On the multi-frequency signature of precipitation water content as observed by passive and active sensors

Pablo Saavedra Garfias[1] (pablosaa@uni-bonn.de), Alessandro Battaglia[2,1], Alexander Ryzhkov[3] and Clemens Simmer[1]

[1]Meteorological Institute, University of Bonn, Bonn, Germany

[2]Department of Physics and Astronomy, University of Leicester, UK

[3]University of Oklahoma and NOAA/OAR/National Severe Storm Laboratory, Norman, OK, USA

1.- Research Objectives

Precipitating Clouds are critical components on the Earth's hydrological cycle. Weather radars have been the main tool to study precipitation, however the use of microwave radiometers on board of satellites TRMM and GPM have been shown the importance of having multi-sensor multi-frequency observation. This work focus on observations by the microwave radiometer ADMIRARI [2, 6] and a weather radar. Rain Liquid Water Content (LWC) has been retrieved by independent methods.

The well known ZPHI method [4, 5] has been extended to radar RHI scans to obtain the rain's attenuation. Similar as [3], attenuation is used to estimate rain LWC at radar's spatial resolution. Retrievals of Cloud and Rain LWC is obtained from ADMIRARI's observations [1]. To have a better insight on the microphysics of precipitating clouds, retrievals from both instruments are presented along with their uncertainties, attenuation effects and melting layer.

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

Microwave Radiometer ADMIRARI

- The University of Bonn's **AD**vanced **MI**crowave **RA**diometer 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 [1].
- Additionally to the MWR, *ADMIRARI* senses the atmosphere with co-located ancillary instruments, i.e. a 24.1 GHz micro rain radar and a 905 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 [1, 2, 6].

Jülich X-band dual-pol weather radar JuXPol

- The JuXPol operational radar is a 9.3 GHz dual-pol and is one of the twin X-band systems in Bonn (BoXPol), Germany.
- The radar with its 1.03° beam-width, performs RHI and volume scans for composite products together with its twin in Bonn.
- The RHI scans have 150 meters range resolution, and 0.2° elevation steps scanning from 0 to 90°.

The picture below shows the radiometer ADMIRARI. Whit its rain radar (right) and a cloud lidar (left) attached to the pedestal.

Measurements have been done at the Jülich Forschung Zentrum (JFZ), a German research facility which also encloses a cloud observatory. One of the main instrument is JuXPol radar. Additionally, the radiometer ADMIRARI has been deployed to the JFZ and measuring at 30° elevation and RHI mode since end of April 2013. Similarly JuXPol performed RHI scans bearing toward ADMIRARI (azimuth 234°) every 5 min.

Although ADMIRARI's long-term measurements comprise of water vapour, Cloud and Rain LWP retrievals, the present work only focuses to rain retrievals since JuXPol is only sensitivity to liquid/ice precipitation.

3.- The ZPHI method applied to radar RHI scans

The ZPHI method is used to correct the measured reflectivity Z_h from attenuation in QPE, PPI scans at low elevation angles and thereafter estimate rainfall [3]. The method couples the profiles of attenuated $Z_h(r)$ and the differential phase shift $\Phi_{dp}(r)$. Assuming that attenuation $A(r) = a(r)\,[Z(r)]^{b(r)}$, where Z is the intrinsic reflectivity factor, then

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

with

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

and the Path Integrated Attenuation (PIA) is given as a function of $\Delta\Phi$ as follow:([5, 4, 3]):

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

The coefficients a and b are temperature dependent and normally are assumed to be constant along the path, which drives to the simplification of equations (independent of a). That assumption, however, is not valid for RHI scans since there is a evident change on temperature for high elevation angles.

