Measuring rainfall from cellular communication networks for a 2.5-year period

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Royal Netherlands Meteorological Institute
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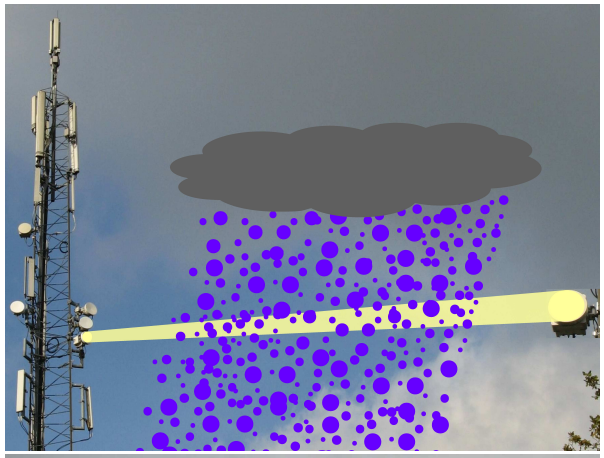
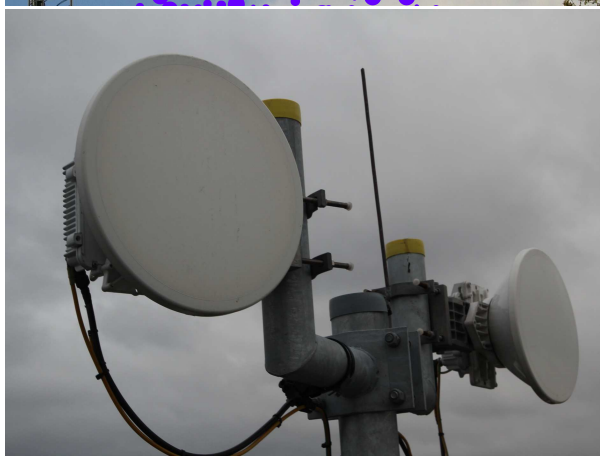
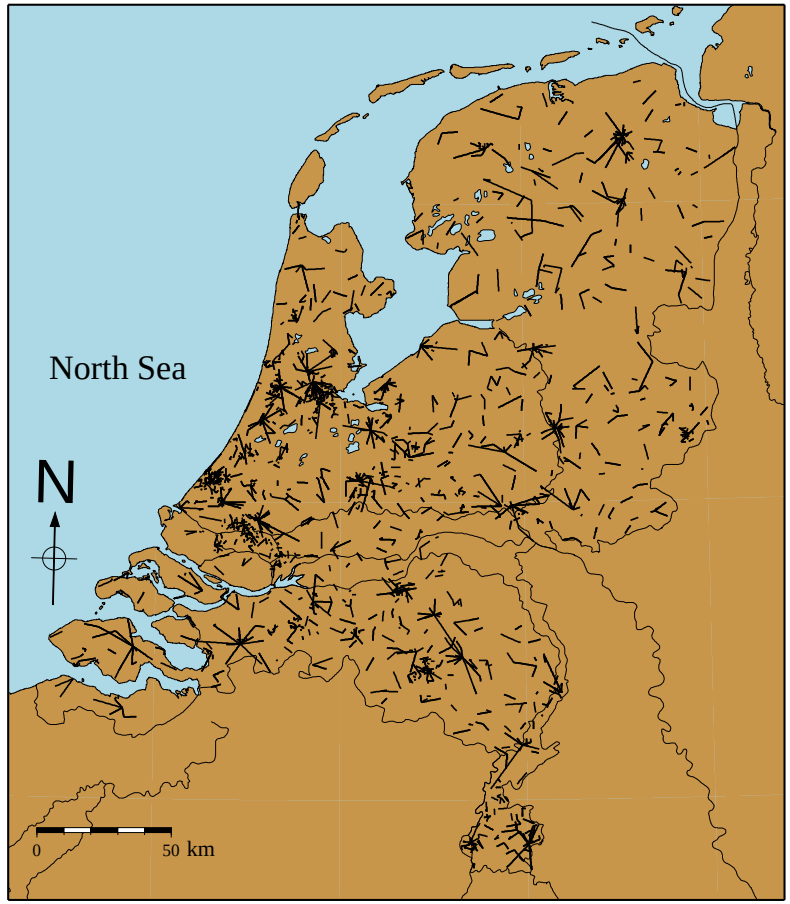
Outline

