), as correction. The uncorrected data can be preserved in selected cases - duplication of data to preserve intermediate states of data is not a general rule, however. Information about the quality settings, such as Doppler filter parameters and thresholding criteria, are accompanied in the data headers. Selected quality indicators may accompany the moment data, bin-by-bin.

Typically, valid moment data are required to meet a non-vanishing level of signal-to-noise ratio (LOG). In addition, data with very high clutter to signal ratio (CSR) are to be thresholded at a level matching the radar clutter cancellation performance. Good pulse-to-pulse coherence (SQI) is required for a valid Doppler velocity estimate. A fair ratio of meteorological signal to noise (SIG) can be required for spectral widths. These quality indicators are computed simultaneously to the actual moments. Advanced radar operating systems, such as IRIS/RDA™, allow operators to configure moment specific quality requirements as logic tables of LOG, CSR, SQI and SIG thresholds. They build on each other i.e. if configured in logical "AND", a threshold applied earlier in the stream is respected. The threshold levels and their decision logic can be configured in each task of scanning strategy, for optimal application performance.

The PMI quality consideration is implemented as a consistent extension to the existing Doppler quality considerations. PMI is computed and used for thresholding in the actual data processing, analogously to other auxiliary quality measurands LOG, CSR, SQI and SIG. PMI is activated and tuned by the common graphical user interface to radar operation, as illustrated in Figure 1. Data headers have been enhanced such that they carry the information on the PMI settings.

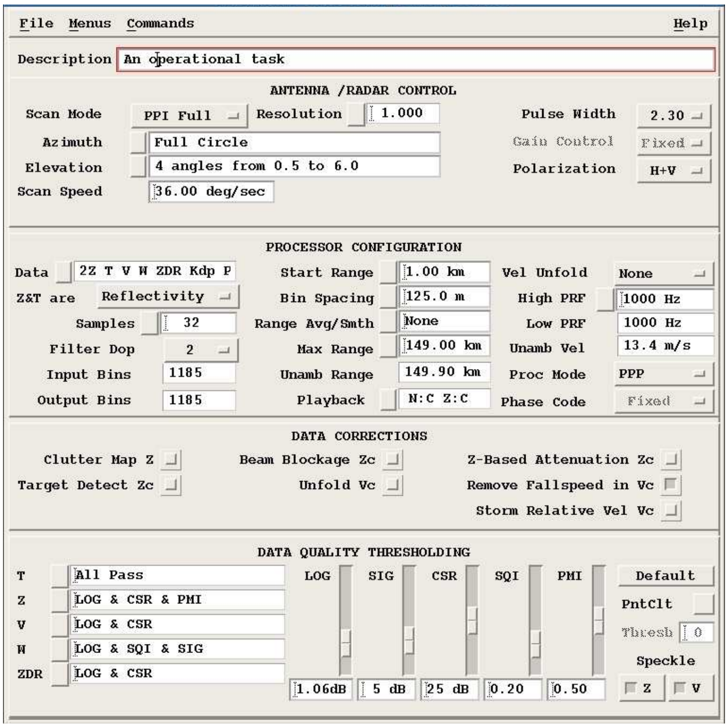

Fig. 1. An instance of radar task configuration user interface, with a handle to the PMI threshold levels (bottom right) and to the activation, as part of the logic table for reflectivity "Z" data (bottom left).

3. Examples of PMI quality consideration applied on varied weather and site conditions

3.1 Ground, sea clutter and precipitation in tropical oceanic climate

The PMI tool was applied on IRIS/RDA™ data obtained in tropical oceanic conditions. Samples acquired by the S-band Kwajalein Polarimetric radar (KPOL) located at Kwajalein Atoll, Marshall Islands were analyzed (see Schumacher et al, 2000 for description of KPOL radar). The site is surrounded by open sea; with noted ground targets at distances up to 40 km. Sea clutter returns are common in low elevation data. No Doppler filtering is applied in this specific example, while SQI is used to suppress significant second range echoes. Echo power must exceed the noise by 1.2 dB.

