Identification of Hydrometeor Mixing Ratio Retrievals Suitable for Dual-Polarimetric C-band Radar Observations over Germany

RealPEP Sub-Project Quantitative Precipitation Forecasting (QPF)

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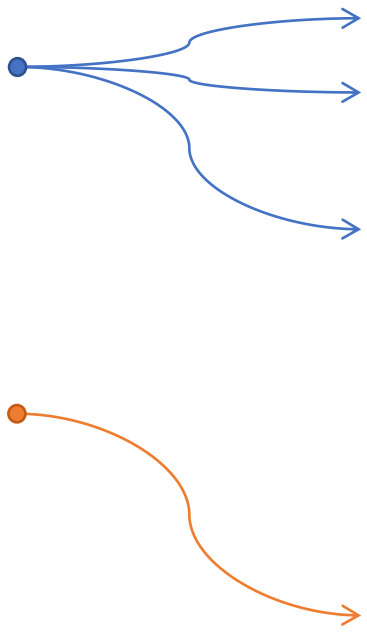
The QPF Sub-Project of RealPEP

Central targets

- *Improvement* in short-term *forecasts* of quantitative precipitation by NWP models
- Achievement of a *seamless* prediction of quantitative precipitation from *minutes to hours*



Strategies to be tested

Assimilation of …

- radar reflectivities/radial winds
- pre-convective information from satellite observations
- dual-polarimetric radar data
  - *i.* *directly* via dual-polarimetric radar observation operator
  - *ii.* *indirectly* via pseudo-observed model state variables such as **hydrometeor mixing ratios**
- nowcasted states

Assimilation of Dual-Pol Observations via Hydrometeor Mixing Ratios

Advantages

Circumvent …

- costly polarimetric forward operator running simultaneously with the NWP models
- difficulties due to e.g. the rather rudimentary appreciation of particle size & shape distributions in the NWP models

Disadvantage

- Need for retrieval algorithms introducing additional uncertainties

In this study we

- focus on liquid water content (**LWC**) & …
- **assess** existing LWC algorithms for C-band radar & …
- **improve** & **adjust** these existing LWC relations to German climatology by analyzing a large DSD data set of DWD.

Data

DSD data

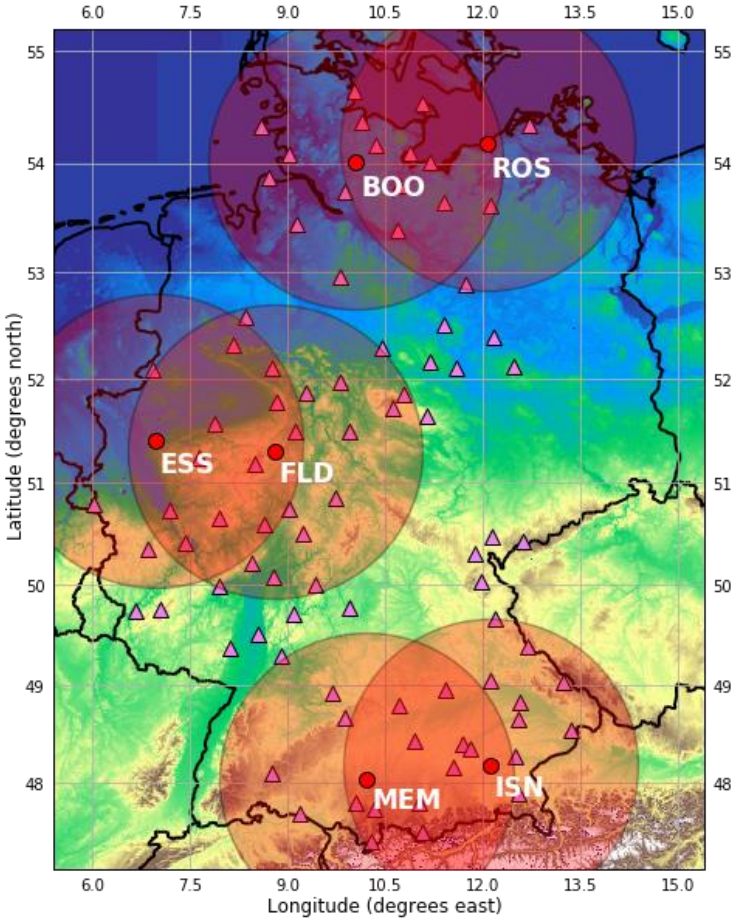
- About 818 thousand DSDs observed by DWD's Thies-disdrometer network
- All seasons & large variety of rainfall types included
- Dual-pol radar quantities
  - **i. reflectivity Z**
  - **ii. specific attenuation A**
  - **iii. specific diff. phase KDP**
  - **iv. diff. reflectivity ZDR**

  simulated for each DSD by T-matrix code

Radar data

- 7 warm rainfall events
  - i. 3 convective
  - ii. 2 stratiform
  - iii. 2 mixed

  observed by 6 of DWD's dual-pol C-band radars
- 0.5 deg elevation with range-resolution of 1 km
- RHOHV > 0.95
- A derived via ZPHI-method (Testud et al. 2000)
- Z & ZDR corrected for att.