- Basic principle
- Data
- Method
- Results
- Applicability
- Conclusions

Basic principle - Estimate rain from attenuation



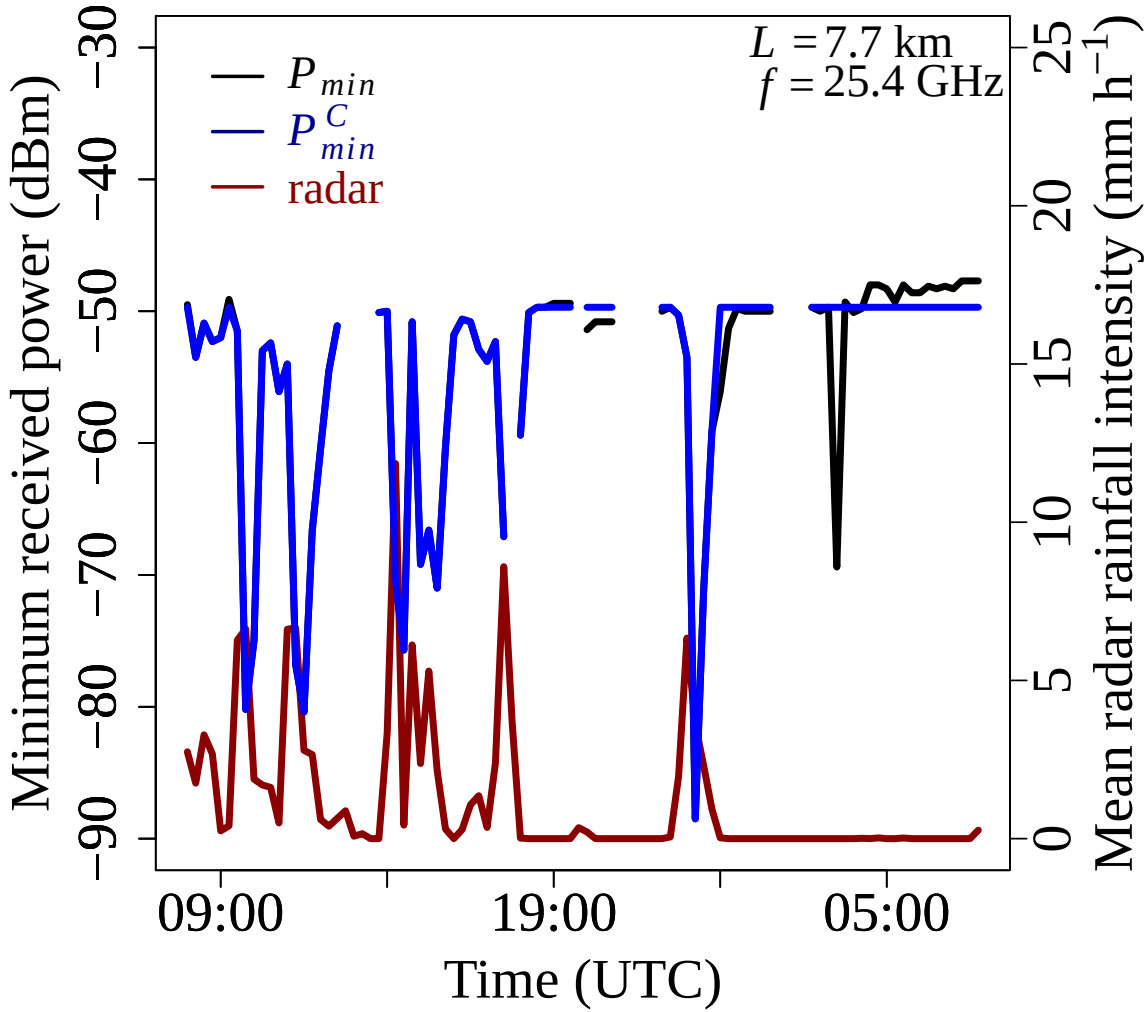




(Overeem *et al.*, 2013)

- Rainfall attenuates electromagnetic signals transmitted from the antenna of one telephone tower to another.
- Pioneers: Messer *et al.* (2006) and Leijnse *et al.* (2007).