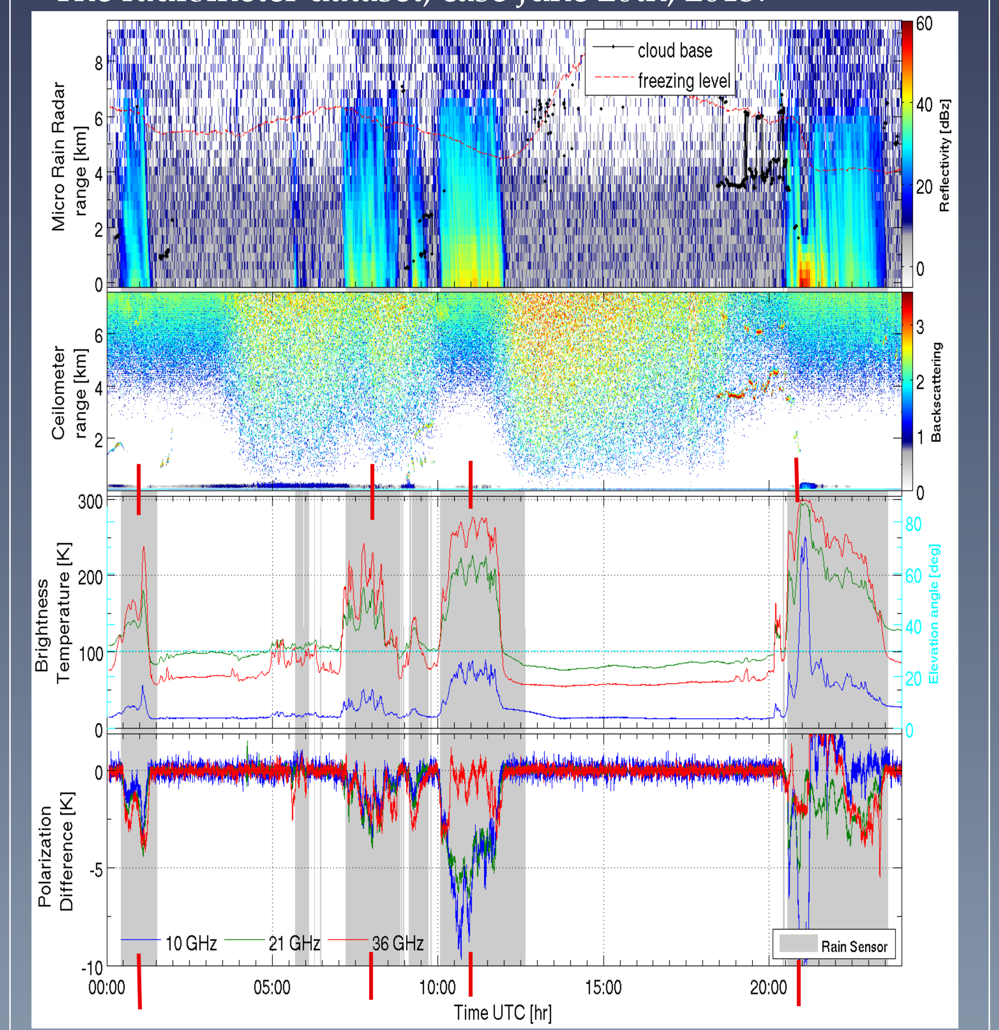
Once $A(r)$ is computed, similar as [3] for rain rate, a power law relationship is applied but to estimate rain liquid water content instead:

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

All the coefficients are obtained from long-term DSD dataset for specific temperatures, subsequently polynomial relationships are used to map the atmospheric temperature profile to each radar range:

