Performance of the enhanced reflectivity in operational dual-polarization radar

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I. Co-polar echo power

Signal covariance matrix in the mode of simultaneous transmission and reception

$$R = \left\langle \begin{bmatrix} H \\ V \end{bmatrix} [H\ V]^* \right\rangle = \begin{bmatrix} R_{hh} & R_{hv} \\ R_{vh} & R_{vv} \end{bmatrix}$$

allows considering three echo power estimators $\hat{R}_{hh}$, $\hat{R}_{vv}$ and $|\hat{R}_{hv}|$ which are highly correlated for precipitation signal $\rho_{co}(0) \sim 1$

$$P_{co} \equiv |R_{hv}^S| \cong \sqrt{R_{hh}^S R_{vv}^S} \equiv \sqrt{P_h^S P_v^S}$$

In presence of thermal noise $R = \begin{bmatrix} R_{hh}^S + P_h^N & R_{hv}^S \\ R_{hv}^{S*} & R_{vv}^S + P_v^N \end{bmatrix}$

the signals can be estimated at finite signal-to-noise ratios from

- the diagonal elements $u=h,v$

$$SNR_u = \frac{\hat{R}_{uu} - N_u}{N_u}$$

ambient noise power δN_u
- known at uncertainty of
- constant for any M samples

- the off-diagonal element, where noise is suppressed:

$$\langle N_{co} \rangle \approx 0.902 \left(\frac{N_h N_v}{M}\right)^{1/2} \qquad Var(N_{co}) \approx 0.187 \frac{N_h N_v}{M}$$

- the signal power is observed at a more favourable effective

$$SNR_{co} = \frac{\hat{P}_{co}}{N_{co}}$$

II. Co-polar radar reflectivity

Effective estimates $\hat{Z}_e^{u,co}$ from radar range equation

$$\hat{Z}_e^u = C_u^{-1} r^2 \hat{P}_u^S$$

$$\hat{Z}_e^{co} = C_{co}^{-1} r^2 \hat{P}_{co} \qquad C_{co} = \sqrt{C_h C_v} = C_h g_{Zdr}^{1/2}$$

$$Z_e^{co} \cong \sqrt{Z_e^h Z_e^v}\, \rho_{co}^*(0) = Z_e^h \sqrt{Z_{dr}^{-1/2}}\, \rho_{co}^*(0)$$

$$Z = V_c^{-1} \sum_{\{V_c\}j} D_j^6$$

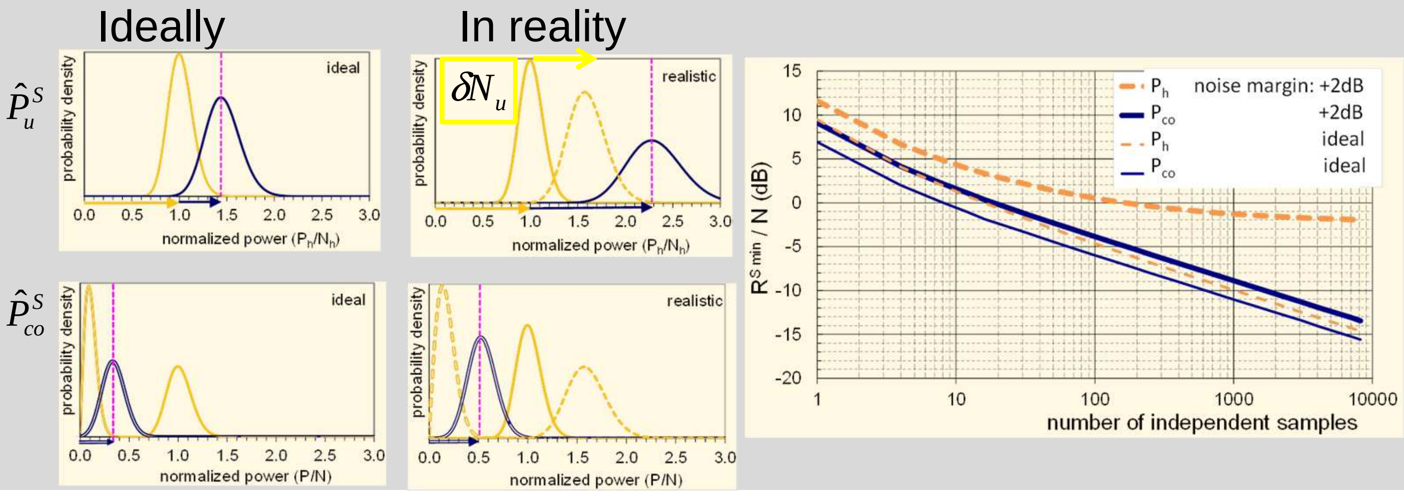
$$\sigma = \frac{\pi^5 |K|^2 D^6}{\lambda^4}$$

$$\bar{\eta} = \frac{\sum_j \sigma_j}{V_c} = \frac{\pi^5 |K|^2}{\lambda^4} Z$$

III. Advantage in signal detection

Detection limits (Gaussian models of noise and precipitation)