Basic principle - Received power for one link



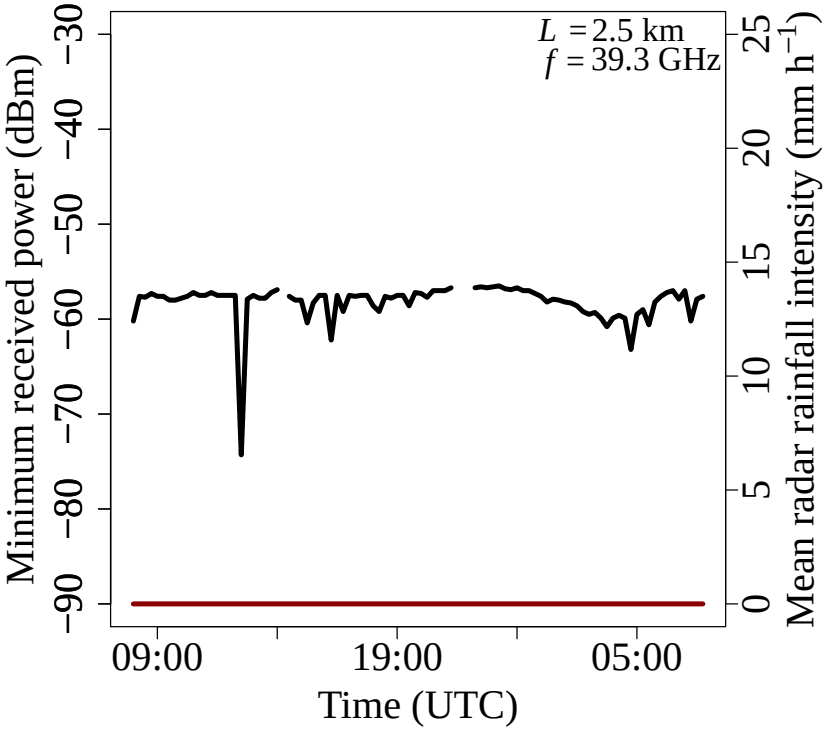
(Overeem *et al.*, 2011)

Radar rainfall intensity over link path ⇑, min received power over 15 min ⇓.

Basic principle

- Signal (P) loss with respect to dry weather.
- Compute path-average rainfall intensity over 15 min.