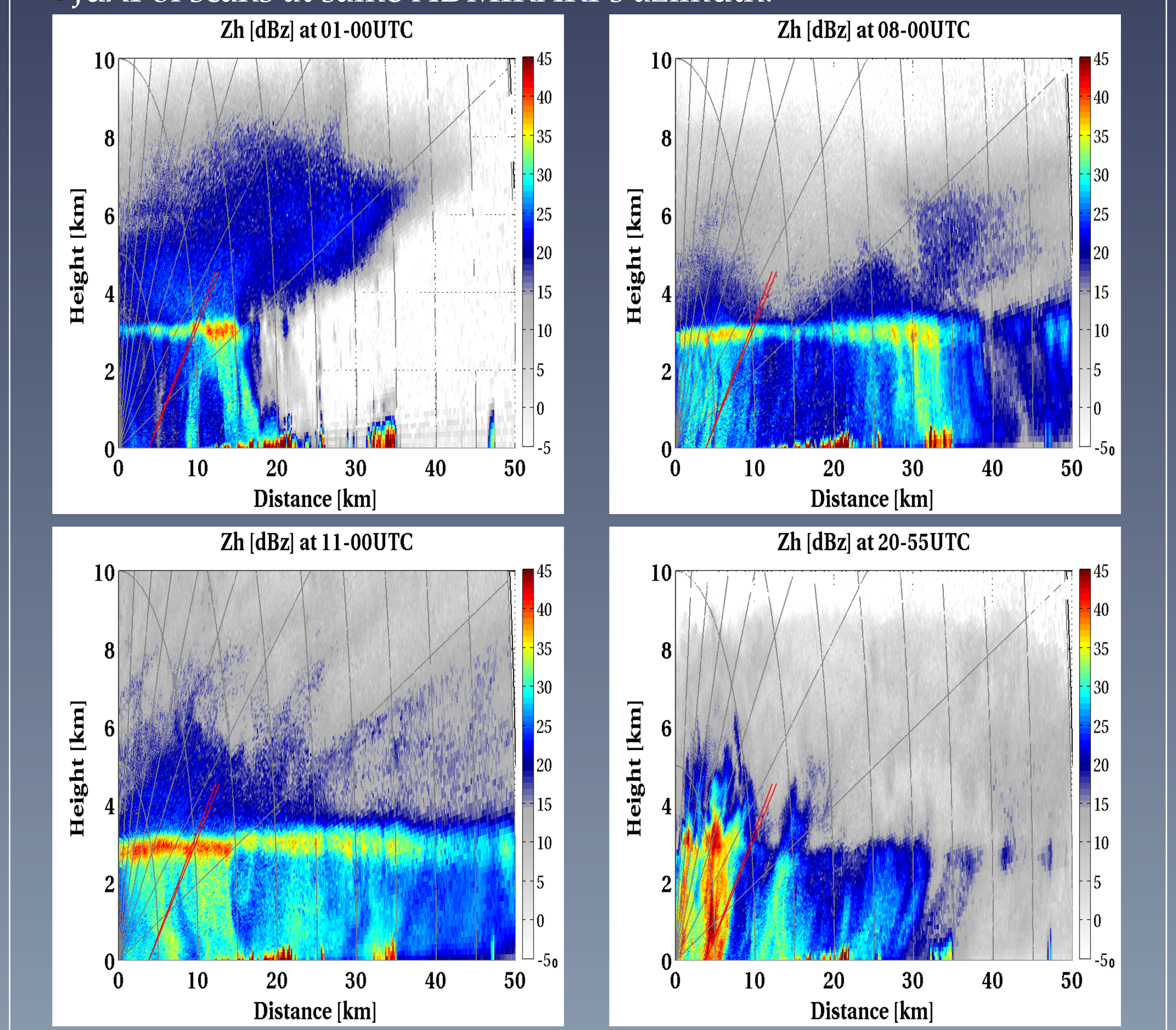
$$\begin{aligned} a(T) &= [16.19 - 0.52\,T + 0.01\,T^2]\,10^{-5}, \quad 0 < T < 30°C \\ \alpha(T) &= [38 - 0.53\,T]\,10^{-2} \\ c(T) &= 2.0410 - 0.0201\,T + 0.0003\,T^2 \\ d(T) &= 0.7651 - 0.0045\,T \end{aligned}$$

- The radiometer dataset, case June 20th, 2013:



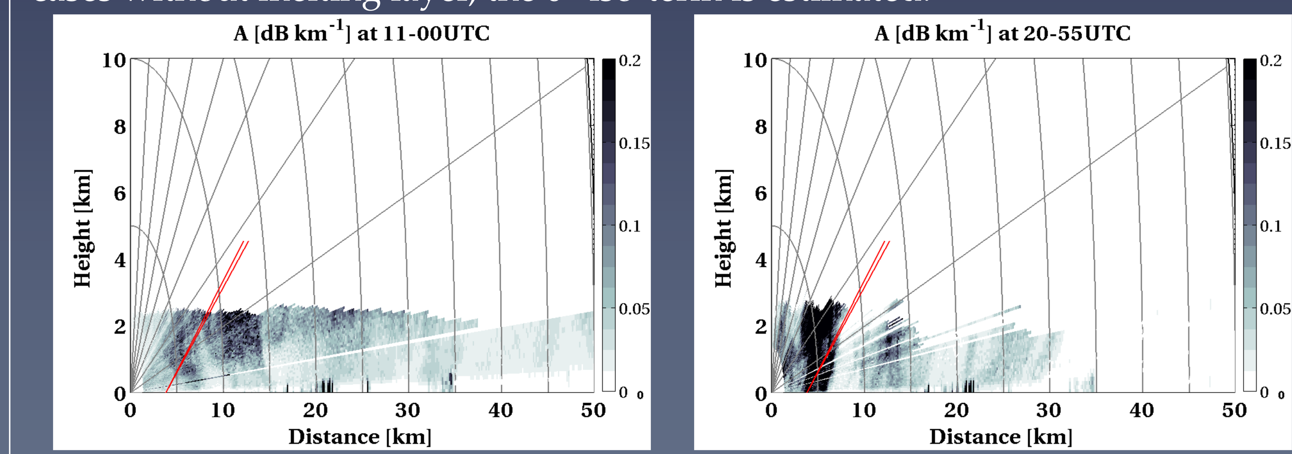
From top to bottom: MRR reflectivity, Cloud-lidar backscattering, radiometer Brightness Temperatures, Polarization Difference. The red-bars on the time axes indicate JuXPol scans →

