COMPARISON OF POLARIMETRIC C BAND DOPPLER RADAR OBSERVATIONS WITH REFLECTIVITY FIELDS OBTAINED AT S BAND; A CASE STUDY OF WATER INDUCED ATTENUATION

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ABSTRACT

Absorption of electromagnetic waves occurs in liquid water at weather radar frequencies, and the impacts are increasingly significant towards shorter wave lengths. Traditionally, this is seen as justification of investment in S Band technology in climates of heavy precipitation. This picture is subject to reconsideration due advent of operational polarimetric weather radars.
Differential phases between orthogonal polarizations are observed at the polarimetric radar, simultaneously with power related reflectivity fields. The range evolution of differential phase can be interpreted as independent measure of propagation effects in precipitating medium, which allows stable and quite accurate corrections to be applied for reflectivity fields, which are of high spatial resolution but subject to attenuation bias.
This case study visualizes the significance of attenuation phenomena and operationally feasible actions for their proper correction. Comparison is obtained through spatial and temporal association of reflectivity fields obtained at operational S Band Doppler radar with concurrent observations at proximately located polarimetric Doppler radar, operated at C Band.

1. INTRODUCTION

Attenuation has been recognized as a major challenge of weather radars since their advent in the 1940's. Attenuation is the reduction of intensity of electromagnetic wave along its path and it is caused by scattering and absorption by the propagation medium. Attenuation due to air molecules is a stable feature that can be corrected for. It is a minor effect as well as the attenuation due to clouds. The precipitation itself is the main and highly variable factor in attenuation. It is a major source of uncertainty in measurement of reflectivity (Z_h) and in interpretation of rain fall intensity (R). Attenuation is a cumulative effect and most significant behind intense rain cells. Ultimately, attenuation limits the detection efficiency, and entire structures of precipitation can be obscured when signals fall below the sensitivity limit.

The amount of attenuation per unit length (specific attenuation, a_h) is strongly dependendent on the wavelength (λ) of the radar. In modest rain of 1 mm/h for example, the specific attenuation at C Band (λ=5 cm) is about three times higher than the case of a S Band weather radar (λ=10 cm), while the effect is a factor of 30 stronger at X band (λ=3 cm), compared to C Band (DOVIAK and ZRNIC 1993). Impacts of attenuation are typically ignored at S Band, while attempts have been made at shorter wavelengths to correct for the cumulative effects of attenuation. The traditional approach uses a power law relation between specific attenuation and reflectivity (HITSCHFELD and BORDAN 1954). Due to the recursive nature, the approach is intrinsically unstable with high sensitivity to calibration errors, and it is of limited use in modest rain, only.

Attenuation has been traditionally taken as a serious obstacle for using shorter wavelength weather radars in climates of intense rain - despite their evident system level advantages, such as the higher intrinsic sensitivity and the lower life-cycle cost. This traditional picture is subject to reconsideration due advent of the operational polarimetric weather radar, which allows for a stable attenuation treatement of the reflectivity data (BRINGI and CHANDRASEKAR 2001) which visualize the precipitation fields at highest spatial resolution.

The polarimetric method is based on the differential phase (Φ_{DP}) which is the power-weighted average phase difference between the received signals in horizontal and vertical channels. The measured differential phase (Φ_{DP}) contains a component which evolves smoothly in range (propagating differential phase Φ_{dp}). Evolution of Φ_{dp} is a reference measure of attenuation, due to the elementary relation between the specific attenuation (a_h) and the specific differential phase (K_{dp}), which is the change of Φ_{dp} per unit ray length interval. In this approach, the quantitative rain fall information delivered by the smooth phase measurements are combined with the reflectivity data. As outcome, the observations are corrected for attenuation bias while their highest spatial resolution is conserved.

2. TRENDS IN TECHNOLOGY

With the transition of dual polarization techniques from laboratory into production weather radar systems, such as the Vaisala WRM200, many weather services that traditionally used S Band systems are now reconsidering to use polarimetric C Band systems. The cost issue is their primary motivation. A turnkey-installed C Band system is 1/2 to 1/3 the price of an S Band system having comparable antenna gain and transmitter power.

Frequently, orography prevents finding a single site to cover complete water basins and significant weather events, whatever the radar technical performance. Multi-sensor approaches are viable. Generally in environmentally and socially sensitive areas, finding sites is easier for lighter instrumentation. In these considerations, C Band radars appear attractive choices. They are significantly less expensive to maintain over the life-cycle of the system, at roughly half the size of an S Band system.

The fundamental difference between the two radar wavelength ranges goes back to Rayleigh scattering theory. For distributed targets, the backscattered power depends on wavelength in proportion to $1/\lambda^2$. This means that all else equal, a C band radar receives 4 times more power (6 dB) than a comparable S band radar. Expressed in linear units of the transmitter power, in order to match the sensitivity of a 250 kW C Band system, a comparable S Band system needs a 1 MW transmitter, a significant cost item. In practice, the C-band radar has an intrinsic advantage for detecting echoes at long ranges such as a typhoon at 500 km.