Typical low elevation sweep data of reflectivity with significant precipitation is displayed in Figure 2. Closer to the radar, the sweep data exhibit sea echoes as well as distinct ground clutter on the islands' shores. These are highly suppressed by PMI thresholding while no precipitation is lost. Optimal ground clutter suppression and weather signal recovery would be achieved by combination with Doppler filtering.

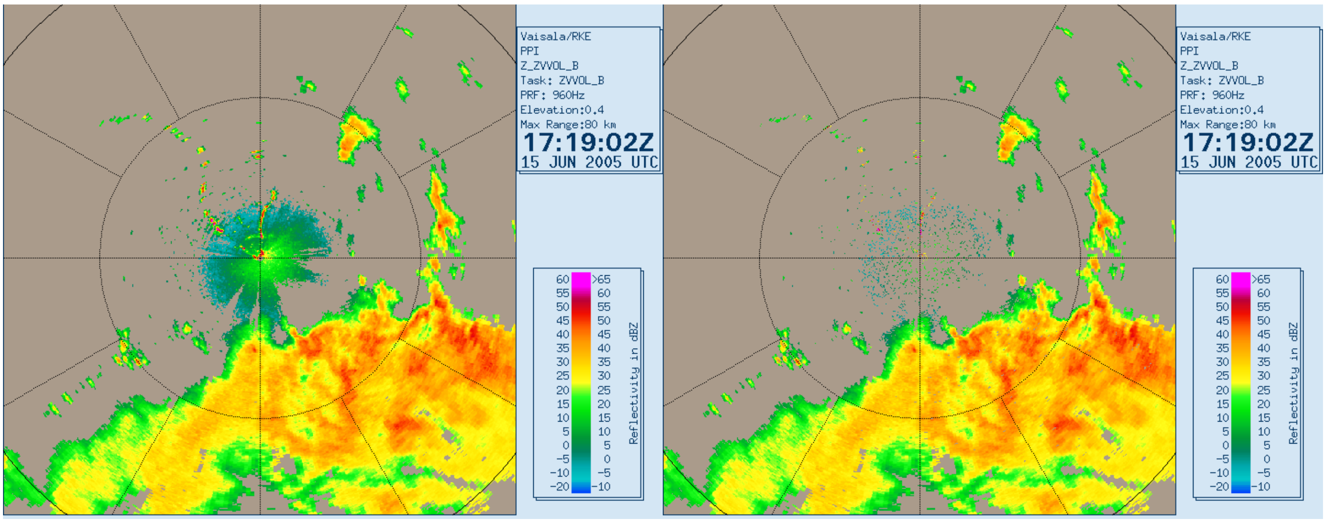

Fig. 2 Left: a single sweep field of unfiltered reflectivity. Right: reflectivity field after additional PMI>0.5 thresholding.

3.2 Performance in presence of ship echoes, urban signal, bio-scatter and radio interference

As a real-time evaluation, the IRIS/RDA™ radar and signal processing software enhanced with the functionality of PMI quality consideration, was installed at the Vaisala C-band polarimetric weather radar at Kumpula campus, University of Helsinki, Finland (Puhakka et al, 2006). The site is challenged by the open view to Gulf of Finland which may generate variety of non-meteorological signals, including anomalous propagation of ground echo from the Estonian coast at some 80 km south. The site is subject to significant urban clutter (traffic) as well as frequent sea traffic (ships). Man-made radio frequency interferences (un-coordinated RLAN) are not uncommon in the region. Vaisala operates a C-band polarimetric radar (WRM200) at Kerava facility some 30 km north from Kumpula, which is used here as a reference as the impacts of sea and urban environment seen at Kumpula.