- JuXPol scans at same ADMIRARI's azimuth:



The red cone indicates the radiometer's field-of-view (FOV), i.e. the scenario that ADMIRARI measures.

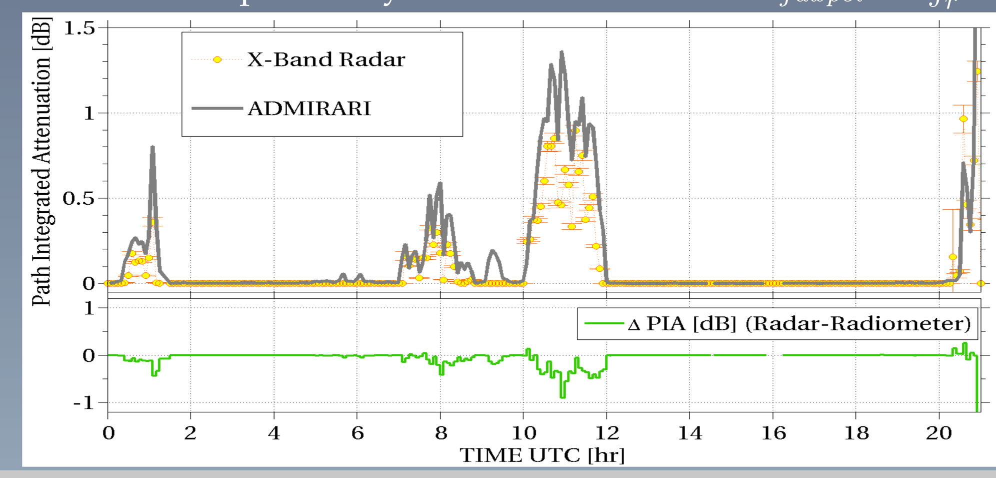
- The method is applied to the rain layer, the range of the Melting Layer bottom (r_{top} in equations) is determined using variables: ρ_{hv}, texture Z_{dr} and Φ_{dp}. For cases without melting layer, the 0° iso-term is estimated.



- ADMIRARI retrieves optical thicknesses (Bayesian method [1]):