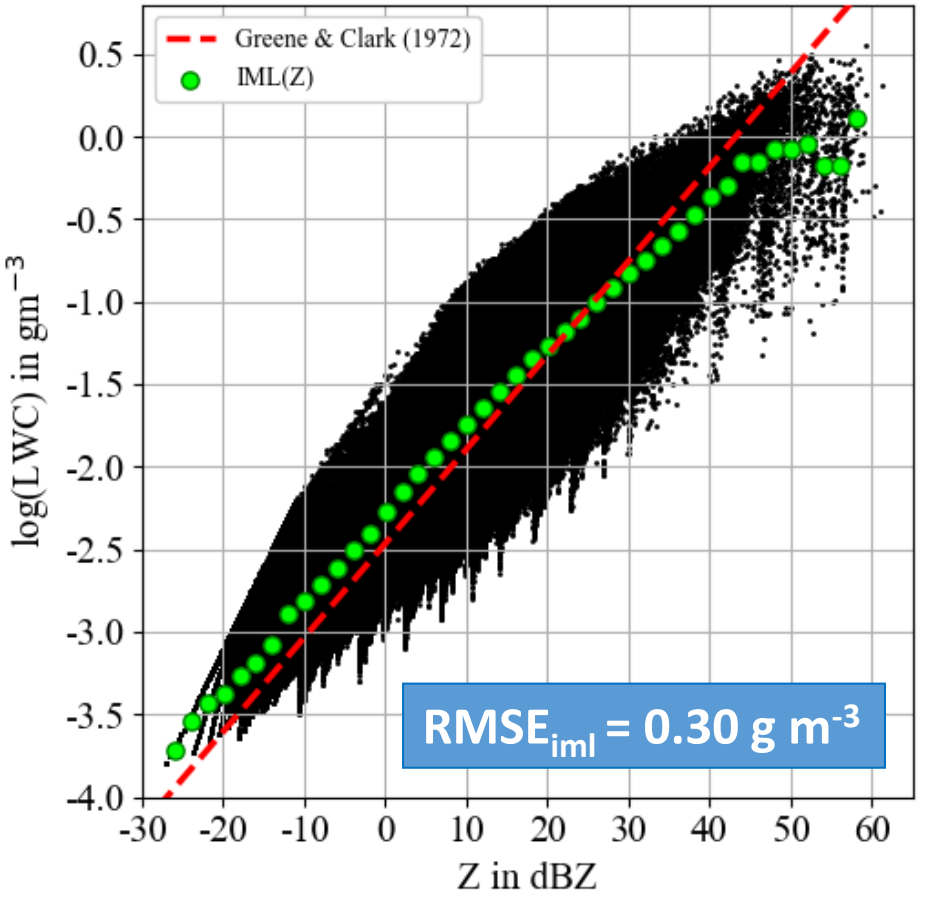
Methodology:
Assessment of LWC-Algorithm Quality

How to assess the quality of retrievals?

A. By skills to follow observed interval-wise mean log(LWC) **IML(·)** along *all intervals* of retrieval input variables

- Skills quantified by RMSE between IML(·) & curve of retrieval called **$RMSE_{iml}$**
- **$RMSE_{iml}$** much less dependent on statistical data distribution than "classical" RMSE

