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

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1.- Research Objectives

At four GPM/GV field campaigns, polarimetric radars have been scanning in synergy with the radiometer ADMIRARI [1, 6]. In order to develop a radiometer-radar retrieval scheme, independent estimations of liquid precipitating parameters are first developed to overview the performance of active and passive sensors when observing the same precipitating system. Earlier studies (LPVEx campaign) have shown that radar can be used to estimated for the rain layer attenuation and the radiometer for the cloud and gases, leaving the attenuation due to bright-band as last unknown which can be determined combining both sensors. LPVEx observed light precipitation which polarimetric variables were negligible and a $A = aZ^b$ relationship were used but results depend strongly on the DSD taken into account for the coefficients a and b. The present study is an attempt to extend the well known ZPHI method [3, 5] to RHI observations along the radiometer Field-of-View (FOV), to obtain precipitation parameters.

2.- X-Band Polarimetric Radar (JuXPol) and ADMIRARI

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. At an azimuth bearing toward ADMIRARI (234°) JuXPol performs RHI scans every 5 min.
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.

Microwave 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.
- Additionally to the MWR, *ADMIRARI* senses the atmosphere with co-located ancillary instruments, i.e. a 24.1 GHz micro rain radar 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 [2, 1, 6].

X-Band dual-pol 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, and 0.2° elevation steps scanning from 0 to 90°.

The picture below shows the radiometer ADMIRARI installed at the JFZ. A rain radar (right) and a cloud lidar (left) attached to the pedestal.

3.- The ZPHI method applied to JuXPol RHI scans (Case study June 20th 2013)

The ZPHI method is used to correct the reflectivity Zh from attenuation in QPE PPI scans at low elevation angles and therewith estimate rainfall. The technique couples the profiles of attenuated $Zh(r)$ and the differential phase shift $\Phi_{dp}(r)$

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

with

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

and the path integrated attenuation (PIA) is given as a function of $\Delta\Phi$ as follow:([3, 4, 5]):

$$PIA = \gamma(r)\,\Delta\Phi, \quad \text{with} \quad \Delta\Phi = \Phi_{dp}(r_{top}) - \Phi_{dp}(r_0)$$

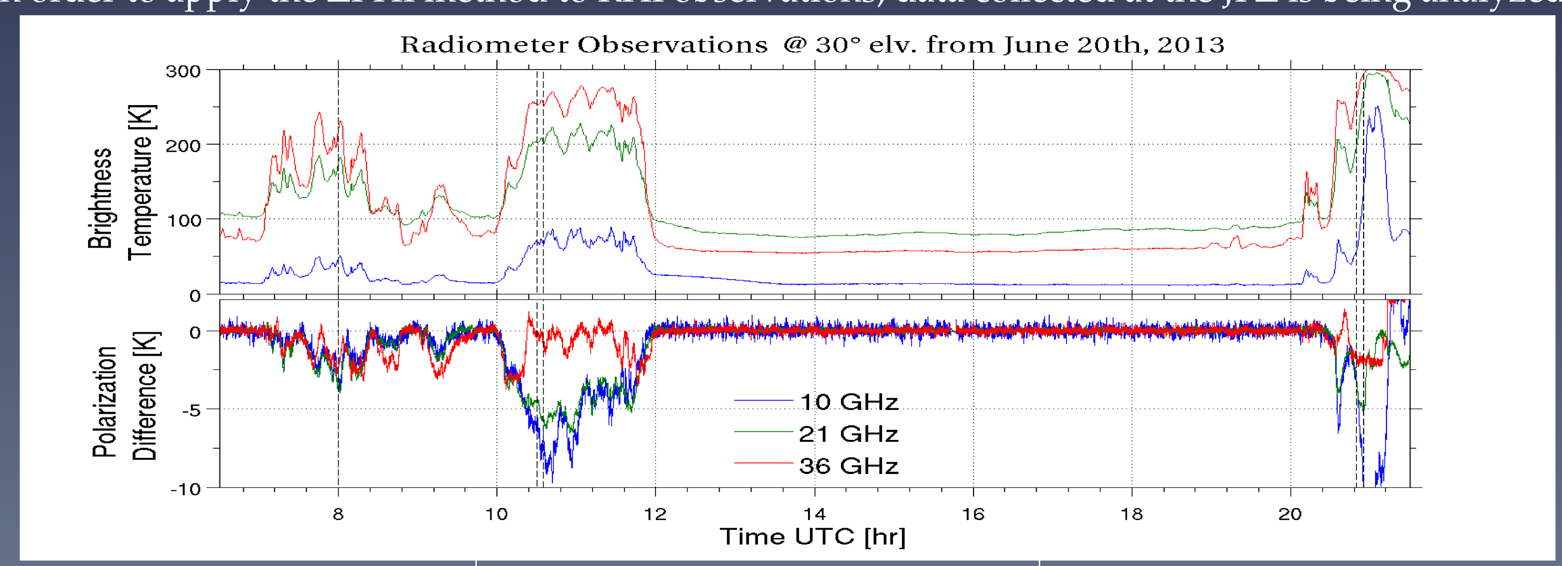
The coefficients a and b are Temperature dependent and normally it is assumed constant along the path and the above equation can be simplified being independent of a. However, for RHI that assumption is not valid since there is a strong change on Temperature for high elevation angles.
Once $A(r)$ is computed, it is being applied a power law relationship between rain liquid water content and specific attenuation according to:

