



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

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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 ...

- \circ radar reflectivities/radial winds
- pre-convective information from satellite observations
- o 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



- About 818 thousand DSDs
 observed by DWD's Thiesdisdrometer 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 ZDRsimulated for each DSD byT-matrix code

Radar data

- o 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 ZPHImethod (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

Greene & Clark 1972 0.057Z - 2.46 0.30 0.33 Carlin et al. 2016 0.066Z - 2.80 0.53 0.50 The present $0.427Z - 22.55$ $0.0005Z^2 + 0.046Z + 9.92$ 0.06 0.30	Study	log(LWC(Z)) =	RMSE _{iml} (gm ⁻³)	RMSE (gm ⁻³)	0.5 Greene & Clark 1972 - Carlin et al. 2016 Rational fit - 0.5 - 0.5
Carlin et al. 2016 0.066Z - 2.80 0.53 0.50 -2.5 The present $0.427Z - 22.55$ 0.06 0.30 -3.5 0.0005Z ² + 0.046Z + 9.92 0.06 0.30 -3.5 -3.5	Greene & Clark 1972	0.057 <i>Z</i> – 2.46	0.30	0.33	
$0.427Z - 22.55$ 0.06 0.30 $0.005Z^2 + 0.046Z + 9.92$ 0.06 0.30	Carlin et al. 2016	0.066Z - 2.80	0.53	0.50	
	The present	$\frac{0.427Z - 22.55}{0.0005Z^2 + 0.046Z + 9.92}$	0.06	0.30	-3.5 -4.0 -30 -20 -10 0 10 20 30 40 50 60

Z: horizontal reflectivity factor in dBZ **LWC**: liquid water content in g m⁻³

A-Based LWC-Algorithms



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)	Due to noisiness: log(KDP)>-3.5 g m ⁻³
Bringi & Chandrasekar 2001	$0.770 \log(KDP) - 0.03$	0.40	0.57	
Doviak & Zrnic 2006	0.700 log(<i>KDP</i>) + 0.04	0.24	0.40	
Carlin et al. 2016	0.710 log(<i>KDP</i>) + 0.10	0.24	0.39	-3.0 -3.5 -3.5 -3.5 -3.5 -3.5 -3.5 -3.5 -3.5
The present	$\begin{array}{c} 0.0266 log(KDP)^2 \\ + 0.590 log(KDP) - 0.09 \end{array}$	0.02	0.29	-4.0 -3.0 -2.0 -1.0 log(KDP) in deg/km

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)	0.5 0.0 E
Carlin et al. 2016	0.070Z - 0.079ZDR + 0.11	0.48	0.55	() M -1.5 Pige -2.0
The present	0. 054Z – 0. 169ZDR – 2. 30	0.22	0.29	-2.5 -3.0

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

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



Results

- Peaks of histograms on ideal diagonals
- **As expected**: LWC(Z,ZDR)-relation slightly better than LWC(Z)-relation

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

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

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		\searrow		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!