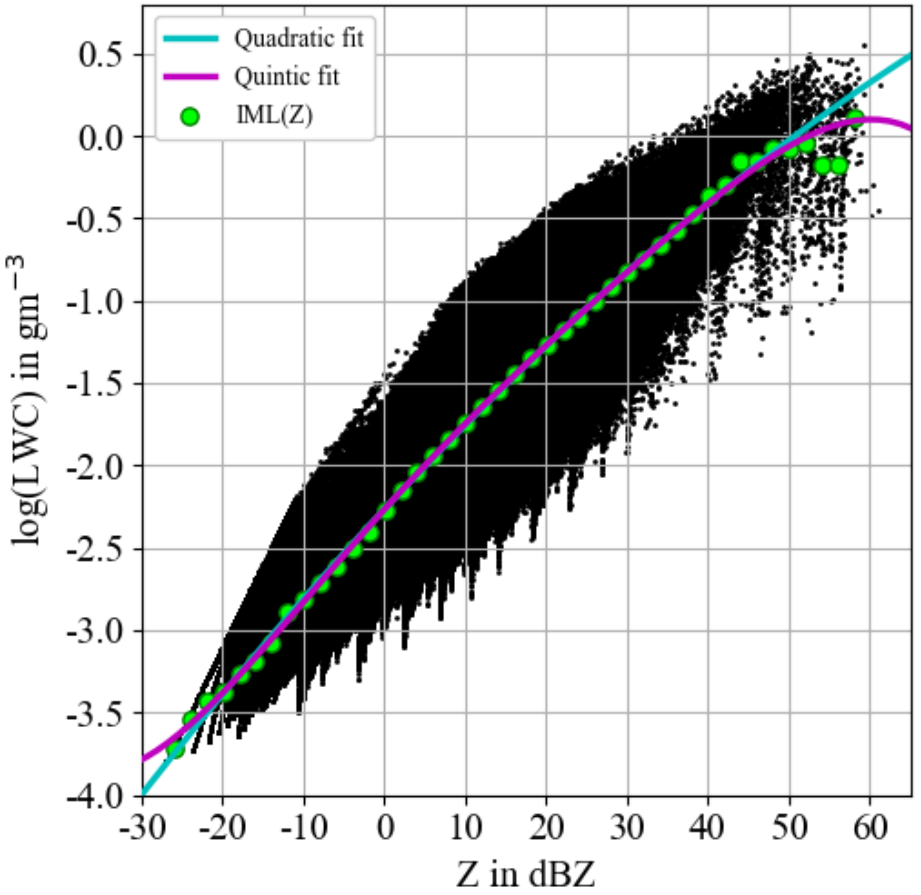
B. By skills to follow *expected course* of the IML(·) beyond data boundaries properly



Methodology:
Development of New LWC-Algorithms

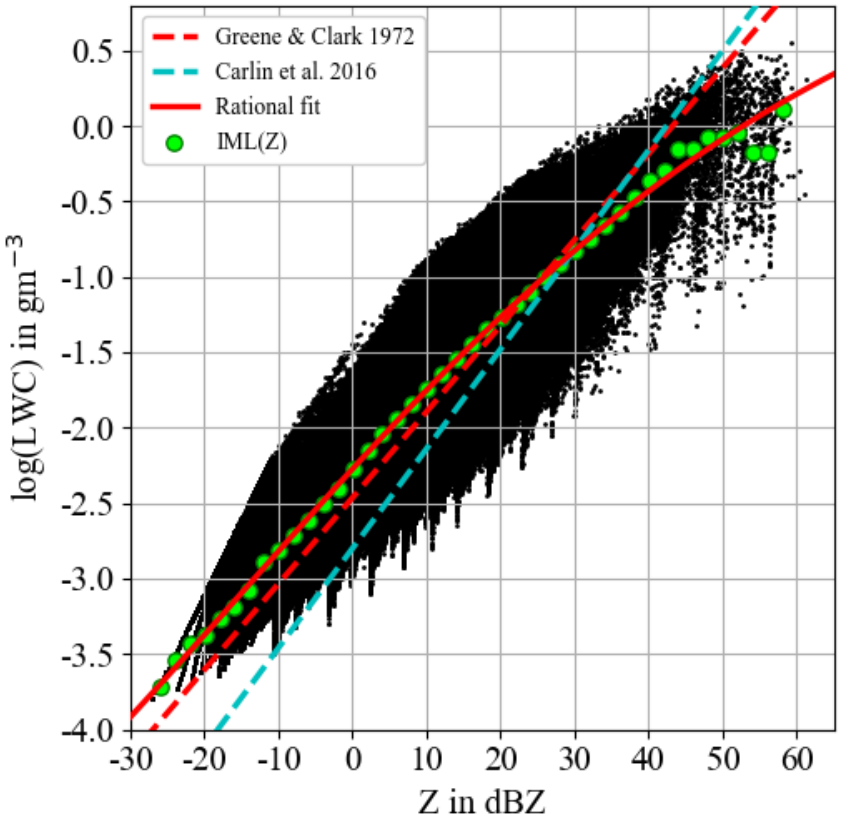
How to develop new retrievals?