The radar scanning strategy included tasks that resemble operational settings (32 pulses, pulse widths of 2 µs, pulse repetition frequency of 1 kHz). Volume scans at pulse width 2 µs, low elevations 0.3 to 3 degrees were duplicated for processing data with and without PMI thresholding, and run consecutively - thus allowing simple sweep level performance evaluation of the PMI functionality. The reflectivity data were subject to Doppler filtering, the echo power must exceed the noise by 1.2 dB (LOG). Bins with clutter power exceeding the weather signal by 25 dB were thresholded (CSR).

A warm season period of 24 hours in Helsinki region from 29th to 30th June 2010 was selected for analysis, see reference radar data and satellite imaginary in Figure 3. The evaluation spanned over period of mostly fair weather, with significant precipitation occurring at distances of 100 km, at the end of the period.

The reflectivity fields of a typical volume scan at Kumpula radar, at elevation 0.5 degrees are shown in Figure 4. After standard quality considerations several sources of non-precipitating echo are present in the reflectivity data:

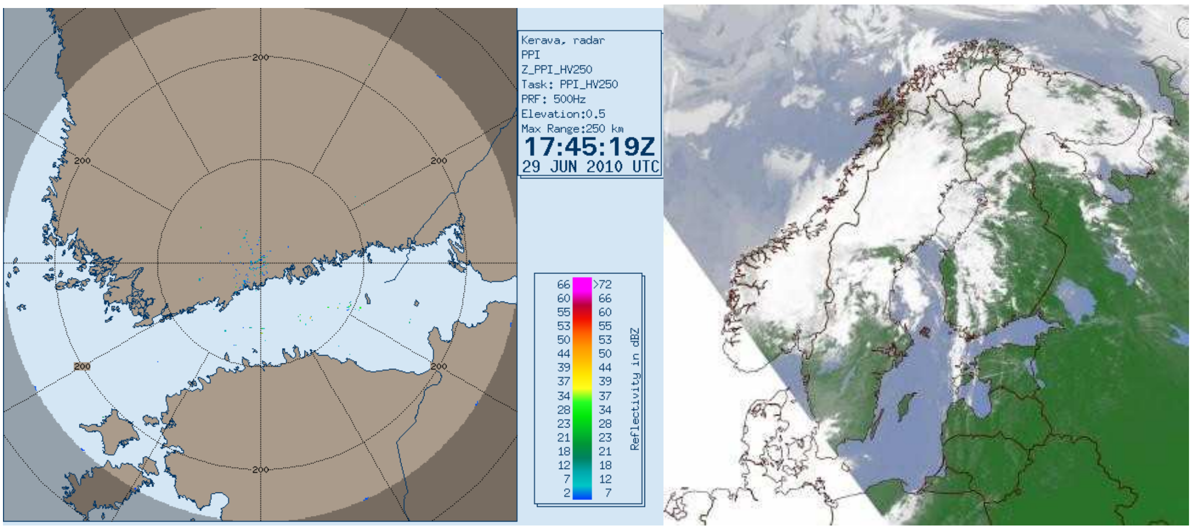

Fig. 3 Surveillance of the large scale weather the evaluation period. Left: reflectivity field up to 250 km, from the Kerava WRM00 radar at beginning of the 24 evaluation period. Right: NOAA infrared imagery in the middle of the evaluation period 2010-06-30 UT 14:54. Precipitation took place in Baltic and at Gulf of Finland later in the evening.

1. large areas of weak echo are left at distances less than 50 km, plausibly from warm season bio-scatter,
2. specific single radial signal from south, plausible radio interference, and
3. strong point-like echoes at sea, surviving through the speckle filters of signal processing.

All these anomalies are suppressed by high degrees after applying PMI (threshold level 0.6), see Figure 4 (right).

