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TEST OF POLARIZATION BASED RETRIEVAL ALGORITHMS AT X-BAND.

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I INTRODUCTION :

X-Band radars represent a cost-effective solution for the monitoring of precipitation systems at short to medium ranges, less than 60 km. The many advantages of X-band radars in term of cost and size has triggered a new interest in these type of instrument for hydrological applications. Traditionally operational use of X-band radars was abandoned because of the strong attenuation they suffer in the presence of rain. However, polarization parameters at X-band can be used to overcome the attenuation problem. Matrosov et al (1999) first studied the prospect of using the specific differential phase shift kdp at X-band to estimate rain. We reminds that the main advantages of kdp are : i/ because kdp is roughly related to the relationship is that the rain estimate on the direct a polarimetric ii/ kdp is not directly affected by attenuation and is immune to calibration problems. iii/ at X-band the additional advantage compared to longer wavelength is that the specific differential phase shift is high and its derivation less sensitive to phase noise. Also compared to even smaller wavelength the influence of the backscattering phase δ is weak.

So X-band is globally a good trade off for the use of kdp. However it has been shown that the estimation of Kdp can be delicate and errors arising in the presence of strong gradients of reflectivity (Gosset, 2003). So, even though Kdp is interesting at X-band, measurements errors encourage to use also other parameters. In this study we have implemented 3 algorithms, in order to assess the usefulness of dual polarization with or without phase measurement. The issue here is to evaluate if the additional investement in Dopplerization represents or not an important improvement. Even though dopplerization is becoming easy with new techniques such as digitalisation at the IF level, insuring enough quality in the differential phase shift might be costly. The 3 algorithms tested here are : The simple use of basic Hitchfield Bordan formula without constraint, a profiling algorithm wich uses total differential attenuation A_{h-v} as a constraint (similarly to what was proposed by Sauvageot 1996) and a profiling algorithm with the differential phase shift as a constraint, as proposed by Testud (2001). In the three cases the rain retrieval is based on the relation between rain and the specific attenuation k.

2. X-BAND ATTENUATION CORRECTION SCHEMES WITH A POLARIMETRIC CONSTRAINT

2-1 Formulas

We remind here the basic formulas. At attenuated frequencies such as X-band, the the measured reflectivity is expressed by

$$Zm(r) = Z(r)10^{-0.2\int_0^r k(s)ds} \qquad (1)$$

where Zm(r) [mm^6m^{-3}] is the attenuated reflectivity, Z(r) is the 'true' value of the reflectivity at range r and k is the one way specific attenuation, expressed in dB/km. where the specific attenuation k(dB/km) can be related to the reflectivity with formula: Combining (1) and assuming that there is a valid average, range independent, power relationship, between k and Z,

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$k = {}_{akz} Z^{bkz}$ (2)

where the coefficients akz and bkz can be calculated with a scattering model, for a given drop size distribution (DSD), it can be shown (Hitchfield and Bordan 1954) that the specific attenuation k(r) at range r can be calculated from the measured reflectivities by the general formula :

$$k(r) = \frac{aZm(r)^b}{\left[\left(Zm(r0) \middle/ Z(r0)\right)^b - 0.46ab\int_{r0}^{r} Zm(s)^b ds\right]}$$

(3)

where r_0 is a distance of reference, and the coef *a* and *b* are the coefficients *akz* and *bkz* above.

If r_0 is the very first gate (r=0) and there is no on site attenuation, the first term in the denominator of (3) is 1. We refer to this formula, hereafter as the simple HB algorithm. The results of the algorithm is very dependent on the coefficient *akz* and very sensitive on the calibration. The minus sign at the denominator can cause the algorithm to diverge, when *akz* is not adapted to the actual DSD of the rain or for numerical reasons (Delrieu) .

If the reference gate r_0 is taken towards the end of the radial so that $r<r_0$ the minus sign in (3) disappears. It can be shown (Amayenc) that if the 2-way path attenuation A_{r0} in dB, at distance r_0 is known the algorithm can be expressed by replacing Zm(r0)/z(r0) by $10^{(-0.1\ Ar0).}$

Assuming that the path attenuation is 0 at the very first gate, the coefficient *akz* can be retrieved and the algorithm tuned with :

$$akz = \frac{1-10^{-0.1bA_{r0}}.}{0.46b\int_{0}^{r0} Zm^b} \qquad (4)$$

If there is no further knowledge, such a tuning of *akz* will compensate for a change in the DSD and/or for calibration error and/or for on site attenuation. Also, the actual interest of such a tuning depends on the quality in the estimation of the path attenuation A_{r0} (dB).

