

Synergies of commercial microwave links and polarimetric weather radars

Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann | October 5, 2020

KIT INSTITUTE OF ATMOSPHERIC ENVIRONMENTAL RESEARCH (IMK-IFU)

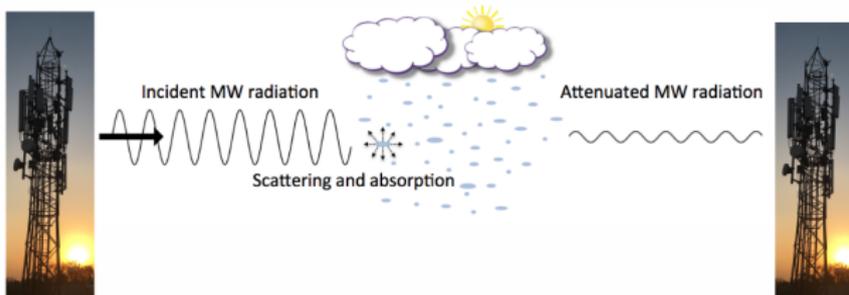


1 CML QPE in Germany: Recent developments

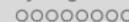
2 Synergies of CMLs and polarimetric weather radars

Commercial microwave links (CMLs)...

... are part of the cellular network.



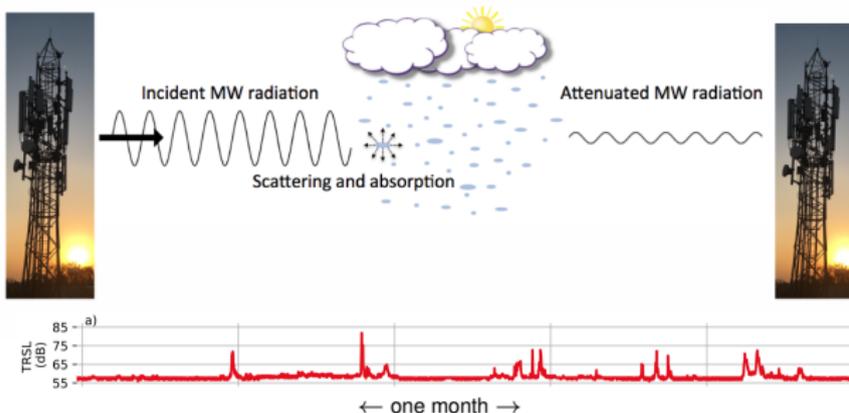
Chwala & Kunstmann, 2019, WIREs Water



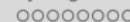
Commercial microwave links (CMLs)...

... are part of the cellular network.

Monitored transmitted minus received signal level (TRSL)



Chwala & Kunstmann, 2019, WIRES Water



Commercial microwave links (CMLs)...

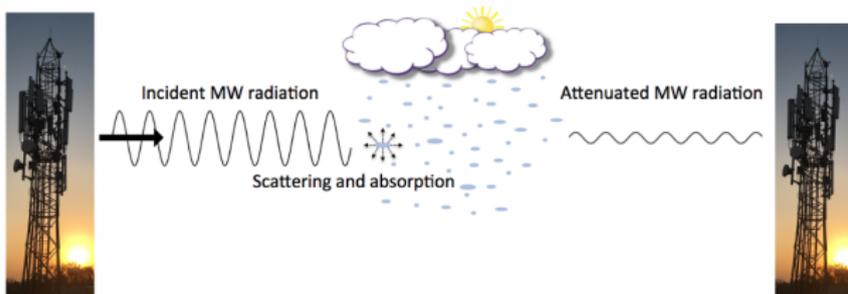
... are part of the cellular network.

Monitored transmitted minus received signal level (TRSL)

↓
Specific attenuation $A \sim$ Path-averaged rain rate R

$$\text{A-R power law: } A = a R^b$$

[mm/h] (above R)
[dB/km] (below A)



Chwala & Kunstmann, 2019, WIREs Water

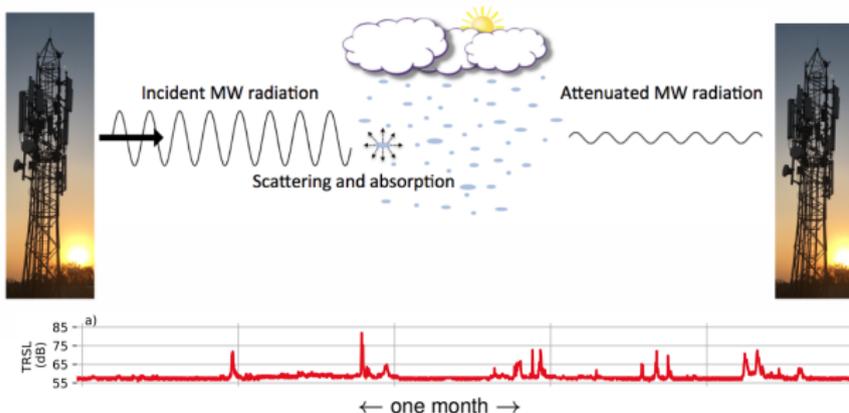


Commercial microwave links (CMLs)...

... are part of the cellular network.

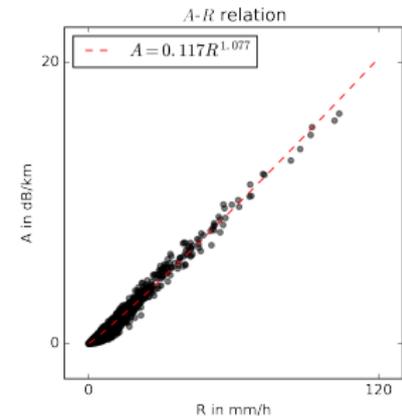
Monitored transmitted minus received signal level (TRSL)

↓
Specific attenuation $A \sim$ Path-averaged rain rate R



$$\text{A-R power law: } A = a R^b$$

[mm/h] ↓
↑ [dB/km]



Chwala & Kunstmann, 2019, WIREs Water



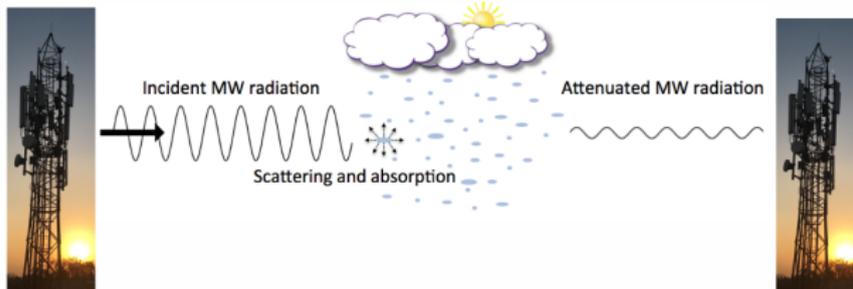
Commercial microwave links (CMLs)...

... are part of the cellular network.

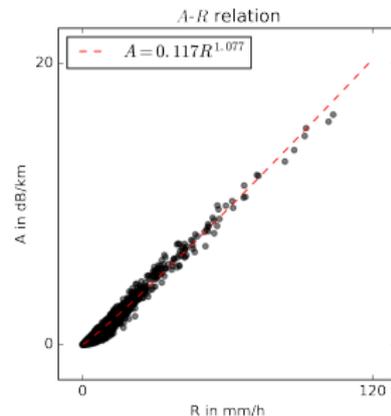
Monitored transmitted minus received signal level (TRSL)

↓
Specific attenuation $A \sim$ Path-averaged rain rate R

↓
Rain rate estimation along the link path.



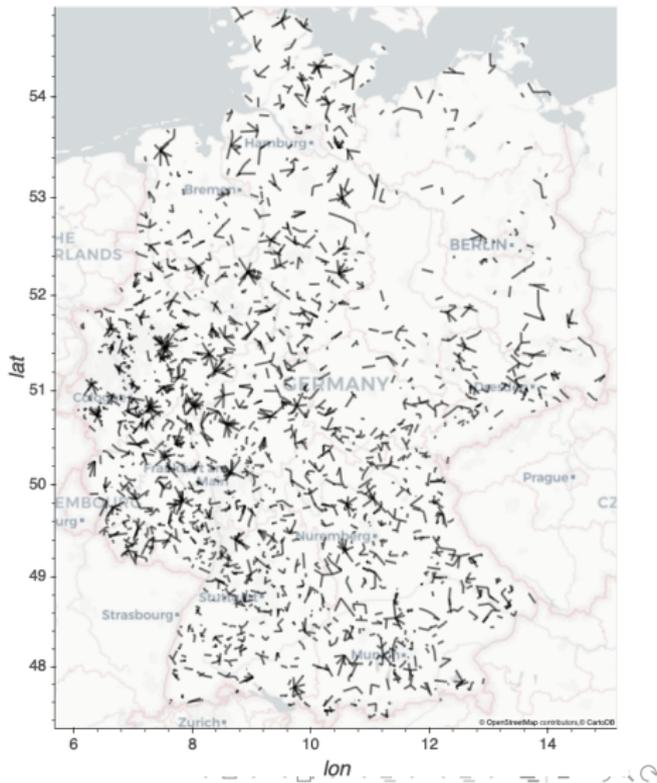
$$\begin{array}{c} \text{[mm/h]} \\ \downarrow \\ \text{A-R power law: } A = a R^b \\ \uparrow \\ \text{[dB/km]} \end{array}$$

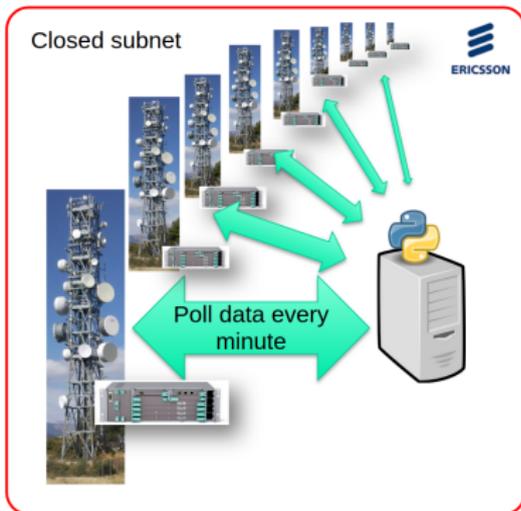


Chwala & Kunstmann, 2019, WIREs Water

The German data set

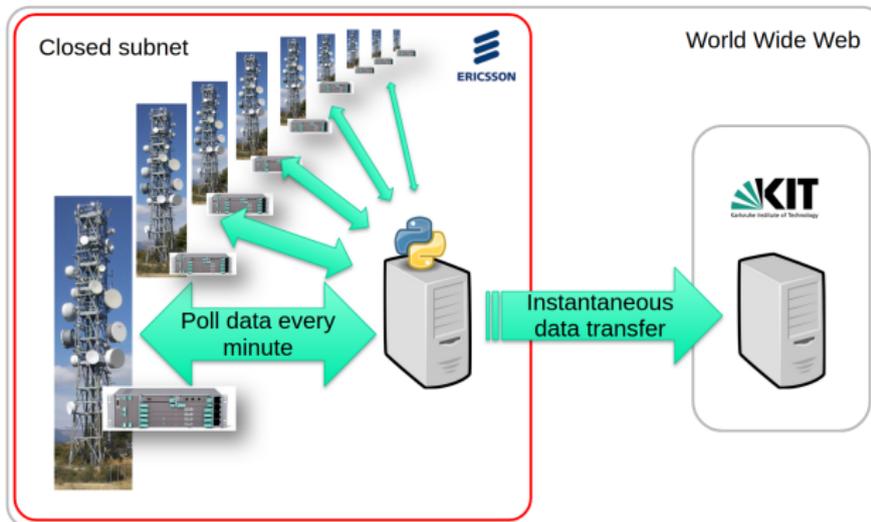
# CMLs	~ 4000
Length	0.3 to 35 km
Frequency	10 to 40 GHz
Temporal resolution	1 Min
Power resolution	0.3 to 1 dB