- Deriving least-squares fits to DSD data
- Focus on low-order (i.e. max. 3rd order) polynomial or rational functions to
  i. keep extrapolation errors low
  ii. reduce potential for overfitting
- Consider a new retrieval as improvement over another relation if it
  i. reduces the $RMSE_{iml}$ by at least 0.01 g m^{-3}
  ii. shows an appropriate extrapolation



Z-Based LWC-Algorithms

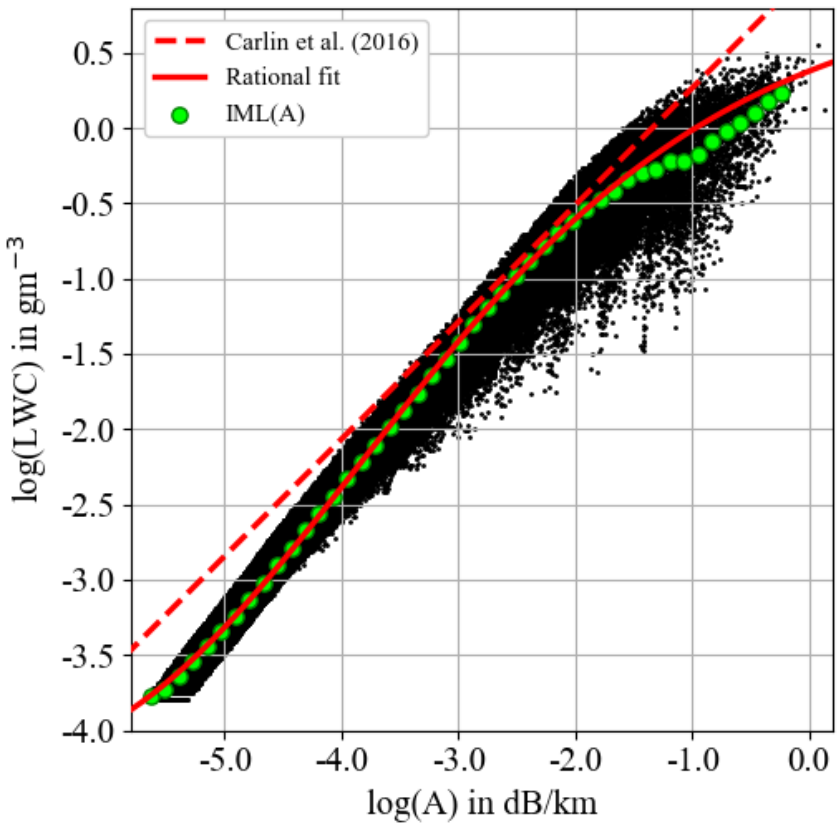
Study	log(LWC(Z)) =	$RMSE_{iml}$ (gm^{-3})	RMSE (gm^{-3})
Greene & Clark 1972	$\mathbf{0.057Z - 2.46}$	0.30	0.33
Carlin et al. 2016	$\mathbf{0.066Z - 2.80}$	0.53	0.50
The present	$\frac{\mathbf{0.427Z - 22.55}}{\mathbf{0.0005Z^2 + 0.046Z + 9.92}}$	0.06	0.30



Z: horizontal reflectivity factor in dBZ **LWC**: liquid water content in g m^{-3}

A-Based LWC-Algorithms

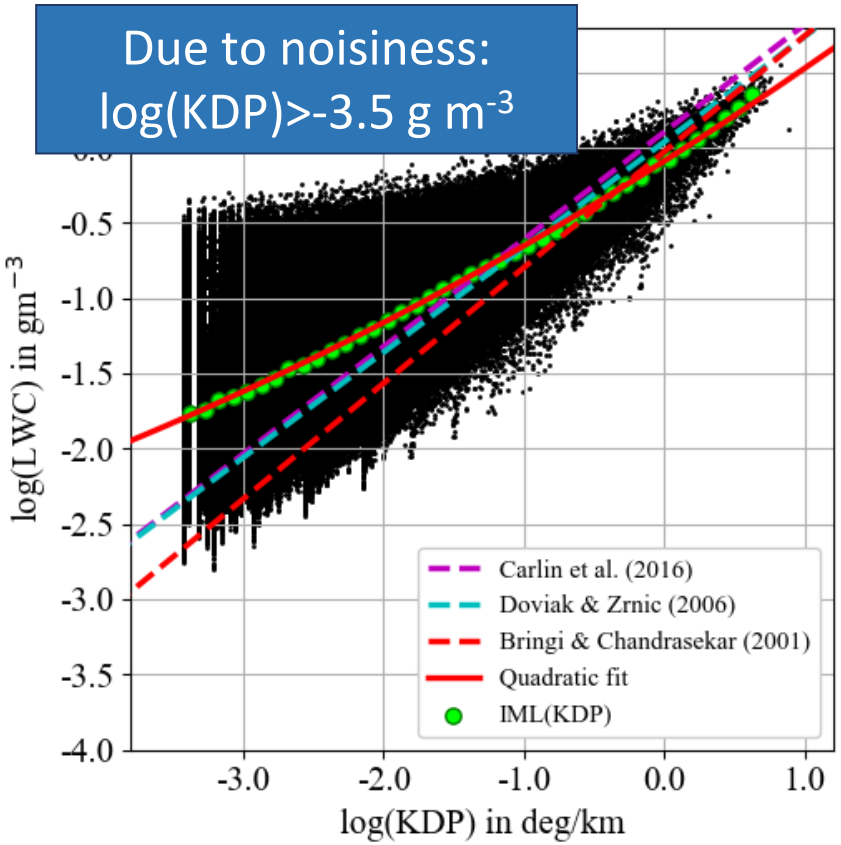
Study	log(LWC(A)) =	$RMSE_{iml}$ (gm^{-3})	RMSE (gm^{-3})
Carlin et al. 2016	$\mathbf{0.780\log(A) + 1.04}$	0.36	0.25
The present	$\frac{3.187\,log(A) + 3.09}{0.1731log(A)^2 + 1.730log(A) + 8.19}$	0.06	0.09