The recent improvements in receiver technology add to the consideration. A decade ago, most radar receivers were specified for 3 dB noise figures. Today, radar receivers such as the one in the Vaisala WRM200 have noise figures approaching 1 dB. This nearly 2 dB gain in sensitivity is equivalent to a 58% increase in transmit power. The greater receiver sensitivity further reduces the instances of total attenuation.

These advances give us additional margin to operate modern polarimetric C Band radars in presence of significantly attenuated echoes in intense rain. The radars are operated in the mode of simultaneous transmission and reception of the horizontally and vertically polarized channels, which allows highly correlated (coherent) polarization data to be acquired. The differential phase (Φ_{DP}) is measured at remarkable precision in this mode. It serves as a valid reference measure of path integral of attenuation in rain. It is a pure phase measurement, free of calibration uncertainties, and available at high gate-to-gate efficiency - like the Doppler velocities that we are familiar with.

3. BASE METHODOLOGY

The propagation effects in rain have been shown (BRINGI et al. 1990) to possess a nearly linear relationship between the specific (differential) attenuation a_h (a_{dp}) and the evolution of the differential propagation phase Φ_{dp} in range. This basic relation applies to all weather radar wavelenghts, with modest dependency on rain drop axis ratios, drop size distributions and drop water temperature. Thus, observing the net change of the differential propagation phase through each radar ray segment in rain, one readily obtains a direct estimate of path integrated attenuation in the rain segment.

Recent experimental evaluations (MAY et al. 1999, CAREY et al. 2000, RYZHKOV et al. 2007, KERÄNEN and YLLÄSJÄRVI, 2008) have determined the effective attenuation coefficient $\alpha = a_h/(\Delta\Phi_{dp}/\Delta r)$ to be in the proximity of 0.1 dgr/dB, with a good consistency between the methods and climatology. Quantiatively, observing differential phases to change by ten degrees, an estimate of path integrated attenuation of 1 dB is obtained.

Various sources of uncertainty can be readily analyzed. The sampling noise of the Φ_{DP} gate data is found to be a few degrees in Rayleigh scattering in rain (BRINGI and CHANDRASEKAR 2001), given the high co-polar correlation coefficient at a good quality radar system, and operationally reasonable scan settings. Non-Rayleigh scatterers such as large drops, and hail/graupel mixtures of rain generate point-to-point back-scatter noise. This phase noise is not expected to exceed far beyond the level of 10 degrees at C Band nor at X Band (RYZHKOV 2001). These non-Rayleigh features are local and can be diminished with advanced filtering techniques.

The echoes of non-meteorological targets (clutter) are often widespread in radar data. Proper Doppler filtering and associated data quality criteria (thresholding) routinely suppress stationary ground clutter, to a high degree. The residual non-stationary clutter can be separated from rain echoes with additional dedicated methods, as their Φ_{DP} spectrum is fundamentally different from the normally distributed $\Delta\Phi_{dp}$ in rain (ZRNIC et al 2006). As an additional quality feature, one needs to be prepared for unfolding large total shifts in differential phase, exceeding the full rotations of 360 degrees, in rays penetrating the highest intensity rain.

In summary, the propagating differential phase can be estimated at sufficient precision, using the differential phase (Φ_{DP}) measured along the ray, as soon as the non-propagating contributions due to sampling noise, back-scatter differential phase and echoes not originating from rain are treated, properly. Indeed, it is feasible to implement these general 'rain-profiling' methods, robust and suitable for real-time signal processing such as the 'dpolatten' feature in RVP8™ (PANOV et al. 2008).

3. CASE STUDY

A weather case of significant precipitation at mid latitudes (34° 38.8'N, 86° 46.3'W) has been analyzed using the observations by the ARMOR polarimetric C Band radar, Huntsville, Alabama USA (PETERSEN et al 2007). The independent observations made at the proximate NEXRAD S Band radar (NEXRAD 2007) are used for comparison to an unattenuated reference.

The weather case is a prefrontal squall line approaching Huntsville from the north-west, displayed in Figure 1. The extended line structure is clearly visible in the S Band data. The maximum reflectivities exceed 58 dBZ. The fields of differential phase are observed at the polarimetric radar, and they evolve significantly along the rays passing through the intense regions of precipition. The effects of attenuation in the C Band are evident in the reflectivity fields beyond the intense precipitation, north-east and west, when compared with the corresponding S Band observations.

