Synergy between polarimetric radar and radiometer ADMIRARI for estimation of precipitating parameters

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Abstract

X-band dual-pol radar observations are used to apply an extended version of the ZPHI algorithm to estimate the specific attenuation for RHI scans. These scans were in synergy at the same azimuth with passive radiometer observations by ADMIRARI. It is shown that the ZPHI algorithm might be feasible to apply for RHI scans, nevertheless special attention must be put in detecting properly the top of the rain layer and avoid contamination due to bright-band. Furthermore it has found that for high elevation angles the difference between two points in differential phase shift Φ_{dp} is in general negligible, in that case the method could produce non-significant attenuation even in presence of precipitation. The estimated attenuation is converted to liquid water content and thereon compared with independent retrievals by ADMIRARI, finding a decent correlation specially for cases with liquid water path larger than $\sim 0.5\, kg\, m^{-2}$.

1. Introduction

Since 2010 in the frame of the Global Precipitation Measurement, Ground Validation (GPM/GV) field experiments, polarimetric radars have been scanning in synergy with the microwave radiometer ADMIRARI Battaglia et al. (2009); ADMIRARI website (2013) in four field campaigns ranging from the tropics to high latitudes and sensing thunderstorms and light stratiform precipitation. In order to take advantage of the multi-sensor data collected, a development of a radiometer-radar retrieval scheme for precipitating cloud parameters is pursued. Nevertheless before to attempt a combined algorithm, independent estimations of liquid precipitating parameters are first developed to overview the performance of the active and passive sensors when observing the same precipitating system.

Earlier studies for the LPVEx campaign in Finland have shown that reflectivity radar can be used to estimate the attenuation for the rain layer and the radiometer for the estimation of the cloud, leaving therefore the attenuation due to the bright-band as last unknown which can be determined combining both sensors. For the LPVEx light precipitation observation, however, the polarimetric variables are negligible and a $A = aZ^b$ power law relationship has been used. The results have shown a strong dependence on the DSD taken into account for the estimation of the coefficients a and b, which can produce nonphysically results e.g. negative optical thicknesses.

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The present study is an attempt to extend the applicability of the well known ZPHI method Testud et al. (2000); Bringi and Chandrasekar (2001) to RHI scans to estimate specific attenuation and thereafter precipitation parameters too. Thus the RHIs, bearing at the same azimuth as the radiometer's observations, might be used to reconstruct the radiometer Field-of-View (FOV).

2. Passive-Active Sensor Instrumentation

The *Jülich Forschung Zentrum* (JFZ) is a German research facility which possess a large instrument suite to make studies on the environment as well as a cloud and precipitation observatory. One of the main instrument is the X-band dual-polarized weather radar (JuXPol). Additionally, the University of Bonn's triple-frequency dual-polarized radiometer ADMIRARI has been deployed to the JFZ and measuring at fixed $30°$ elevation and RHI mode since end of April 2013. JuXPol performs RHI scans every 5 minutes to an azimuth bearing toward ADMIRARI ($234°$).
ADMIRARI is located at a distance of 3.8 km southwest from JuXPol and its scan strategies comprise of fixed elevation observation for 5 minutes followed by a RHI from 21 to $60°$. Normally the RHI mode is only started when precipitation is expected.

a. *X-band Radar JUXPOL*

The JFZ operational radar is a 9.3 GHz dual-pol and is one of the twin X-band systems in Bonn and Jülich, Germany.
The RHI scans have typically 150 meters range resolution with a maximum range of 50 km, and $0.2°$ elevation steps scanning from 0 to $90°$. Typical scan schedule is a cycle of 5 min with volume scans and RHIs over Bonn radar and ADMIRARI.

b. *Radiometer ADMIRARI*

The University of Bonn's **AD**vanced **MI**crowave **RA**diometro for **R**ain **I**dentification ADMIRARI is a triple-frequency (10.7, 21.0 and 36.5 GHz) dual-polarized (H & V) scanning passive microwave radiometer (MWR), its polarization capabilities gives the ability to retrieve slant Liquid Water Path (LWP) and distinguish the cloud and rain component separately.

Figure 1: ADMIRARI radiometer at Jülich Research Center. Note the auxiliary active sensors MRR (right) and cloud lidar (left).