It has been shown that propagation polarimetric parameters such as the differential propagation phase shift ϕ_{dp} or the differential attenuation $A_{h\text{-}v}$ could be used to estimate the path integrated attenuation A (for say polarization h).

Calculations with a scattering model show that for the usual DSD and drop shapes, the specific differential attenuation $a_{h\text{-}v}$ and the specific phase differential shift k_{dp} are well correlated to the specific attenuation k and that the relation is quasi linear. In that case the path attenuation at the reference range r_0 can be estimated by

$A_{r0} = \phi_{dp}(r_0) * a_{kkdp}$ (5)

Or

$A_{r0} = -Z_{drmes}(r_0) * a_{kahv}$ (6)

The equation above assumes that the actual – non attenuated- differential reflectivity at range r_0 is close enough to 0, so that the measured or attenuated Z_{drmes} is a direct measurement of the path differential attenuation.

The coeeficients a_{kkdp} and a_{kahv} are derived from a least square fitting through calculated values of k, k_{dp} and k, a_{hv} respectively, forcing the exponent of the relationships to 1.

2-2 Implementation

The choice of the first and last gate used to calculate the ϕ_{dp} constraint is quite delicate, as ϕ_{dp} is a very noisy and variable field. For these tests we didn't try to partition the radial according to rain type (as suggested by Testud, 2001) but we based our choice on the estimated quality of the polarimetric variable. ϕdp is smoothed over 7 range gates (which is equivalent to about bins and 5 azimuths (which is about 1 km*km at 50 km range); within that bin only gates where the cross correlation rhohv is geater then .96 . This limits the range of the last gate as RHOhv falls in distance with the SNR (as illustrated on figure 1). However the correction scheme can be applied after r_ref, but might diverge because of the minus sign appearing at the denominator like in the HB formula (3). See Fig 1.

An example is given below for one radar beam.

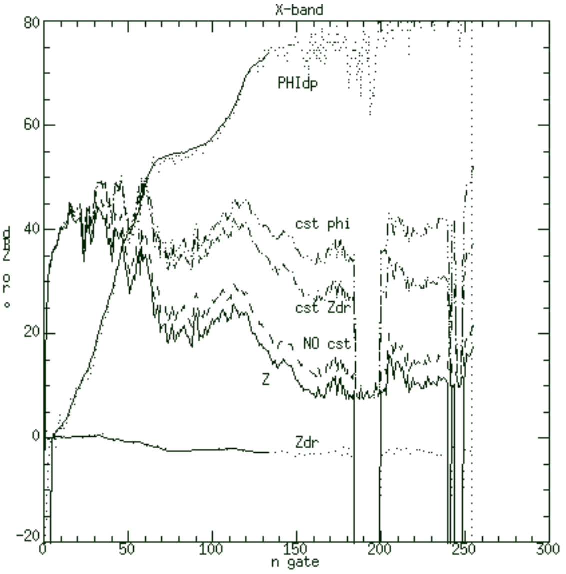


Fig 1 : example of implementation on one radar beam (250 gates): the plain lines represent the measured reflectivities Z, the measured and smoothed ϕdp and the measured and smoothed Zdr used for the constraint. The dashed curves are the reflectivities corrected by the 3 algorithms as indicated. The last gate used for the constraint is gate 130 where the smoothed lines for ϕdp and Zdr stop.

2-3 Examples of tuning results

The variation between the 'tuned' akz and the original one can be attributed to variations in the drop size distribution (parameter No in Testud 2001), a wrong assumption about the shape (important for the a_{kkdp} coefficient), a mis-calibration of the radar or the omission of initial attenuation due to a radome for example. Fig 2 show the variations of the retrieved coefficients akz, over several radar beams (all belonging to the same PPI) for the 2 constrained algorithms. Fig 3 compares for the same beams the path attenuations retrieved by the 3 algorithms. Further investigation is needed for this set of data to determine what is the most likely origin for this examples.

