Karlsruhe Institute of Technology

Rainfall estimates from opportunistic sensors in Germany across spatio-temporal scales

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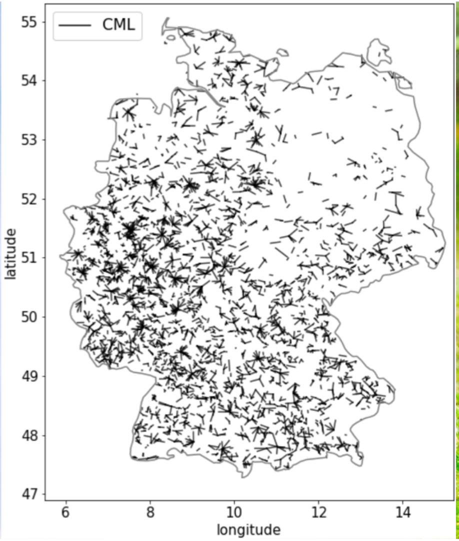
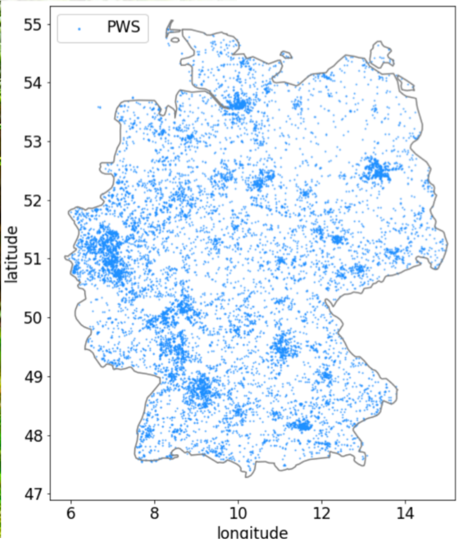
3 IGUA, University of Augsburg, Germany

Opportunistic sensors (OS) can be used for rainfall monitoring





Commercial Microwave Links (CMLs)

- ~ 4000 CMLs
- fixed set of CMLs with custom real time application[1] together with Ericsson
- 10 to 40 GHz with 0.3 to 30 km length

Personal Weather Stations (PWSs)

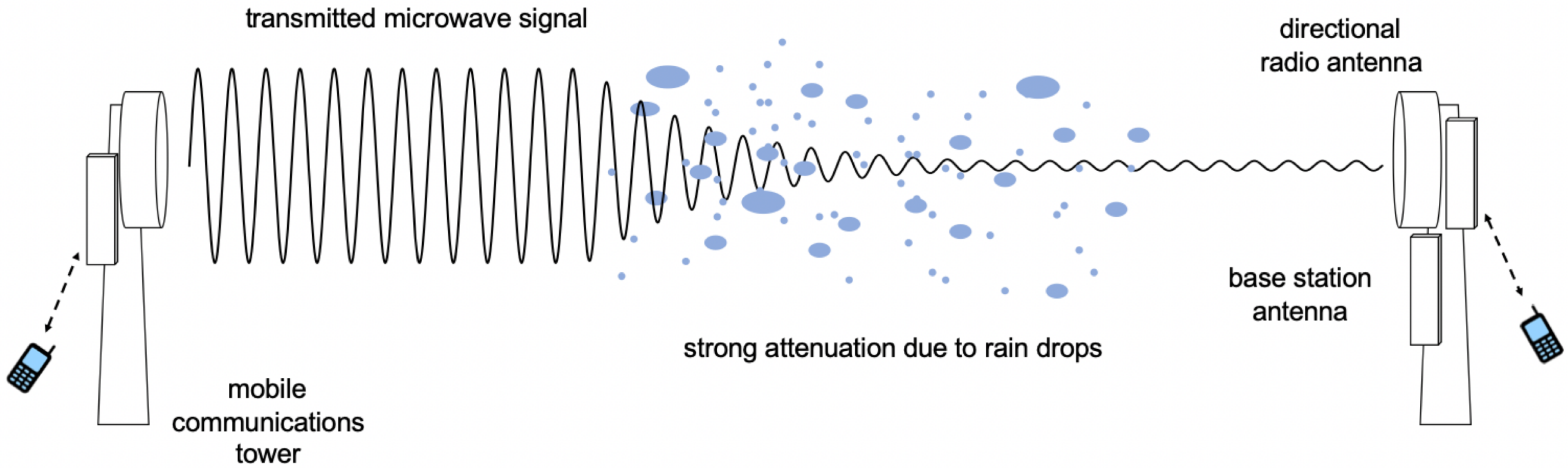
- up to 20,000 PWSs from netatmo
- number of PWSs is increasing

Other examples from a growing number of opportunistic sensor for environmental monitoring

- Smart phones → temperature, pressure, light
- Windshield wipers → rainfall binary info from windshield wipers
- Satellite TV link path → rainfall
- Surveillance cameras → rainfall

[1] Chwala et al. 2016, AMT

Commercial Microwave Links

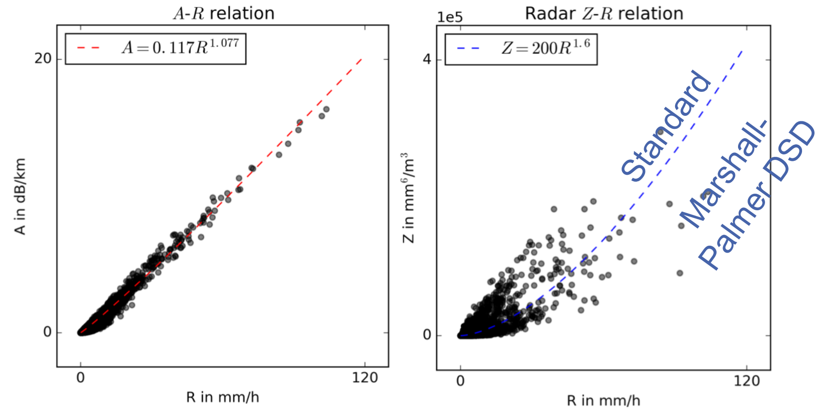


→ Relation between attenuation and rain rate is defined as

[mm/h]

A-R power law: $A = aR^b$

[dB/km]



more information on CML processing

Chwala and Kunstmann, 2019 (Wires)
Polz et al., 2020 (AMT)
Graf et al., 2020 (HESS)

Personal weather station (PWS)

wireless weather station for the ”smart home” here from Netatmo

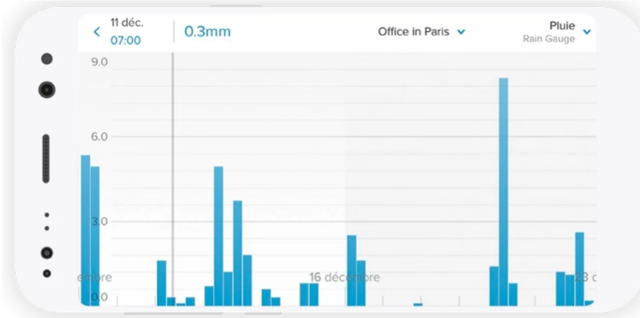
indoor/outdoor units to measure:

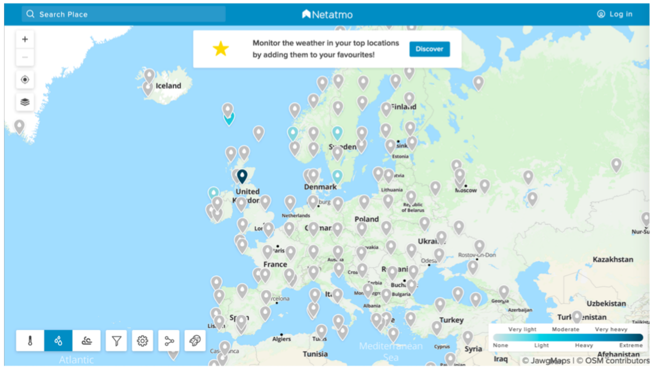
- temperature
- humidity
- pressure
- CO2
- wind
- rainfall

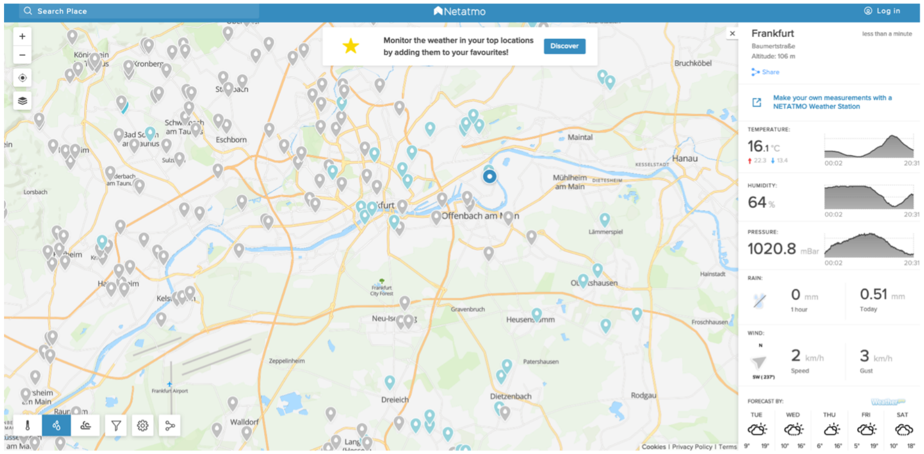
manufacturer's specifications

- range of 0.2–150 mm/h
- precision of 1 mm/h
- 13 cm diameter

Personal weather station (PWS)







Owners of a netatmo PWS can access data from all other publicly shared PWS via an API

https://weathermap.netatmo.com/

Evaluating rainfall estimates through scales

What are the challenges?