Additionally to the MWR, ADMIRARI senses the atmosphere with co-located ancillary instruments, i.e. a 24.1 GHz micro rain radar (MRR) and a 902 nm cloud lidar.
Typical ADMIRARI data set comprise of Brightness Temperature (V & H), Polarization Difference (V - H) and the ancillary active instruments: Reflectivity at 24.1 GHz and backscattering factor at 902 nm Saavedra at al. (2012); Battaglia et al. (2009); ADMIRARI website (2013).

3. The ZPHI method applied to RHI

The ZPHI method is widely used to correct the attenuated reflectivity Z_h applied to low elevation PPI scans and therewith estimate rainfall in Quantitative Precipitation Estimation (QPE). The technique couples the profiles of attenuated $Z_h(r)$ and the differential phase shift

$\Phi_{dp}(r)$ (hereafter $Z_h(r)$ will be represented as Z) following the power law equation which relates attenuation and reflectivity as $A(r) = a(r)\,[Z]^b$, from that and the relationship between attenuation and differential phase shift the following equation can be derived (for the detailed derivation, see Bringi and Chandrasekar (2001); Testud et al. (2000)):

$$A(r) = \frac{a(r)\,[Z(r)]^{\bar{b}}\,[exp(0.23\,\bar{b}\,PIA) - 1]}{I_a(r_0, r_{top}) + [exp(0.23\,\bar{b}\,PIA) - 1]\,I_a(r, r_{top})} \tag{1}$$

in $[dB\,km^{-1}]$ units and with

$$I_a(r, r_{top}) \;=\; 0.46\,\bar{b}\int_r^{r_{top}} a(s)\,[Z(s)]^{\bar{b}}\,ds \tag{2}$$

and Z the measured radar attenuated reflectivity. The path integrated attenuation (PIA) in equation 1 is given as proportional to $\Delta\,\Phi$ as follow:(Testud et al. (2000); Ryzhkov et al. (2013); Bringi and Chandrasekar (2001)):

$$PIA \;=\; \gamma(r)\,\Delta\,\Phi \tag{3}$$

with

$$\Delta\Phi \;=\; \Phi_{dp}(r_{top}) \;-\; \Phi_{dp}(r_0) \tag{4}$$

The coefficients a and b are frequency and temperature dependent and normally it is assumed to be constant along the path leading the coefficient a to be canceled out in equation 1, which is an acceptable assumption since the ZPHI method is normally applied to PPI scans at low elevation angles. However, for RHI scans the above mentioned assumption is not valid since there is a significant change on Temperature from the nearest to the furthermost ranges for high elevation angles. That is specially true for the coefficient $a(r)$, while for the coefficient b the change with range and elevation angle is constant, therefore note the use of the average $\bar{b}$ in equations 1 and 2

Once $A(r)$ is computed, it is straightforward to apply a power law relationship between rain liquid water content and specific attenuation according to:

$$lwc(r) = c(r)\,[A(r)]^{d(r)} \tag{5}$$

with lwc in $[g\,m^{-3}]$ and the coefficients c and d given by 6. The coefficients c and d were estimated at specific temperatures by T-matrix simulations applied to representative DSD for continental precipitation, which values are summarized in table 1 (Ryzhkov et al. 2013, and personal comunication).

Table 1: Coefficients c and d in equation 5 for different temperatures.

T [$^\circ C$]	a $\times 1E-5$	b	c	d
0	16.2	0.74	2.04	0.765
10	11.5	0.78	1.88	0.724
15	–	–	1.81	0.705
20	7.99	0.82	1.78	0.689
30	5.50	0.86	1.75	0.661

In order to assign every range bin with its corresponding couple of coefficients c and d, a quadratic and linear relationships correspondingly has been fitted with Temperature as independent variable, therefore every single range is first mapped to a temperature and then to its corresponding coefficients following equations 6.

$$\begin{aligned} a(T) &= [16.19 - 0.52\,T + 0.01\,T^2]\,10^{-5} \\ \gamma(T) &= [38 - 0.53\,T]\,10^{-2} \\ c(T) &= 2.0410 - 0.0201\,T + 0.0003\,T^2 \\ d(T) &= 0.7651 - 0.0045\,T \end{aligned} \tag{6}$$

In order to apply the ZPHI method to RHI observations, data is being analyzed collected on June 20th, 2013 at the Jülich Forschung Zentrum (figures 2 for ADMIRARI and 3 for JuxPol).