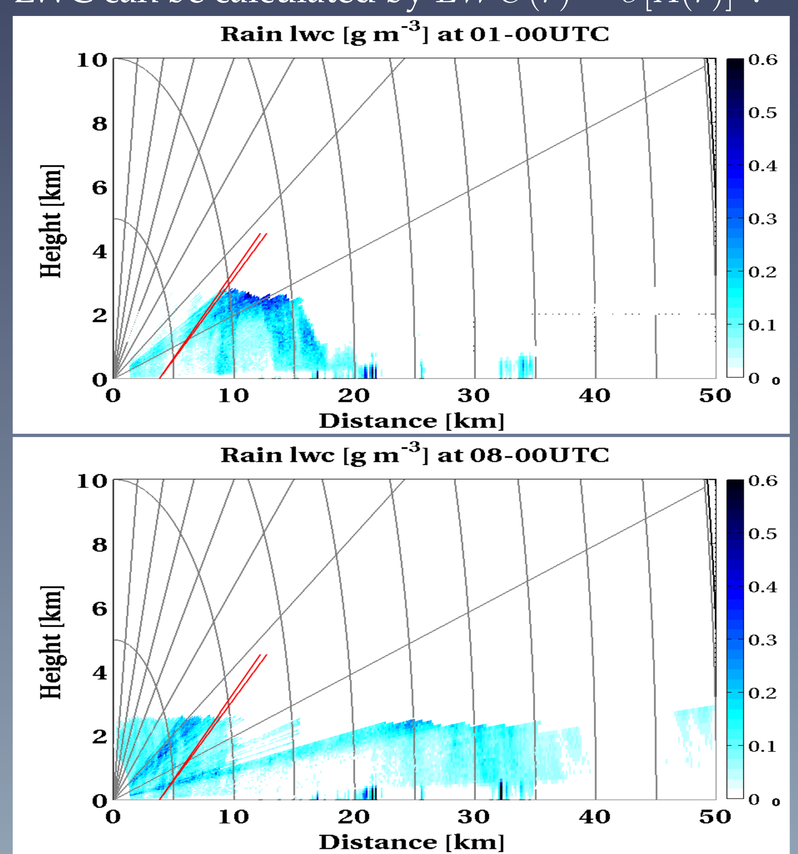
$$\tau_\nu = \frac{p_f(y_O|\mathbf{x})\,p_{pr}(\mathbf{x})}{\int p_f(y_O|\mathbf{x})\,p_{pr}(\mathbf{x})\,d\mathbf{x}}, \quad \rightarrow \quad PIA_{admi} = 10\log_{10}(e)\,\tau_\nu\ [dB]$$

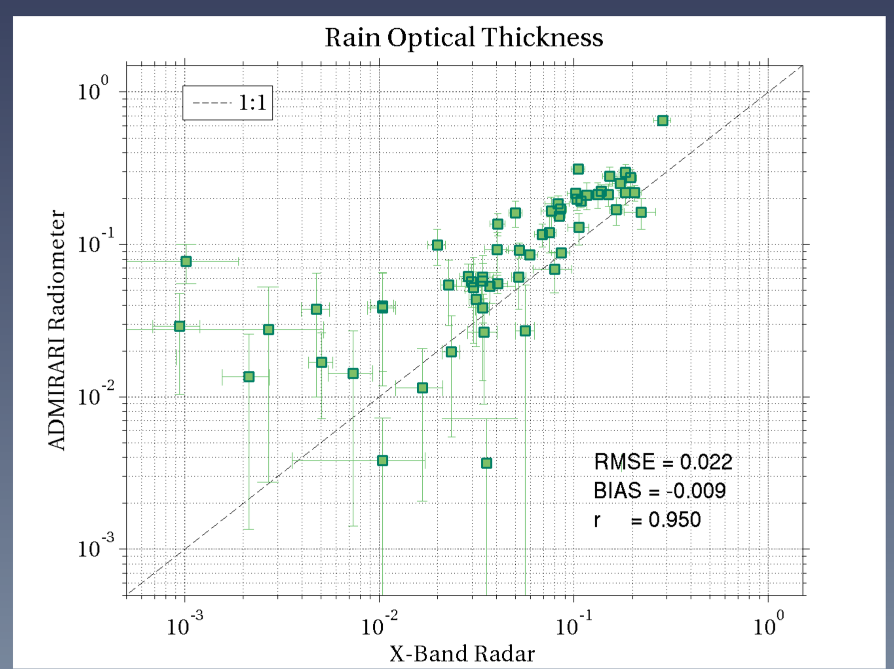
- PIA is calculated independently from the radar → $PIA_{juxpol} = \int_r^{r_{top}} A(s)\,ds$