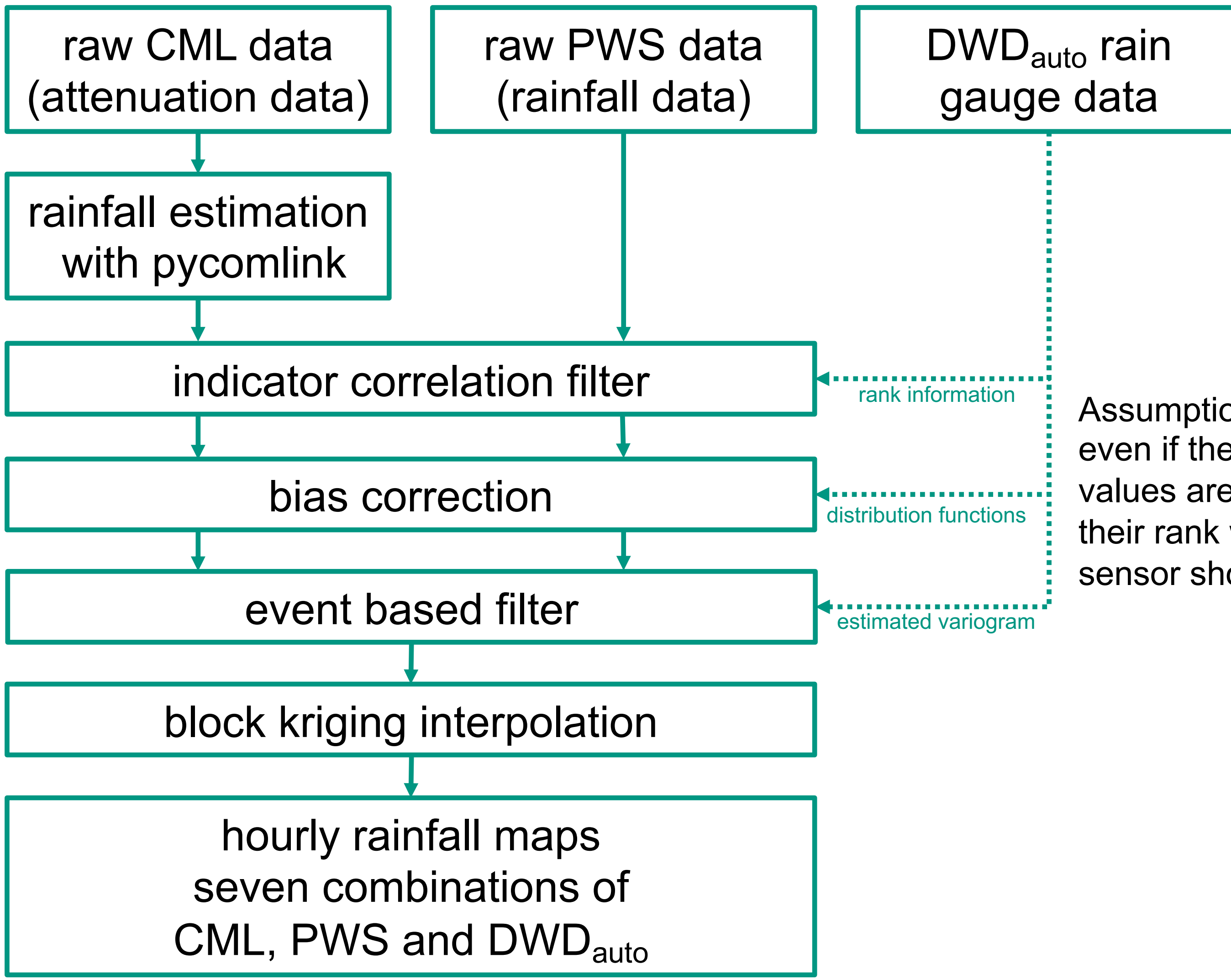
- an adequate quality control routine has to be used for opportunistic sensors

→ remove only as much data as necessary to profit from high number of sensors

- interpolate sensors individually and in combination

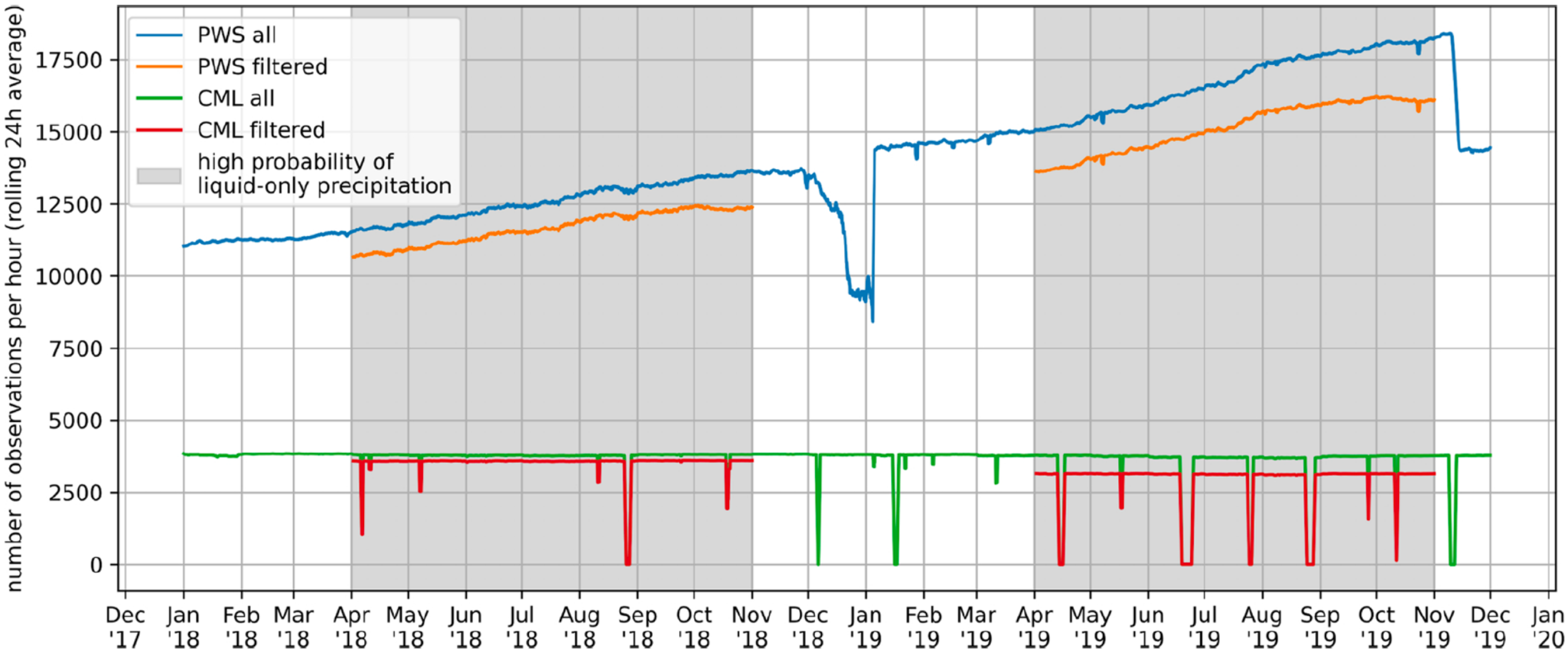
- find suitable reference data sets to evaluate rainfall estimates from OS

Processing and Interpolation



Assumption:
even if the exact OS values are wrong, their rank within one sensor should be fine

Data availability after filtering



~ 92% of the data are assumed to be ok and used for seven interpolated products

Evaluating rainfall estimates through scales

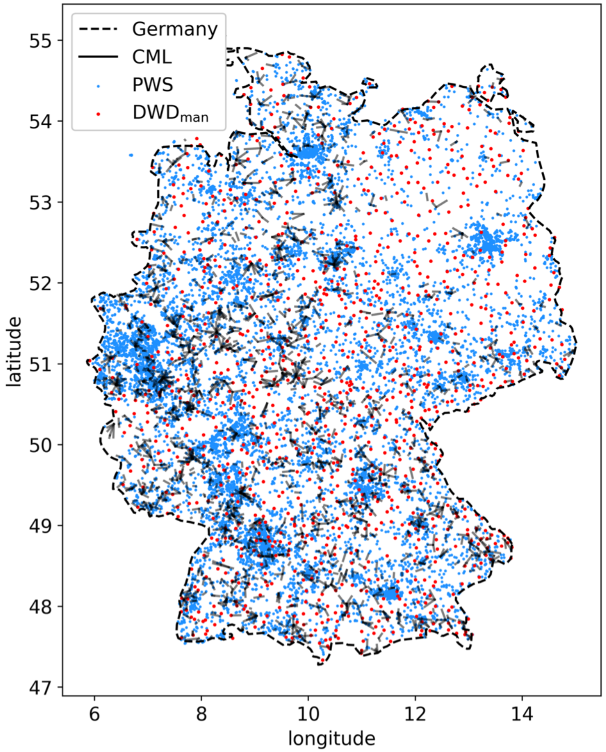
Concept of evaluation

- seven interpolated products with hourly resolution which consist of PWS, CML and DWD (hourly, automatic stations) and their combinations
- evaluation of seven interpolated products for three scales

scale	region	temporal	n stations	data provider
country	Germany	daily	1062	DWD (manual gauges)
regional	Rhinland-Palatinate	hourly	169	Agrometeorological Agency of Rhinland-Palatinate
local	Reutlingen	hourly	12 (10)	Municipality of Reutlingen