The method is only applied to the rain layer, therefore the range of the Bright-band bottom (r_{top} in equations) is determined using an iterative approach taking advantage of polarimetric variables which fulfill the following conditions: drop on ρ_{hv}, increase of texture Z_{dr}. The range where these conditions are found is then assumed as a start of the iteration, thereafter reducing a range gate till the following condition is achieved:

$$\left|\frac{1}{N}\sum_{i=r_0}^{r_{top}-1} \rho_{hv}(i) - \rho_{hv}(r_{top})\right| \;<\; 0.05 \tag{7}$$

thereon it is assumed that the ranges from r_0 to r_{top} contains only the rain layer and possible contamination

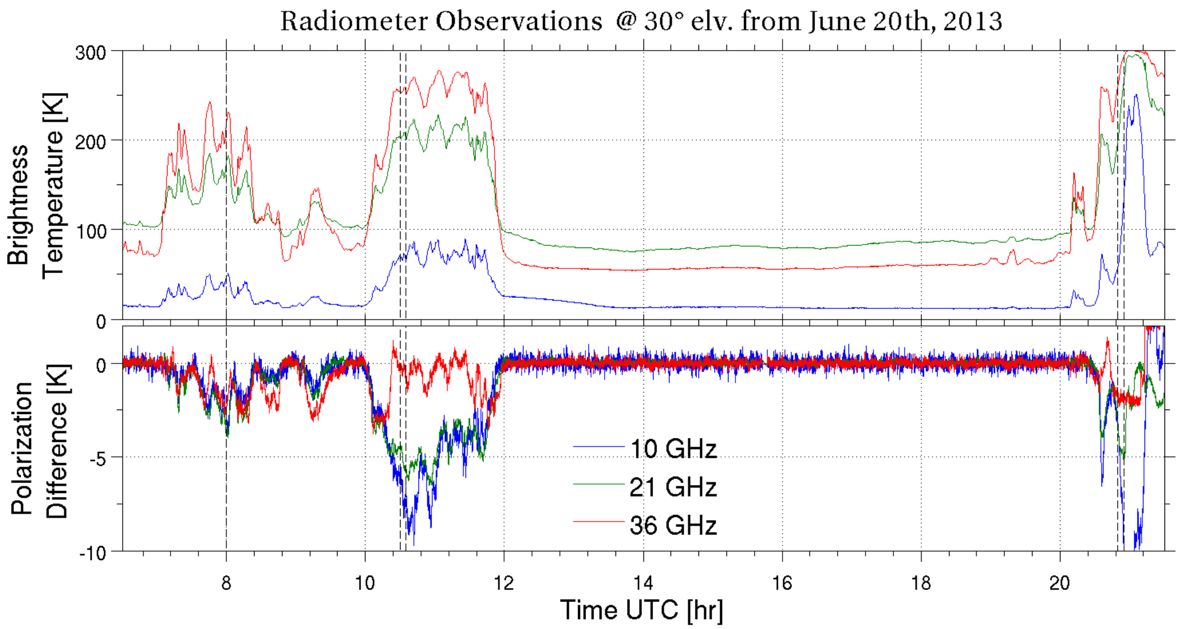

Figure 2: ADMIRARI time series of Brightness Temperatures and Polarization Difference at 10.7 (blue), 21.0 (green) and 36.5 (red) GHz. Case study from June 20th, 2013. Gray area represent rain periods.

from bright-band is completely avoid. Alternatively, in cases where the signal from the polarimetric variables are not strong enough to apply the method, the ambient temperature is used to estimate the range corresponding to the 0° iso-thermal to complement with the method mentioned here.

The ZPHI algorithm applied to QPE for low elevation PPI scans, normally requires a $\Delta\Phi$ minimum of 5°, to ensure that it exceeds significantly the noise on Φ_{dp} measurements Testud et al. (2000). In the present study that constrain might, however, jeopardize the feasibility of the ZPHI algorithm applied to RHI cases since at high elevation angles ,e.g. 25° up, $\Delta\Phi$ may be around or less than 5° even in presence of strong precipitation (Fig. 5), therefore that minimum threshold must be flexible in order to achieve the applicability of the ZPHI at RHI scans.