A: horizontal specific attenuation in dB km^{-1} **LWC**: liquid water content in g m^{-3}

KDP-Based LWC-Algorithms

Study	log(LWC(KDP)) =	$RMSE_{iml}$ (gm^{-3})	RMSE (gm^{-3})
Bringi & Chandrasekar 2001	$\mathbf{0.770\log(KDP) - 0.03}$	0.40	0.57
Doviak & Zrnic 2006	$\mathbf{0.700\log(KDP) + 0.04}$	0.24	0.40
Carlin et al. 2016	$\mathbf{0.710\log(KDP) + 0.10}$	0.24	0.39
The present	$\mathbf{0.0266log(KDP)^2 + 0.590\,log(KDP) - 0.09}$	0.02	0.29



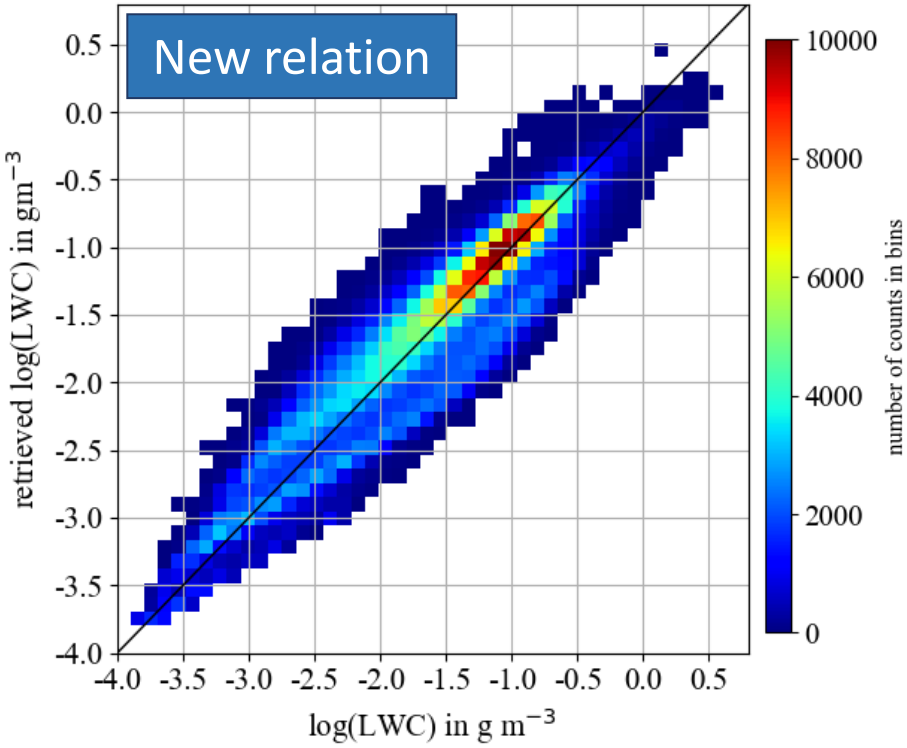
KDP: specific differential phase in deg km^{-1} **LWC**: liquid water content in g m^{-3}

