9.5 DPATC – Dual-Pol based Attenuation Correction

Concept

Due to precipitation, the radar radiation is attenuated. An algorithm to correct reflectivity for attenuation, based on the reflectivity data only, is described in section 9.4. That ZATC algorithm has the disadvantage that the attenuation correction might be too weak or might become unstable, depending on the accuracy of the Z-R relation used therein. In case of polarimetric radar systems, the differential reflectivity (ZDR) also suffers from attenuation effects, since the horizontally polarized radiation usually is attenuated stronger than the vertical polarized attenuation, resulting in negatively biased ZDR data.

For a fully polarimetric radar system, the differential phase shift provides more stable measurement of the attenuation. Furthermore, ZDR bias from differential attenuation can also be corrected for. The dual-pol based attenuation correction algorithm (DPATC) performs the corresponding correction of dBZ and, if available, ZDR data.

The algorithm can be applied on any scan type (azimuth scan, volume scan, or elevation scan) which samples reflectivity data (dBZ or dBuZ) and differential Phase data (PhiDP). The scan may also contain ZDR data, which then also are corrected. Note that the PhiDP data are usually already filtered according to the algorithm described in section 9.6.

Product Definition

[Diagram of DPATC interface]
A – General parameters

dBZ Correction (⇒ steps 1, 2 and 3)

Linear PhiDP dBZ attenuation correction linear in PhiDP
ZPHI dBZ attenuation correction using the so-called ZPHI-Algorithm (option)
Iterative ZPHI dBZ attenuation correction using an iterative ZPHI-Algorithm (option)

ZDR Correction (⇒ steps 4 and 5)

Linear PhiDP ZDR attenuation correction is linear in PhiDP
Ah-scaled ZDR attenuation correction proportional to the dBZ correction

B – dBZ Correction parameters

General (⇒ step 1)

Alpha automatic Uses a fixed α for the attenuation relation (automatic for the radar wavelength)
Alpha user-def Uses the given user-defined α for the attenuation relation

ZPHI and Iterative ZPHI parameters (⇒ steps 2 and 3)

Exponent B The exponent b of the ZPHI attenuation equation
PhiDP threshold The threshold of total path PhiDP, below which the iteration is not used

C – ZDR Correction parameters

Linear PhiDP Correction (⇒ step 4)

Beta automatic Uses a fixed β for the ZDR attenuation relation (automatic for the radar wavelength)
Beta user-def Uses the given user-defined β for the ZDR attenuation relation
Optimize Beta Uses an optimization method for β based on far-range data (⇒ step 6)
**Algorithm**

The correction of attenuation and differential attenuation using dual-polarization data follows the procedures described in the Gematronic Dual-Polarization Handbook (Gematronik, 2007). In particular, the following correction methods can be selected:

Correction of reflectivity:
- Linear PhiDP method (Gematronik, 2007; chapter 4.1) (⇒ step 1)
- ZPHI (Gematronik, 2007; chapter 4.2) (optional, separate license) (⇒ step 2)
- Iterative ZPHI (Gematronik, 2007; chapter 4.3) (optional, separate license) (⇒ step 3)

Correction of differential reflectivity:
- Linear PhiDP method (Gematronik, 2007; chapter 5.1) (⇒ step 4)
- Ah-scaled method (Gematronik, 2007; chapter 5.2) (⇒ step 5)

The correction methods are performed on ray basis, i.e. each ray of data is processed independently. Thus the correction can be applied to any scan: AZI, VOL, ELE.

All methods are based on filtered differential phase data (PhiDP). For such filtered PhiDP, data are only given in areas of sufficient PhiDP accuracy. Furthermore, the PhiDP system offset has been taken into account, i.e. PhiDP values start with 0 deg for small ranges. For details of the PhiDP filtering, please refer to section 9.6.

**Step 1: dBZ-Correction using the linear PhiDP method**

For this correction, the total path attenuation of dBZ, i.e. the amount of correction along radar range \( r \), is proportional to PhiDP:

\[
\text{dBZ}_{\text{corr}}(r) = \text{dBZ}(r) + \alpha \cdot \text{PhiDP}(r)
\]

The proportionality factor \( \alpha \) can be selected according to the “General” parameters of the “dBZ Correction” part:

- **Automatic**: \( \alpha \) is selected automatically according to the radar frequency:
  - S-Band: \( \alpha \approx 0.018 \text{ dB/deg} \)
  - C-Band: \( \alpha \approx 0.08 \text{ dB/deg} \)
  - X-Band: \( \alpha \approx 0.25 \text{ dB/deg} \)
• User-def: The selected (user-defined) value of α is used.