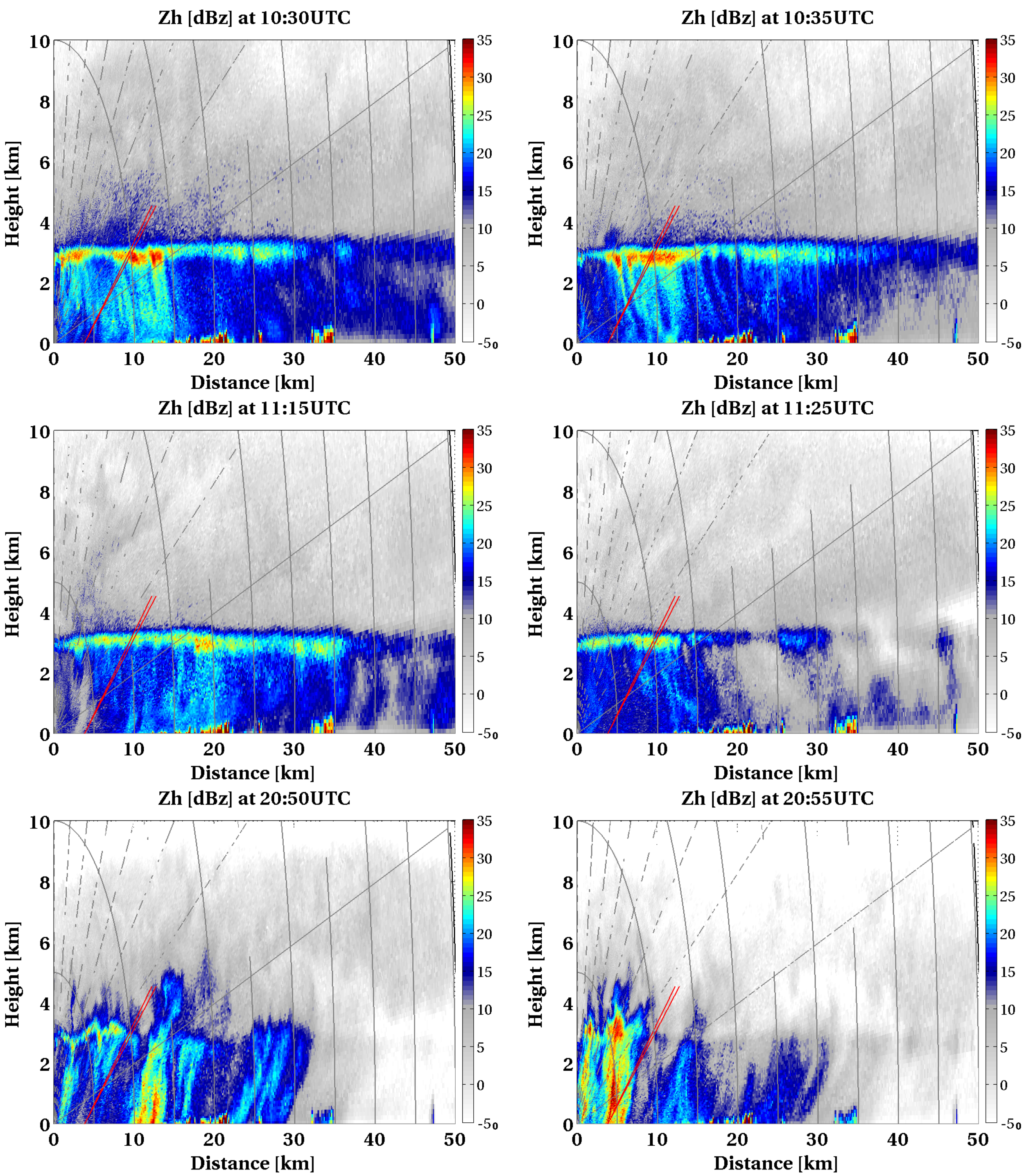

Figure 3: JuXPol radar RHI sequence at same ADMIRARI's azimuth. Red cone represent the instantaneous radiometer FOV.