Z-ZDR-Based LWC-Algorithms

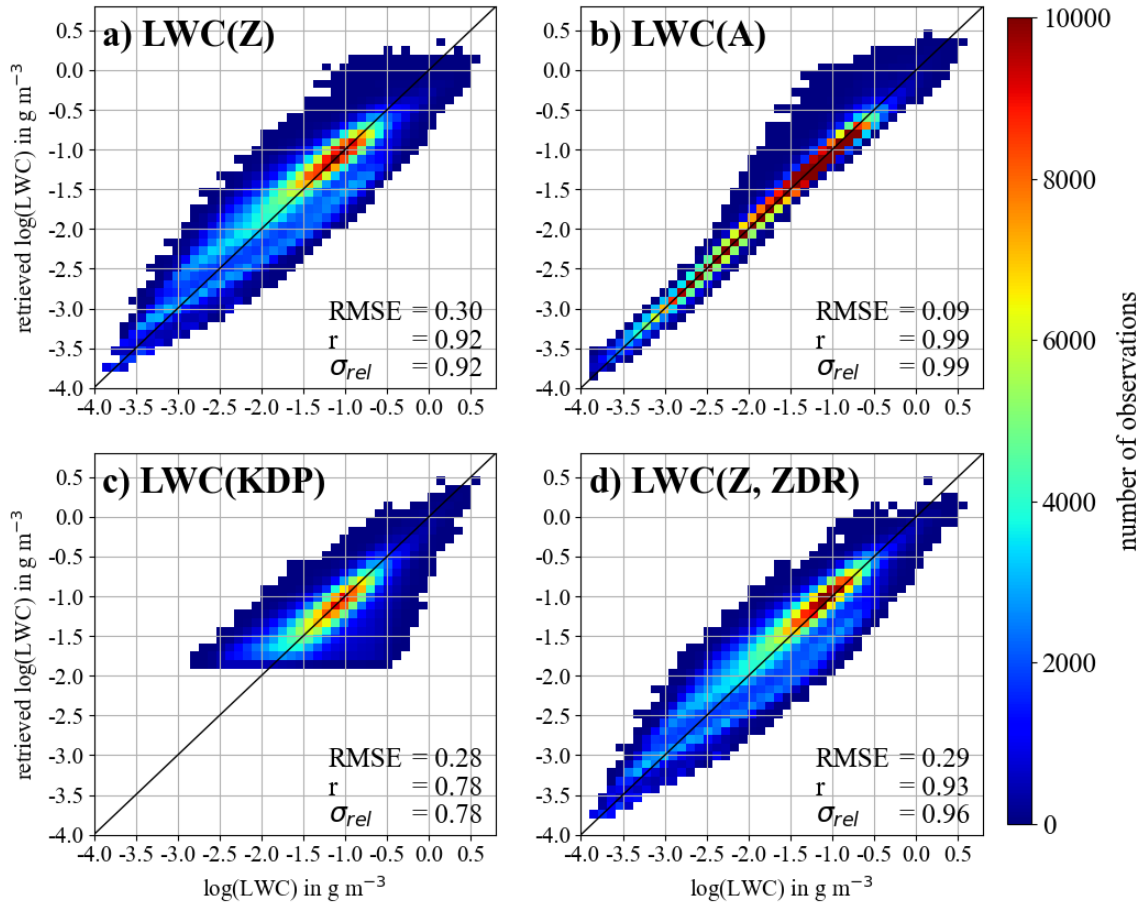
Study	log(LWC(Z,ZDR)) =	$RMSE_{iml}$ (gm^{-3})	RMSE (gm^{-3})
Carlin et al. 2016	$0.070Z - 0.079ZDR + 0.11$	0.48	0.55
The present	$0.054Z - 0.169ZDR - 2.30$	0.22	0.29

Z: horizontal reflectivity factor in dBZ **ZDR**: differential reflectivity in dB

More complex relations such as **bivariate polynomial** equations showed increased errors in real-world application