$$\langle R \rangle \approx a \cdot \left[\frac{(P_{ref} - P)}{L} \right]^b$$

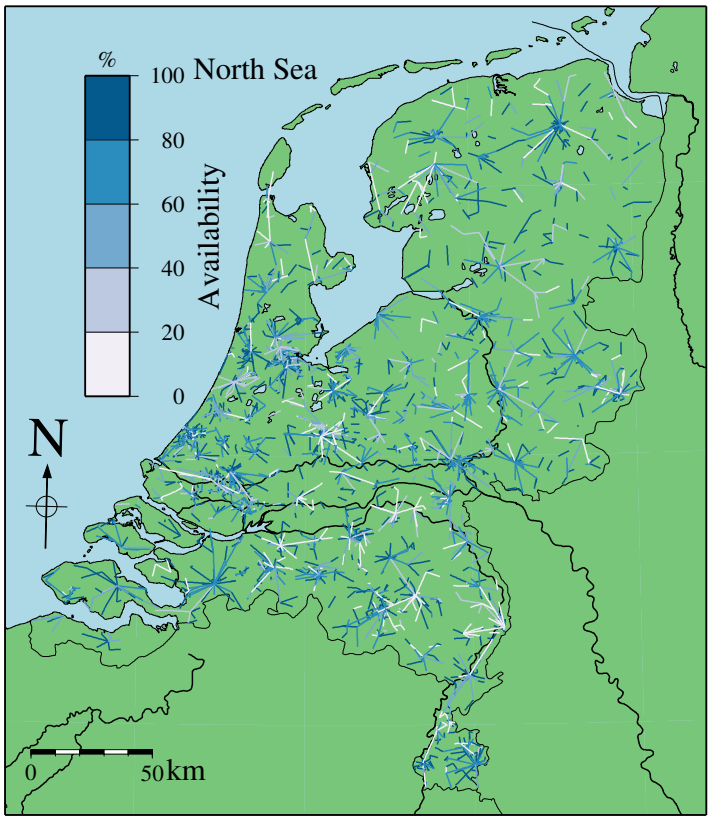


Challenges (a.o.):

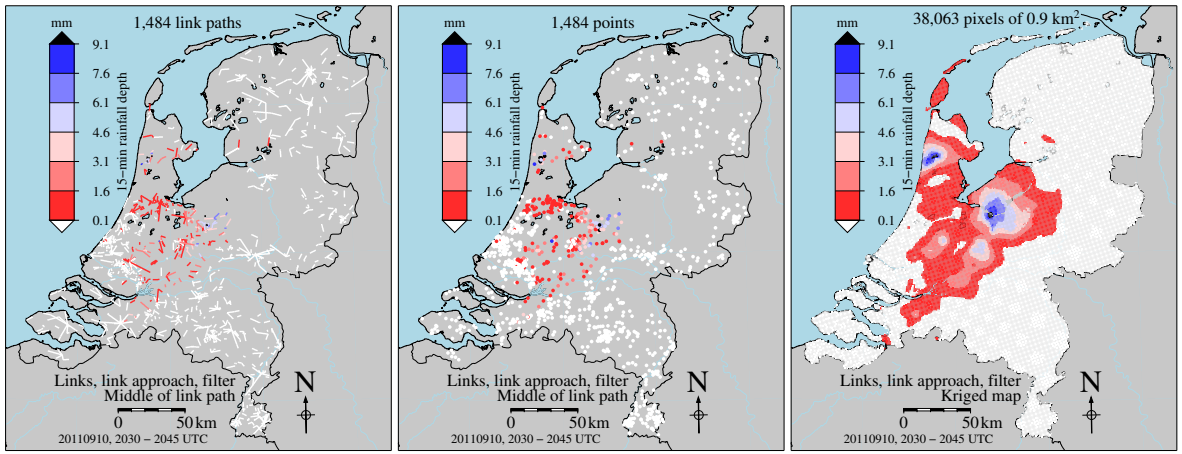
- Signal losses during dry weather.
- Hence, wet/dry classification = important (also for P_{ref}).
- Estimate mean rain rate from min and max power over 15 min.
- Attenuation due to wet antennas.

Data - Characteristics

Availability per link path:



- Resolution: 1 dB (majority) & 0.1 dB
- 12 days CAL + $\sim$ 894 days VAL
- Minimum and maximum powers over 15 min (10-Hz sampling)
- January 2011 - July 2013
- Gauge-adjusted radar data (CAL/VAL)
- On average $\sim$ 2000 link paths
- Netherlands: $\sim 3.5 \times 10^4$ km^2

