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Full Polarimetric and Doppler Measurements with Poldirad: A Practical Application of the 3-PolD Method.

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***Abstract*—The Poldirad radar possess the capability to transmit any sequence of polarizations while receiving their co- and cross-polar components. In particular, in this paper the rain data obtained after transmission of horizontal, vertical, right hand circular and left hand circular polarizations has been used to validate the 3-PolD method. This method considers estimation of the covariance matrix and Doppler parameters from coherency matrix measurements at lags 0 and T. Coherency matrices should be obtained for at least three different polarizations. The full polarimetric covariance matrix at lags 0 and T is then obtained through least squares estimation. Doppler parameters are obtained from the covariance matrix at lag T.**

I. INTRODUCTION

The Poldirad radar of the DLR at Oberpfaffenhofen has been operated with research purposes since 1986. The main characteristics of the C-band system comprise the polarisation agility for transmitting, the dual-channel receiving, the Doppler capability, and the real time processing and display [1]. Its polarization agility unique capabilities allow to explore and validate different polarimetric measurement techniques as it enables alternate transmission and reception of pulses with different polarizations, providing great flexibility in defining the sequence of pulse polarizations to be transmitted [2].

The 3-PolD method, proposed in [3], allows obtaining full polarimetric and Doppler information of the target if at least three different polarizations are alternately transmitted while simultaneously receiving the co- and cross-polar components. It has been theoretically demonstrated that this method possesses interesting properties. In particular, it provides minimum variance unbiased linear estimates of the polarimetric covariance matrix elements while allowing computation of the Doppler parameters. Interestingly, Doppler capabilities are not reduced as compared to a non-polarimetric radar with the same baseline PRF. Importantly, so long as the 3-PolD method does not make any assumption about the target properties and provides all elements of the covariance matrix, estimation of parameters defined for any other polarimetric basis, as for example the CDR or the ORTT, are straightforwardly obtained through a change of basis.

Table 1 summarizes its main characteristics in comparison with the two well-known and established ATSR (Alternate Transmission Simultaneous Reception) and STSR (Simultaneous Transmission Simultaneous Reception) methods.

	3-PolD	ATSR	STSR
Horizontal reflectivity, Zh	Yes	Yes	Yes
Vertical reflectivity, Zv	Yes	Yes	Yes
Differential reflectivity, $\mathrm{Z_{dr}}$	Yes	Yes	Yes
Linear depolarization ratio, $\mathrm{L_{dr}}$	Yes	Yes	No
HV co-polar correlation coefficient, ρ_{hv}	Yes	Yes[1]	Yes
Maximun unambiguous speed, $v_{max} = \lambda \cdot PRF/4$	Yes	No[2]	Yes
Assumes $S_{hv} = S_{vh} = 0$	No	No	Yes
Assumes Gaussian Doppler Spectrum	No	Yes	No

[1] Requires low Doppler spectrum width (less than around $0.3v_{max}$)

[2] v_{max} is halved

Table 1. Comparison of ATSR, STSR and 3-PolD methods polarimetric capabilities.

II. POLDIRAD DATA

The data was acquired on october the 1st, 2014. Four polarizations were alternately transmitted: vertical (V), horizontal (H), right-hand circular (R) and left-hand circular (L). At reception, the co- and cross-polar components of each transmitted pulse were recorded. The baseline PRF was

1200 Hz, therefore, the PRF for each one of the polarimetric channels was 300Hz. The pulse width was 1 μs.

Fig. 1 shows the horizontal reflectivity RHI scan. The stratiform rain event data (the framed area in the RHI) was chosen to test the 3-PolD method.

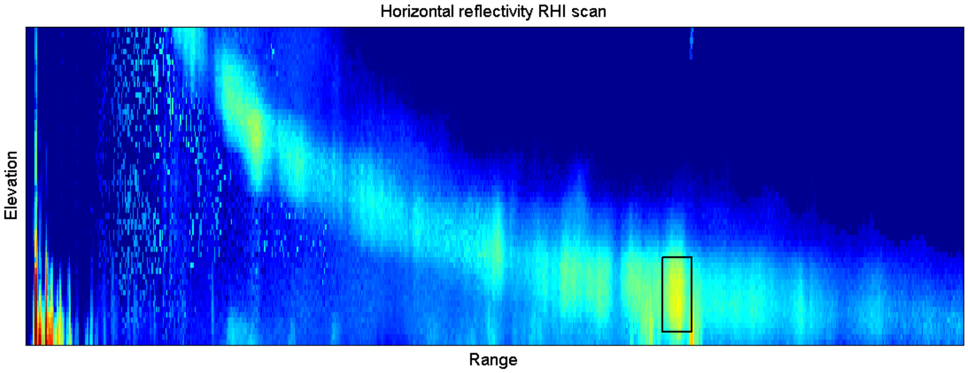

Figure 1. Horizontal reflectivity RHI scan. The data corresponding to the framed area was used to test the 3-PolD method.