Summary of New Retrievals



According to simulation …

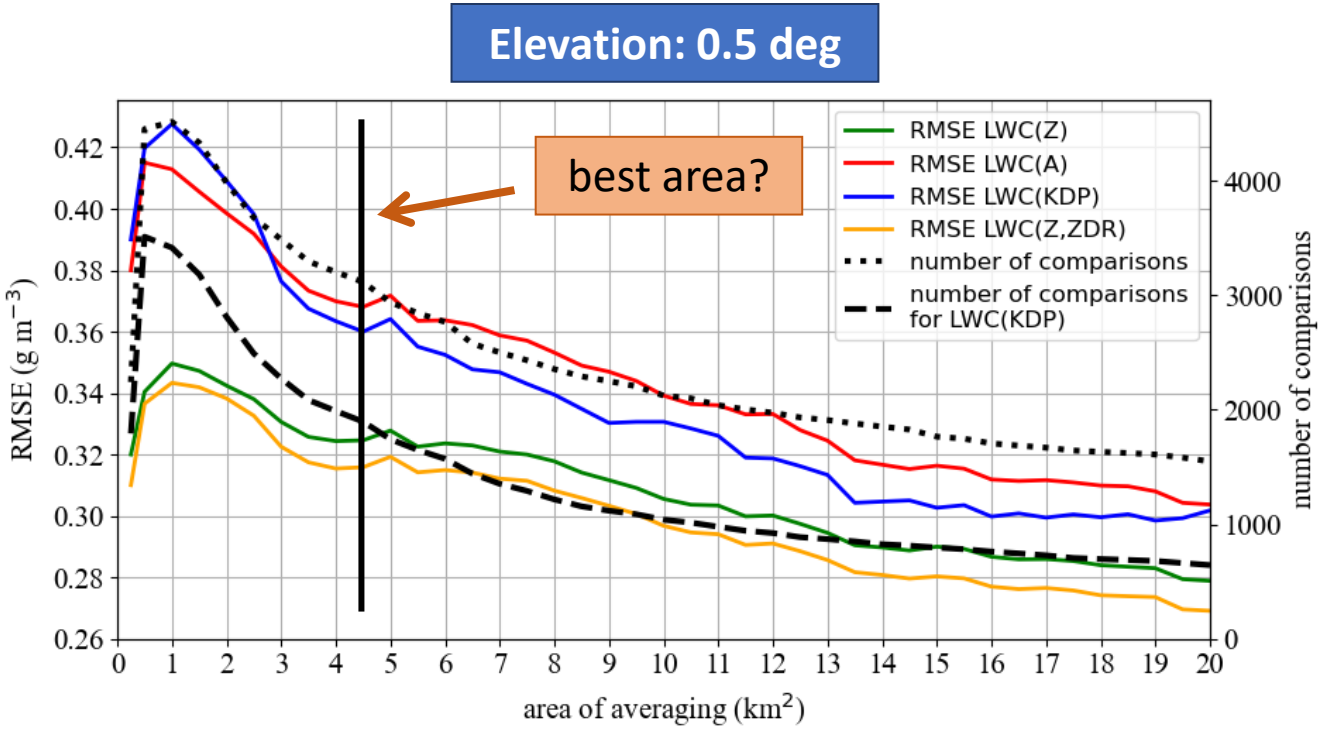
- The LWC(A)-retrieval shows best results with the lowest RMSE & lowest correlation r
- The LWC(Z, ZDR)-relation is slightly superior to the relation based on Z exclusively
- For the highest LWC values the LWC(KDP)-relation is best

Fig.: DSD-based comparison of actual log(LWC) with log(LWC) retrieved via new retrieval-relations based on T-matrix code simulated dual-pol variables