Chwala et al. 2016, AMT



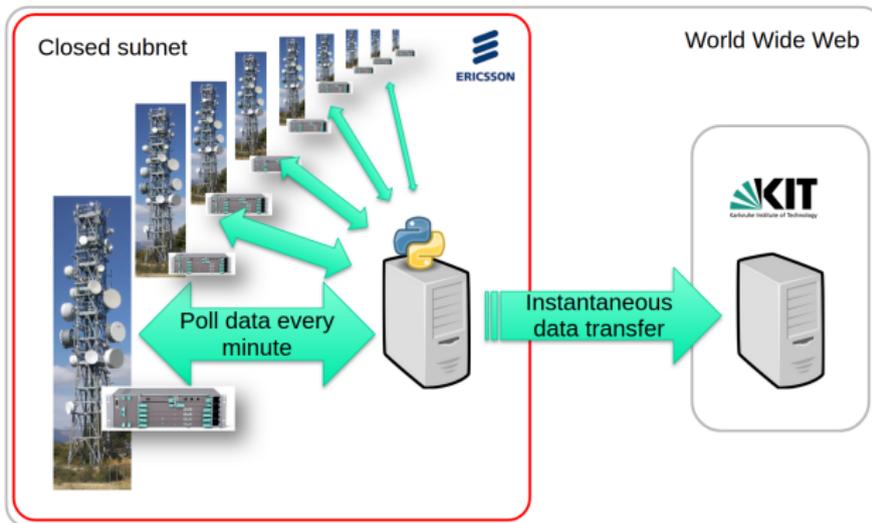


Chwala et al. 2016, AMT



Data acquisition

+ Potential real-time operation

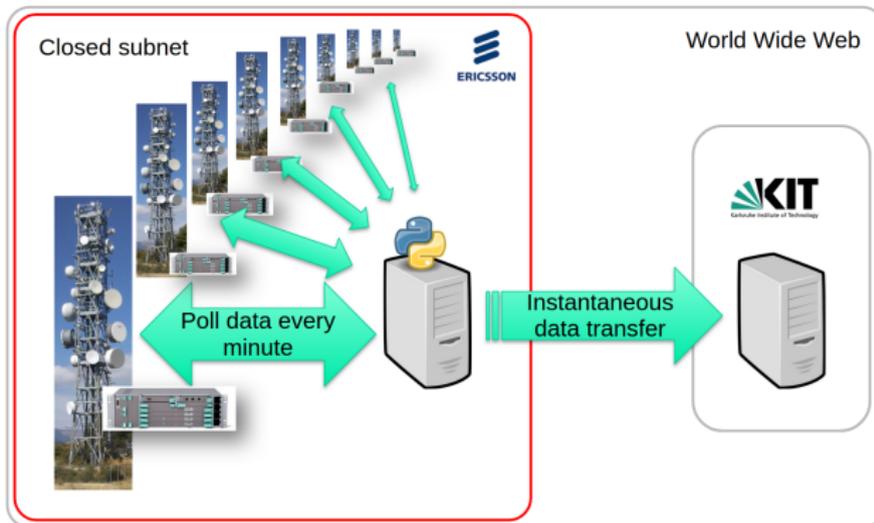


Chwala et al. 2016, AMT



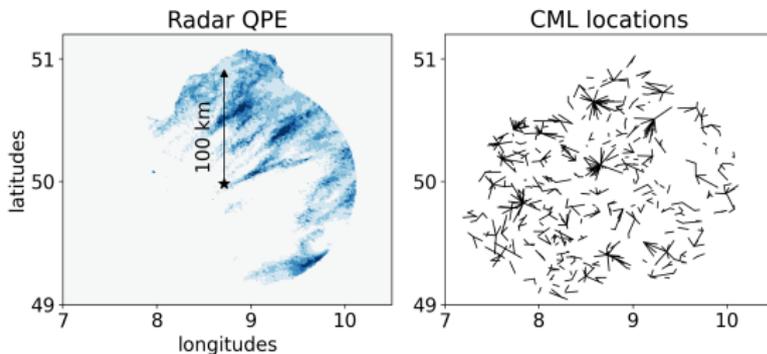
Data acquisition

- + Potential real-time operation
- + 3 years of collected data

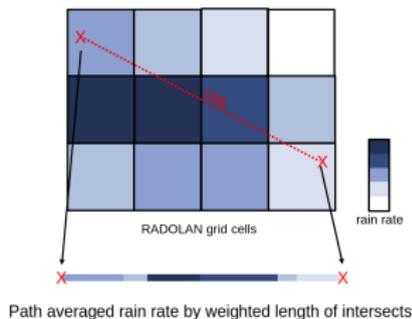
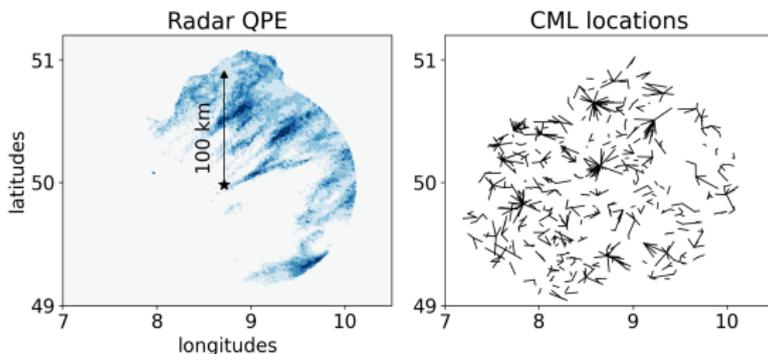


Chwala et al. 2016, AMT

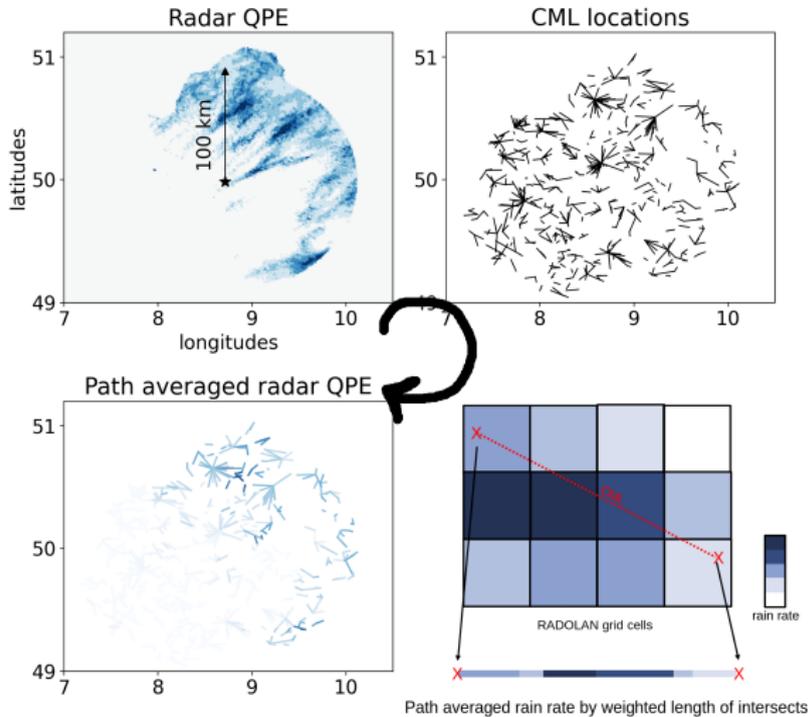
Comparing Radar and CML QPE



Comparing Radar and CML QPE

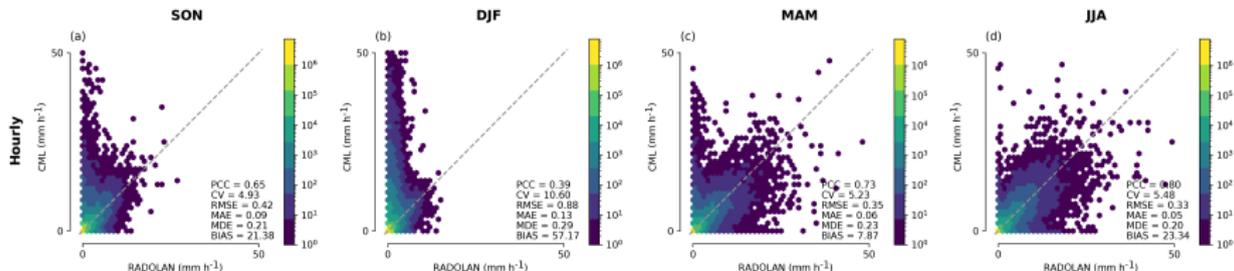


Comparing Radar and CML QPE



Seasonal scatter density comparison of rainfall sums

CML vs. gauge adjusted weather radar product RADOLAN-RW by DWD



Graf et al. 2020, HESS

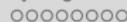


CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars

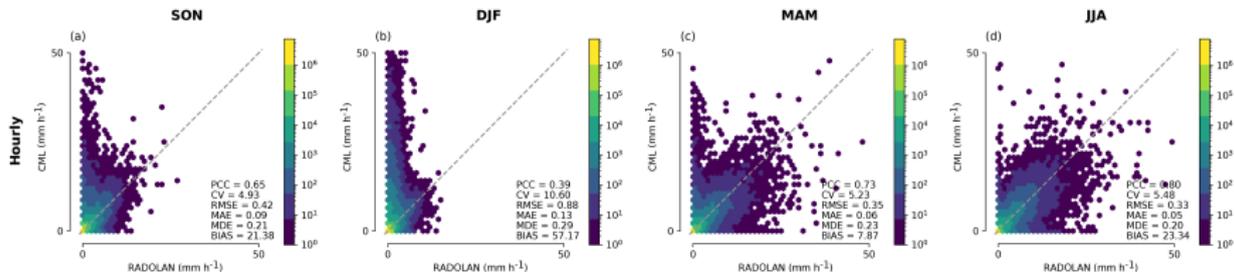


October 5, 2020

7/21

Seasonal scatter density comparison of rainfall sums

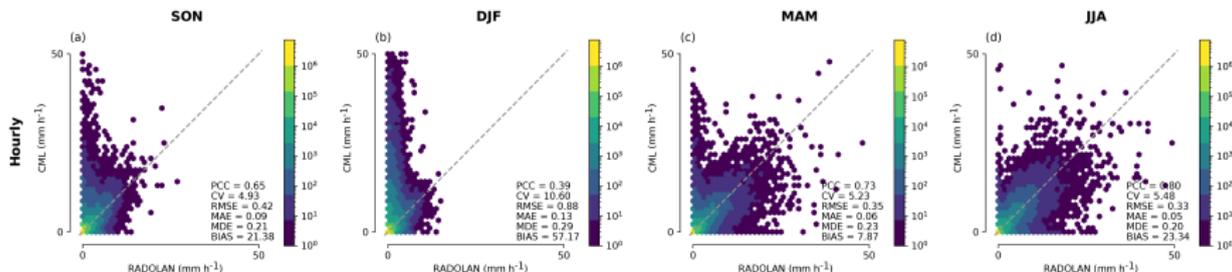
CML vs. gauge adjusted weather radar product RADOLAN-RW by DWD