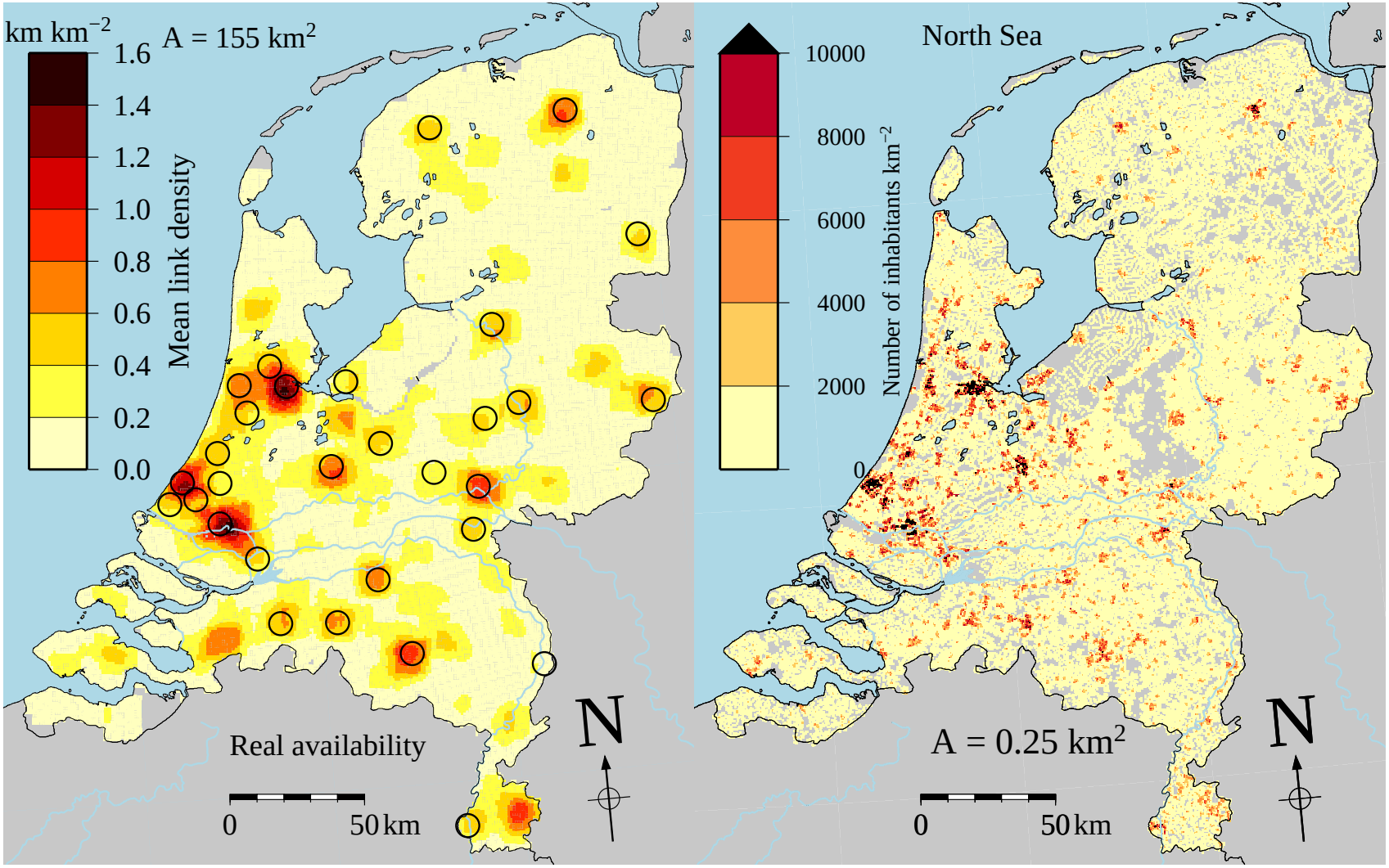


(Overeem *et al.*, 2015)

Data - Network & population density

Spatial density:

Number of inhabitants per km^2 at January 1, 2013:



County-wide average: 0.21 km km^2

Method

- A 15-min period is wet if nearby links show a mutual decrease in minimum received powers.
- Correction for signal fluctuations during dry weather. Reference signal level is determined. Apply filter to remove outliers.
- Calculate mean rainfall intensity from P^C_{min} and P^C_{max}.

$$A_{min} = P_{ref} - P^C_{max} \tag{1}$$

$$A_{max} = P_{ref} - P^C_{min}$$

$$\langle R \rangle = \alpha \cdot a \left(\frac{A_{max} - A_a}{L} \right)^b + (1 - \alpha) \cdot a \left(\frac{A_{min} - A_a}{L} \right)^b \tag{2}$$

$$\langle R \rangle = \alpha \langle R_{max} \rangle + (1 - \alpha) \langle R_{min} \rangle \tag{3}$$

Calibrate rainfall retrieval algorithm with daily radar rainfall depths.