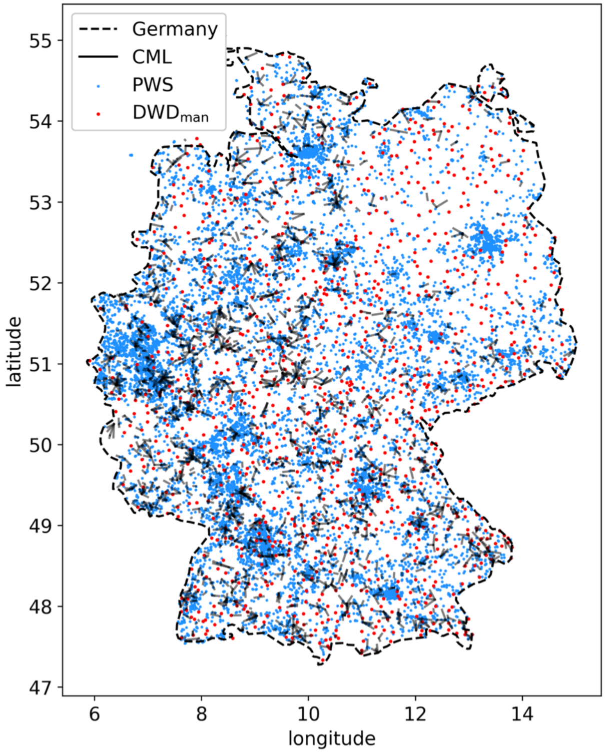
[1] $DWD_{daily} \neq DWD_{hourly}$, these are two different gauge dataset with different locations

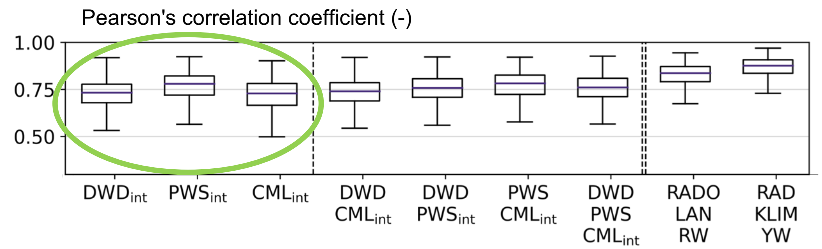
Country-wide, daily scale: Germany



performance of interpolated products for 1062 manual, daily rain gauges from DWD (DWD_{man})

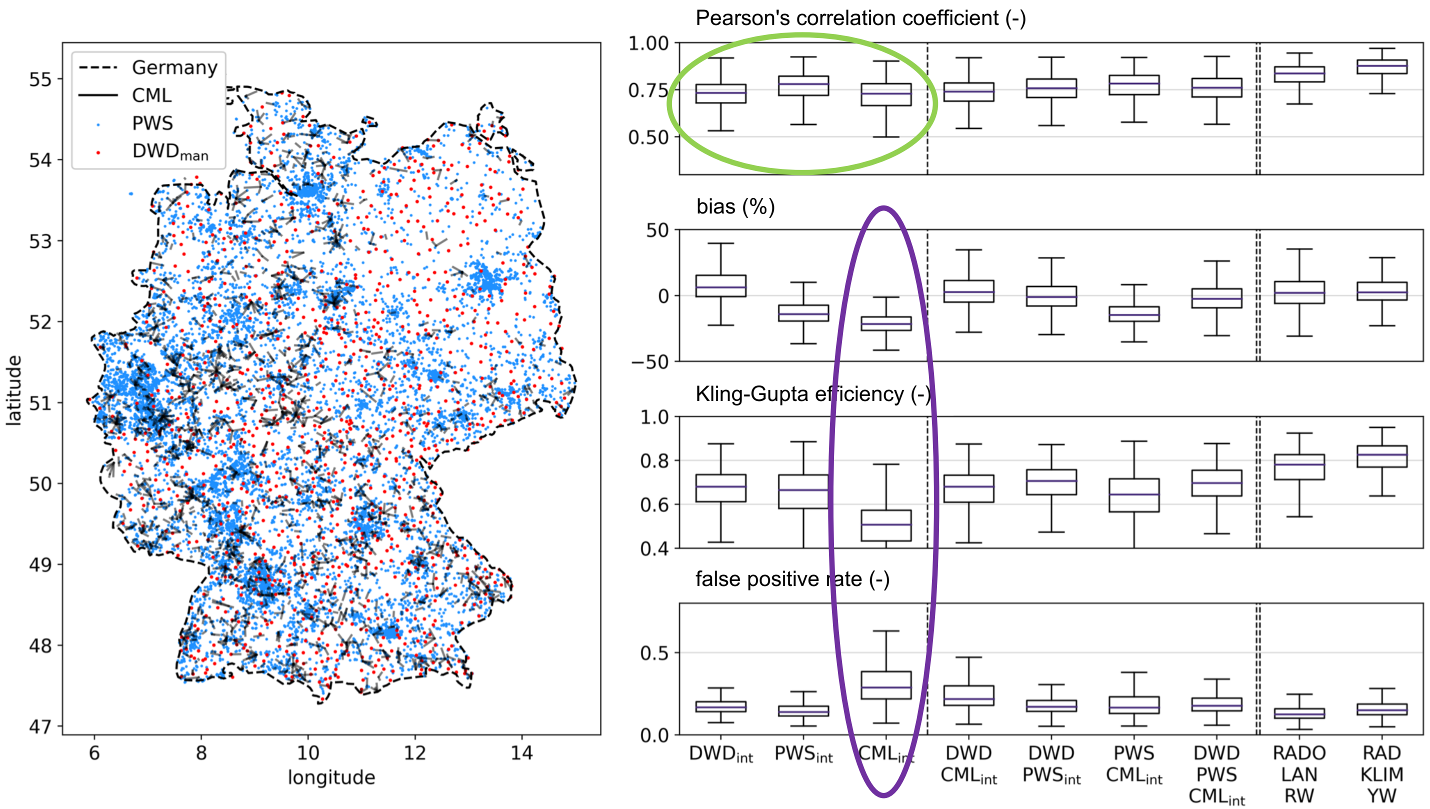
Country-wide, daily scale: Germany





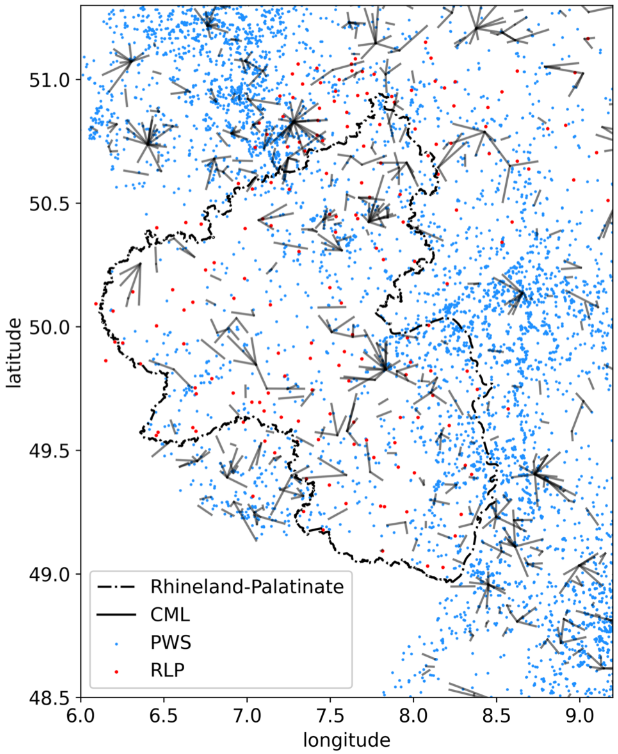
- OS products correlate similar or better to the reference than one of DWD rain gauges

Country-wide, daily scale: Germany



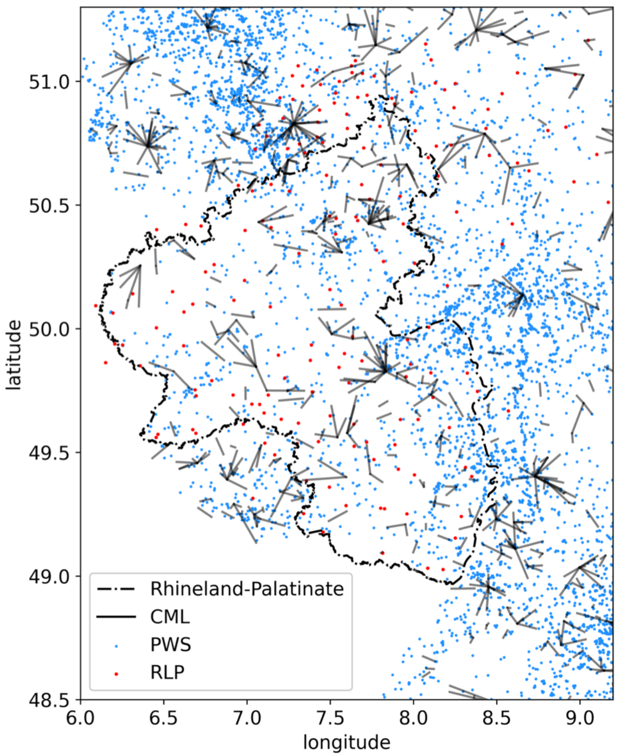
- OS products correlate similar or better to the reference than one of DWD rain gauges
- interpolated CMLs show a negative bias and high false positive rate mainly due to their uneven spatial distribution in relation to the DWD$_{man}$ gauges