+ Good agreement in the warm season

Seasonal scatter density comparison of rainfall sums

CML vs. gauge adjusted weather radar product RADOLAN-RW by DWD



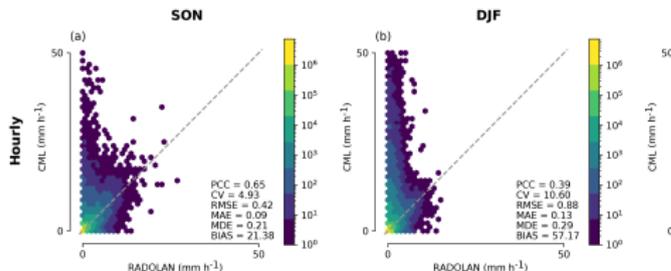
+ Good agreement in the warm season

- Large CML overestimation possible in the cold season

Performance evaluation

Seasonal scatter density comp

CML vs. gauge adjusted weather radar p



- + Good agreement in the warm season
- Large CML overestimation possible in

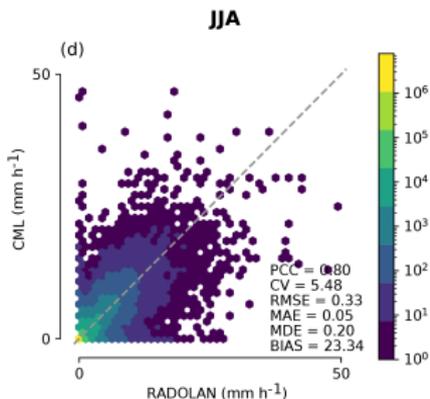


'Caution! Slippery in cold conditions'

Graf et al. 2020, HESS

Seasonal scatter density comparison of rainfall sums

CML vs. gauge adjusted weather radar product RADOLAN-RW by DWD



+ Good agreement in the warm season

+ Cold condition predictable

Video showcase

<https://doi.org/10.5281/zenodo.3759208>

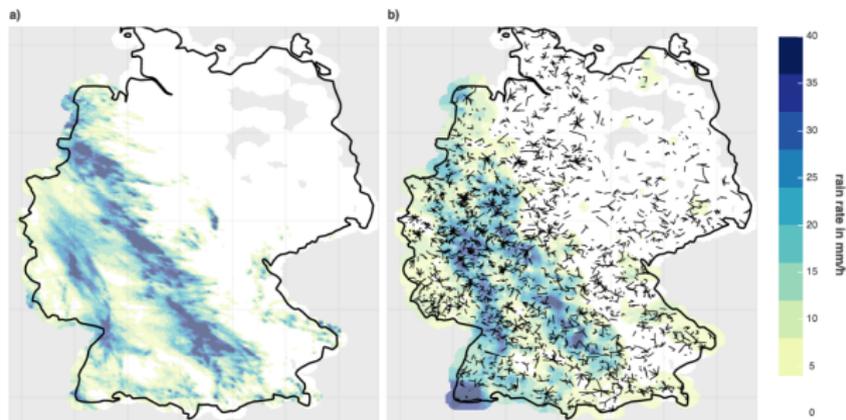


Figure 8. Accumulated rainfall for a 48 hour showcase from 12.05.2018 until 14.05.2018 for a) RADOLAN-RW and b) CML-derived rainfall. CML-derived rainfall is interpolated using a simple inverse distance weighting interpolation.