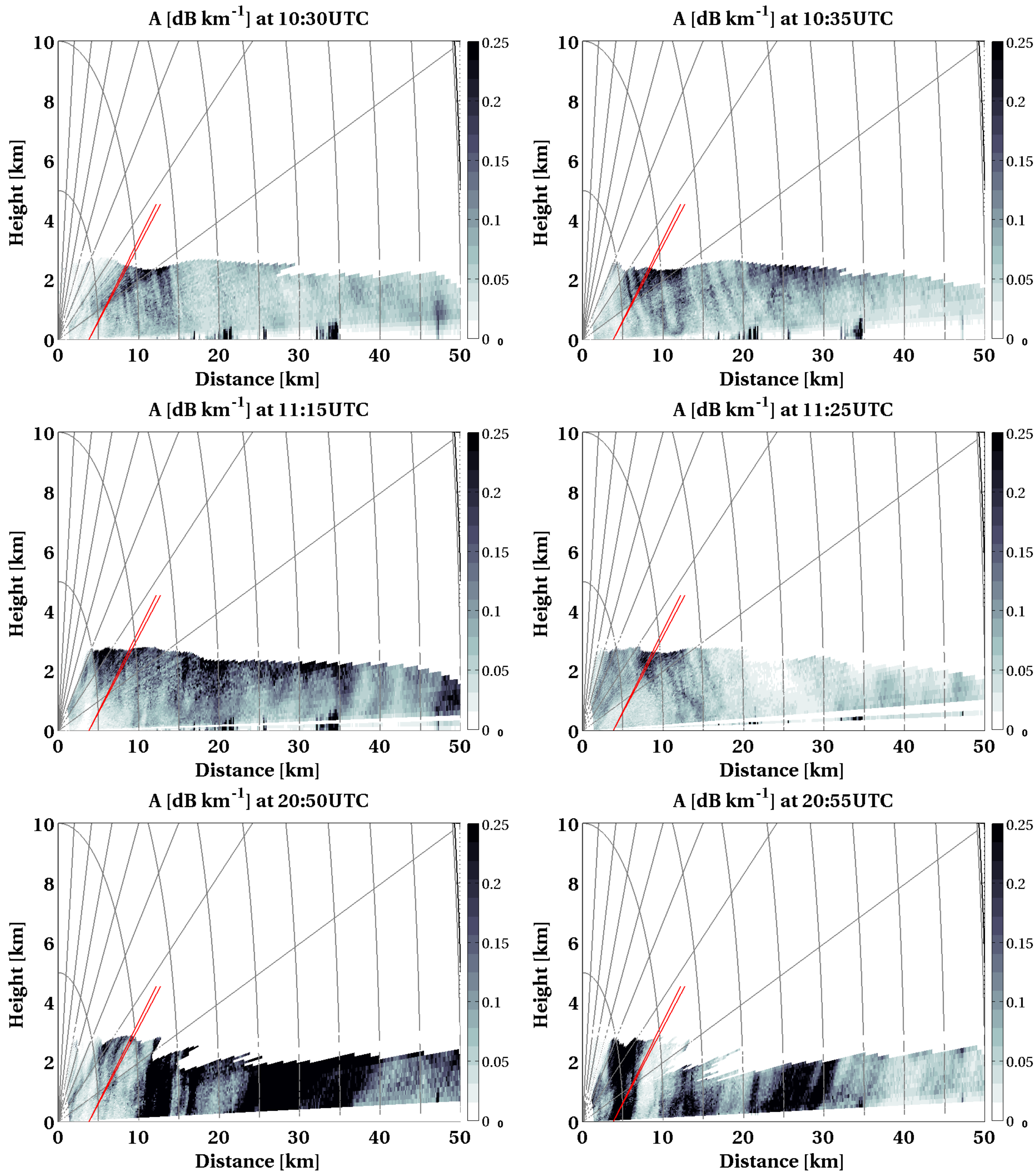

Figure 4: X-band specific attenuation for RHI sequences. Red cone represent the instantaneous radiometer FOV.

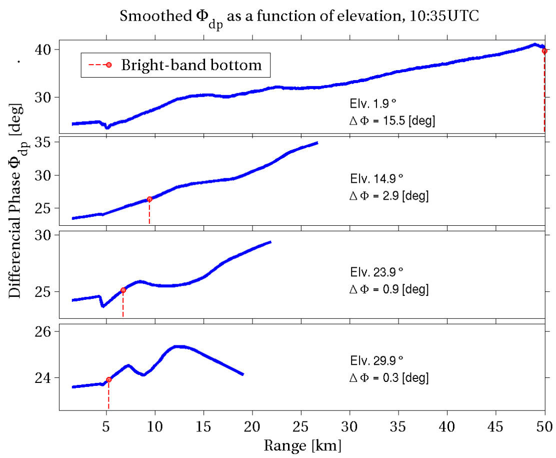

Figure 5: PHIdp range profile for different elevation angles. The red circle denotes the bottom of the bright-band i.e. the top range for the integration.

