Detection of electric fields using full polarimetric C-Band radar

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1 Introduction

Weather radar is mainly used for observation of meteorological phenomena like clouds and precipitation. It is frequently used to study microphyisical processes in thunderstorms, like hail genesis and associated electrification. Measurements of aligned particles cause by electric fields are only rarely reported. A theoretical description of the effects and how it influences the radar observables can be found in (Ryzhkov, 2001). Measurements of electric fields and lightning in clouds using circular polarization have been performed by (Krehbiel, et al., 1996)**.** Nevertheless, no measurements using the common H/V polarization basis in C-Band have been reported, yet.

2 Measurement setup and description

The data shown in this paper are recorded using the full polarimetric C-Band weather radar POLDIRAD (Schroth, et al., 1988). It operates in alternating H/V mode to gather the complete scattering matrix. Recent improvements in system calibration pushed the limit for depolarization measurements near -40dB (Reimann, 2013). Thus, new features in the measurements became visible.

Special interest is given to the co-/cross correlation coefficient echo. It is defined as

$$\rho_{x,H} = \frac{COV(S_{HH},S_{VH})}{\sigma(S_{HH})\cdot\sigma(S_{VH})} = \frac{\sum(S_{HH}\cdot S_{VH}^{*})}{\sqrt{\sum(S_{HH})^2\ \sum(S_{VH})^2}}$$

$$\rho_{x,V} = \frac{COV(S_{VV},S_{HV})}{\sigma(S_{VV})\cdot\sigma(S_{HV})} = \frac{\sum(S_{VV}\cdot S_{HV}^{*})}{\sqrt{\sum(S_{VV})^2\ \sum(S_{HV})^2}}$$

where COV(…) is the covariance and σ the standard deviation. This parameter is not yet widely used, since linear receivers with high dynamic range are necessary to sample the weak cross polar echo with sufficient signal-to-noise-ratio (SNR). In general ρ_x is a complex value, which can be displayed as an absolute value or modulus $|\rho_x|$ and a phase $\arg(\rho_x)$.

The Figures 2-11 show RHIs from case record on 30th May 2012, 12:58 UTC. It's a thunderstorm near the German Alps.

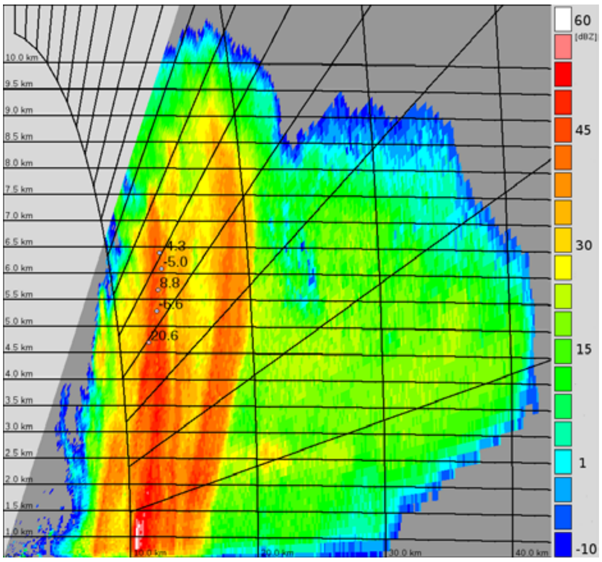

Figure 1: Radar Reflectivity and independent measured flashes (location and peak current in kA)

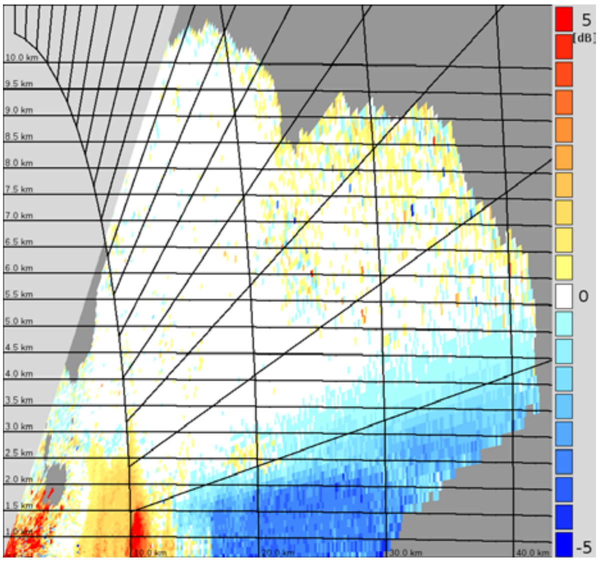

Figure 2: Differential Reflectivity, Z_{DR}

Figure 2 also includes flashes independently measured by the LINET system.