Graf et al. 2020, HESS



CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars



October 5, 2020

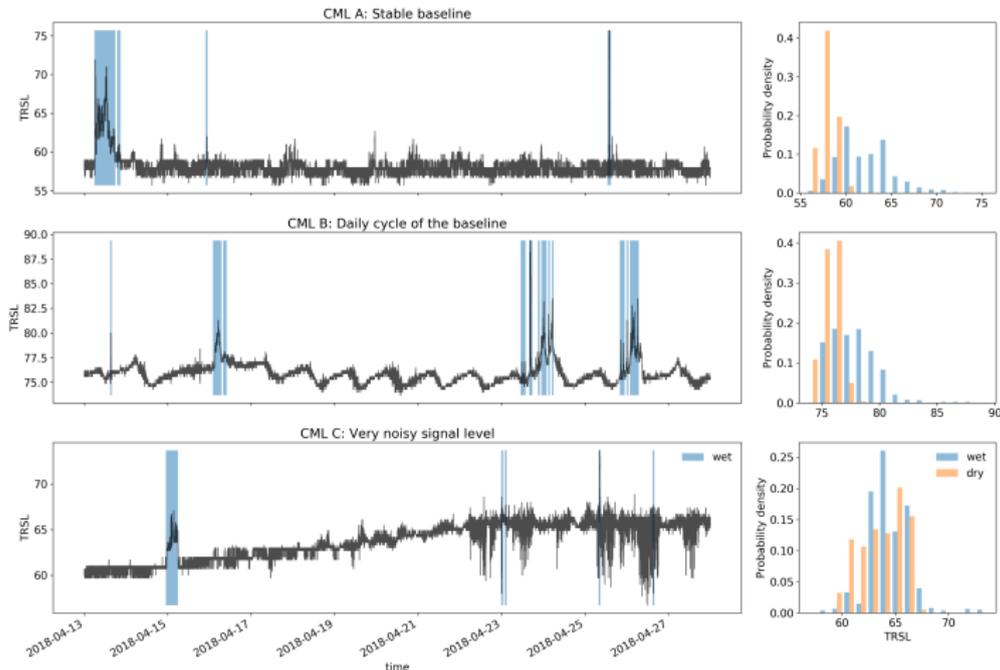
9/21

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible



Polz et al. 2020, AMT

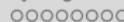


CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars

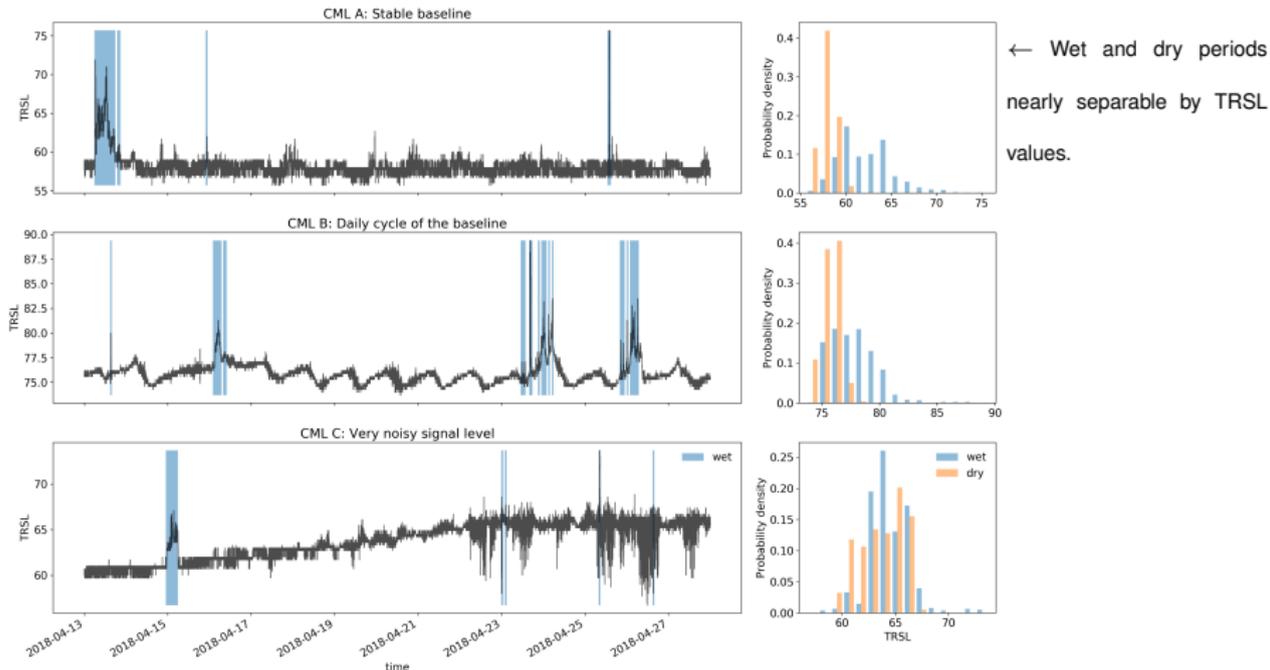


October 5, 2020

10/21

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible



Polz et al. 2020, AMT



CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars

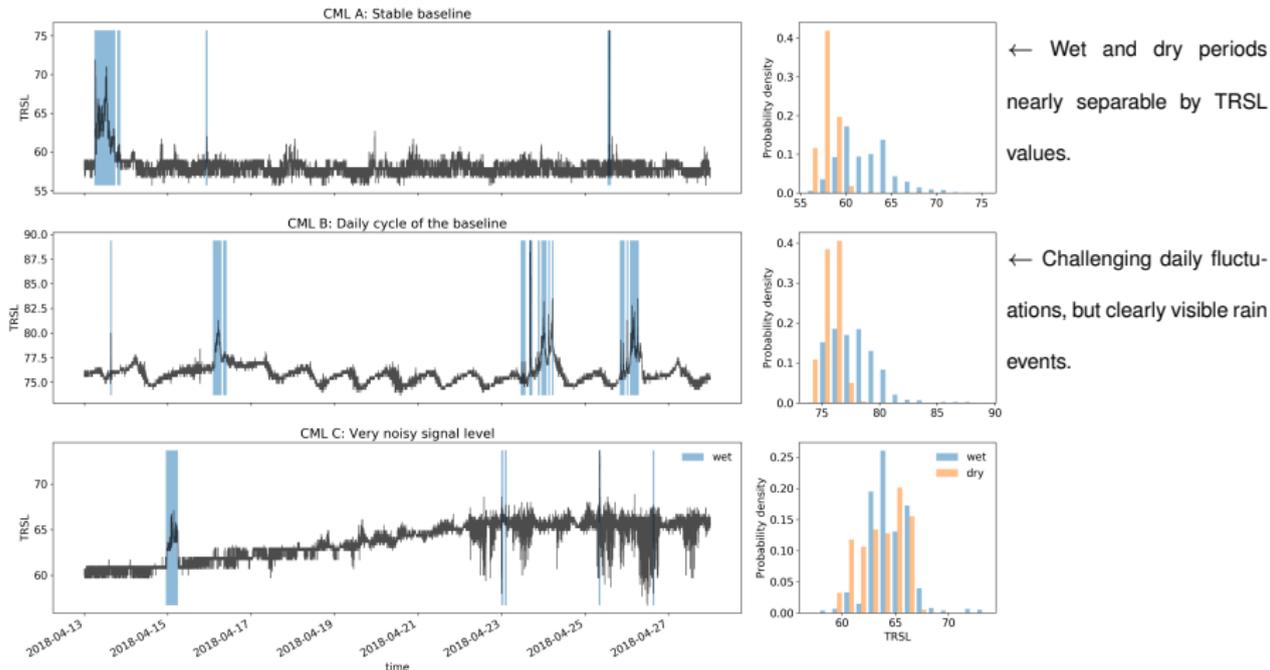


October 5, 2020

10/21

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible



Polz et al. 2020, AMT



CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars

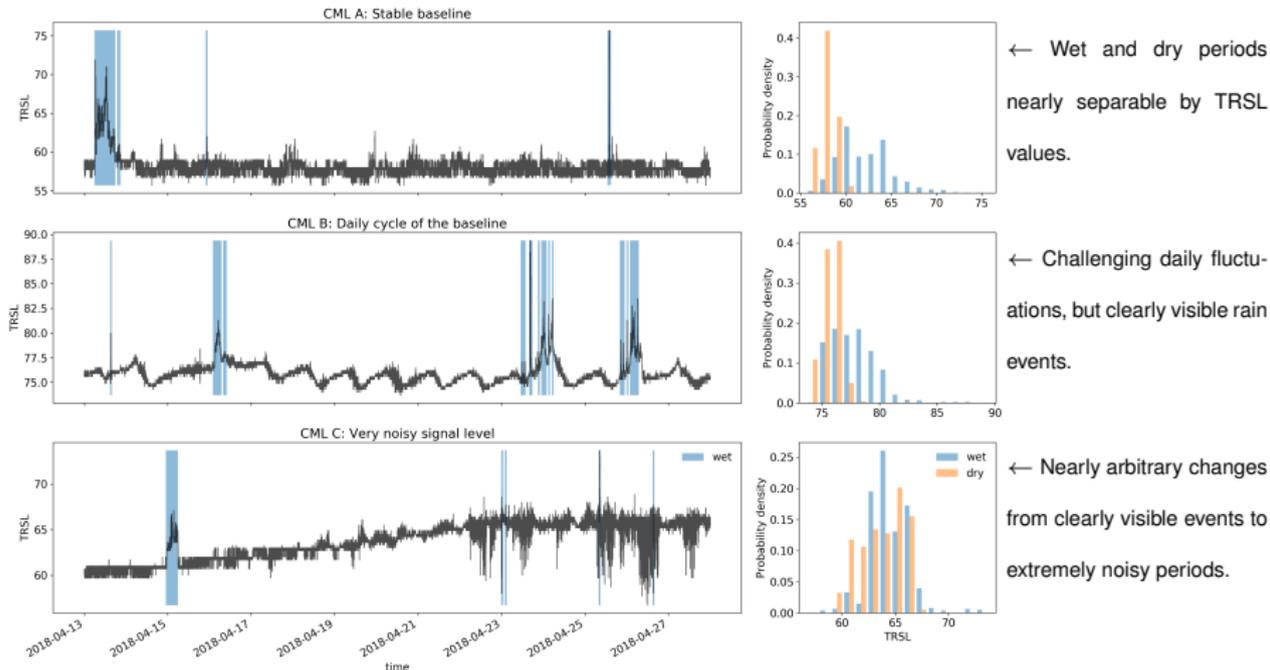


October 5, 2020

10/21

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible



Polz et al. 2020, AMT

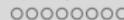


CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

Synergies of CMLs and polarimetric weather radars

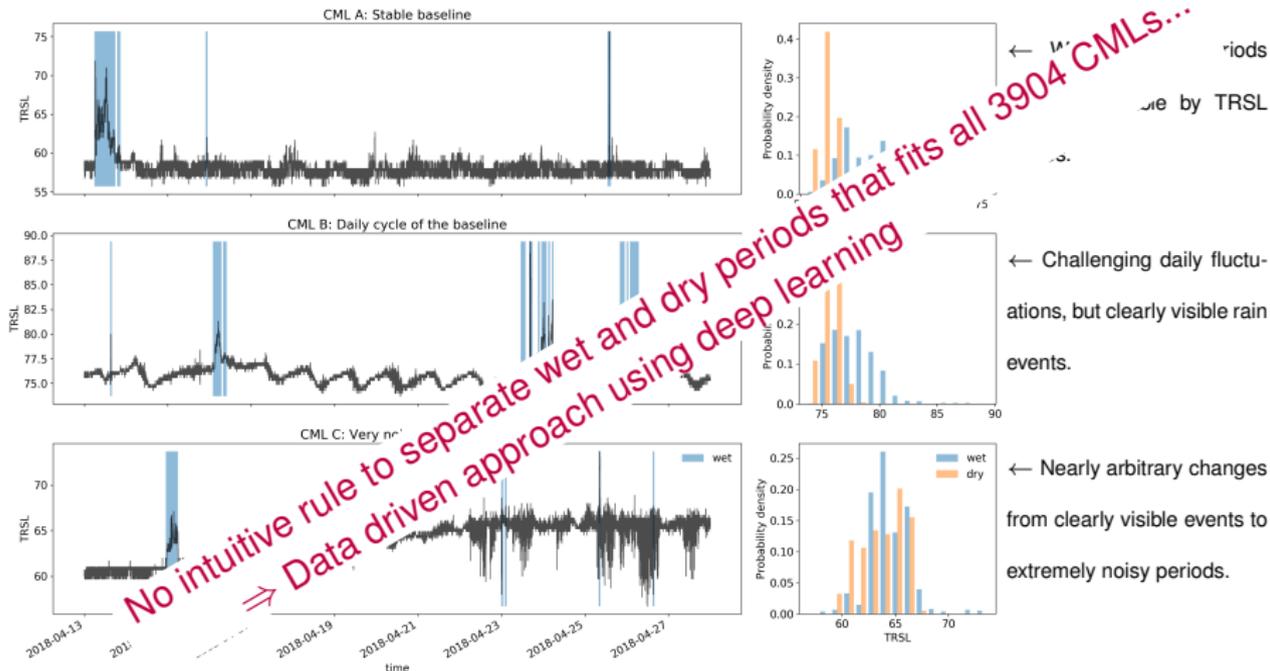


October 5, 2020

10/21

The challenge of false positives

CML signal levels not always stable → large fluctuations during dry periods possible



Polz et al. 2020, AMT

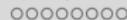


CML QPE in Germany: Recent developments



Julius Polz, Christian Chwala, Maximilian Graf, Harald Kunstmann

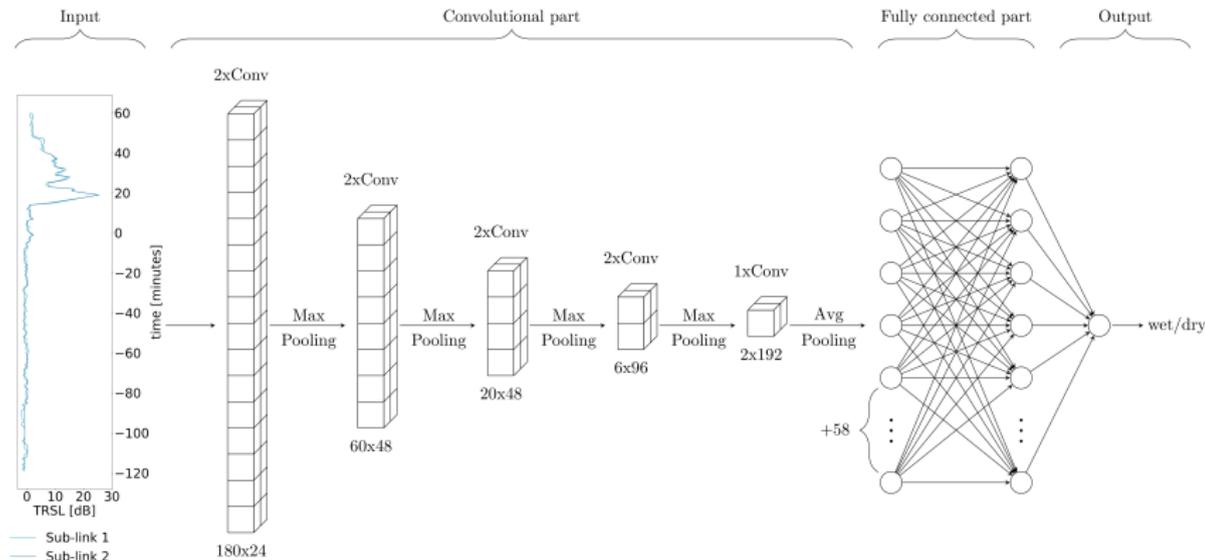
Synergies of CMLs and polarimetric weather radars