4. Results for Liquid Water Content

In order to validate the method, the Liquid Water Content lwc is going to be compared as estimated from the radar by equation 5 and the retrievals from ADMIRARI for rain LWP.
Thus the ZPHI method is applied to the radar's RHI angles (typically from 0 to 35° for the specific observational setup in JFZ) which sweep the radiometer's FOV at the azimuth of 234°. Once the specific attenuation is estimated, the liquid water content is calculated using 5 for all the RHI ranges and elevation angles where the method is applicable.

From the radar derivatives i.e. specific attenuation and liquid water content, the ADMIRAR's FOV is extracted considering the instrument's beam-width obtaining thus the radiometer's observation column represented in the slant profile (see for instance figure 6 for the reflectivity corrected by attenuation as ADMIRARI would have seen it).

To have two comparable magnitudes, the radar LWC along ADMIRARI's FOV must be first integrated along the path, the result is shown in figure 8. The ADMIRARI retrieval scheme allows to estimate also the standard deviation for every point, that is shown in figure 8 as a error-bar corresponding to $\sim 93\%$ of the whole distribution of values over which the most probable is obtained according to the Bayesian technique Saavedra at al. (2012).

5. Discussion

A reasonable correlation is found specially for rain LWP values above $\sim 0.5 kg\, m^{-2}$. That is obviously because the ZPHI method performs better when significant attenuation is observed. In general a RMSE of 1.2 $kg\, m^{-2}$ is found, this however is largely affected by the widespread dispersion of point at low LWP values. The bias, on the other hand, is slightly negative and small. Moreover figure 8 shows a overestimation of ADMIRARI's retrievals, that may be explained since the radiometer's observations include the effect of the bright-band while the radar estimation is due to only the rain layer.
Regarding the large scattered point for low LWP, it can be understood due to the low attenuation produced by the rain corresponding to those points which yields to poor estimations of LWC. On the other hand, Saavedra at al. (2012) have also shown that ADMIRARI retrievals are prone to produce large errors for the partition of LWP below $\sim 450 g\, m^{-2}$ into its cloud and rain components. Therefore, it is difficult to interpret the scatter out of the 1:1 line shown in figure 8 since the origin can range from weaknesses on the radar and radiometer algorithms to errors corresponding to the instruments (minimum detectable values) or to the retrieval methods themselves.

On the other hand, the advantage to have a good correlation radar-radiometer ,for cases when both methods perform properly, is that PIA can be mapped to all ADMIRARI frequencies i.e. X, K and Ka-band, and therefore estimate the attenuation due to bright-band in all these frequencies, mimicking the work which has been done for light precipitation observed at the GPM LPVEx campaign (see ADMIRARI website (2013) and posters therein), this time however with a more robust method to estimate the specific attenuation using the ZPHI algorithm.