Ideally   In reality

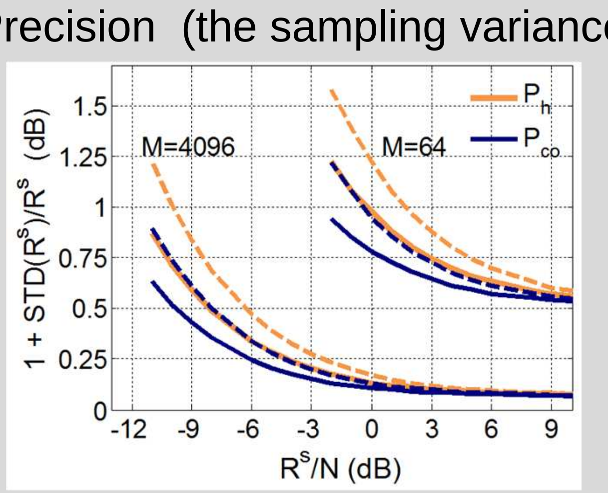


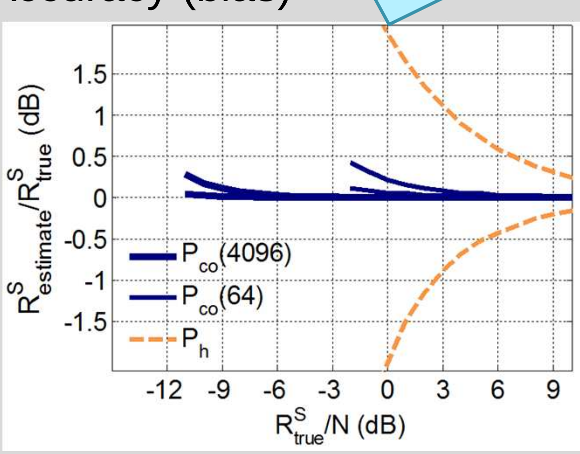
IV. Advantages in measurement of reflectivity

Gaussian models of noise and precipitation $\rho_{co}(0) \sim 1$

Detection: $\hat{P}_{co}$
Measurement: $\hat{Z}^{co}$

Precision (the sampling variance)   Accuracy (bias)





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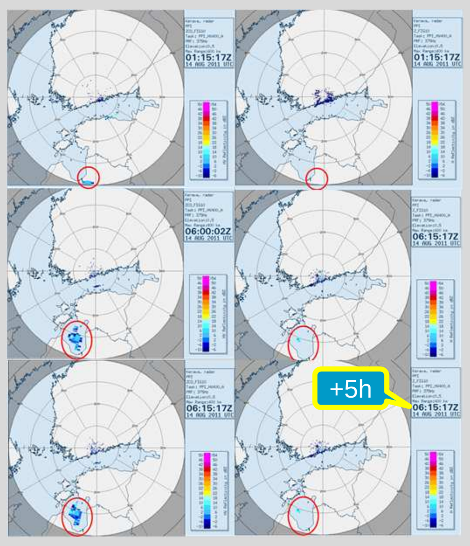
V. Detection advantage: increased lead times