October 5, 2020

10/21

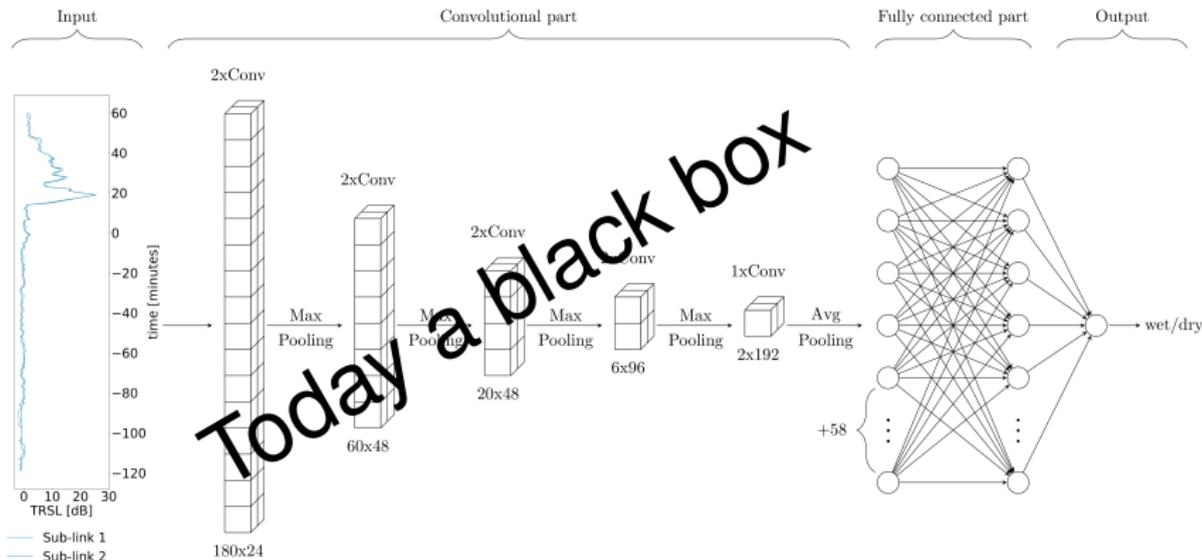
The deep learning approach



Our approach to separate wet and dry periods:

Rain event detection in commercial microwave link attenuation data with convolutional neural networks (CNNs) → Polz et al. 2020, AMT

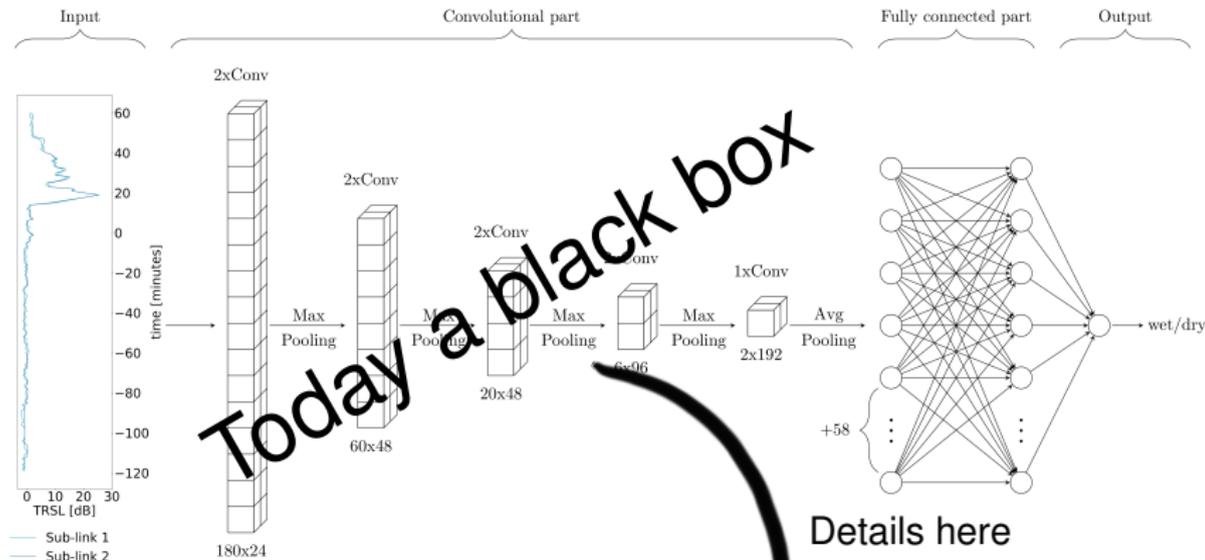
The deep learning approach



Our approach to separate wet and dry periods:

Rain event detection in commercial microwave link attenuation data with convolutional neural networks (CNNs) → Polz et al. 2020, AMT

The deep learning approach

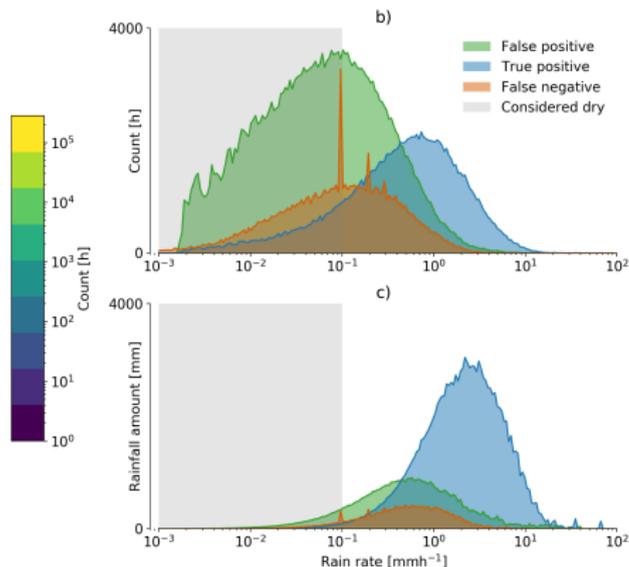
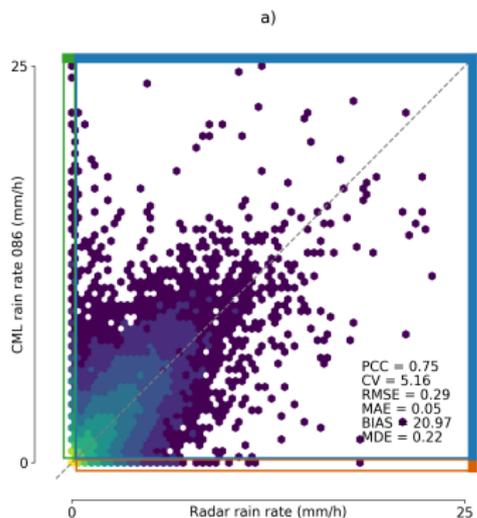


Our approach to separate wet and dry periods:

Rain event detection in commercial microwave link attenuation data with convolutional neural networks (CNNs) → Polz et al. 2020, AMT

The reference event detection method

Graf et al. (2020) improved version of Schleiss and Berne (2010) referred to as Q80.

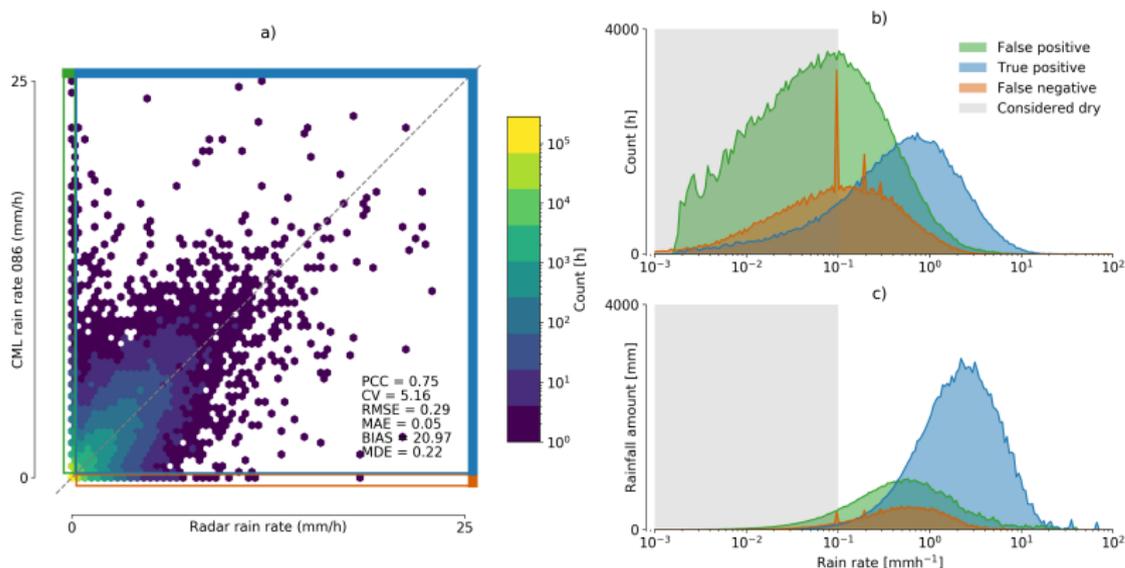


b) Histogram of the hourly rain rates derived from a)

c) Rainfall amount per Histogram bin in b)

The reference event detection method

Graf et al. (2020) improved version of Schleiss and Berne (2010) referred to as Q80.



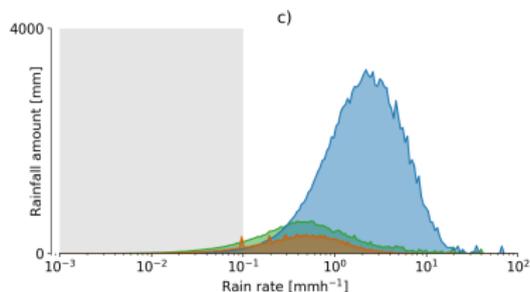
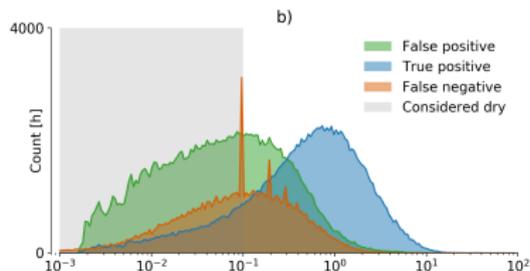
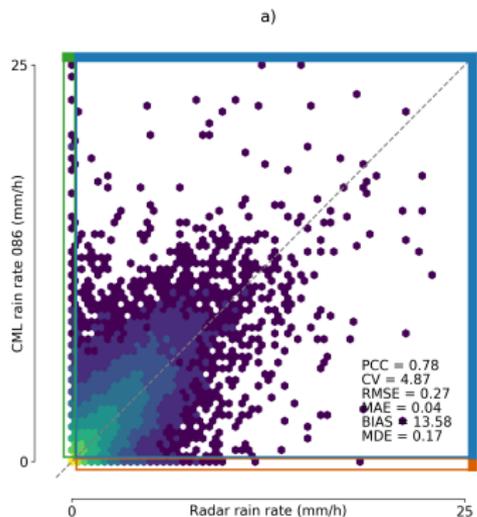
b) Histogram of the hourly rain rates derived from a)

c) Rainfall amount per Histogram bin in b)

⇒ Reduction of falsely detected rainfall (green) by 40% while at the same time improving on True positive and False negative rates.