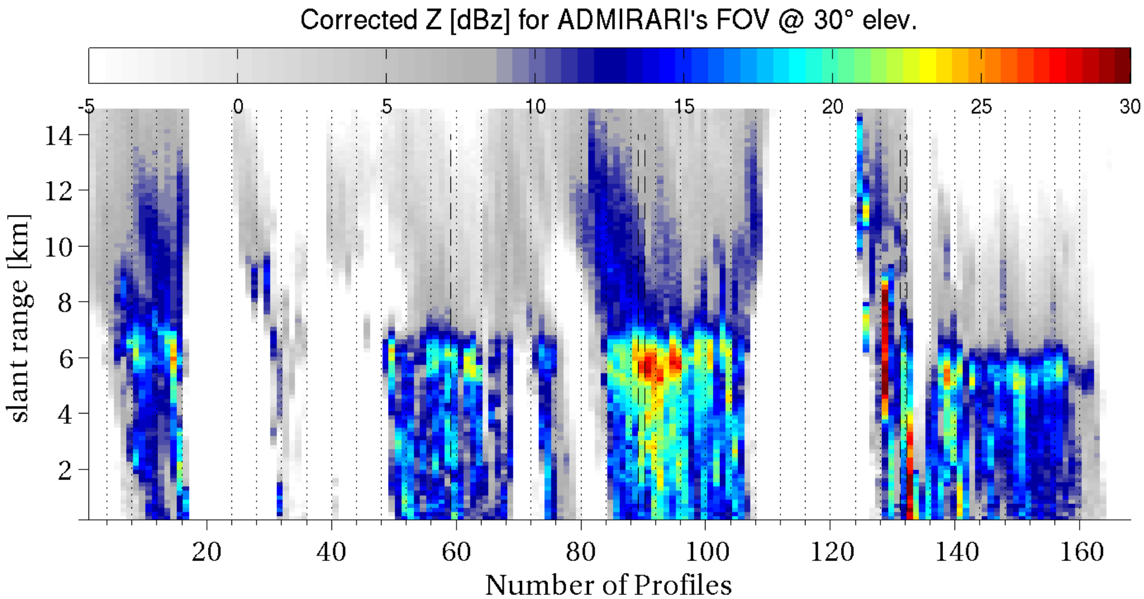

Figure 6: Sequence for slant profiles of X-band reflectivity corrected by attenuation and extracted from RHIs into ADMIRARI's FOV.

It is worth to note that the number of point shown in figure 8 are largely reduced due to fact that some cases are not possible to retrieve neither by the radiometer nor the radar. Thus a natural next step is to extend this study to larger data set in order to improve the statistics shown in figure 8 and find out whether the results are a case specific behavior or involves a more general pattern. In addition it is pursued to apply the methodology presented here to the GPM/GV field experiments where ADMIRARI observations were eventually in synergy with either C or X-band radars.

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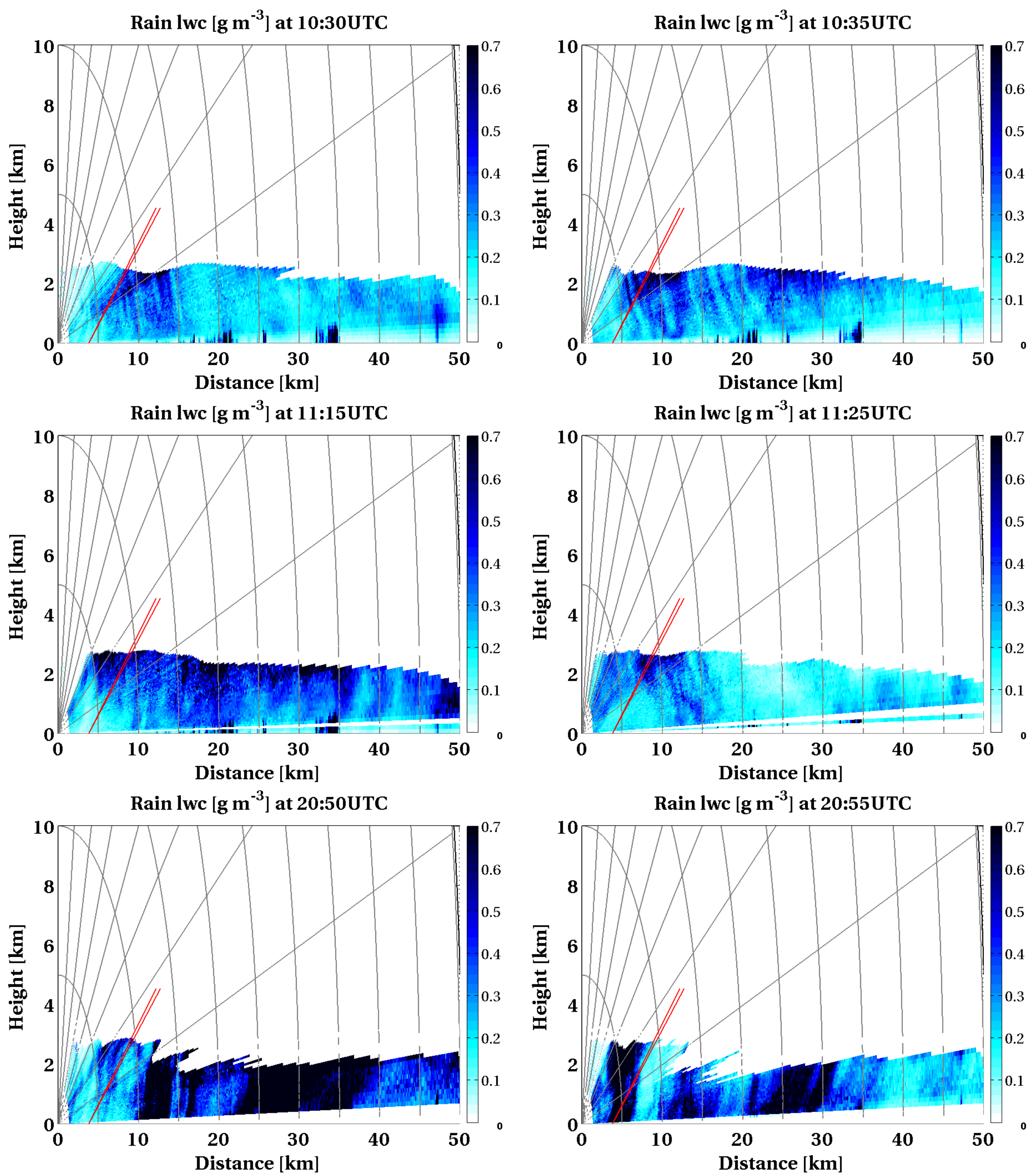