The integrated impact of these non-precipitating signals was inspected by computing accumulated rain fall estimates over the period of 24 hours. The RAINN products were obtained from reflectivity data converted first into momentary "Surface Rainfall Intensities", then collected into hourly rain fall estimates and eventually into 24 hour accumulated rain fall. The outcomes are shown in Figure 5. The attention was focused on significant rain (R > 1 mm) of operational interest. There are two distinct features:

1. the sources of short distant urban clutter, which accumulate into visible accumulated rain fall > 1 mm in 24 hours - these are likely marginal for most short term applications, but complicate applications of longer integration (hydrology, climatology);
2. the point-like echoes at sea accumulate into a regular pattern that reveals their origin to be in the regular ship traffic at Gulf of Finland. The signals generate fake rain fall that approaches and occasionally exceeds 10 mm in 24 hours. Such fake accumulations are harmful to many applications, and may bring the off-shore rainfall data unusable.

Both of these anomalies are suppressed to highest degree, by applying the PMI threshold. As comparison, true rain fall accumulated at end of the evaluation period is fully preserved up to far distances, see Figure 6.

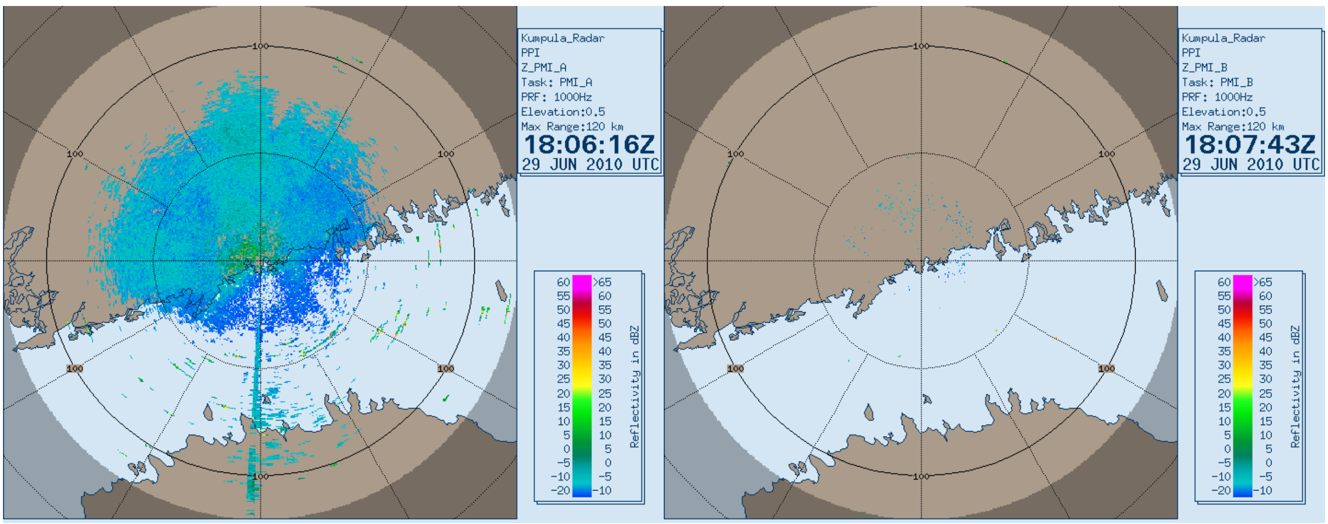

Fig. 4. Left: a single sweep field of reflectivity acquired at the Kumpula C-band weather radar, using Doppler filtering and related quality considerations (LOG, CSR). Right: the reflectivity field after additional PMI>0.6 thresholding.