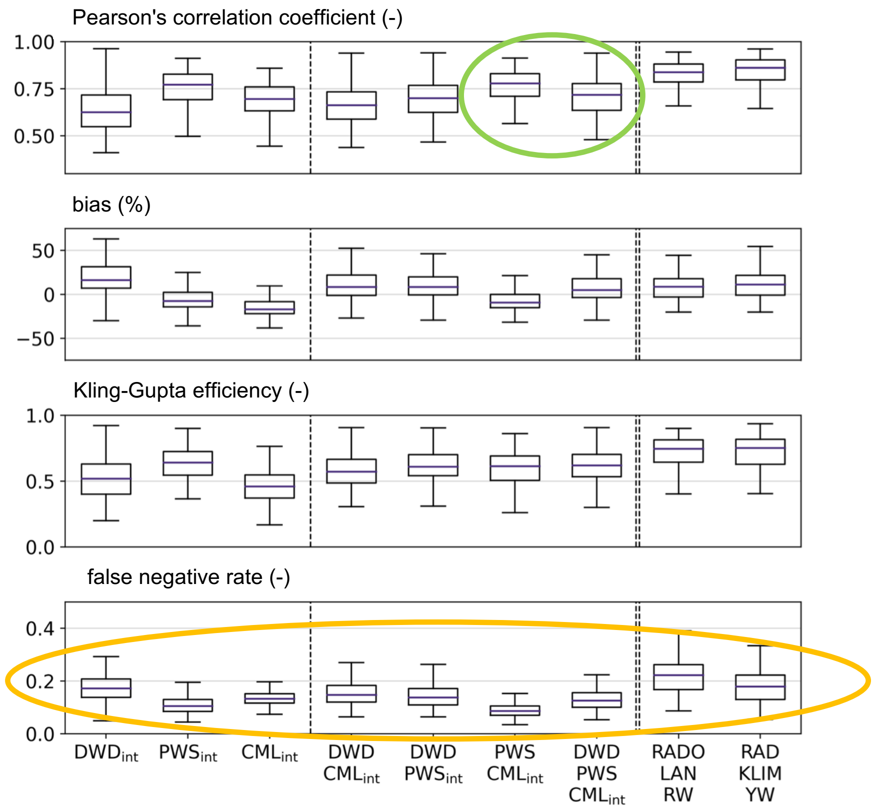
Regional, hourly scale: Rhineland-Palatinate



performance of interpolated products compared to 169 hourly rain gauges operated by the Agrometeorological Agency of Rhineland-Palatinate

Regional, hourly scale: Rhineland-Palatinate

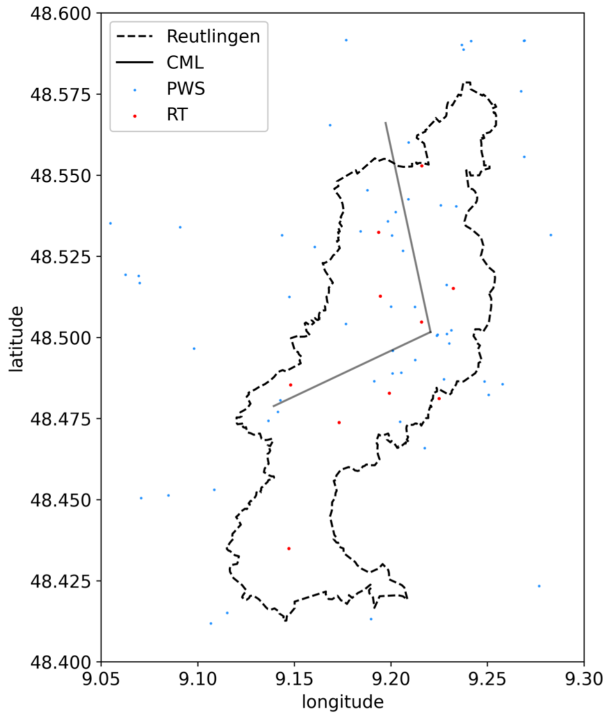




- combination of OS performs better than combination of OS with DWD
- False negative rate of OS and combinations is lower than DWD or radar

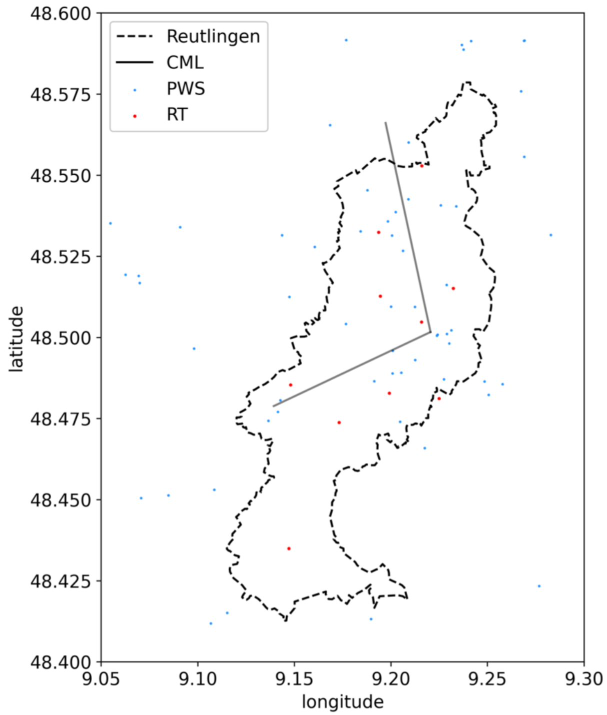
→ Even though OS do not measure at the validation stations (RLP) they perform reasonable in comparison to radar measurements at such locations

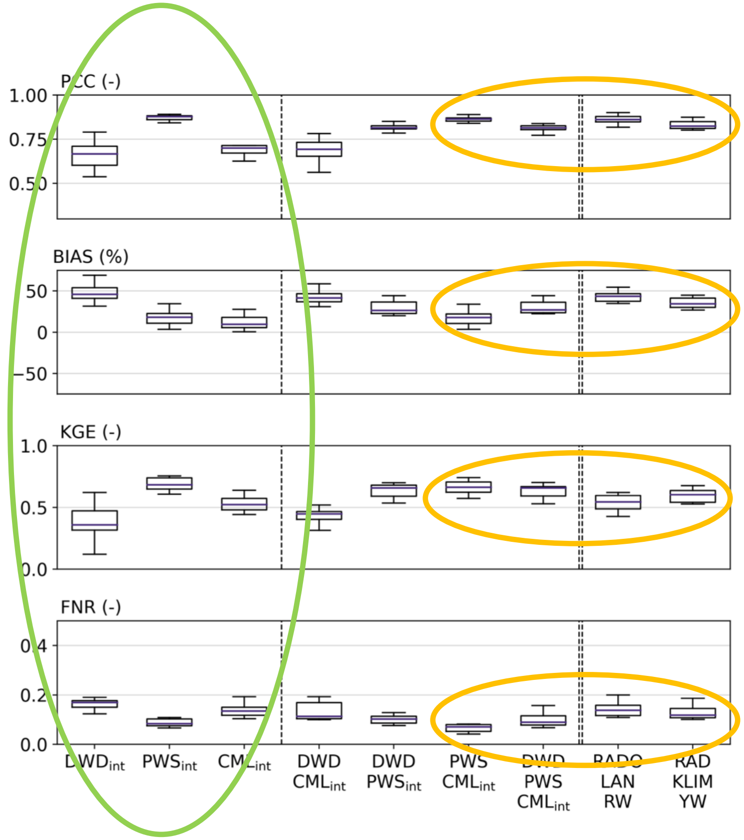
Local, hourly scale: Reutlingen



performance of interpolated products compared to 10 hourly rain gauges operated by the Municipality Reutlingen (RT)