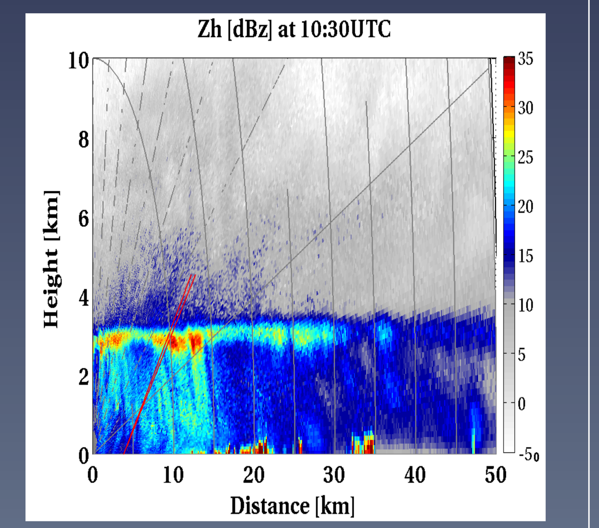
$$lwc(r) = c\,[A(r)]^d \quad [g\,m^{-3}]$$

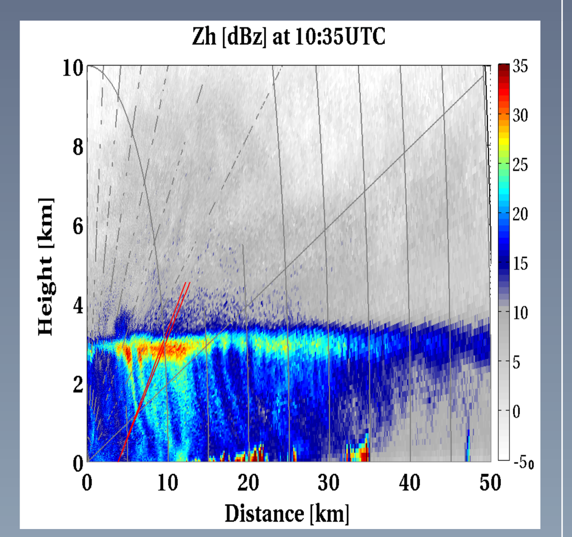
It has been determined relationships for the above mentioned coefficients with the Temperature, which is mapped to each radar range:

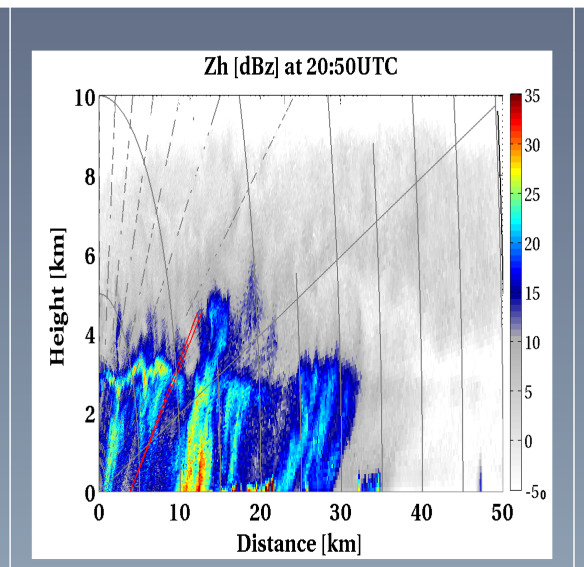
$$\begin{aligned} a(T) &= [16.19 - 0.52\,T + 0.01\,T^2]\,10^{-5} \\ \gamma(T) &= [38 - 0.53\,T]\,10^{-2} \\ c(T) &= 2.0410 - 0.0201\,T + 0.0003\,T^2 \\ d(T) &= 0.7651 - 0.0045\,T \end{aligned}$$

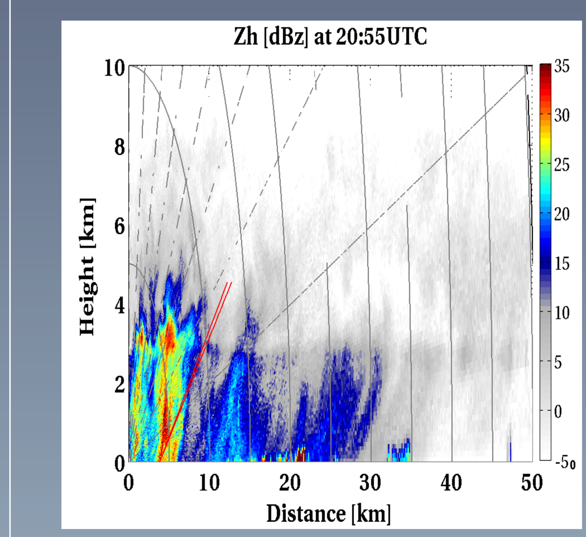
- In order to apply the ZPHI method to RHI observations, data collected at the JFZ is being analyzed.