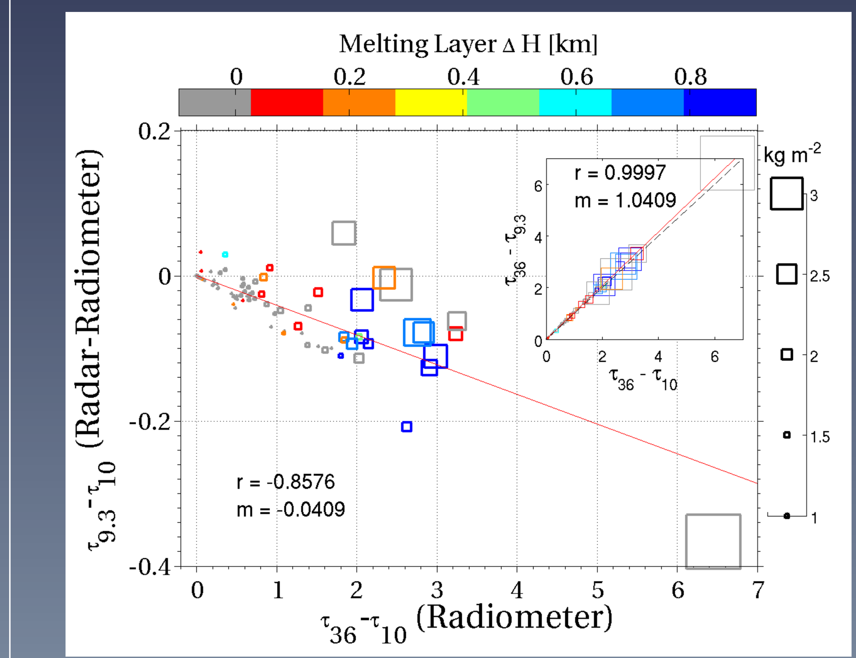
4.- Results for Rain LWP and Rain Attenuation Coefficients

RHI scans map the radiometer's FOV to obtain the specific attenuation from the ZPHI method. Thereon the LWC can be calculated by $LWC(r) = c\,[A(r)]^d$.



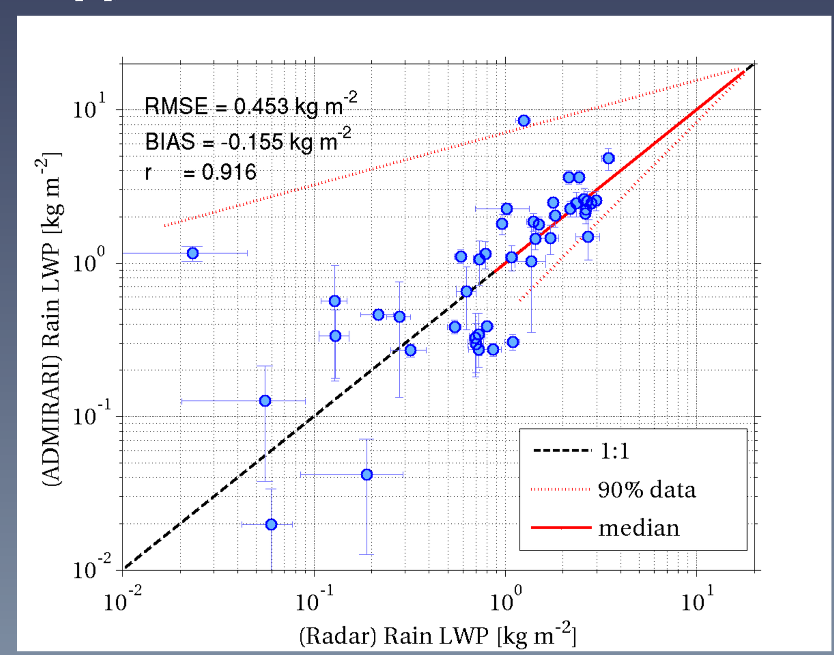


THE OPTICAL THICKNESSES RETRIEVED FROM AMIRARI (X-BAND FREQUENCY) AND JUXPOL ARE COMPARED. THERE IS A BIAS TOWARDS THE RADIOMETER RETRIEVALS, THIS IS UNDERSTOOD AS THE EFFECT INTRODUCED BY THE MELTING LAYER WHICH IS INTRINSICALLY MEASURED BY THE RADIOMETER.



THE MULTI-FREQUENCY SIGNATURE IS MAINLY DOMINATED BY THE AMOUNT OF LWC. THE THICKNESS OF THE MELTING LAYER HAS AN EFFECT BUT APPARENTLY NOT THAT STRONG AS THE LWC. WHILE THE X-BAND FREQUENCIES MISMATCH FROM ADMIRARI AND JUXPOL DOES NOT INTRODUCE SIGNIFICANT ERRORS.

ADMIRARI's rain LWP is obtained by means of a Bayesian method [1], 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.

5.- References

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[6] ADMIRARI website http://www2.meteo.uni-bonn.de/admirari

6.- Acknowledges

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