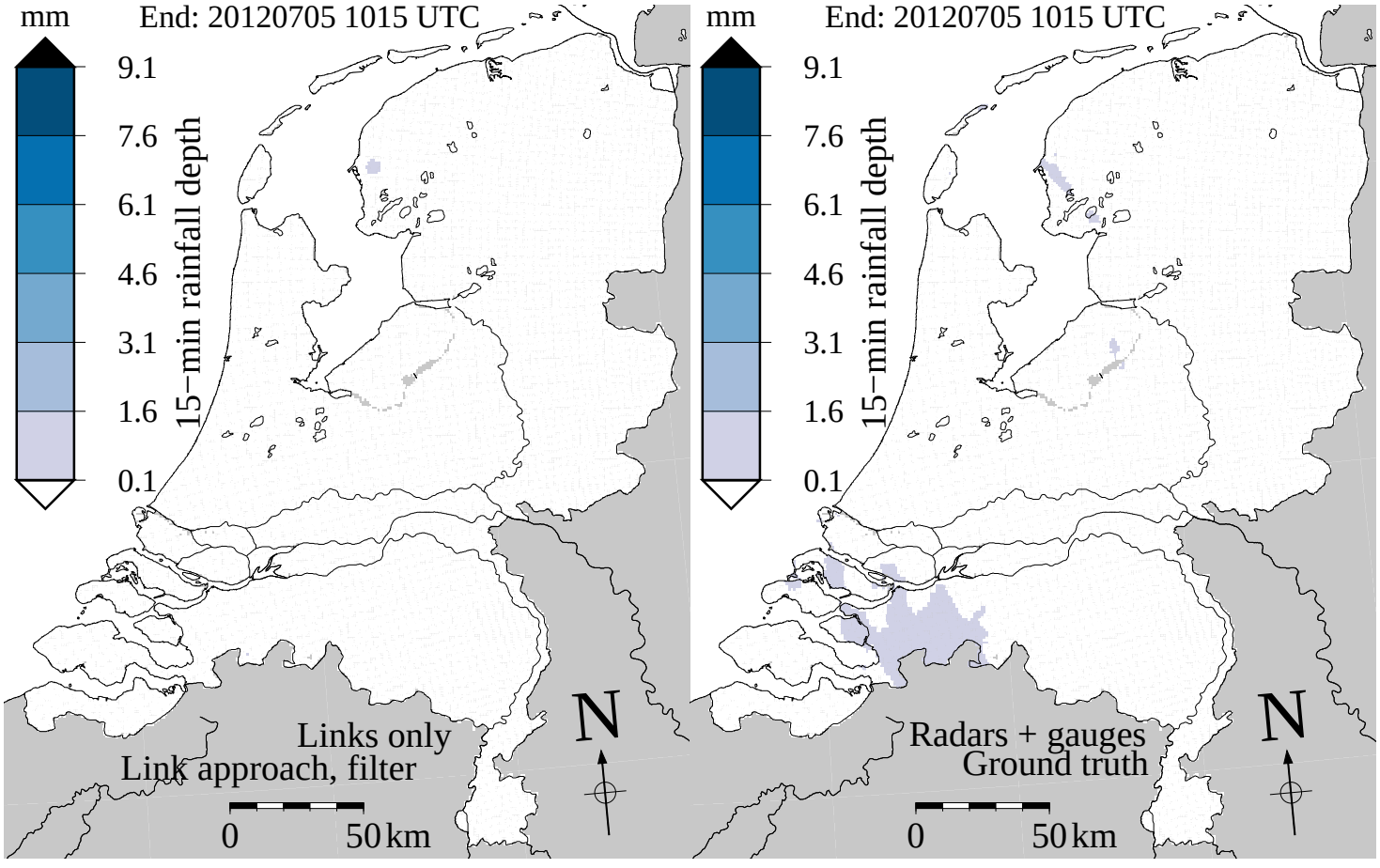
$A_a = 2.3$ dB

$\alpha = 0.335$

$b = 0.81$ - 1.06 (13-40 GHz)