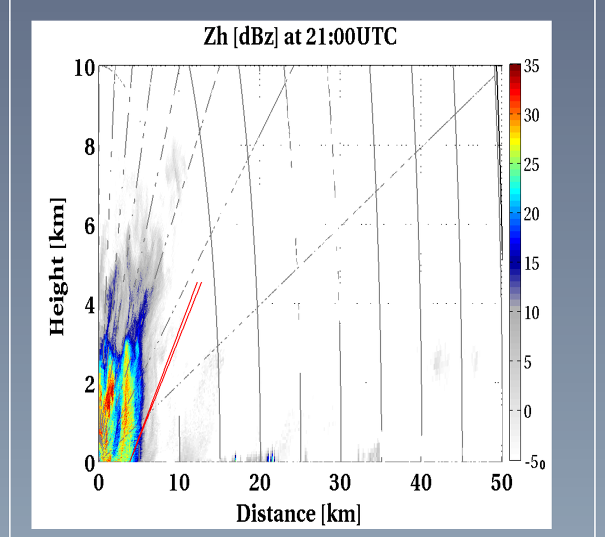




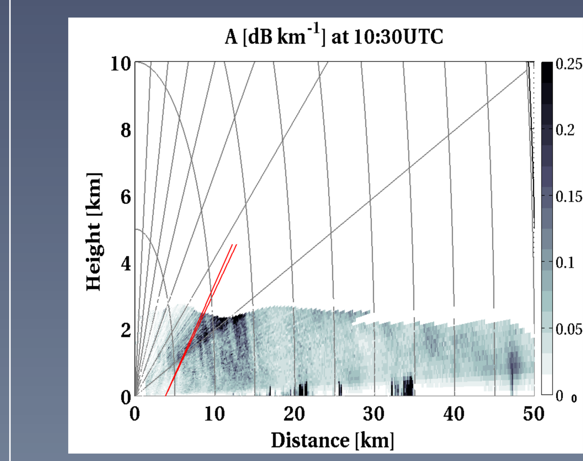


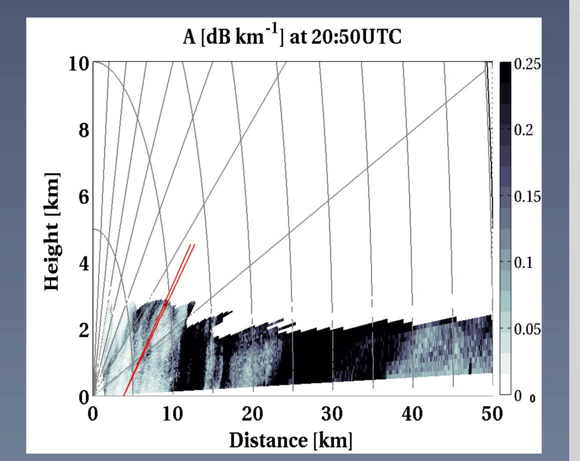




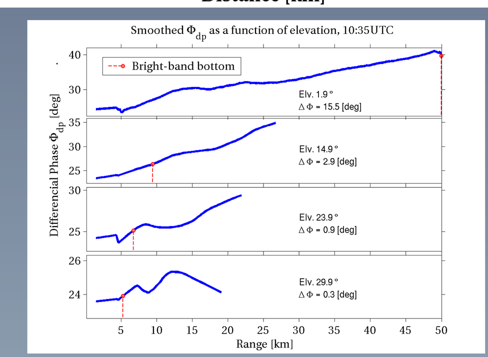


- The method is only applied to the rain layer, therefore the range of the Bright-band bottom (r_{top} in equations) is determined iteratively using polarimetric variables ρ_{hv}, texture Z_{dr} and Φ_{dp}. As auxiliary information, ambient temperature is also used to estimate 0° iso-term for cases when Bright-band signal is not too strong.



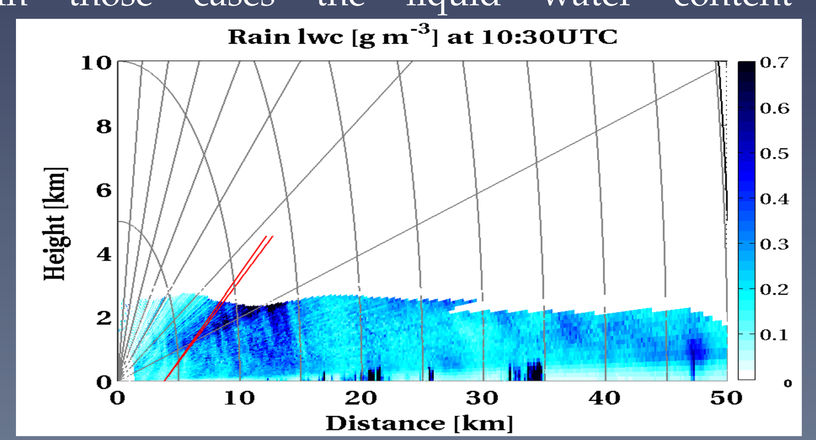


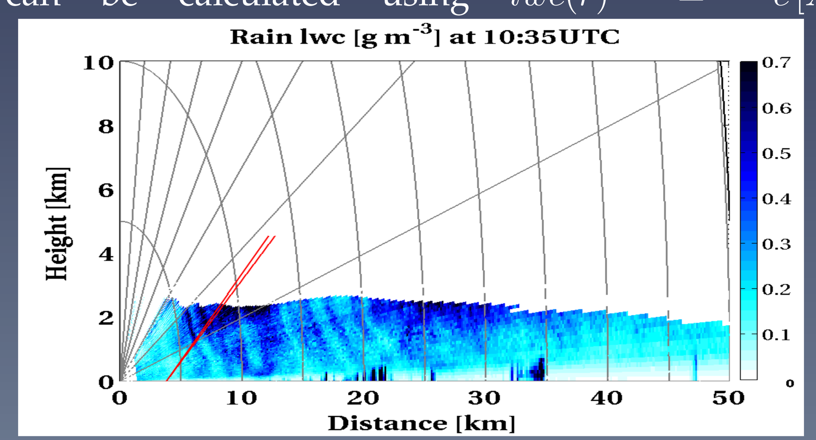
- The ZPHI method normally requires a $\Delta\Phi$ minimum of 5°, to ensure that it exceeds significantly the noise on Φ_{dp} measurements. That might, however, jeopardize the reliability of the ZPHI algorithm applied to RHI cases as it is shown in the next picture.