Local, hourly scale: Reutlingen

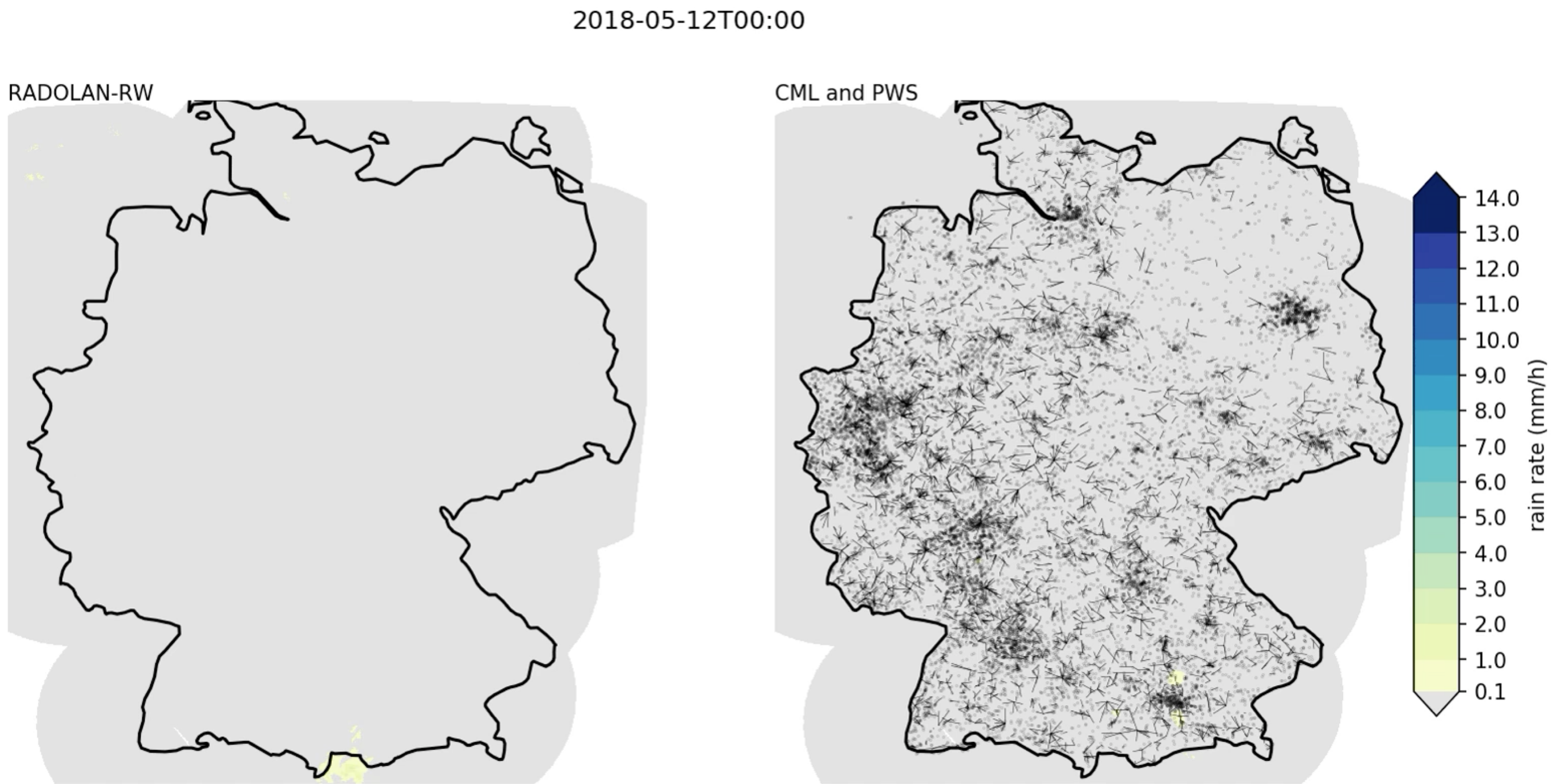




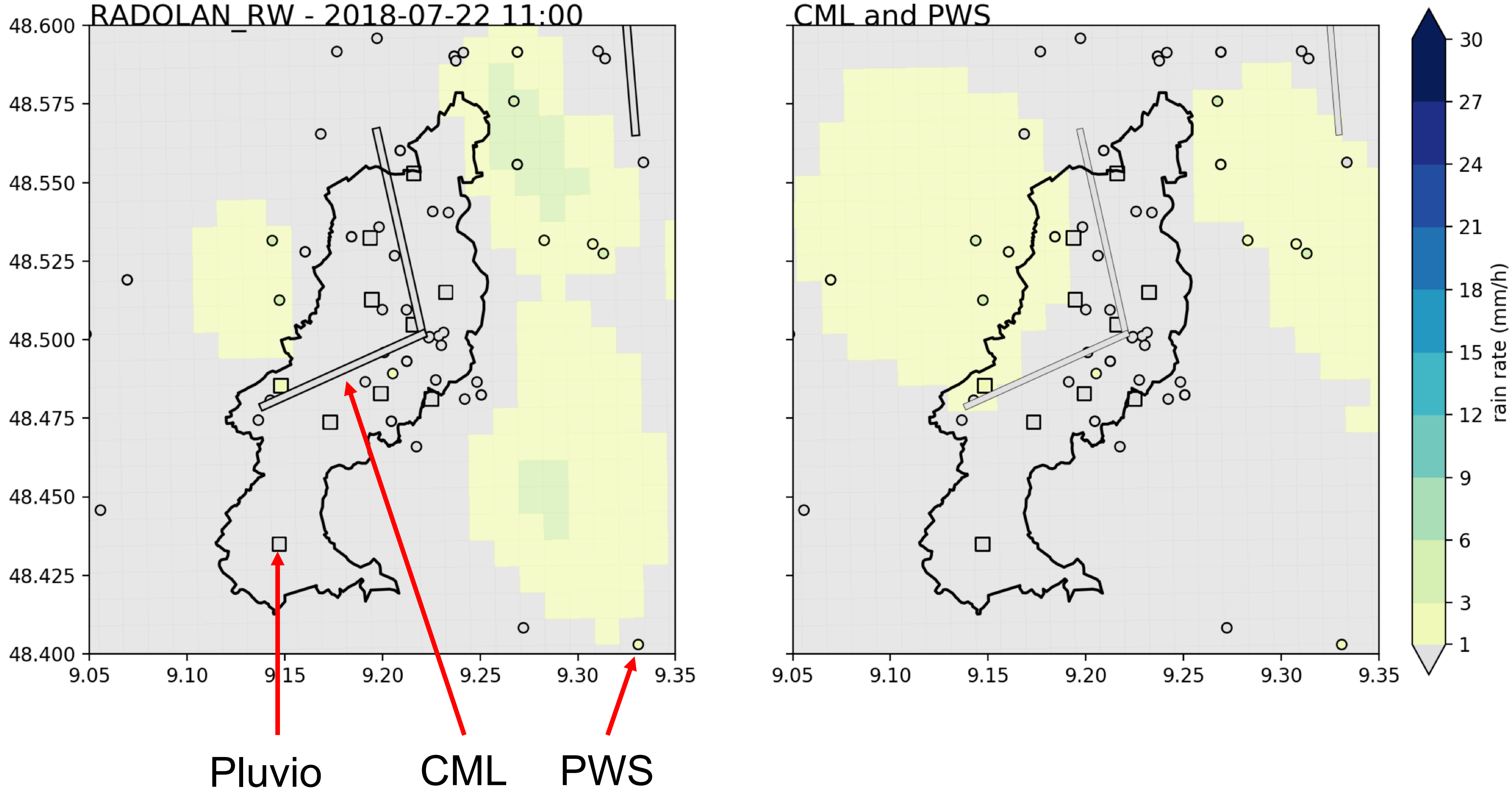
- with sparse spatial coverage (no gauge in the Figure), interpolated DWD gauges perform worse than OS for this local example
- OS and combinations perform similar good as radar products