Statistics for the CNN.



b) Histogram of the hourly rain rates derived from a)

c) Rainfall amount per Histogram bin in b)

1 CML QPE in Germany: Recent developments

2 Synergies of CMLs and polarimetric weather radars

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Is in a close to linear ($c \approx 1$) relationship with specific differential phase K_{DP} :

$$A_h = \alpha K_{DP}^c \quad (2)$$

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Is in a close to linear ($c \approx 1$) relationship with specific differential phase K_{DP} :

$$A_h = \alpha K_{DP}^c \quad (2)$$

\Rightarrow 2-way path integrated attenuation PIA_2 related to differential phase φ_{DP} :

$$PIA_2 = \alpha \Delta \varphi_{DP}(r) \quad (3)$$

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Is in a close to linear ($c \approx 1$) relationship with specific differential phase K_{DP} :

$$A_h = \alpha K_{DP}^c \quad (2)$$

\Rightarrow 2-way path integrated attenuation PIA_2 related to differential phase φ_{DP} :

$$PIA_2 = \alpha \Delta \varphi_{DP}(r) \quad (3)$$

\Rightarrow **Attenuation correction potential through polarimetry**

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Is in a close to linear ($c \approx 1$) relationship with specific differential phase K_{DP} :

$$A_h = \alpha K_{DP}^c \quad (2)$$

\Rightarrow 2-way path integrated attenuation PIA_2 related to differential phase φ_{DP} :

$$PIA_2 = \alpha \Delta \varphi_{DP}(r) \quad (3)$$

\Rightarrow **Attenuation correction potential through polarimetry**

\Rightarrow **Synergies with CML derived 1-way PIA_1** (Troemel et al. 2014, JTECH)

Specific attenuation A_h

Is used for the $R(A)$ rainfall retrieval.

Affects the reflectivity Z_h at range r :

$$\Delta Z_h(r) = 2 \int_0^r A_h(s) ds \quad (1)$$

Is in a close to linear ($c \approx 1$) relationship with specific differential phase K_{DP} :

$$A_h = \alpha K_{DP}^c \quad (2)$$

\Rightarrow 2-way path integrated attenuation PIA_2 related to differential phase φ_{DP} :

$$PIA_2 = \alpha \Delta \varphi_{DP}(r) \quad (3)$$

\Rightarrow **Attenuation correction potential through polarimetry**

\Rightarrow **Synergies with CML derived 1-way PIA_1** (Troemel et al. 2014, JTECH)

Estimating α

Goal: Use attenuation along CML path to estimate α

Estimating α

Goal: Use attenuation along CML path to estimate α

CML frequency: 10-40 GHz \leftrightarrow Radar frequency at C-band: 5.6 GHz

Estimating α

Goal: Use attenuation along CML path to estimate α

CML frequency: 10-40 GHz \leftrightarrow Radar frequency at C-band: 5.6 GHz

\Rightarrow **Frequency conversion needed for comparable attenuation!**

Goal: Use attenuation along CML path to estimate α

CML frequency: 10-40 GHz \leftrightarrow Radar frequency at C-band: 5.6 GHz

\Rightarrow **Frequency conversion needed for comparable attenuation!**

Option 1: exact with known DSD

Goal: Use attenuation along CML path to estimate α

CML frequency: 10-40 GHz \leftrightarrow Radar frequency at C-band: 5.6 GHz

\Rightarrow **Frequency conversion needed for comparable attenuation!**

Option 1: exact with known DSD

Option 2: 20-30% of relative errors via $A - R$ relation

Goal: Use attenuation along CML path to estimate α

CML frequency: 10-40 GHz \leftrightarrow Radar frequency at C-band: 5.6 GHz

\Rightarrow **Frequency conversion needed for comparable attenuation!**

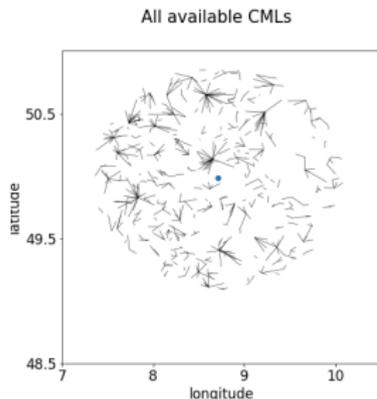
Option 1: exact with known DSD

Option 2: 20-30% of relative errors via $A - R$ relation

$$\alpha = \frac{2PIA_1(5.66GHz)}{\Delta\varphi_{DP}} \quad (4)$$

Estimating α

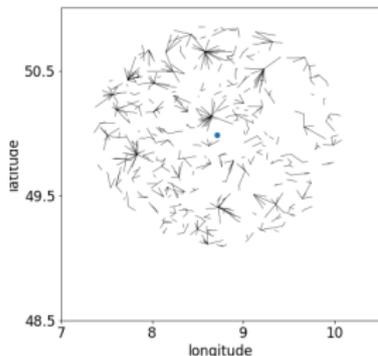
Only CMLs parallel to radar ray can be used



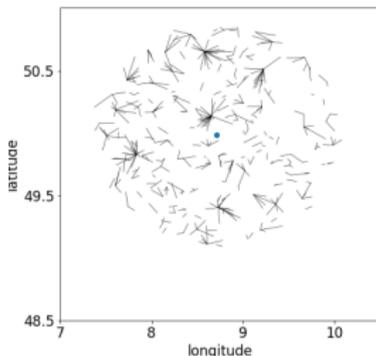
Estimating α

Only CMLs parallel to radar ray can be used

All available CMLs



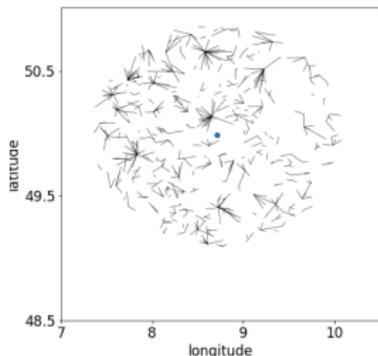
Well performing CMLs



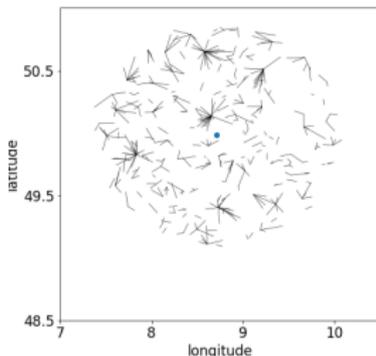
Estimating α

Only CMLs parallel to radar ray can be used

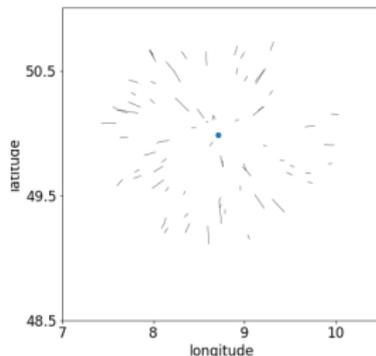
All available CMLs



Well performing CMLs

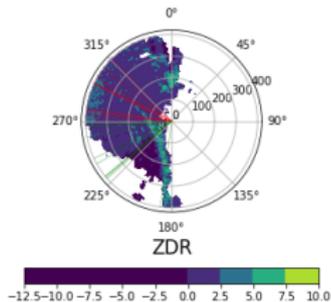
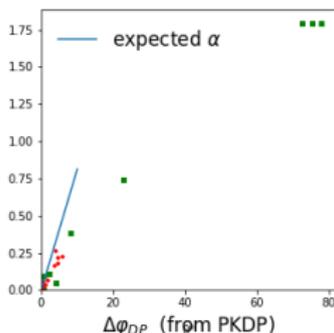


CMLs parallel to the radar ray



Estimating α

2017-07-19T16:25

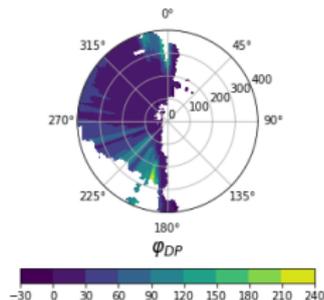
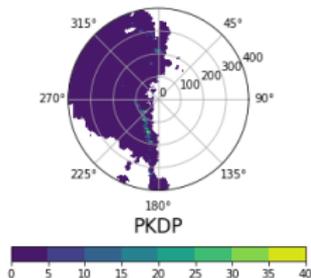


Scatterplot:
Unique CML vs. radar ray pairs

Event:
Convective rainfall with hail

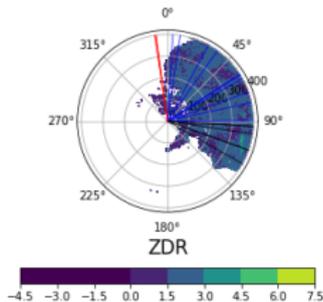
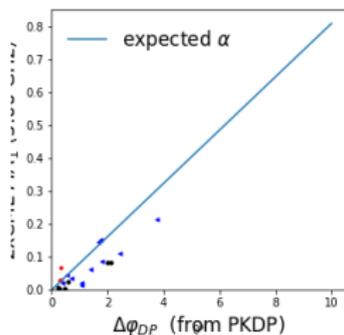
Expected alpha:
from ZDR slope

Estimated alpha:
Lower



Estimating α

2017-07-19T16:30

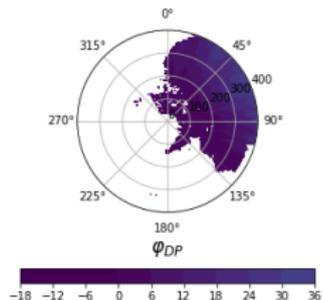
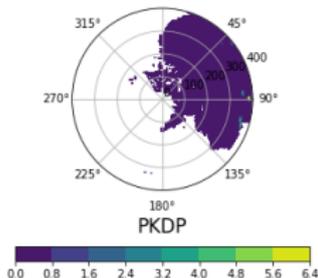