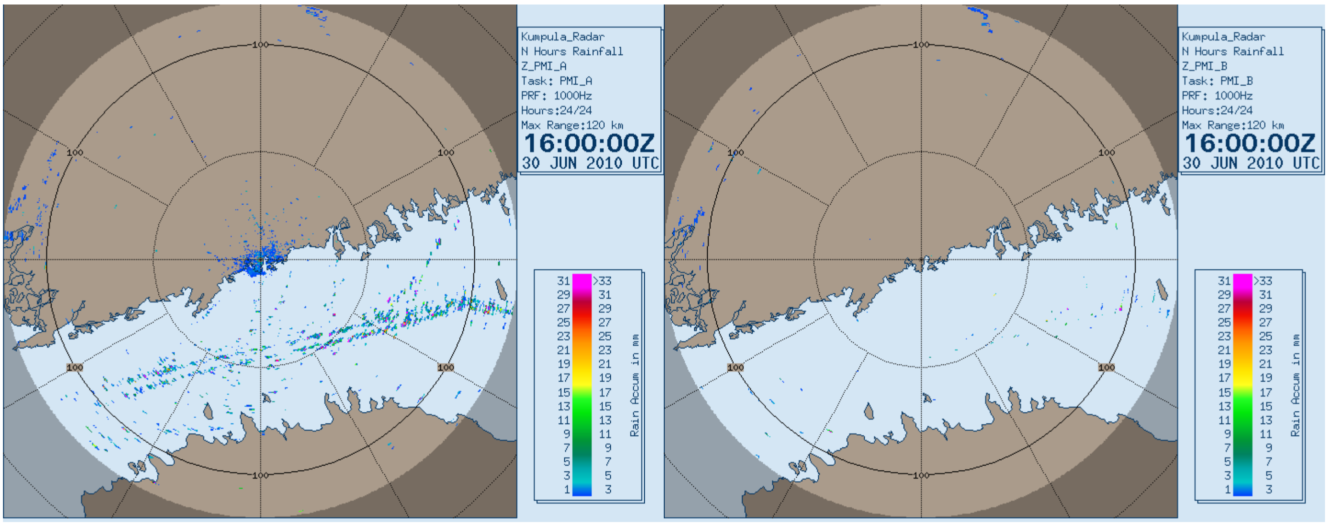

Fig. 5 Estimates of non-negligible rain fall (>1 mm) accumulated over a period of 24 hours in the Helsinki region. Left: rain fall integrated from reflectivity data that are subject to Doppler filtering and quality considerations of (LOG, CSR). Right: as left, but reflectivity data are subject to additional threshold PMI>0.6.

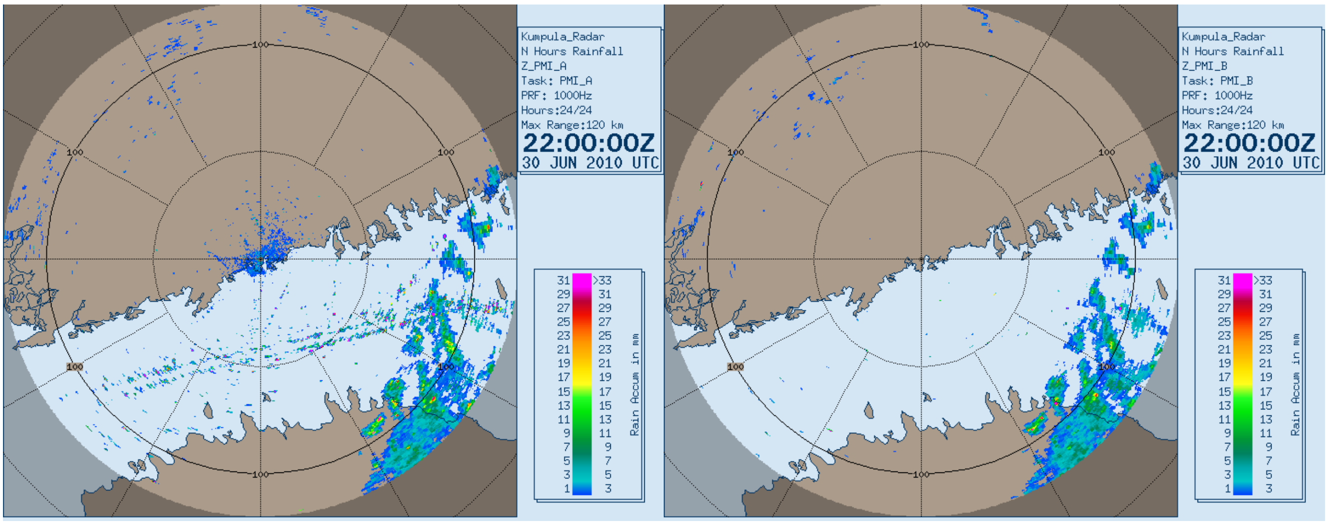

Fig. 6. As Figure 5 but the 24h data accumulation extended to include a period of precipitation in south-east.