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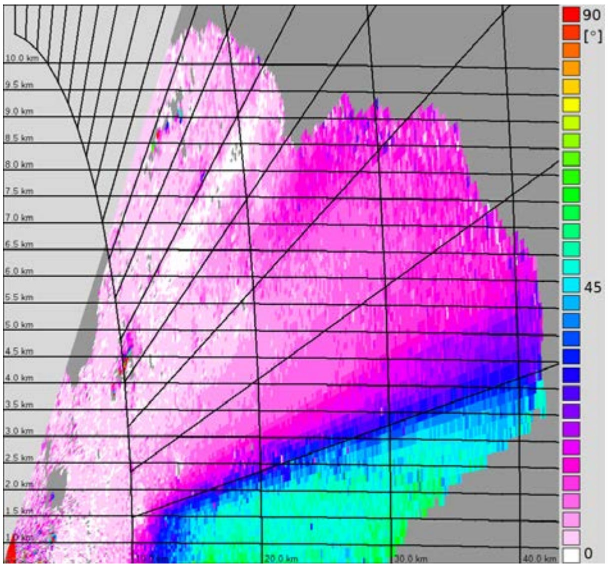

Figure 3: Differential Phase, φ_{DP}

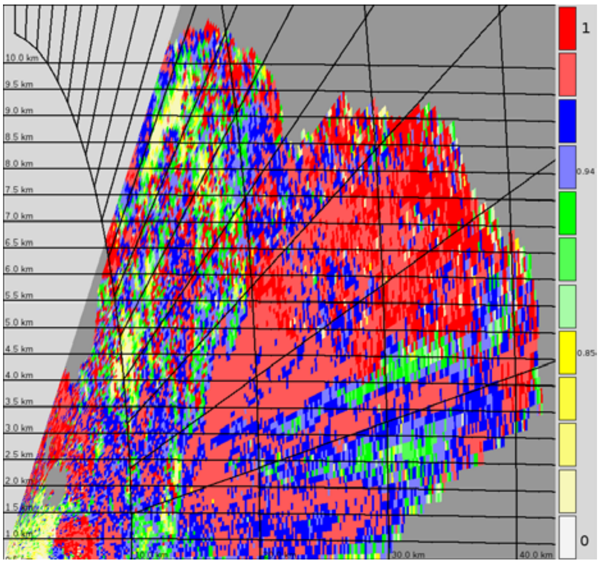

Figure 4:Copolar Correlation Coefficient, ρ_{HV}

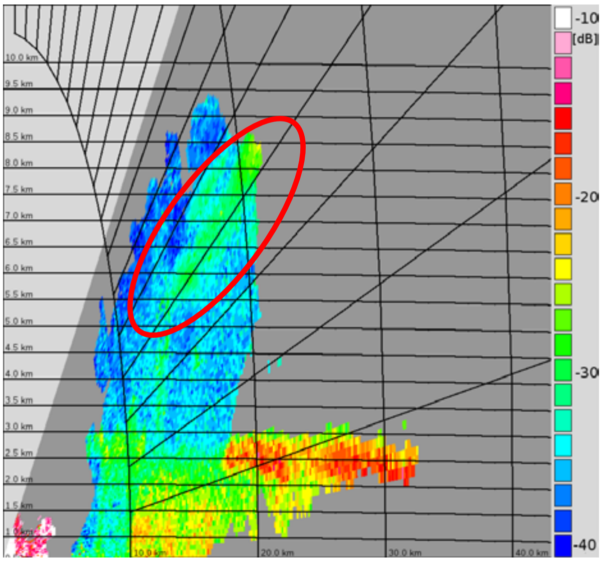

Figure 5: Horizontal Linear Depolarization Ratio, $L_{DR,H}$

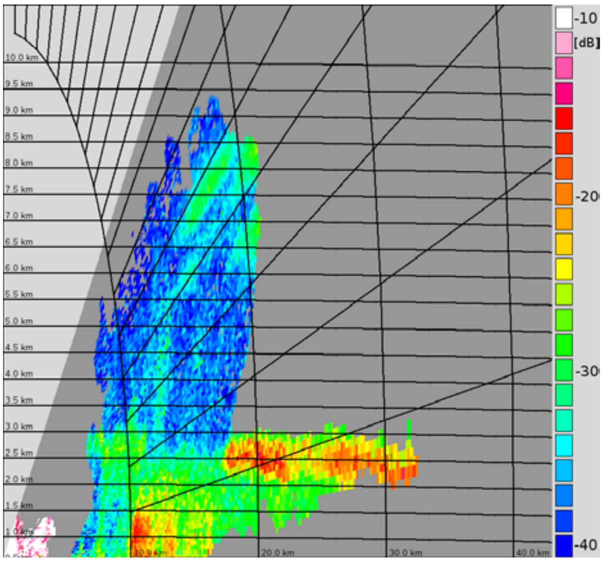

Figure 6:Vertical Linear Depolarization Ratio, $L_{DR,V}$

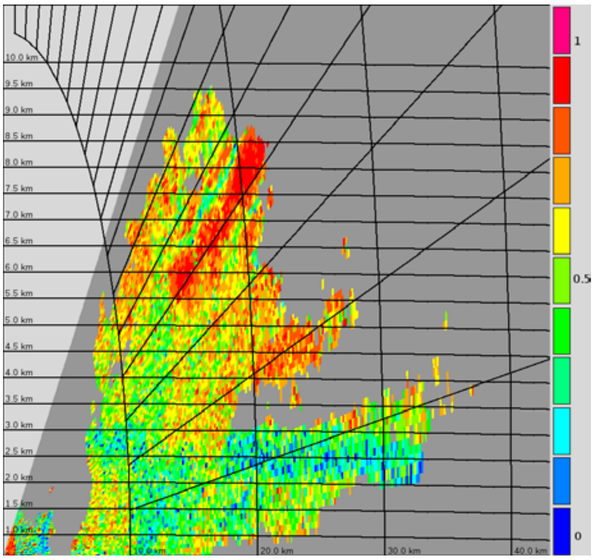

Figure 7: Modulus of Co-/Cross Correlation Coefficient, $\rho_{x,H}$

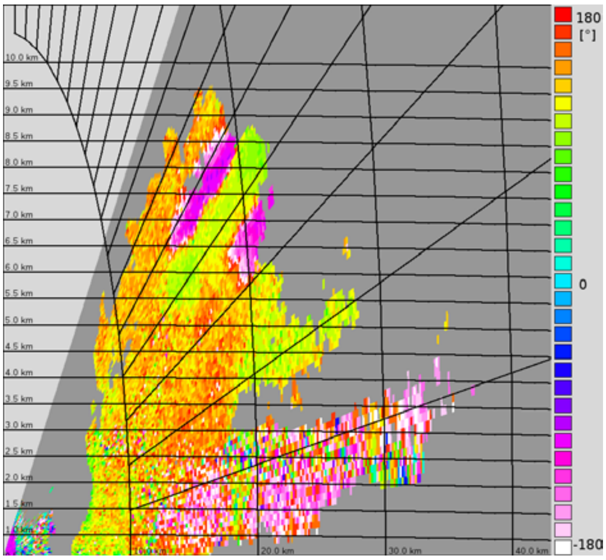

Figure 8:Phase of Co-/Cross Correlation Coefficient, $\rho x,_{H}$

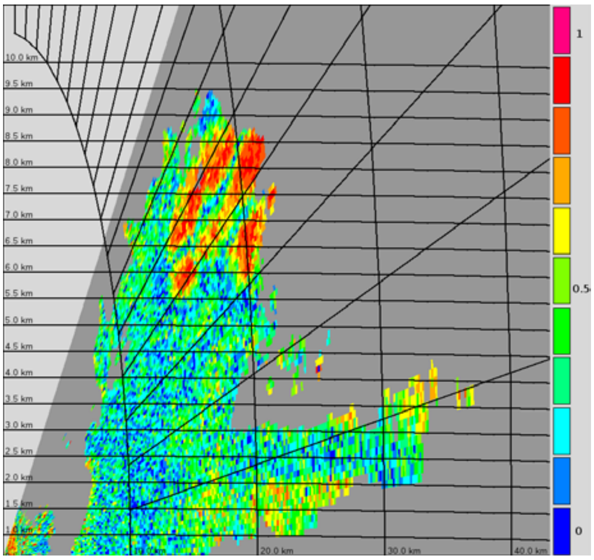

Figure 9: Modulus of Co-/Cross Correlation Coefficient, $\rho x_{,V}$

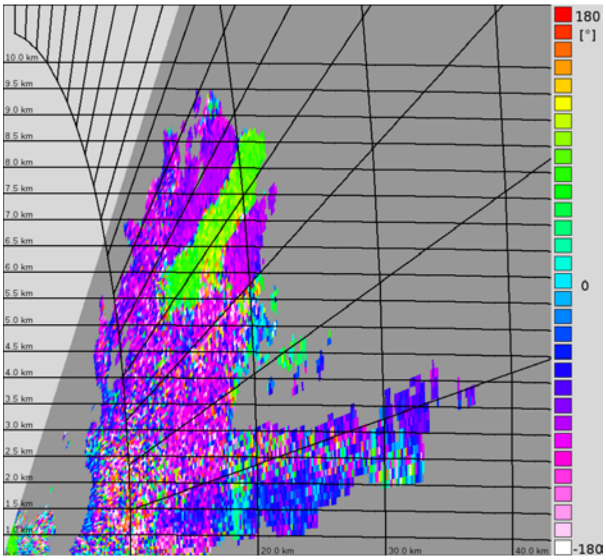

Figure 10:Phase of Co-/Cross Correlation Coefficient, $\rho x_{,V}$

The melting layer is clearly visible in the both L_{DR} plots at 2.5km height by its strong depolarization. Above this height there are mostly ice particle as indicated by the zero Z_{DR} values and low Depolarization. Strong rain with large drops can be found at the bottom of the thunderstorm cell at 10.0km range creating high Z_{DR} values. Behind this region the Z_{DR} values drop below zero due to differential attenuation effects. This is also clearly visible in the φ_{DP} plot.