→ while PWS have better correlation, CML improve the bias

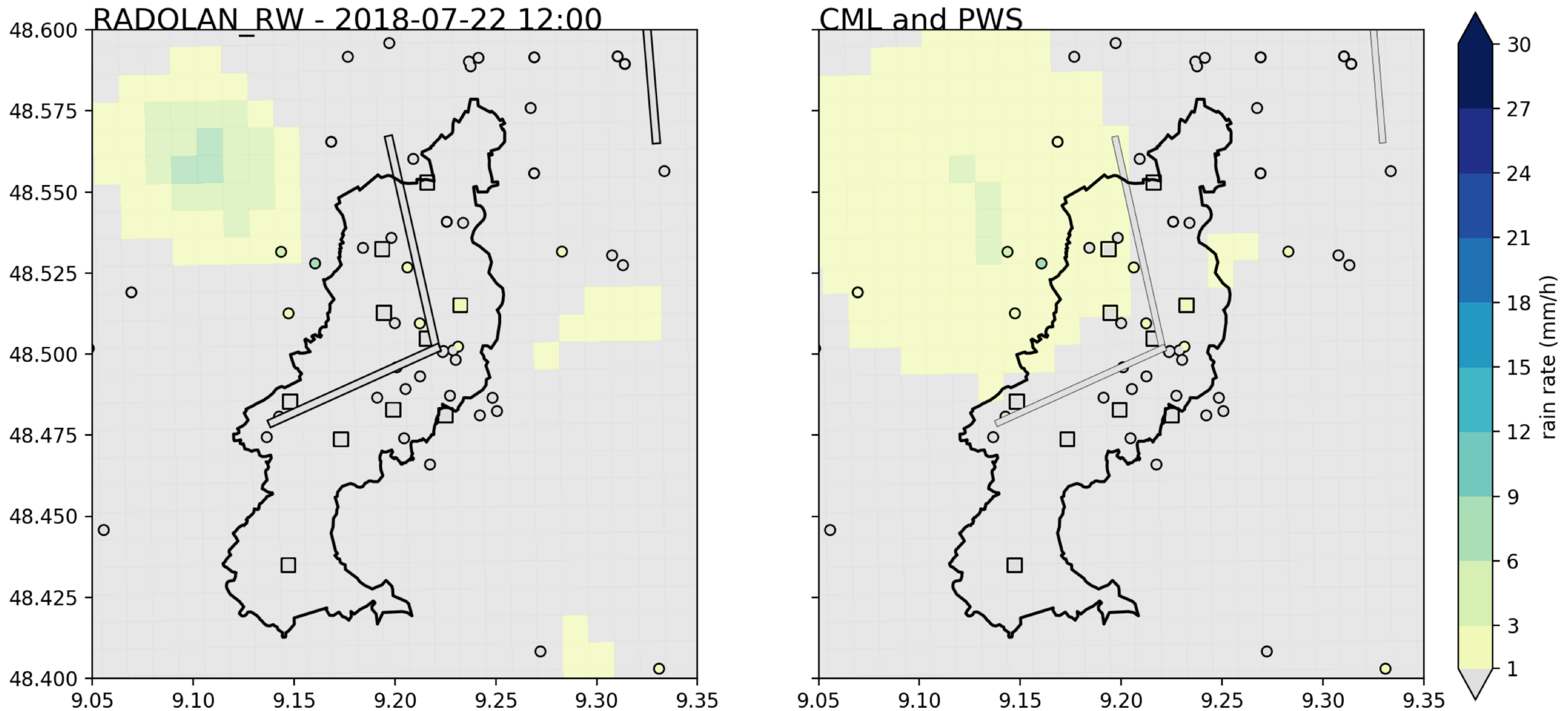
Map example country-wide



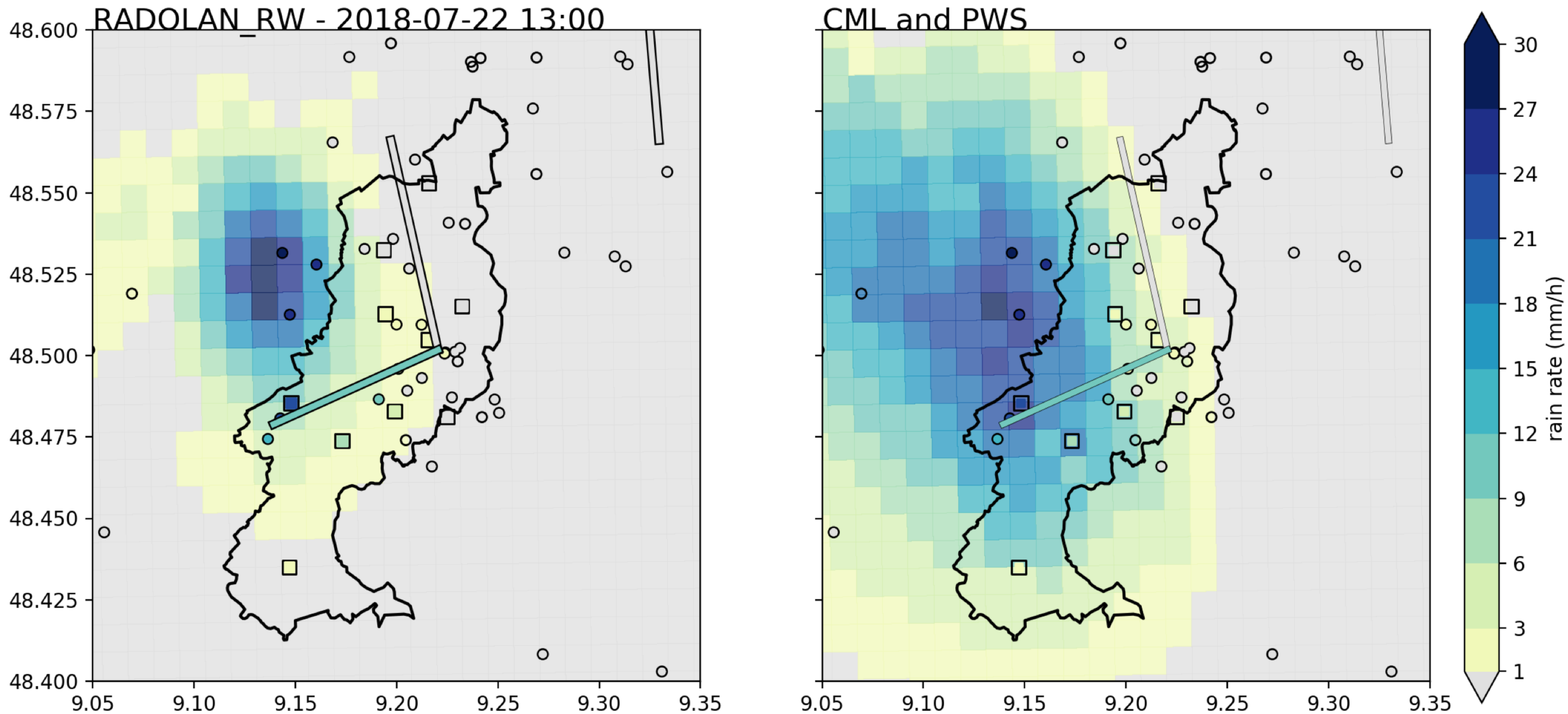
Example Reutlingen



Example Reutlingen



Example Reutlingen



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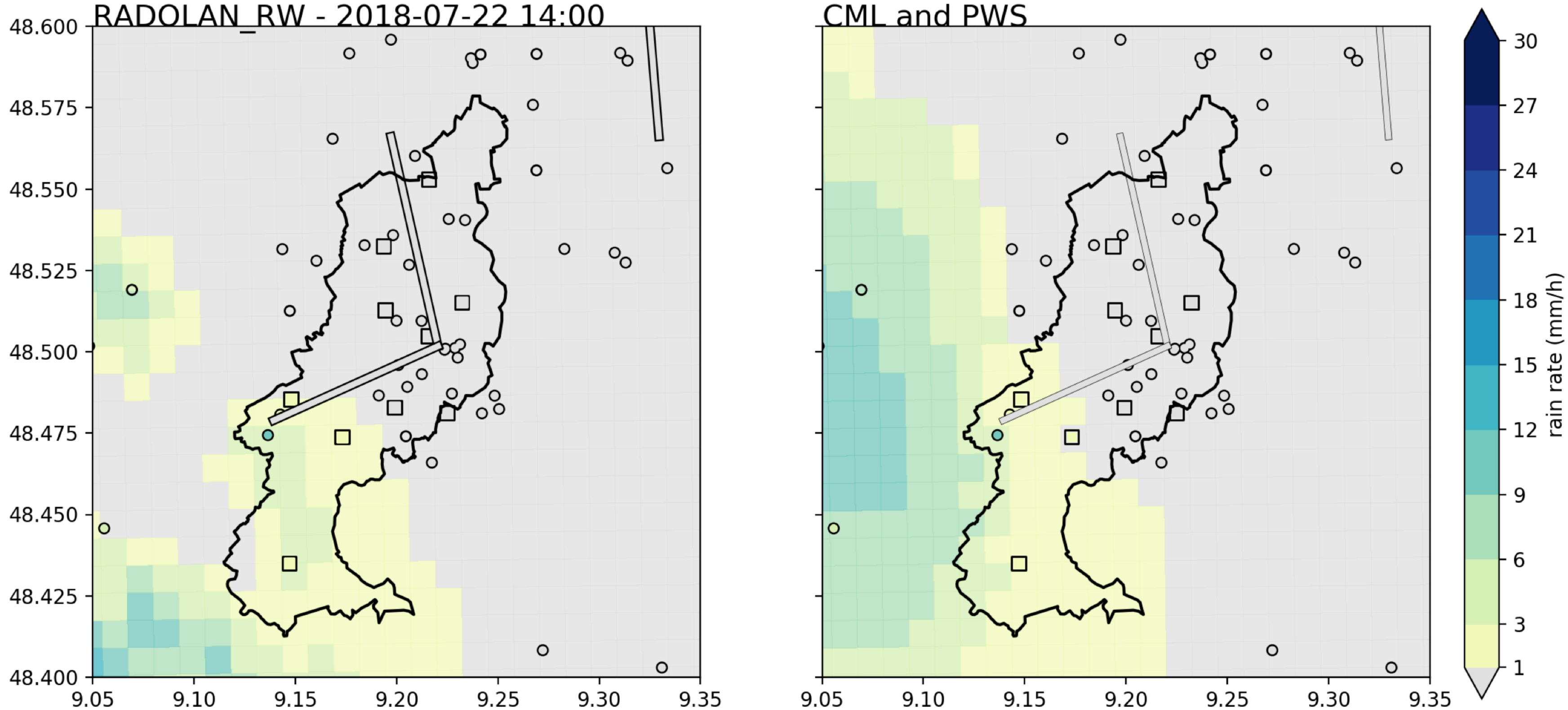