Data from 11 consecutive range gates was selected to test the 3-PolD method performance. From each range gate 2816 pulses are available. Since the radar is scanning in elevation, 11 resolution cells have been defined at different elevation angles for each range gate. Therefore, a total of 121 resolution cells are considered with 256 received pulses available at each cell for polarimetric and Doppler parameter estimation.

III. DATA PROCESSING

The received data has been processed using the 3-PolD method to obtain the polarimetric parameters of interest. Besides, some polarimetric parameters have been obtained using sample estimation for comparison with the 3-PolD results. Fig 2. shows a scheme of the two processing methods.

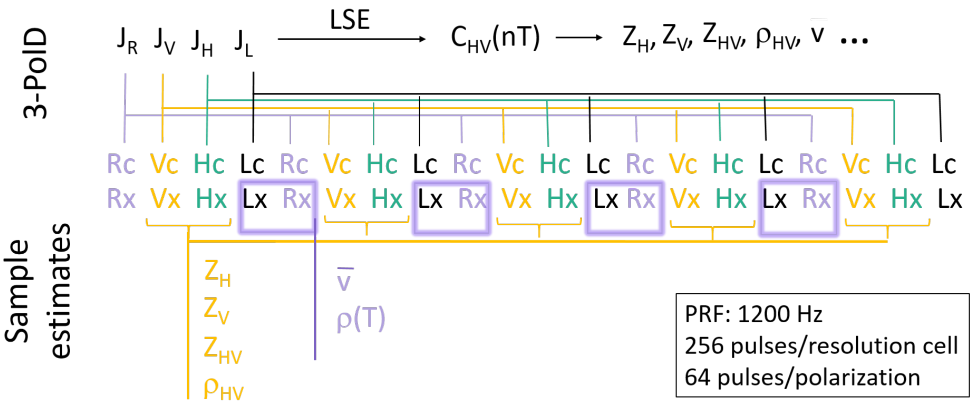

Figure 2. Data processing scheme.

Sample estimation of the received co-polar echos when the horizontal (vertical) polarization is transmitted provide an alternative estimate of the horizontal (vertical) reflectivity Z_H (Z_V). Since, vertical and horizontal polarizations are consecutively transmitted, estimation of the differential reflectivity Z_{HV} and the co-polar correlation coefficient ρ_{HV} is performed as in the ATSR method. Temporal correlation $\rho(T)$ and mean drop velocity $\overline{v}$ are obtained from the cross-polar responses to consecutively transmitted left hand circular and right hand circular polarizations.

These parameters are also calculated with 3-PolD method. For this the coherency matrices for the 4 transmitted polarizations, J_H, J_V, J_R and J_L are obtained from the co- and cross-polar responses to H, V, R, and L transmitted polarizations respectively. Then, it is important to remind that any of these coherency matrices can be related to the polarimetric covariance matrix in the HV-basis:

$$\mathbf{J}_\alpha = \mathbf{P}\mathbf{M}_{HV-\alpha\alpha^\perp}\mathbf{C}_{HV}\mathbf{M}^{t*}_{HV-\alpha\alpha^\perp}\mathbf{P}^{t*} \tag{1}$$

where α represents any of the transmitted polarizations, $\alpha^{\perp}$ its corresponding orthogonal polarization,

$$\mathbf{P} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

and $\mathbf{M}_{HV-\alpha\alpha^{\perp}}$, is the unitary matrix to change the polarimetric covariance matrix from the HV-basis to the $\alpha\alpha^{\perp}$-basis.

Therefore, since measurement of the four coherency matrices provides 16 equations with 9 unknowns (the elements of $\mathbf{C}_{HV}$), least squares estimations is used to obtain the polarimetric covariance matrix $\mathbf{C}_{HV}$ and then the polarimetric parameters.