Figure 7: Liquid water content for RHI sequences. Red cone represent the instantaneous radiometer FOV.

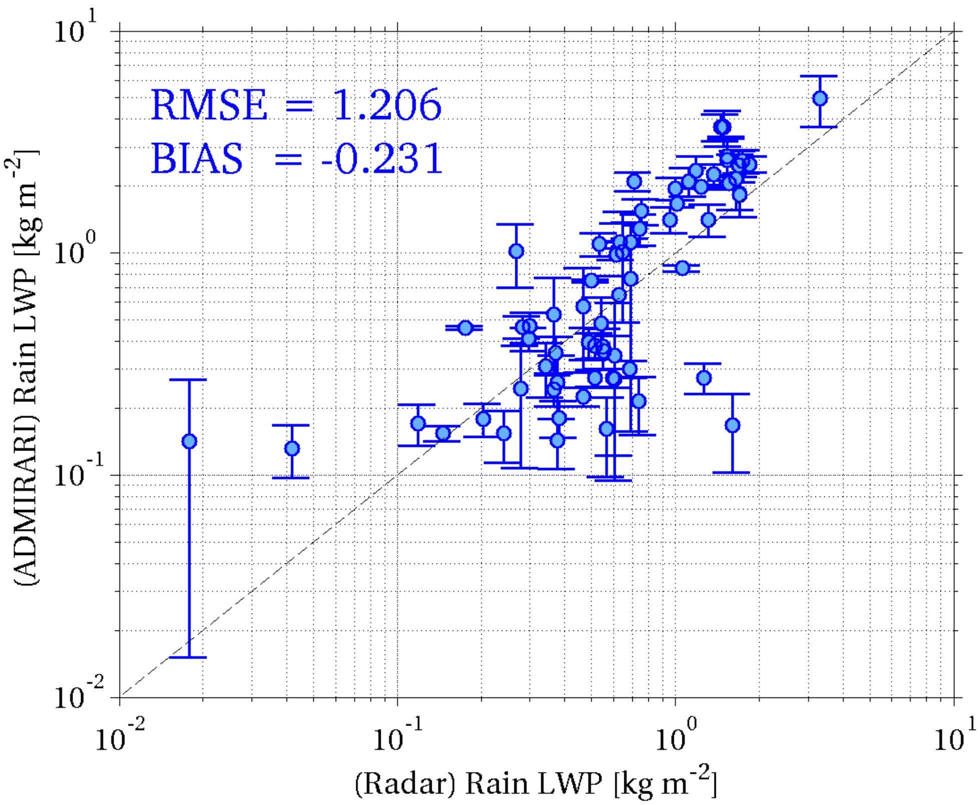

Figure 8: Scatter plot for LWP as retrieved from ADMIRARI versus computed using the ZPHI algorithm from RHI radar data. Note that ADMIRARI's retrievals are shown with error-bars corresponding to 2σ. The black-dashed line represent a 1:1 relation.

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List of Publications:`http://www2.meteo.uni-bonn.de/admirari/admirari_publications.html`