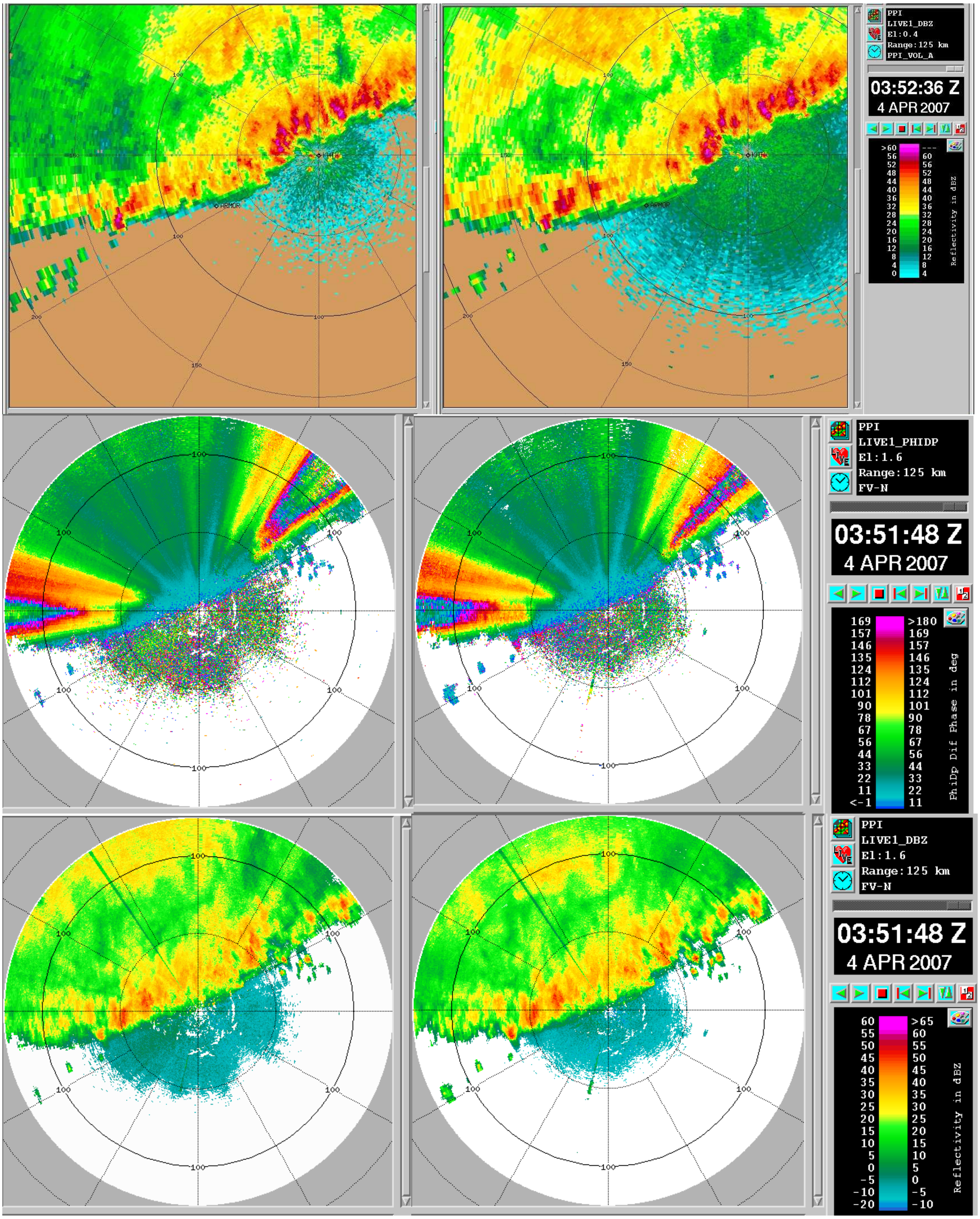

Figure 1. The fields of reflectivity S-band radar at elevation of 0.5 degrees (top left), and 1.3 degrees (top right), and the concurrent observations of differential phase at the C Band polarimetric radar (middle left and right), and of reflectivity (bottom left and right), at elevations of 0.5 degrees and at 1.6 degrees, respectively. The ARMOR location is marked in the centre of top windows. The displays are in the same approximate geographical scale.

Attenuation effects have evaluated quantitatively considering the differences of reflectivities between the set of common measurement volumes of these proximately located weather radars. The main challenge in such a two radar comparison relates to association of reflectivites made at separated locations, approximately coincident in time. In the context of the case study, the impacts of the geometric effects have been diminished by averaging the radar volumes over each other along the rays, and interpolating the observations in elevation. The advection hs been compensated by modelling of the advection field. Upper air synoptic soundings (UNIVERSITY OF WYOMING 2007) and 2D wind fields derived from the radar observations of Doppler velocity (IRIS 2008) were used as drift measures.