in convection   in fronts



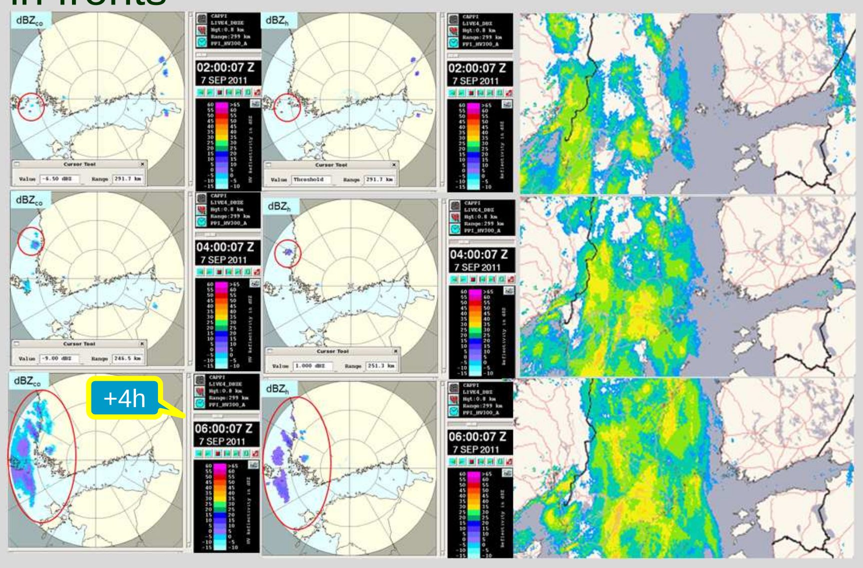


Fig 1. Fields of co-polar (left column) and horizontal (right column) reflectivity in a case of a convective system approaching from South. Scan parameters: elevation 0.5º, pulse repetition rate 500 Hz, max range *400 km*, *M=256*, scan time *130 s*, gate spacing 250m, *Az* resolution=*2º*, range resolution 250..4000m. Radar parameters (Vaisala WRM200, Kerava, Finland) pulse width=2 *µs* . Observations are censored for equivalent FAR for thermal noise.

Fig 2. Fields of co-polar (left column) and horizontal (right column) reflectivity in a case of a frontal system approaching from West, as observed by the Kerava radar with comparison to the NORDRAD regional radar composite. Scan parameters: elevation 0.5º, pulse repetition rate 500 Hz, max range *300 km*, *M=128*, scan time *97 s*, gate spacing 250m, *Az* resolution=*1º*, range resolution 250..4000m. Observations are censored for equivalent FAR for thermal noise.

VI. Consistency of measurements Z_e^h and Z_e^{co}

In large scale precipitation

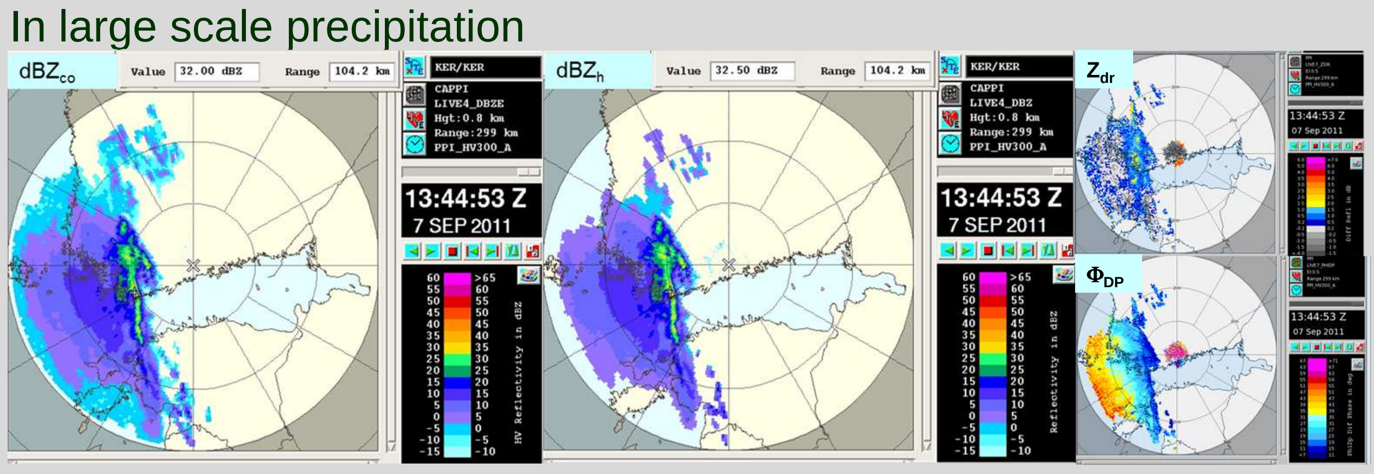


Fig 3. Fields of co-polar (left column) and horizontal (right column) reflectivity in a case of large scale precipitation. 0ºC isotherm is at the height of 2900m (range of ~160 km). Parameters as in Fig.2