Scatterplot:
Unique CML vs. radar ray pairs

Event:
Convective rainfall with hail

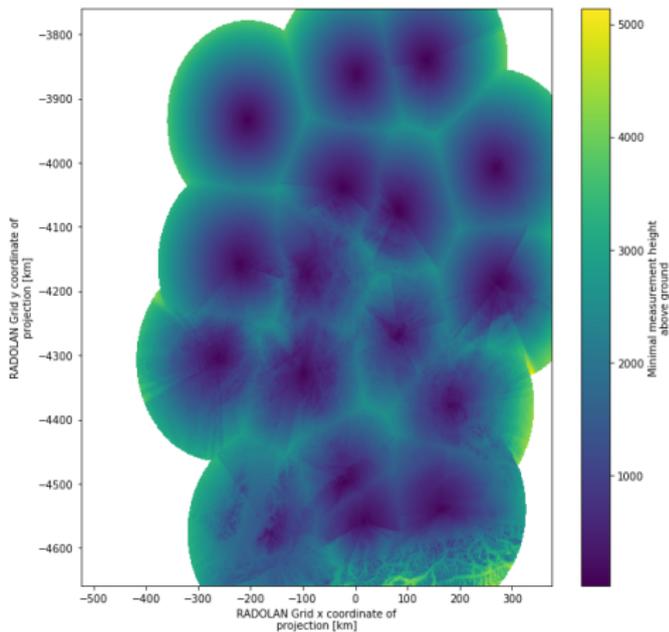
Expected alpha:
from ZDR slope

Estimated alpha:
Lower



Sources of uncertainty

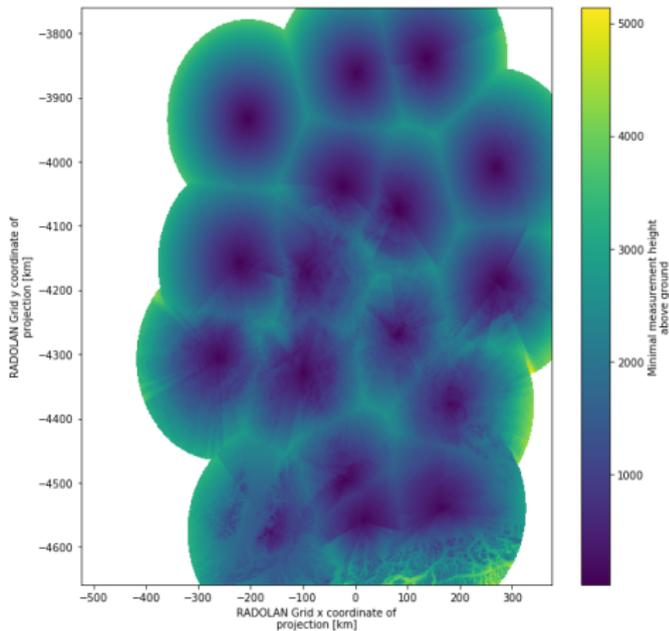
Radar height above ground up to 3km



Sources of uncertainty

Radar height above ground up to 3km

Fall speed \Rightarrow Temporal mismatch

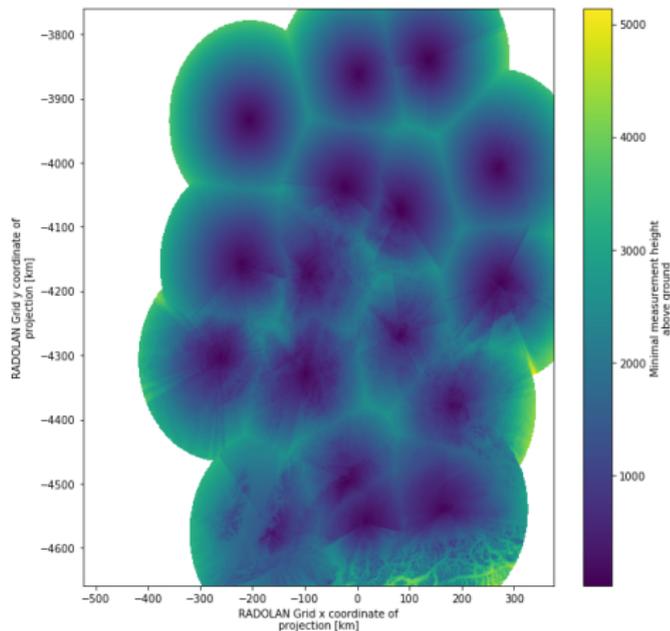


Sources of uncertainty

Radar height above ground up to 3km

Fall speed \Rightarrow Temporal mismatch

Wind \Rightarrow Spatial mismatch



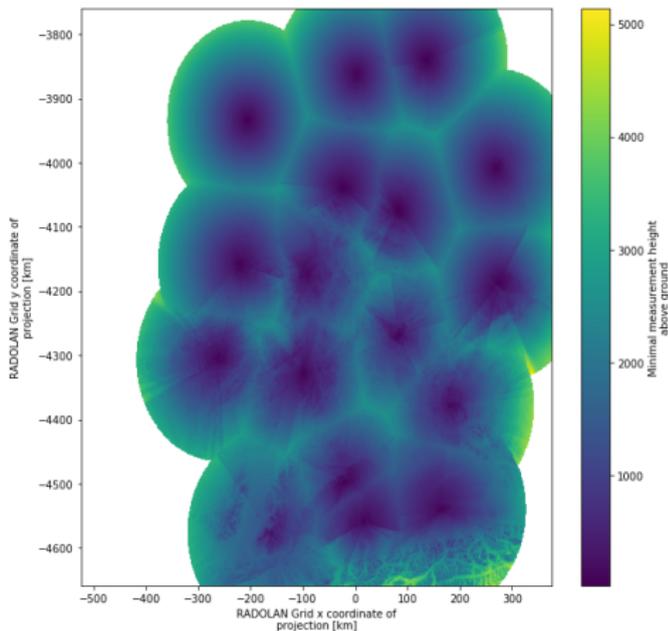
Sources of uncertainty

Radar height above ground up to 3km

Fall speed \Rightarrow Temporal mismatch

Wind \Rightarrow Spatial mismatch

Evaporation \Rightarrow DSD mismatch



Sources of uncertainty

Radar height above ground up to 3km

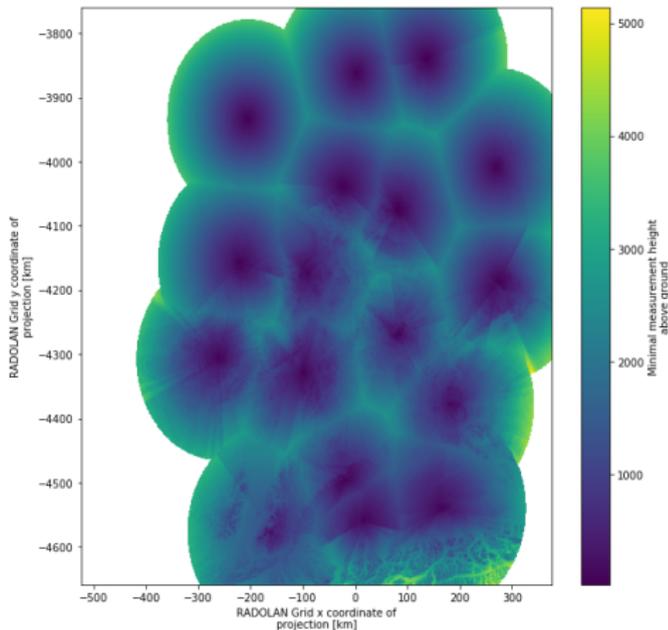
Fall speed \Rightarrow Temporal mismatch

Wind \Rightarrow Spatial mismatch

Evaporation \Rightarrow DSD mismatch

Spatio-temporal mismatch

My hot topic for future applications



Conclusions

- + Germany wide CML rainfall observations, potential real time operation

Conclusions

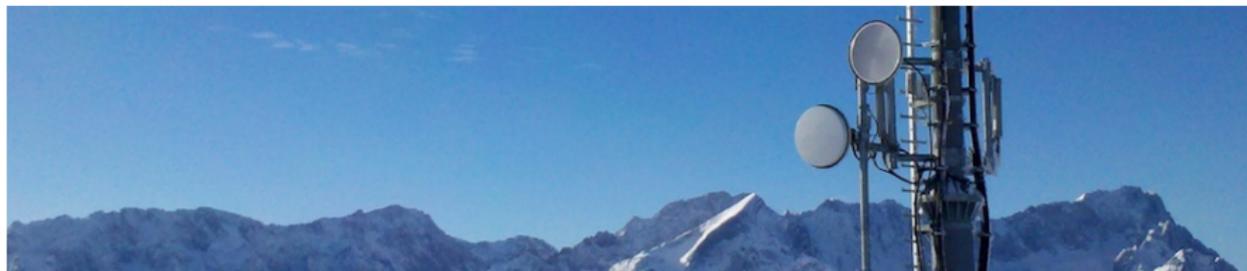
- + Germany wide CML rainfall observations, potential real time operation
- + Novel processing techniques increase the confidence in CML QPE

Conclusions

- + Germany wide CML rainfall observations, potential real time operation
- + Novel processing techniques increase the confidence in CML QPE
- + Potential for synergies between CML and pol. weather radar through specific attenuation

Conclusions

- + Germany wide CML rainfall observations, potential real time operation
- + Novel processing techniques increase the confidence in CML QPE
- + Potential for synergies between CML and pol. weather radar through specific attenuation
- Spatio-temporal mismatch and a possible DSD mismatch lead to uncertainties



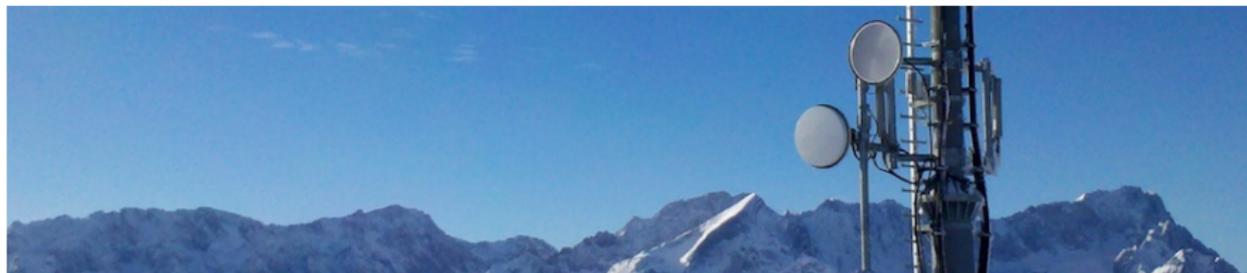
Acknowledgements to



Questions/Suggestions?

Ask me anything via julius.polz@kit.edu or on Twitter

Interested in our open source model? Get it at github.com/jpolz.



Acknowledgements to

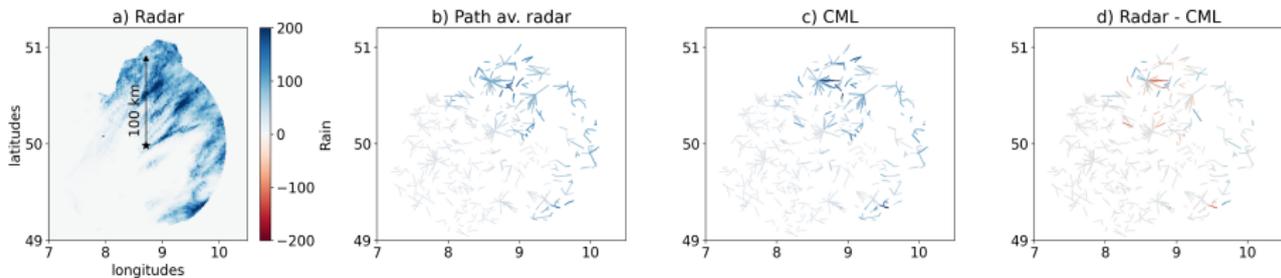


- [1] Chwala, C. and Kunstmann, H.: Commercial microwave link networks for rainfall observation: Assessment of the current status and future challenges, *Wiley Interdisciplinary Reviews: Water*, 6, e1337, 2019.
- [2] Chwala, C., Keis, F., and Kunstmann, H.: Real-time data acquisition of commercial microwave link networks for hydrometeorological applications, *Atmos. Meas. Tech.*, 9, 991–999, 2016.
- [3] Graf, M., Chwala, C., Polz, J., and Kunstmann, H.: Rainfall estimation from a German-wide commercial microwave link network: Optimized processing and validation for one year of data, *Hydrol. Earth Syst. Sci. Discuss.*, 2019.
- [4] Schleiss, M. and Berne, A.: Identification of Dry and Rainy Periods Using Telecommunication Microwave Links, *IEEE Geoscience and Remote Sensing Letters*, 7, 611–615, 2010.
- [5] Polz, J., Chwala, C., Graf, M., and Kunstmann, H.: Rain event detection in commercial microwave link attenuation data using convolutional neural networks, *Atmos. Meas. Tech. Discuss.*, 2020.
- [6] Trömel, S., M. Ziegert, A. V. Ryzhkov, C. Chwala, and C. Simmer, 2014: Using Microwave Backhaul Links to Optimize the Performance of Algorithms for Rainfall Estimation and Attenuation Correction. *J. Atmos. Oceanic Technol.*, 31, 1748–1760, <https://doi.org/10.1175/JTECH-D-14-00016.1>.