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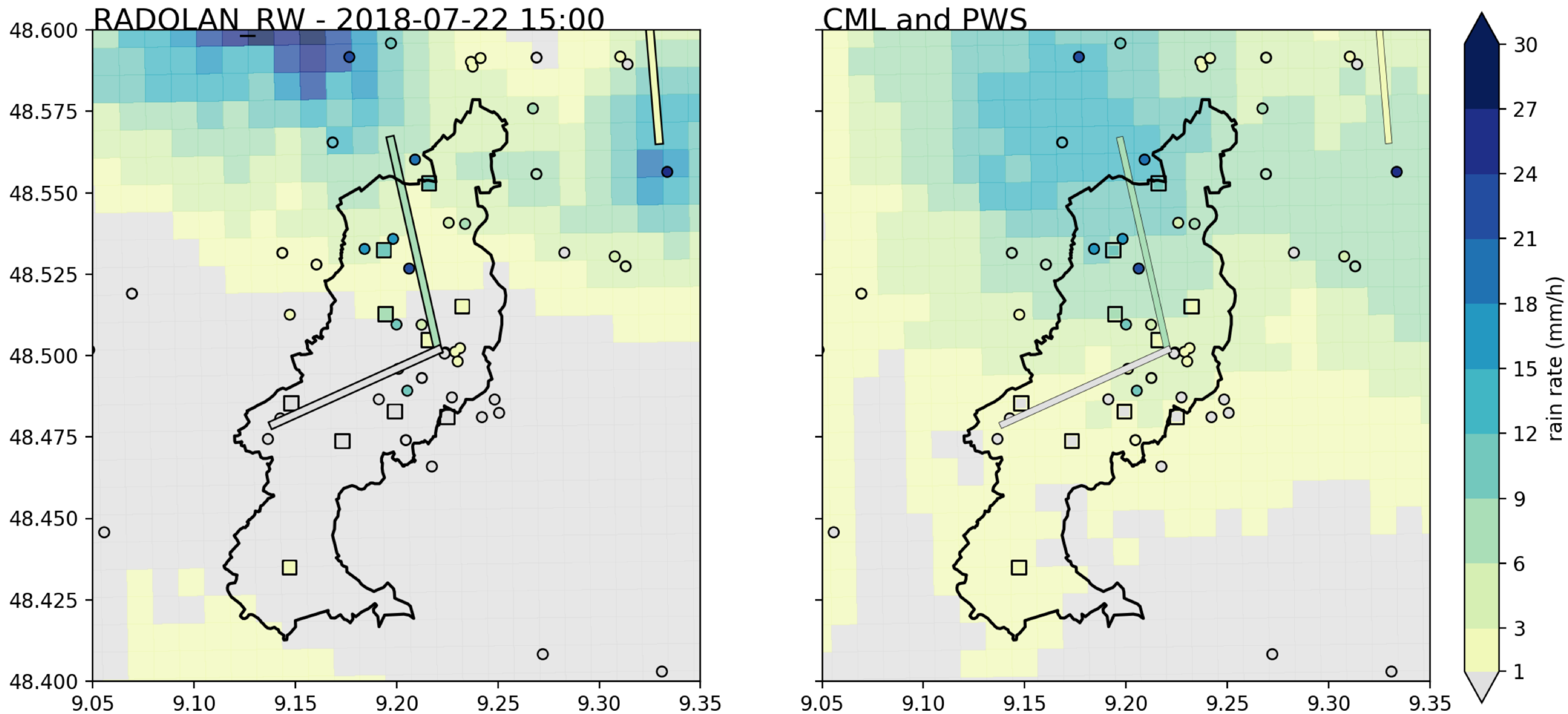

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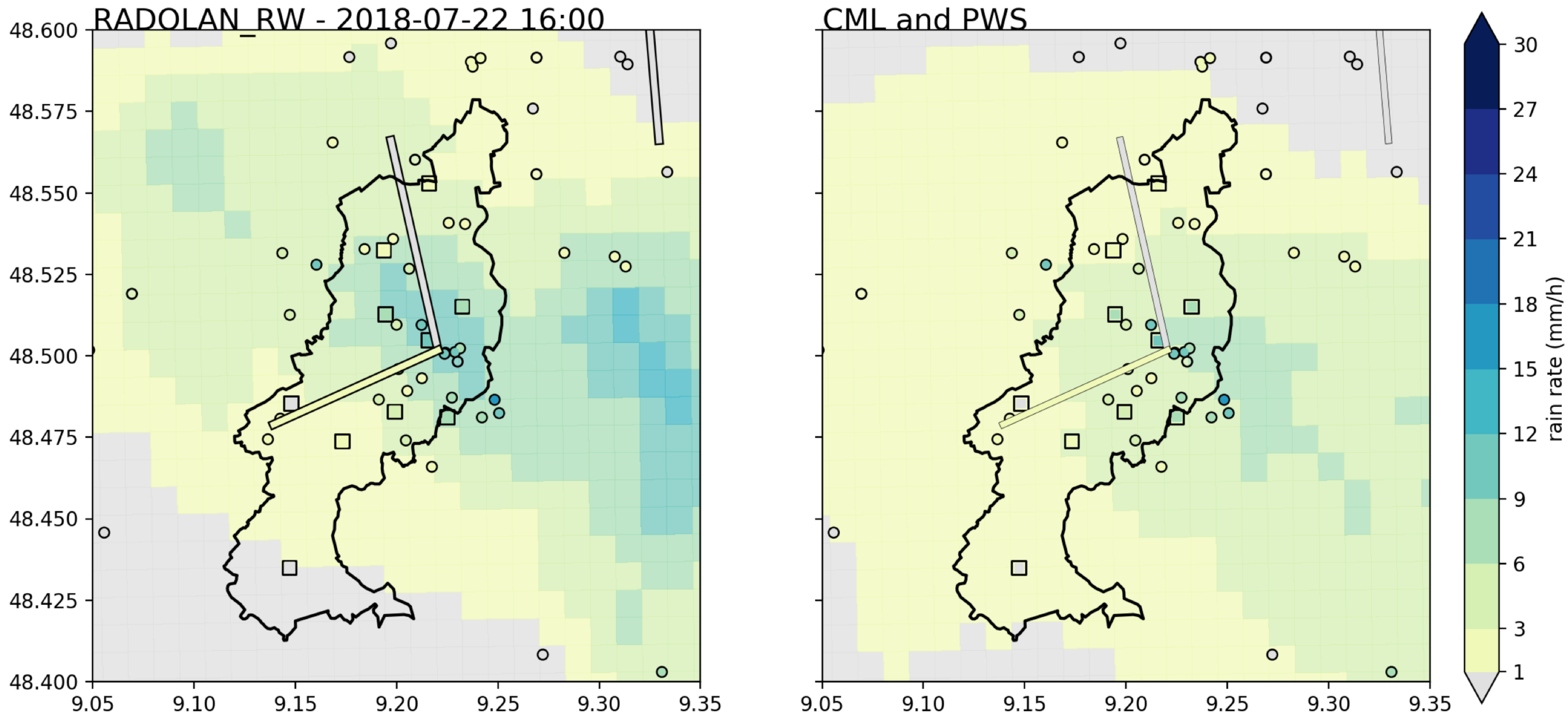

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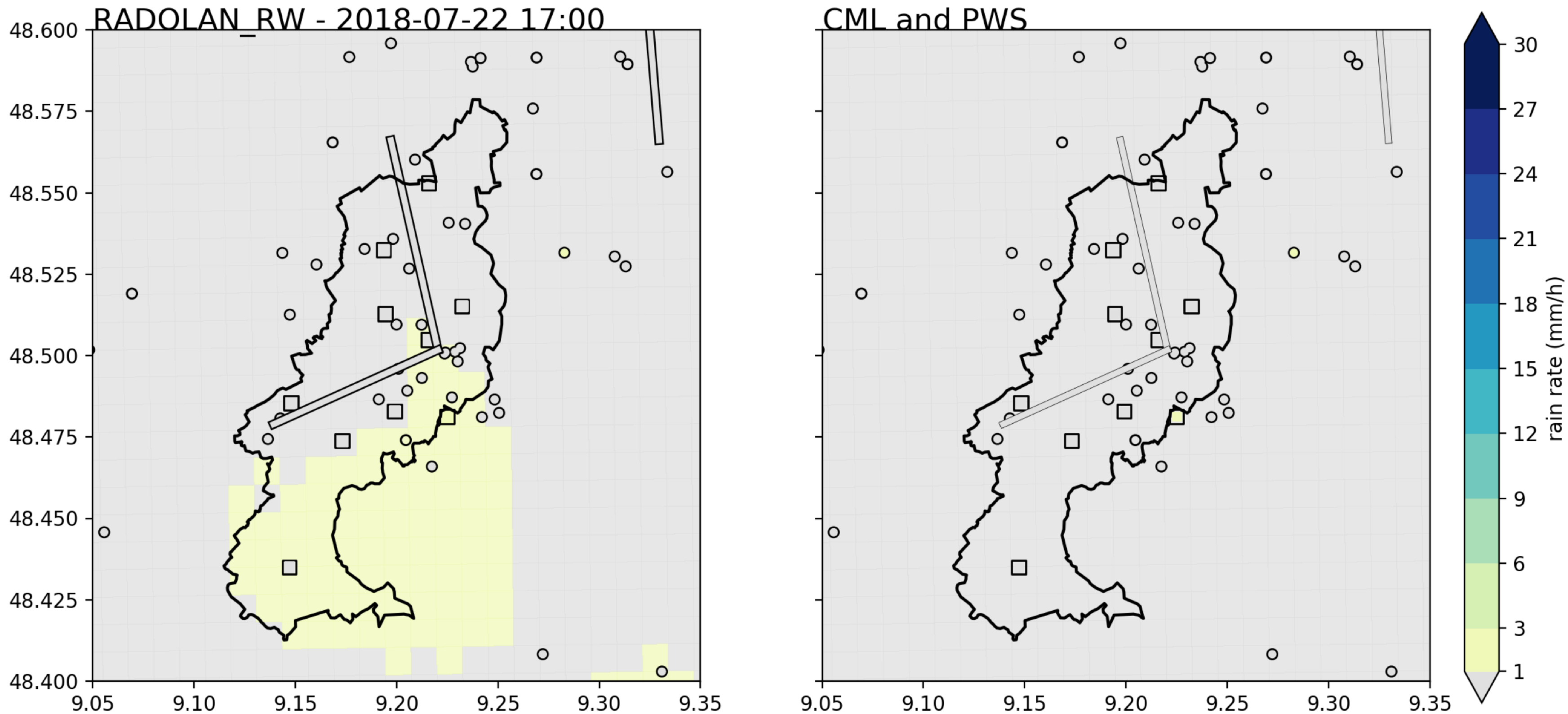
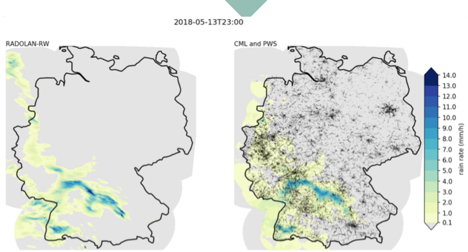