In variable precipitation and in non-precipitation echo

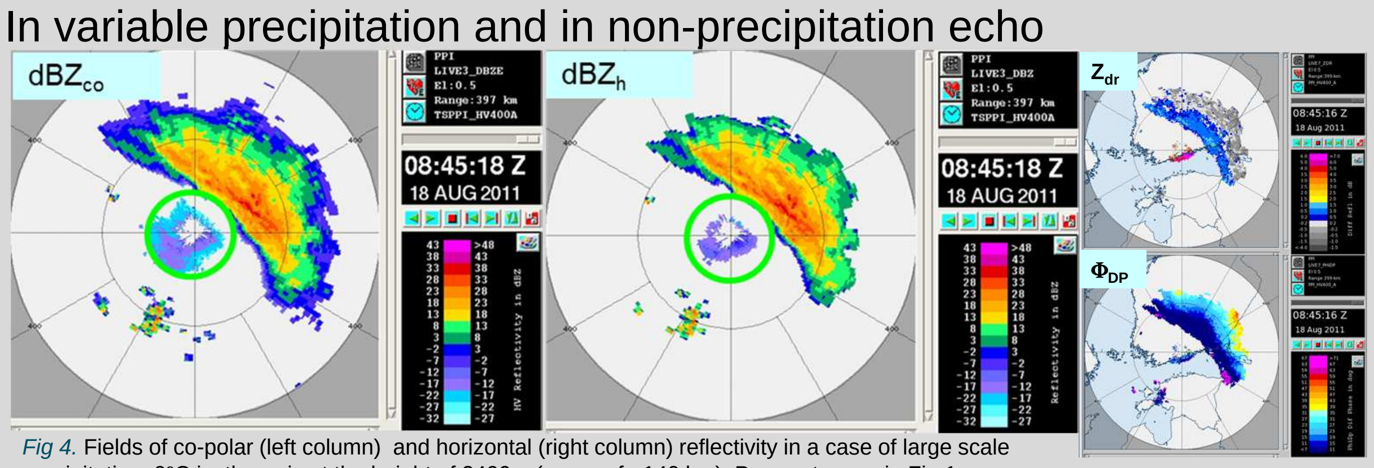
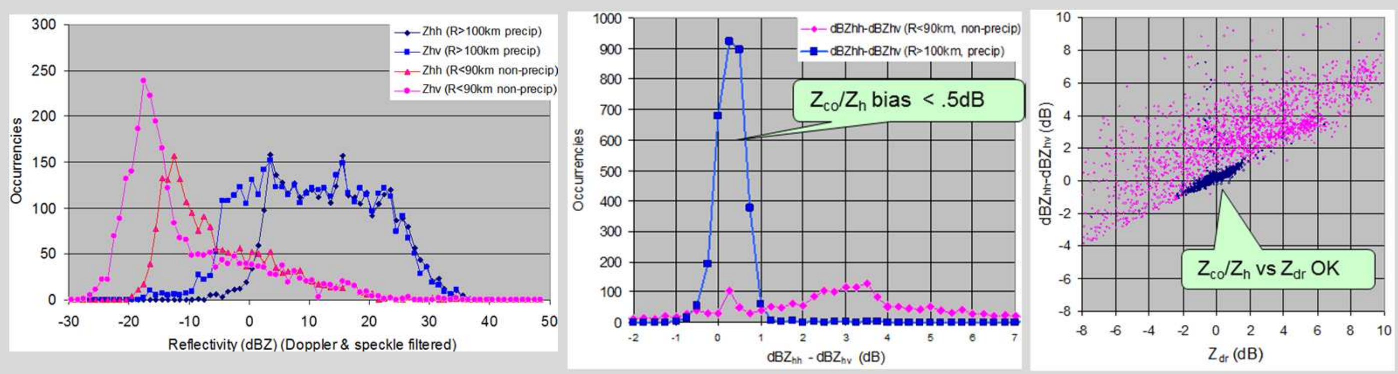


Fig 4. Fields of co-polar (left column) and horizontal (right column) reflectivity in a case of large scale precipitation. 0ºC isotherm is at the height of 2400m (range of ~140 km). Parameters as in Fig.1

Quantitatively gate-by-gate



- the microphysics of precipitation binds together Z_e^h and Z_e^{co}

note: Z_{dr}, $\rho_{co}(0)$ and K_{dp} are observables, the mapping of Z_e^h and Z_e^{co} explicit SNR>>1; at low SNR, natural ranges of precipitation apply

- consistent basis for the smooth synthesis of Z_e^h and Z_e^{co}

VII. Conclusions

- ✓ Co-polar echo power $\hat{P}_{co}^S$ enables consistent observations of precipitation weak echo, well below the detection limits of $\hat{P}_{h,v}^S$
- ✓ Estimates of co-polar reflectivity $\hat{Z}_e^{co}$ are computable and intrinsically more precise and less prone to bias, in relative terms, in comparison to $\hat{Z}_e^{h,v}$ in the limit of low SNR
- ✓ Lead times improve by hours in observing remote weather systems

Bibliography

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