4. Conclusions

The echo identification capability of the polarimetric weather radar offers strong tools for improved data quality considerations. Given the general purpose identification methods available in real-time signal processing, the identification results can be applied, promptly, to quality consideration for moment data bin-by-bin.

There is generality in polarimetric echo classifier methods in the sense that the separation power of bulk precipitation from other echoes is mostly based on the unique features of precipitation - not on details of non-precipitating signals of varied kind. This defines the robustness of this type of classifiers. As soon as conceived reasonably, polarimetric classifiers are well suited for selecting precipitation from a variety of non-precipitating echoes, such as sea clutter, urban clutter, chaff, and bio-scatter and radio interference. Depending on local conditions a specific source of non-precipitating signals may dominate, such as persistent sea echo. A general purpose classifier is readily addressing that particular source - the high configurability of the tool will enable further optimization.

The polarimetric meteorological index (PMI) is now implemented as an enhancement to legacy data quality considerations within the RVP8 and RVP900 signal processors. It is a complementary, promising approach to mitigate non-stationary non-precipitating signals, in favor of high quality precipitation fields.

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References

Straka, J. M. and D. S. Zrnic, 1993: An algorithm to deduce hydrometeor types and contents from multiparameter radar data. *26th Conf. on Radar Meteorology,* Norman, OK, Amer. Meteor. Soc., 513–516;

Liu, H., and V. Chandrasekar, 2000: Classification of hydrometeors based on polarimetric radar measurements: development of fuzzy logic and neuro-fuzzy systems, and in situ verification. *J. of Atmos. Oceanic Technology*, **17**, 140-164;

Lim, S., Chandrasekar V. and Bringi V.N., 2005: Hydrometeor classification system using dual polarization radar measurements: model improvements and in situ verification. *IEEE Trans. Geoscience and Remote Sensing*, **43**, 792-801;

Park H., Ryzhkov A.V., Zrnic, D.S. Kyung-Eak K. 2008: The Hydrometeor Classification Algorithm for the Polarimetric WSR-88D: Description and Application to an MCS *Weather and Forecasting,* **24**, 730-748;

Keränen R., Saltikoff E., Chandrasekar V., Lim S., Holmes J., Selzler J 2007: Real-time Hydrometeor Classification for the Operational Forecasting Environment, *33rd Conf. on Radar Meteorology,* Cairns, QLD, Australia, Amer. Meteor. Soc., P11.B1;

Ryzhkov A. V, Schuur T.J., Burgess B.W., Heinselman P.L, Giangrande S, Zrnic, D.S. 2005: The Joint Polarization Experiment Polarimetric Rainfall Measurements and Hydrometeor Classification, *Bull. of Amer. Meteor. Soc, June 2005,* 809-824*;*

Wang Y., Chandrasekar V. 2009: Algorithm for Estimation of the Specific Differential Phase *J. of Atmospheric and Oceanic Technology,* **26**, 2565-2578;

Schumacher, C. and R. A. Houze Jr., 2000: Comparison of radar data from TRMM satellite and Kwajalein oceanic validation site, *J. Appl. Meteor. ,* 39*;*2151-2164;

Puhakka, T., M. Leskinen, P. Puhakka, S. Niemi, L. Konkola, N. Tollman, 2006: University of Helsinki research radar setup. *4th European Conf. on Radar Meteorology and Hydrology*, Barcelona, Spain.