Fig. 3 shows the results obtained for horizontal and vertical reflectivities that have been calculated using the classical sample estimator (black lines) and the 3-PolD method (green lines). The differences observed between both estimates are well explained by the statistical variability of the data.

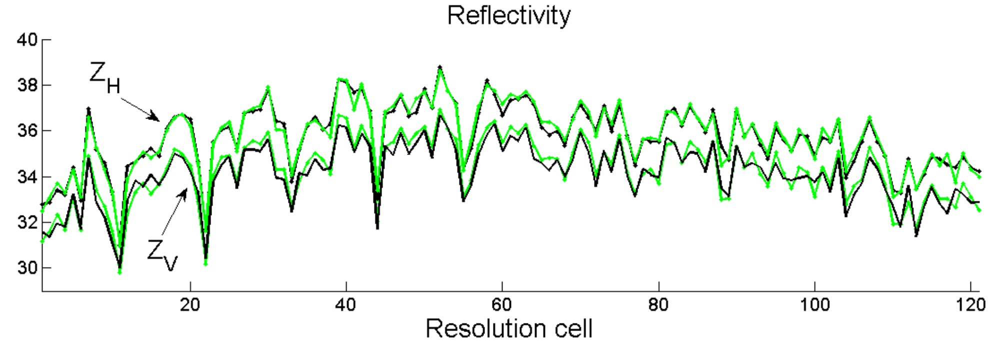

Figure 3. Vertical and horizontal reflectivities.

Fig. 4 shows the co-polar correlation estimates for the 3-PolD method and the ATSR method. The small differences between both methods are due to statistical variation and a slight misscalibration of the transmitted circular polarizations.

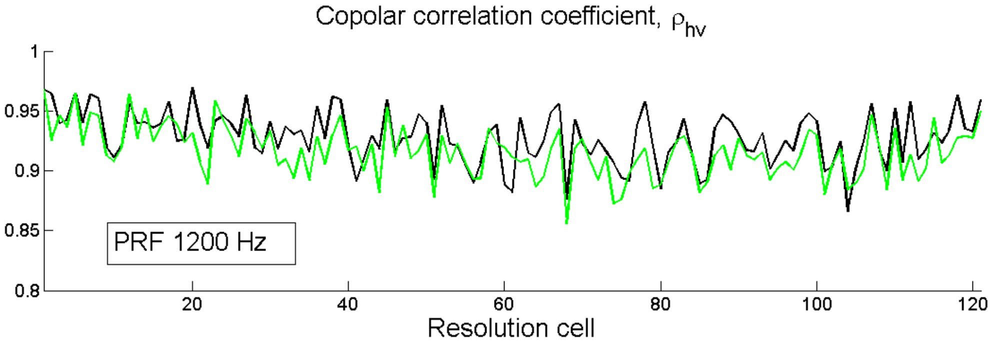

Figure 4. Co-polar correlation coefficient estimates $\widehat{\rho}_{HV}$.

One of the most significant potentials of the 3-PolD method is that despite it alternates the transmission of different polarizations, it can provide estimates of the co-polar correlation even for wide Doppler spectrum widths or highly decorrelated temporal samples. To show this, the received data has been decimated by a factor 5, this ensures to preserve the original sequence of transmitted polarizations; however, the actual PRF of this decimated data is much lower, 240 Hz and received echos are almost completely decorrelated. Fig. 5 shows the estimated co-polar correlation coefficient from this decimated sequence, clearly, the 3-PolD method provides valid estimates while, as it is well known, sample estimation does not.

Finally, estimates of the normalized mean velocity obtained with both processing methods are shown in Fig. 6. Agreement for these estimates is very good.

IV. CONCLUSIONS

Preliminary results show a good agreement of the 3-PolD method estimates with the sample estimates. For the co-polar correlation the values observed are slightly low, but it is thought this to be due to some miscalibration of the right- and left-hand circular polarization.