Sources of uncertainty

Event: Convective rainfall with hail
2017-07-19 15:00 to 2017-07-20 00:00

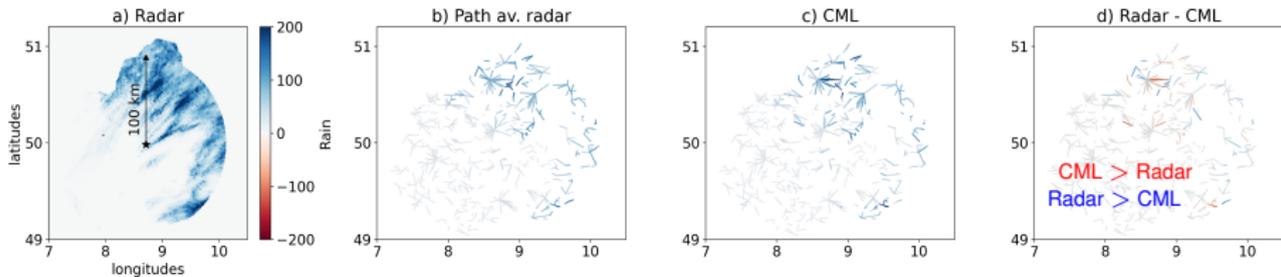
Rainfall sum over full event duration



Sources of uncertainty

Event: Convective rainfall with hail
2017-07-19 15:00 to 2017-07-20 00:00

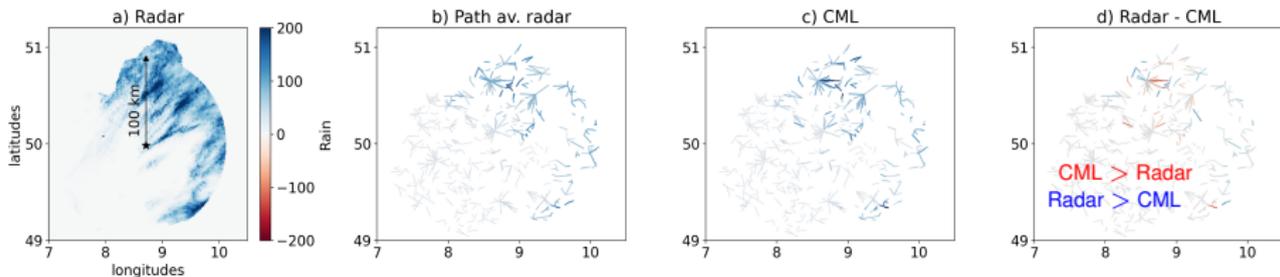
Rainfall sum over full event duration



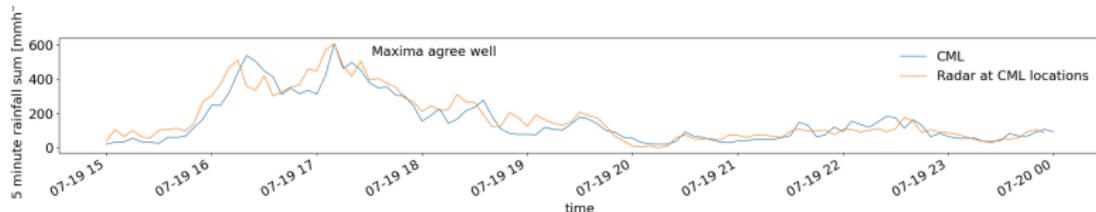
Sources of uncertainty

Event: Convective rainfall with hail
2017-07-19 15:00 to 2017-07-20 00:00

Rainfall sum over full event duration



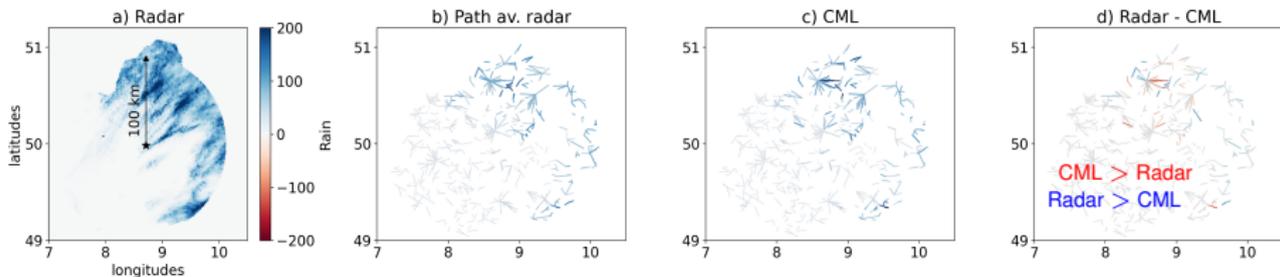
5 minute rainfall aggregated over all measurements



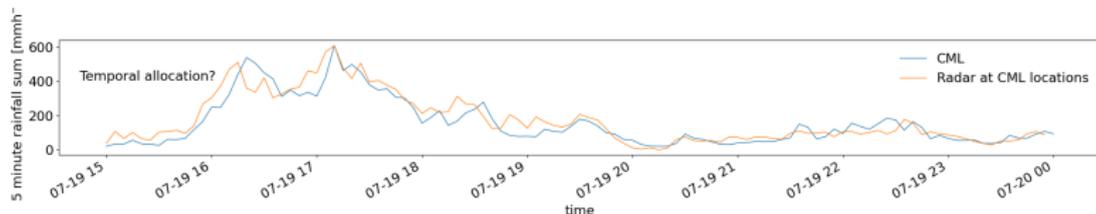
Sources of uncertainty

Event: Convective rainfall with hail
2017-07-19 15:00 to 2017-07-20 00:00

Rainfall sum over full event duration

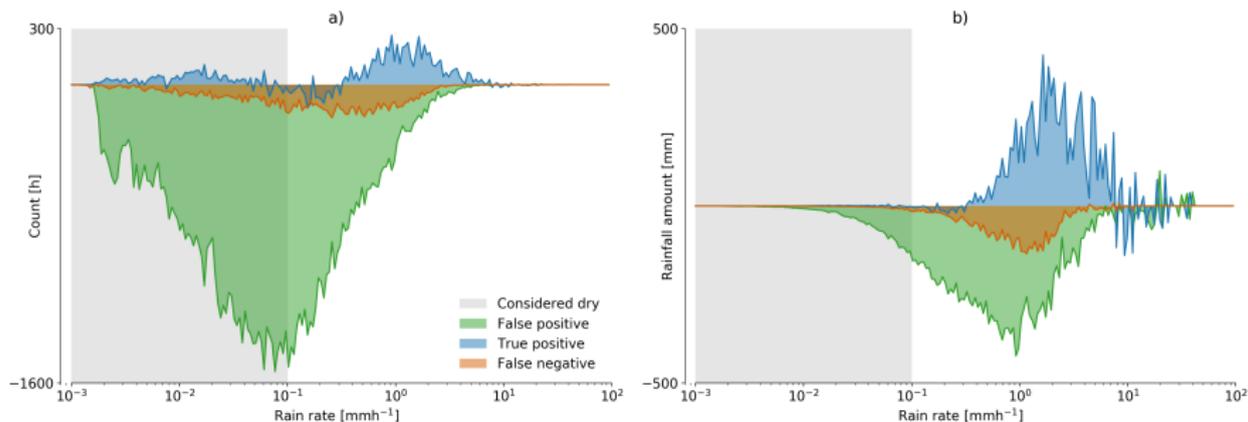


5 minute rainfall aggregated over all measurements



Improvement through the CNN

Difference in plots a) and b) from the previous slides
(numbers of Q80 subtracted by the numbers of the CNN)

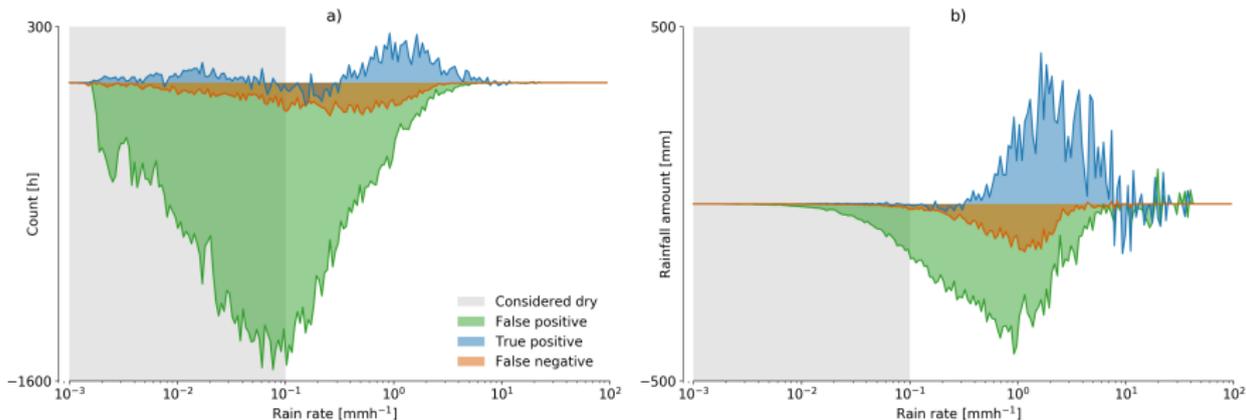


a) Histogram of the difference in hourly rain rates

b) Rainfall amount per histogram bin in a)

Improvement through the CNN

Difference in plots a) and b) from the previous slides
(numbers of Q80 subtracted by the numbers of the CNN)



a) Histogram of the difference in hourly rain rates

b) Rainfall amount per histogram bin in a)

⇒ Reduction of falsely generated rainfall (green) by 40% while at the same time improving on True positive and False negative rates.