Conclusion

Goal
- Estimation of rainfall in Germany with opportunistic sensors

Challenge
- OS need extra care during quality control and processing

Results
- OS can yield rainfall estimates of reasonable high quality



Graf, M., El Hachem, A., Eisele, M., Seidel, J., Chwala, C., Kunstmann, H., & Bárdossy, A. (2021). **Rainfall estimates from opportunistic sensors in Germany across spatio-temporal scales.** *Journal of Hydrology: Regional Studies*, *37*, 100883.

Outlook

DFG proposal HiPOSY
High-resolution Precipitation Products from Opportunistic Sensors and their Impact on Hydrological Modelling

1. Improve OS sensor data quality control
2. Improve rainfall fields using OS data
3. Evaluate new rainfall products using hydrological modelling
4. Assess uncertainties using inverse hydrological modelling
5. Evaluate OS rainfall products with respect to rainfall statistics

Acknowledgments

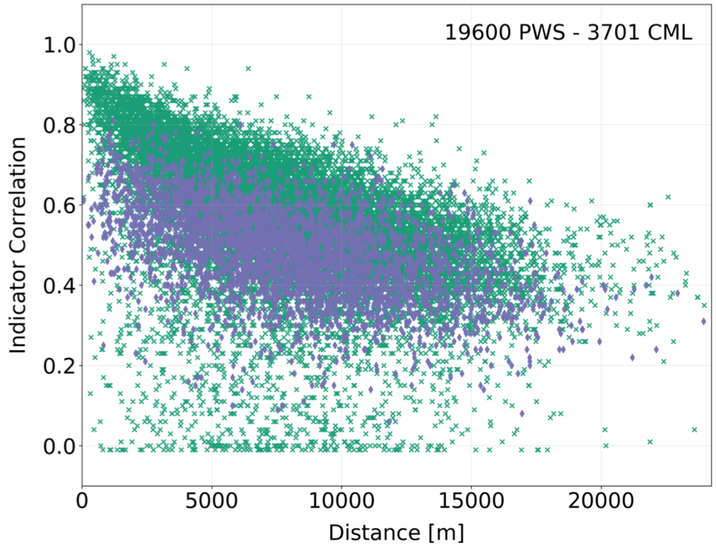
We want to thank Ericsson Germany, in particular the IT team, for their support with the CML data acquisition

and HGF, DFG and BMBF for funding and supporting our research.

Indicator correlation filter

indicator correlation (IC):

- rank correlation of individual PWS, CMLs or DWD_{auto} 99% quantile to their next neighbors
- PWS and CML are removed when their IC is lower then the IC with the next DWD_{auto} station



Assumption: even if the exact values are wrong, their rank within one sensor should be fine

Bias correction and event based filter

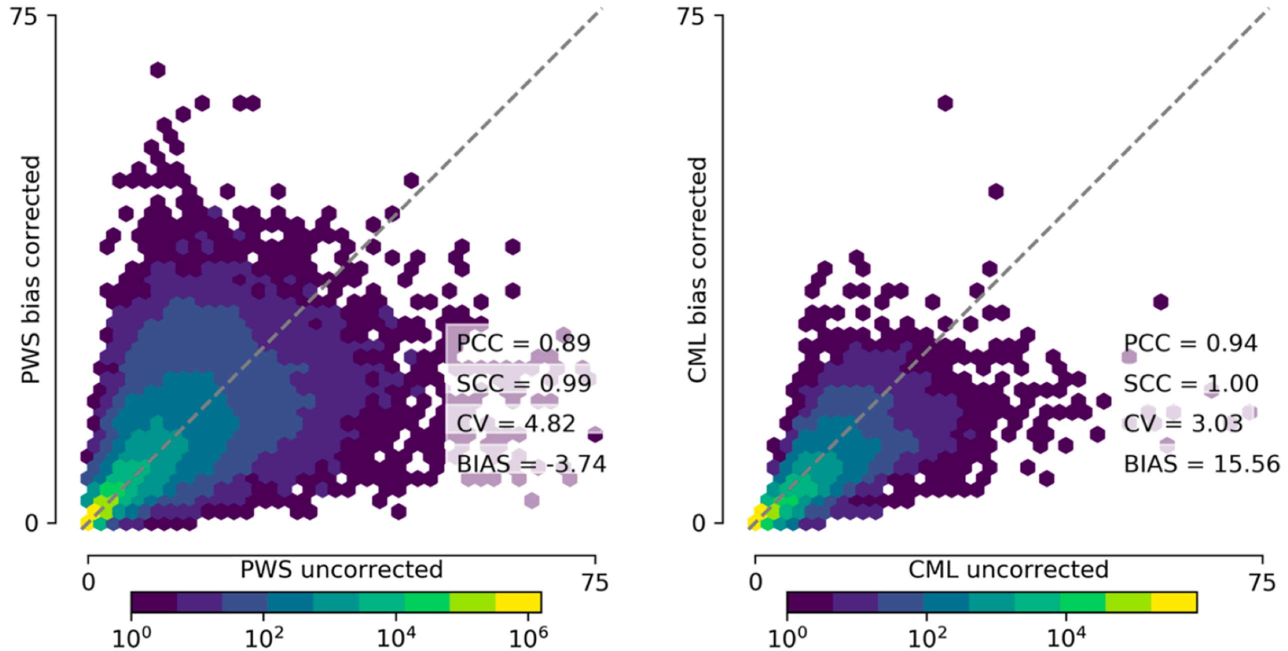


Fig. B1. Comparison of uncorrected and bias corrected hourly PWS and CML rain rates.

bias correction: precipitation distribution function of DWDauto are used to adjust OS values

event based filter: square root of each OS precip value is compare to the estimated variogram value of the next 30 DWD_{auto} gaugea in order to remove (mostly) faulty zeros

Interpolation Framework: (Block-) Kriging

Include uncertainty of opportunistic sensors

$$Z(x^*) = \underbrace{\sum_{i=1}^{n} \lambda_i Z(x_i)}_{\text{DWD}_{\text{auto}}} + \underbrace{\sum_{i=1}^{m} \alpha_i Z(y_i)}_{\text{PWS}} + \underbrace{\sum_{i=1}^{k} \beta_i Z(L_i)}_{\text{CML}}$$

$$\sum_{i=1}^{n} \lambda_i + \sum_{i=1}^{m} \alpha_i + \sum_{i=1}^{k} \beta_i = 1$$

Account for line characteristic of CMLs

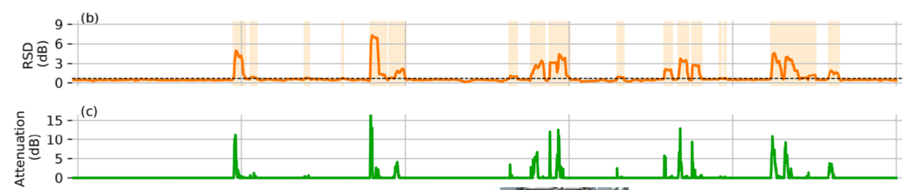
$$\bar{\gamma}(x_i, L_j) = \frac{1}{|L_j|} \int_{L_j} \gamma(x_i, u)\, du$$

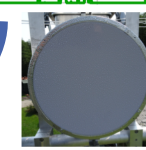
$$\bar{\gamma}(L_i, L_j) = \frac{1}{|L_i||L_j|} \int_{L_i} \int_{L_j} \gamma(u, v)\, du\, dv$$

abbreviation	input data
DWD_{int}	DWD_{auto}
PWS_{int}	PWS
CML_{int}	CML
$\text{DWD\_CML}_{\text{int}}$	DWD_{auto}, CML
$\text{DWD\_PWS}_{\text{int}}$	DWD_{auto}, PWS
$\text{PWS\_CML}_{\text{int}}$	PWS, CML
$\text{DWD\_PWS\_CML}_{\text{int}}$	DWD_{auto}, PWS, CML

CML processing

1. Remove erratic data
2. Rain event detection
3. Attenuation from baseline level
4. Compensate wet antenna attenuation
5. Derive rain rate





$$A = aR^b$$