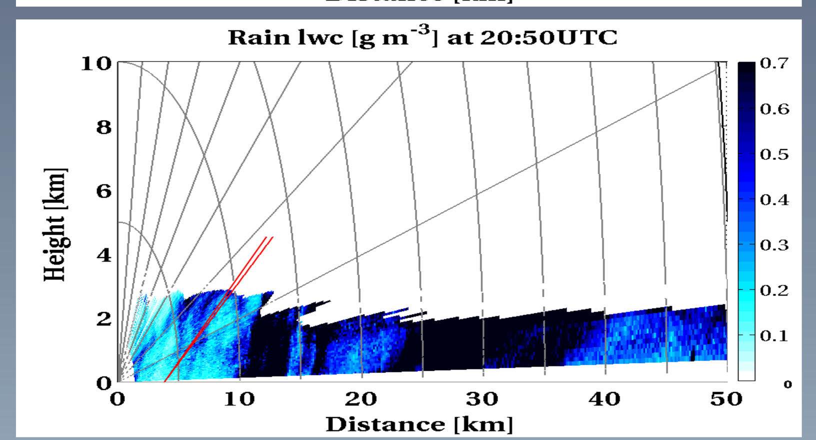


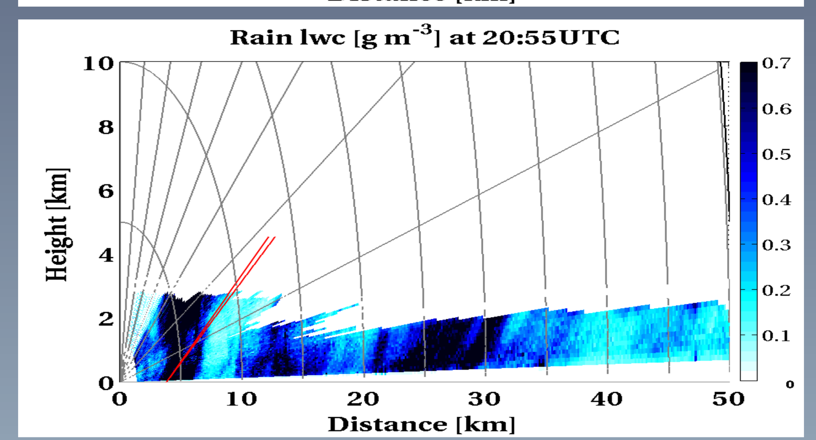
4.- Results for Liquid Water Content

The RHI angles must map the radiometer's FOV (typically from 0 to 35°) in order to estimated from the ZPHI method the specific attenuation along ADMIRARI's FOV. In those cases the liquid water content can be calculated using $lwc(r) = c\,[A(r)]^d$.