Step 2: dBZ-Correction using ZPHI (optional)

ZPHI is an attenuation correction method which uses method described by Hitschfeld and Bordan (1954) (cf. section 9.4 of the Products and Algorithms Manual), and takes the total attenuation, derived from the total PhiDP, as a constraint. A starting point can be found e.g. in Marecal et al. (1997), where a corresponding equation for the specific attenuation coefficient is given (their equation (1)). Marecal et al. (1997) also give a correction function (their eq. (5)), taking care for the total attenuation constraint. By combination of these two equations, and using the total PhiDP as a measure for the attenuation constraint (as e.g. in Ryzhkov and Zrnić, their eq. (5)), one obtains an equation for the attenuation correction based on measured dBZ and filtered PhiDP data (cf. Gematronik, 2007, eq. (4.3) to (4.5)):

\[
Z_{\text{meas}}(r) = Z_{\text{corr}}(r) \exp\left( -0.46 \int_{r_0}^{r} A(s) ds \right) \\
A(r) = \frac{\left[ Z_{\text{meas}}(r) \right]^b}{I(r_0; r_m)} \cdot \left( \frac{10^{0.1\alpha Z(r_0, r_m)} - 1}{10^{0.1\alpha Z(r_0, r_m)} - 1} \right) \\
I(r_0; r_m) = 0.46 b \int_{r_0}^{r_m} \left[ Z_{\text{meas}}(r) \right]^b dr
\]

\[
dBZ = 10 \log_{10}(Z) \iff Z = 10^{\text{dBZ}/10}
\]

In the above, \( r_0 \) is the smallest range with valid PhiDP data, \( \alpha \) is the proportionality factor (see step 1), and \( b \) is the exponent of the power-law relation between reflectivity \( Z \) and specific attenuation \( A \) as used in Hitchfeld and Bordan (1954). The parameters \( \alpha \) and \( b \) are taken from the PPDF parameters.

The above method was later called ZPHI by Testud et al. (2000).

Step 3: dBZ-Correction using Iterative ZPHI (optional)

Bringi et al. (2001) improved the attenuation correction using ZPHI. According to them, the parameter \( \alpha \) should not be taken as fixed. Instead, using any value of \( \alpha \), a PhiDP(\( r \)) profile can be re-constructed, and an error function can be defined as the difference between the filtered and the re-constructed PhiDP(\( r \)) profile:

\[
\text{Error} = \sum_{j=1}^{N} \left| \Phi_{\text{dp}}^{\text{ft}}(r_j) - \Phi_{\text{dp}}^{\text{c}}(r_j; \alpha) \right|
\]

In an iterative approach, an optimum value of \( \alpha \) can be found where the error function becomes minimal.

There are two caveats for this iteration:
The iteration tends to become instable if the total PhiDP is small. Thus it is omitted (and the normal ZPHI method is used with the initial $\alpha$), when the total PhiDP is smaller than the ‘PhiDP Threshold’ from the PPDF parameters.

It may happen that the iteration converges for values of $\alpha$ which are not meaningful. In that case, an optimised $\alpha$ is taken which is very close to the initial $\alpha$.

**Step 4: ZDR-Correction using the Linear PhiDP method**

Due to oblate particles like medium-size or big raindrops, ZDR experiences a negative bias because the horizontal radiation is stronger attenuated than the vertical radiation. PhiDP can also be used to correct for that kind of attenuation.

For this the linear PhiDP, the total differential attenuation, i.e. the amount of ZDR correction along radar range $r$, is proportional to PhiDP:

$$ ZDR_{\text{Corr}}(r) = ZDR(r) + \beta \cdot \Phi\text{DP}(r) $$

The proportionality factor $\beta$ can be selected according to the “Linear PhiDP correction” parameters of the “ZDR Correction” part:

- **Automatic:** $\beta$ is selected automatically according to the radar frequency:
  - S-Band: $\beta = 0.0025$ dB/deg
  - C-Band: $\beta = 0.02$ dB/deg
  - X-Band: $\beta = 0.035$ dB/deg

- **User-def:** The selected (user-defined) value of $\beta$ is used.