The impact of the attenuation correction on the reflectivity fields of the case study is quantified in Figure 2. Attenuation effects up to 20 dB are resolved in the C-band reflectivity data rendering them comparable to S-band observations. In sweep display, the quality and high spatial resolution of the reflectivity fields are found to be preserved within all the radar ranges, including significant regions of non-meteorological echoes, from south west to south east.

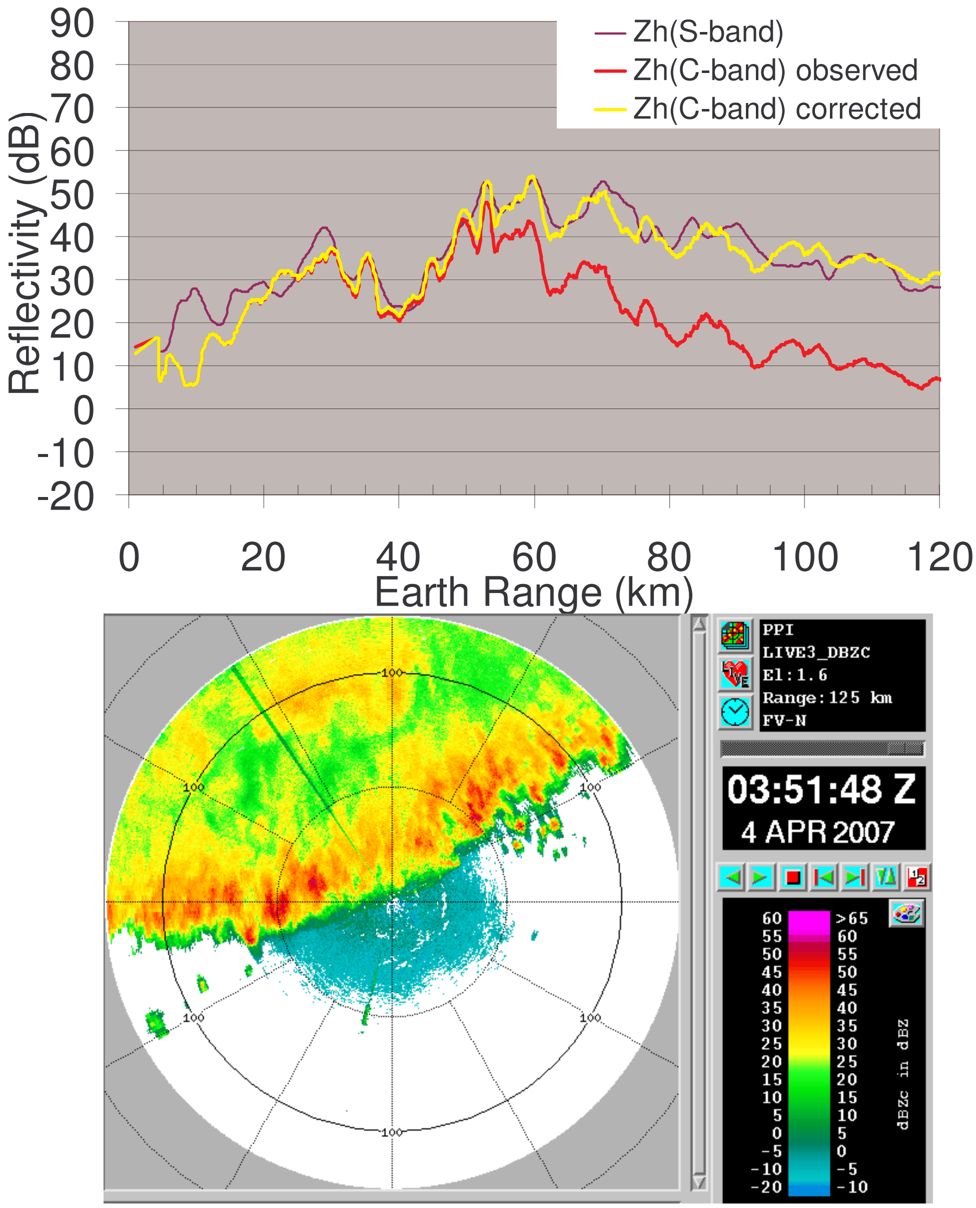

Figure 2 top: a single ray comparison of C Band reflectivities (observed and corrected for attenuation) versus S-band reflectivity, in the direction of intense rain azimuth 40 degrees. Bottom: corrected reflectivity fields at C Band, elevation of 1.6 degrees, to be compared with Figure 1 (middle right).

4. CONCLUSIONS

Transition of dual polarization techniques from laboratory into the production models of C Band polarimetric weather radar triggers a re-consideration of optimal composition of automatic weather observing systems, specified to 'all climate weather conditions'.

Polarimetric C Band weather radars, equipped with advanced signal processing techniques, offer now new methods to mitigate attenuation, which has been seen previously as a major limitation for broader use of short wave lengths technology in climates of intense rain.

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