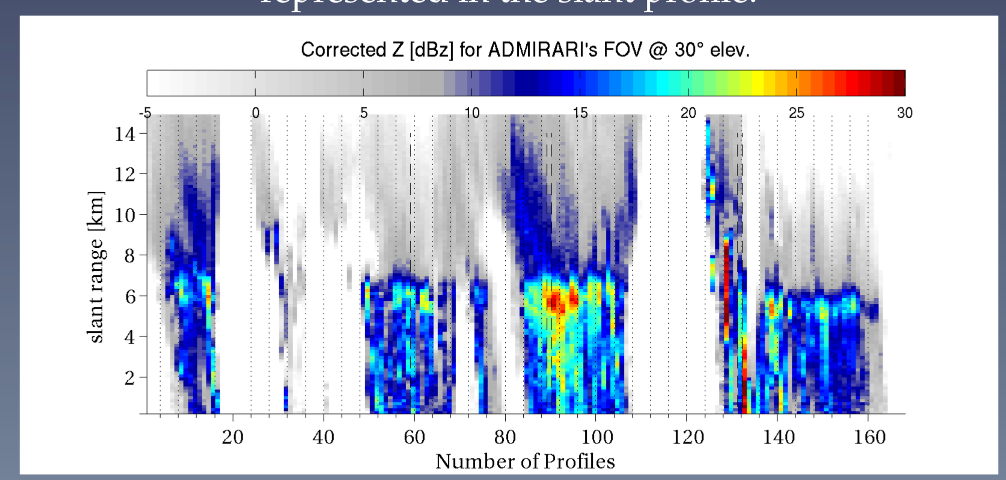






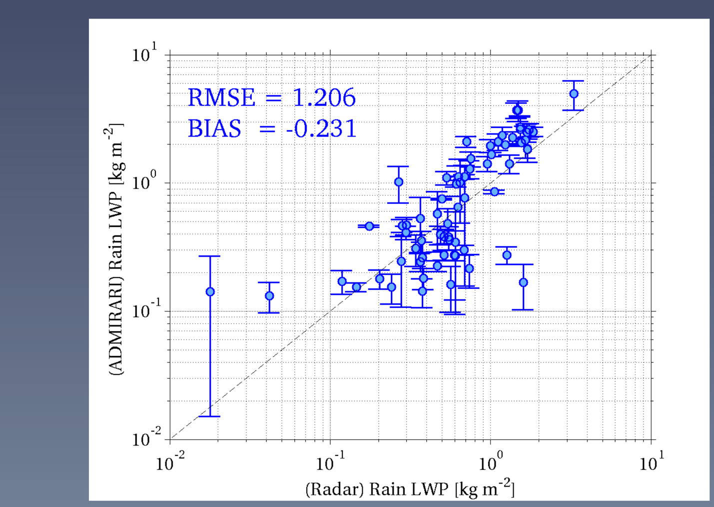


Once the Specific Attenuation is estimated, the reflectivity is corrected by attenuation, moreover from the RHI scans the ADMIRAR's FOV is extracted in order to have the radiometer's observation volume represented in the slant profile.



These profiles are also obtained for the specific attenuation and rain LWC, therefrom integrated values are computed to compare with the independent radiometer's retrievals (LWP or PIA). The advantage to have a good correlation radar-radiometer is that PIA can be mapped to all ADMIRARI frequencies i.e. X, K and Ka-band, as it was done for the GPM LPVEx campaign (see [6] and posters therein).

ADMIRARI's rain LWP is obtained by means of a Bayesian algorithm as explained by [2], and it is shown below versus radar estimates:



A reasonable correlation is found specially for RLWP values above 0.5 $kg\,m^{-2}$. That is obviously because the ZPHI method performs better when significant attenuation is observed. This method will be applied to the GPM GV field experiments where radiometer measurements are available together with C and X-band radars.

5.- References

[1] Battaglia A., Saavedra P., Rose T., Simmer C., 2009, Rain observations by a multi-frequency dual polarized radiometer. IEEE Geo. Rem. Sens. Lett., 6(2), 354-358.
[2] Saavedra P., Battaglia A., Simmer C., 2011, Partitioning of cloud water and rain water content by ground-based observations with the Advanced Microwave Radiometer for Rain Identification (ADMIRARI) in synergy with a micro rain radar. J. Geo. Research., 117,D05203,doi:10.1029/2011JD016382.
[3] Testud J., Le Bouar E., Obligis E., Ali-Mehenni M., 2000, The Rain Profiling Algorithm Applied to Polarimetric Weather Radar. J. Atmos. Ocean. Tech., Vol. 17,pp. 332-356.
[4] Ryzhkov A., Diedrich M., Zhang P., Simmer C., 2013, Potential utilization of specific attenuation for rainfall estimation, mitigation of partial beam blockage, and radar networking. Pt 1. Description of the method. *in preparation.*
[5] Bringi V.M. and Chandrasekar V., 2001, Polarimetric Doppler Weather Radar. Principles and Applications. Cambridge University Press., pp. 394-414.
[6] ADMIRARI website http://www2.meteo.uni-bonn.de/admirari

6.- Acknowledges

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