Observations have shown that the proportionality factor $\beta$ is not constant. Thus the above scheme might cause an over- or under-correction of ZDR. For that reason $\beta$ can be optimized if “Optimize beta from ray end” is selected. See step 4 for the detailed description.

**Step 5: ZDR-Correction using the Ah-scaled method**

The assumption that both the dBZ and ZDR attenuation are proportional to PhiDP means that there is also a proportionality between the amount of dBZ correction and the amount of ZDR correction. Using eqs. (1) and (2), the proportionality factor between these two amounts is just $\gamma = \beta / \alpha$; i.e.

$$ ZDR_{\text{Corr}}(r) - ZDR(r) = \gamma \cdot [dBZ_{\text{Corr}}(r) - dBZ(r)] $$

Such a method for the ZDR correction is called the “Ah-scaled” method (where “Ah” means the specific attenuation of horizontal reflectivity).

If both dBZ and ZDR are corrected using the Linear PhiDP method, this means also that the ZDR correction is “scaled” to the dBZ correction. However, if the dBZ correction is performed using the ZPHI or the iterative ZPHI method, an “Ah-scaled” correction of ZDR according to
eq. (5) means that the ZDR correction is not linear with PhiDP, but proportional to the amount of dBZ correction.

The proportionality factor $\gamma$ is given from the PPDF parameters:

- User-def: The selected (user-defined) value of $\gamma$ is used.
- From optimized beta: An optimized proportionality factor $\beta_{\text{Opt}}$ is derived (see step 6), and $\gamma$ is then calculated from this $\beta_{\text{Opt}}$ and the previously given $\alpha$ (see step 1), using $\gamma \beta_{\text{Opt}} / \alpha$.

**Step 6: Optimization of $\beta$ and $\gamma$**

According to a method proposed by Bringi et al. (2001) and as described in Gematronik (2007; see eq. (5.3) and figs. 5.1 to 5.3), theoretical values of ZDR can be estimated based on dBZ values: At the (ray's) end of a precipitation system, i.e. in a rather stratiform area, the ZDR values should be close to zero dB for very week rain, and can be related to the (already corrected) dBZ values for light rain according to Figs. 5.1 to 5.3 of Gematronik (2007). This allows a calculation of theoretical estimates of the proportionality factors $\beta$ and $\gamma$ using eq. (5.3) of Gematronik (2007).

“Optimization” here means that a quality parameter (or: weight factor) $w$ between 0.0 and 1.0 is determined together with the theoretical estimate $\beta_{\text{Est}}$ according to eq. (5.3) of the DP-Handbook. The optimized proportionality factors $\beta_{\text{Opt}}$ and $\gamma_{\text{Opt}}$ for each ray are then calculated as a weighted average of the initial values and the theoretical estimates:

$$\beta_{\text{Opt}} = w \cdot \beta_{\text{Est}} + (1-w) \cdot \beta$$

$$\gamma_{\text{Opt}} = \beta_{\text{Opt}} / \alpha$$

The weight factor $w$ is the larger the “better” a ray-end with slight precipitation can be detected. A “good” ray end means e.g. that it is:

- at least, say, 5 km long,
- with small reflectivity (say, below 20 dBZ),
- but sufficiently above noise (SNR say > 10 dB),
- with small dBZ and ZDR variability (stddev say < 5dB for dBZ, < 2dB for ZDR),
- not too far away from the last (i.e. outmost) dBZ echoes,
- with total Phi being significant.

The weight factor $w$ is calculated based on that parameters.
13 References


Maki, M., et al. (2001): Observations of Volcanic Ashes with a 3-cm Polarimetric Radar. 30th Conf. on Radar Meteorology, Munich (Germany), pp 226-228.


Schuur, T., A. Ryzhkov and P. Heinselman (2003): Observations and classification of echoes with the polarimetric WSR-88D radar, NOAA National Severe Storms Laboratory Tech Report, Norman, Oklahoma, USA.