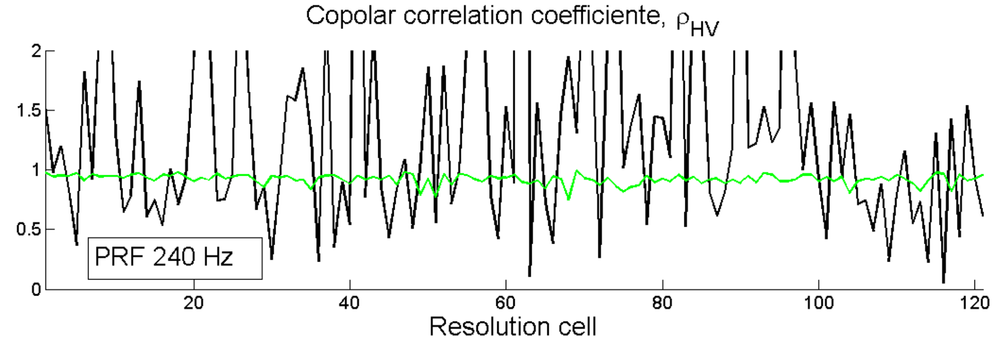

Figure 5. Co-polar correlation coefficient estimates from decimated data. PRF=240 Hz.

Besides, it is important to note that now that the possibility of using radars with a phased array antenna instead of a mechanically steered parabolic reflector is being investigated, it has been shown that [4] to cope with the loss of polarization purity and the increase of polarization channels coupling inherent to phased array antennas [5], the 3-PolD method requires some corrections only at reception.

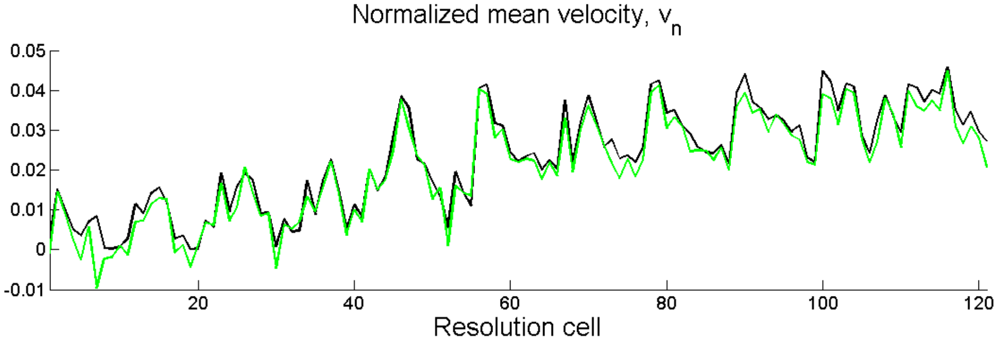

Figure 6. Velocity estimates.

On the other hand, using of the 3-PolD method allows correction of the bias caused by the antenna radiation patters [6], [7] if these radiation patterns are known. This correction is possible because backscattering from the targets can be decoupled from the antenna effects.

Finally, it should be noted that the 3-PolD method provides an algorithm for polarization calibration based only on previously recorded data.

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REFERENCES

[1] A. Schroth, M. Chandrai, and P. Meischner, "A c-band coherent polarimetric radar for propagation and cloud physics research," *Journal of Atmospheric and Oceanic Technology*, vol. 17, pp. 257–278, 2000.

[2] J. Reimann and M. Hagen, "Multipolarization measurements concerning various aspects of the star mode," *ERAD2012. The Seventh European Conference on Radar in Meteorology and Hidrology.*, Toulouse, France. 24-29 June 2012.

[3] V. S. del Rio, "Least squares estimation of doppler and polarimetric parameters for weather targets." *IEEE Trans. on Geosc. and Rem. Sens.*, vol. 45, pp. 3760–3772, 2007.

[4] V. S. del Rio, J. M. Pidre-Mosquera, and M. Vera-Isasa, "3-pol polarimetric weather measurements with agile-beam phased-array radars," *IEEE Trans. on Geosc. and Rem. Sens.*, vol. 52, pp. 5783–5789, 2014.

[5] G. Zhang, R. Doviak, D. Zrnic, J. Crain, D. Staiman, and Y. Al-Rashid, "Phased array radar polarimetry for weather sensing: A theoretical formulation for bias corrections," *IEEE Trans. on Geosc. and Rem. Sens.*, vol. 47, pp. 3679–3689, 2009.

[6] Y. Wang and V. Chandrasekar, "Polarization isolation requirements for linear dual-polarization weather radar in simultaneous transmission mode of operation," *IEEE Trans. on Geosc. and Rem. Sens.*, vol. 44, pp. 2019–2028, 2006.

[7] D. Zrnic, G. Zhang, and R. Doviak, "Bias correction and doppler measurement for polarimetric phased-array radar," *IEEE Trans. on Geosc. and Rem. Sens.*, vol. 49, pp. 843–853, 2011.