Evaluation of New LWC-Algorithms

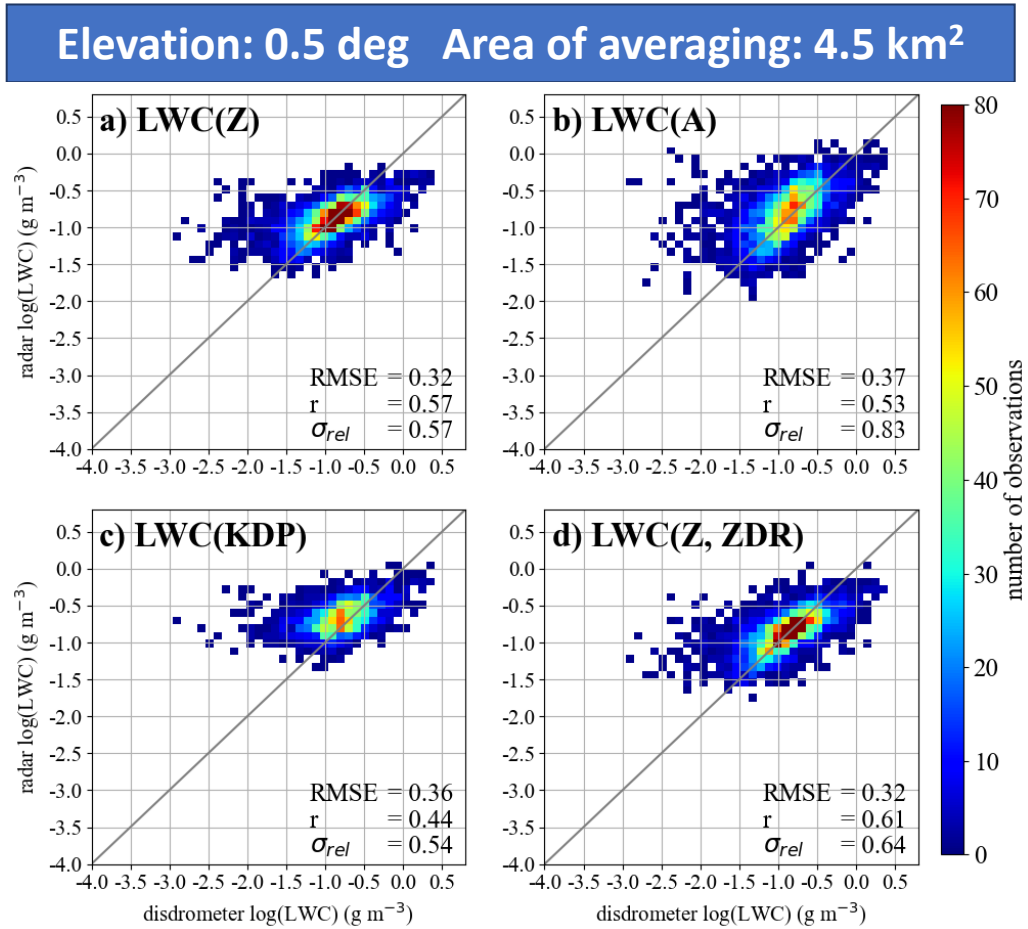
Strategy

- Estimate LWC from dual-pol radar observations via new LWC-algorithms
- Compare radar-retrieved LWC averaged over **suitable area** with disdrometer-observed LWC at disdrometer locations
- Measure real-world skill of retrievals by RMSE, r & σ_{rel}



*Evolutions of RMSE between **radar-retrieved** and **disdrometer-observed** log(LWC) for 4 new LWC-algorithms (colored curves) and of number of comparisons (black curves) as functions of the area over which the radar-retrieved LWC is averaged*

Evaluation of New LWC-Algorithms



Results

- Peaks of histograms on ideal diagonals
- **As expected**: LWC(Z,ZDR)-relation slightly better than LWC(Z)-relation
- **Against expectation**: LWC(A)- and LWC(KDP)-relations worse than Z-based relations ⟶ most likely reason: uncertainties in C-band differential phase
- Positive bias in KDP (need for investigation)

Fig.: Comparison of disdrometer-log(LWC) with log(LWC) retrieved via new retrieval-relations based on dual-pol DWD radar data

Evaluation of New LWC-Algorithms

Differences between rainfall types

Retrieval	Stratiform	Convective	Mixed
LWC(Z)	**0.22**	**0.42**	**0.34**
LWC(A)	**0.25**	**0.48**	**0.38**
LWC(KDP)	**0.28**	**0.43**	**0.36**
LWC(Z,ZDR)	**0.21**	**0.41**	**0.33**

Values of RMSE between disdrometer- and radar-log(LWC) in g m^{-3} for different rainfall types and retrievals

Main findings

- For all rainfall types the LWC(Z, ZDR)-is superior to the LWC(Z)-relation
- For all rainfall types the LWC(A)- & LWC(KDP)-relations are worse than the Z-based algorithms
- Stratiform rainfall leads to smaller RMSE than convective or mixed
- Convective rainfall shows largest values of RMSE

Evaluation of New LWC-Algorithms

Comparison of new with existing relations

Retrieval	Our new relations	Greene & Clark 1972	Bringi & Chandrasekar 2001	Doviak & Zrnic 2006	Carlin et al. 2016
LWC(Z)	**0.32**	**0.35**			**0.35**
LWC(A)	**0.37**				**0.42**
LWC(KDP)	**0.36**		**0.35**	**0.37**	**0.39**
LWC(Z,ZDR)	**0.32**				**0.34**

Values of RMSE between disdrometer- and radar-log(LWC) in g m^{-3} for the different existing and newly developed LWC retrievals

Main findings

- Our new LWC(Z)-, LWC(A)- & LWC(Z,ZDR)-relations are superior to the existing ones when applied to radar data
- The LWC(KDP)-relation by Bringi & Chandrasekar (2001) shows slightly lower values of RMSE than our new relation **BUT:** should possibly not be overrated due to positive bias in KDP!

Conclusions

Based on a large DSD data set of DWD we found …

- that the existing, mainly power-law (on linear scale) LWC-retrieval algorithms are inappropriate for C-band dual-polarimetric radar observations over Germany
- New, more suitable LWC-relations:
  a. Rational functions for the LWC(Z)- & LWC(A)-relations
  b. A quadratic function for the LWC(KDP)-relation
  c. A bivariate linear function for the LWC(Z, ZDR)-relation

Based on DWD's dual-pol C-band radar data & the DSD data we identified …

- that our new LWC(Z,ZDR)-relation outperforms our LWC(Z)-relation
- that our LWC(A)- & LWC(KDP)-relations show worse skills due to difficulties in A- and KDP-derivation (maybe a standard problem at C-band?)
- that our new relations outperform the existing relations except for the LWC(KDP)-relation by Bringi & Chandrasekar (2001) showing slightly better skills than our new LWC(KDP)-retrieval when applied to radar data (but should possibly not be overrated)

Questions?

Thanks for your attention!