We find that the use of the integrated phase shift represent a big improvement in the simplicity and robustness of the schemes. The use of the Zdr_{meas} constraint is more delicate because it assumes that the actual Zdr is 0. A more sophisticated approach, allowing to take into account an estimated value of the non attenuated Zdr should be used to improve the results. Globally the ϕdp retrieved attenuation is more consistent with the integral value derived from the HB formula.

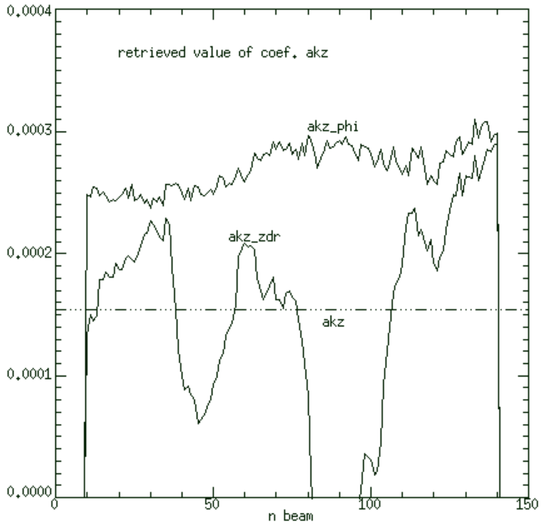
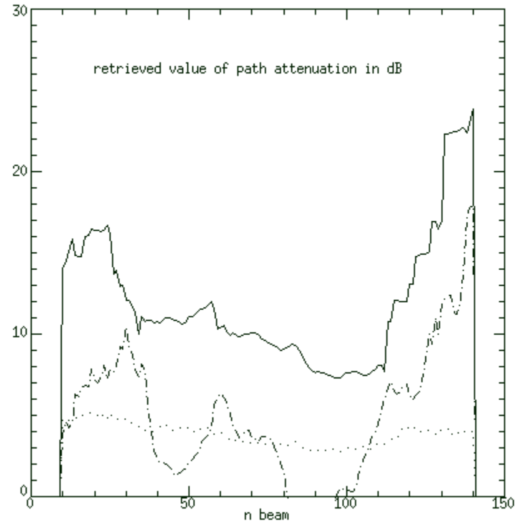


Fig 2 : retrieved values of the coef akz for the constrained algorithms, and value originally entered in the algorithm.

Fig 3: calculated values of path attenuation for the 3 algorithms. It explains the variations of akz, specially for the Zdr constraint.



3 PERSPECTIVES.

A new X-band polarimetric radar is now developped in our group. The main characteristics of that instrument, called X-port, are gathered in table 1 below. For 2004 an experiment is planned in the Grenoble area. The radar will be overlooking the Gresivaudan valley a region surrounded by mountains. The aim of the experiment is to compare the Mountain reference technique, tested in the same area by Delrieu et al (1997) with the polarimetric techniques. A disdrometer will also be installed on the site to monitor drop size variability together with raingages for calibration the rain retrieval. Such a setup will give a good absolute calibration for the relationships between path attenuation and ϕ_{dp}, or between the path attenuation and the differential attenuation. The results will help understanding and interpreting the variations observed in the retrieved values of the coefficient *akz*.

X-Port is a Doppler system with dual polarization based on transmission and reception at 45 degrees thanks to an orthomode antenna.. The transmitter is magnetron based. The acquisition system is PC based with digitalization at IF level. The technique used to achieve Doppler measurements is to over-sample the IF signal and keep the phase reference from the very first gate. The principal characteristics of the radar are summarized in Table 1.The polarimetric parameters that can be measured are the differential reflectivity, the cross-correlation between the two channels and the differential phase shift.

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Table 1 . Main characteristics of X-Port

System	X-Port
Frequency band	X band
Wavelength	3.2 cm
Transmitted power	50 kW / channel
Beam-width (degrees)	1.2
Polarization Transmission Reception	 H and V simultaneous H and V simultaneous
Transmitter type	Magnetron
Acquisition system	PC linux based digital processor
Pulse width	.3 to 1 microsecond
Pulse Repetition Frequency	1 to 2.5 kHz
Scanning mode	Full 3D scans Elevation range 0 to 90 °

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