An interesting feature can be found in the L_{DR} plots above 5km height (red circle in Figure 6). In some regions L_{DR} grows from the expected −35dB…−40dB to −30dB. These feature range along the propagation path of the radar pulse. The same feature can be found in the co-/cross correlation coefficient ρ_x. The modulus enlarges to nearly 1 and the phase jumps. This is true for the independent measurements using horizontal and vertical transmission polarization.

3 Analysis

The feature reported show strong L_{DR} signatures in the ice phase region and propagate along the radar range. In contrast to the melting layer, the magnitude of co-/cross correlation coefficient ρ_x rises to nearly one. This can be explained by a change of the polarization while propagating through this region at approx. 15km range and 5.5km height, which is also the area of lighting.

For horizontal transmitted pulse, the electric field vector is altered to include a strong vertical component while travelling through the aligned ice particles. Upon scattering this vertical component is preserved as no further strong depolarization occurs. Hence, a high vertical return creating a high L_{DR} value is measured at the radar when compared to the original transmitted wave. Since the vertical component recorded by the radar is only an altered version of the original pulse and is not caused by incoherent scattering the correlation coefficient is also high. This stands in contrast to the melting layer, which also creates high L_{DR} signatures, but upon scattering with low ρ_x.

What causes the polarization of the radar pulse to change? An interpretation was given in (Krehbiel, et al., 1996), which describes observation of electric field and lightning in a circular polarization basis. It is known, that any polarization basis holds the same information. Hence, observation of electric field should also be possible in H/V basis. Ryzhkov gave a theoretical description in (Ryzhkov, 2001) for the effect of canted ice particles. The start of the feature in range and the area of lightning match well, which gives another indication that aligned ice particles are the origin of this effect.

Since, a very good isolation between the polarization channels is needed to observe the effect it was hidden for a long time, even on a research radar like POLIDRAD. Besides L_{DR}, ρ_x also needs high channel isolation to produce low correlation coefficients.

4 Conclusion

Measurements in H/V polarization basis with high channel isolation at C-Band have been shown which feature areas of high L_{DR} and ρ_x. A detailed description of all radar observables has been given as well as an explanation of the physical effects, which may lead to these features. Although a consistent theory was given, only in situ measurements can really proof the effect of aligned ice particle. Nevertheless, L_{DR} and ρ_x may open a door for the detection of electric fields and area of potential lightning using weather radar.

References

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