12-day calibration data set

Results - 15-min rainfall maps

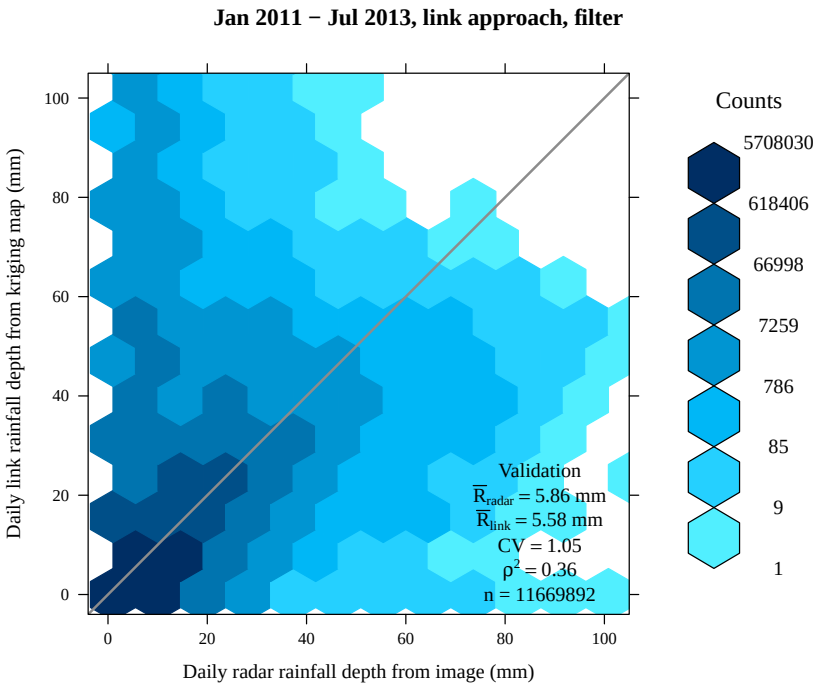


Links only (kriged map)

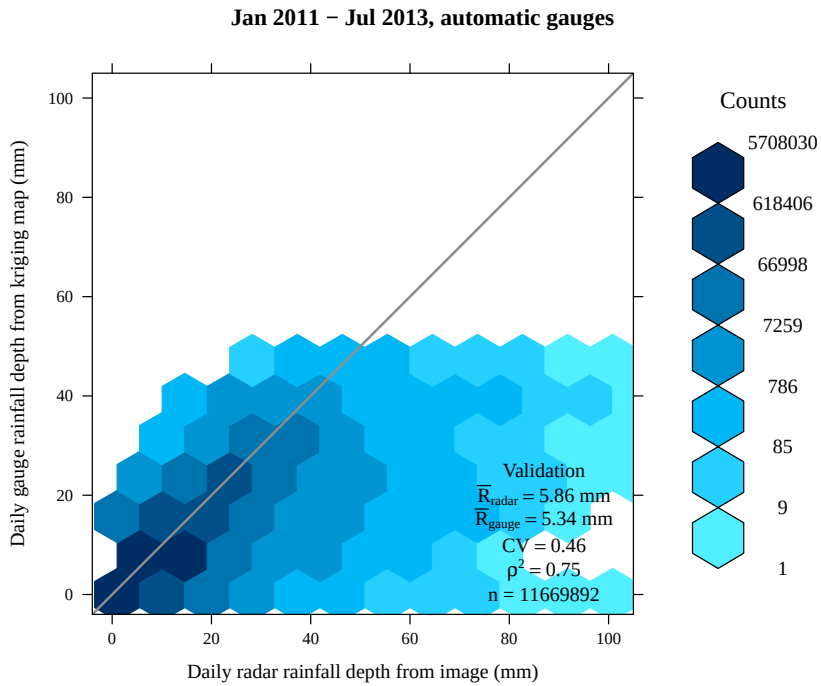
Radars + gauges

Results - Scatter density plots daily rainfall map

Links only:



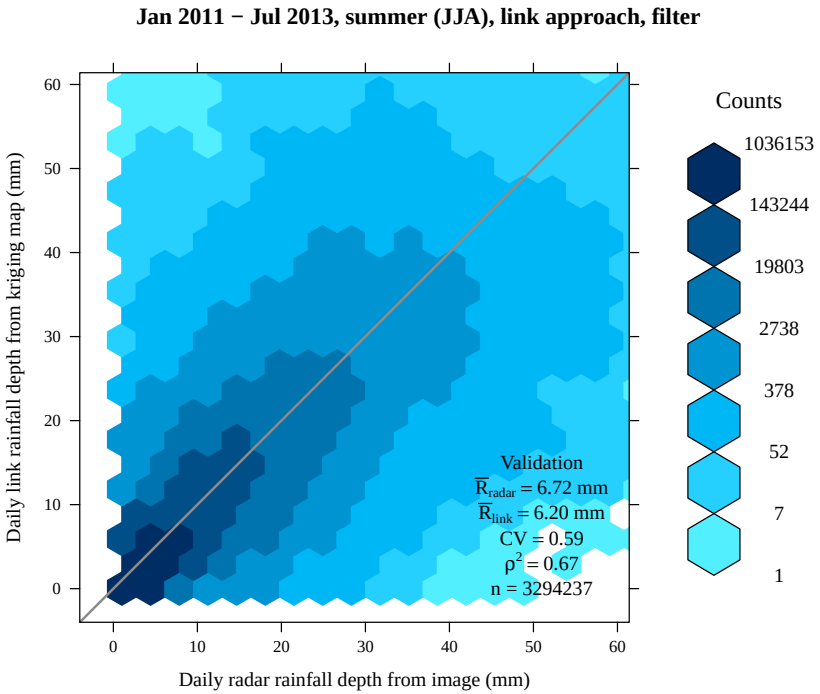
Automatic rain gauges:



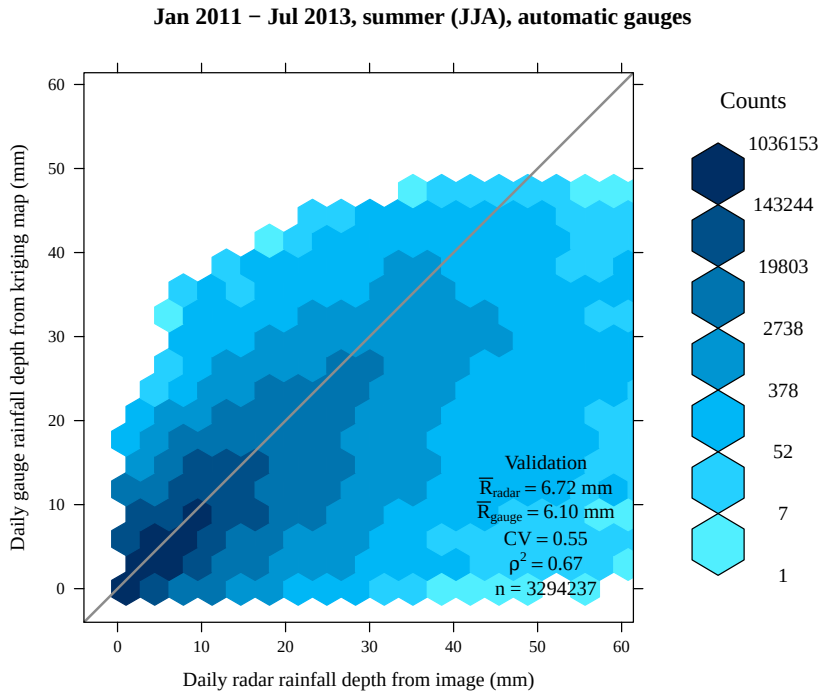
- Entire 2.5-year period.
- Verification against gauge-adjusted radar rainfall maps.
- Less extremes captured by 30 rain gauges compared to 2000 microwave links.

Results - Scatter density plots daily rainfall map

Links only:



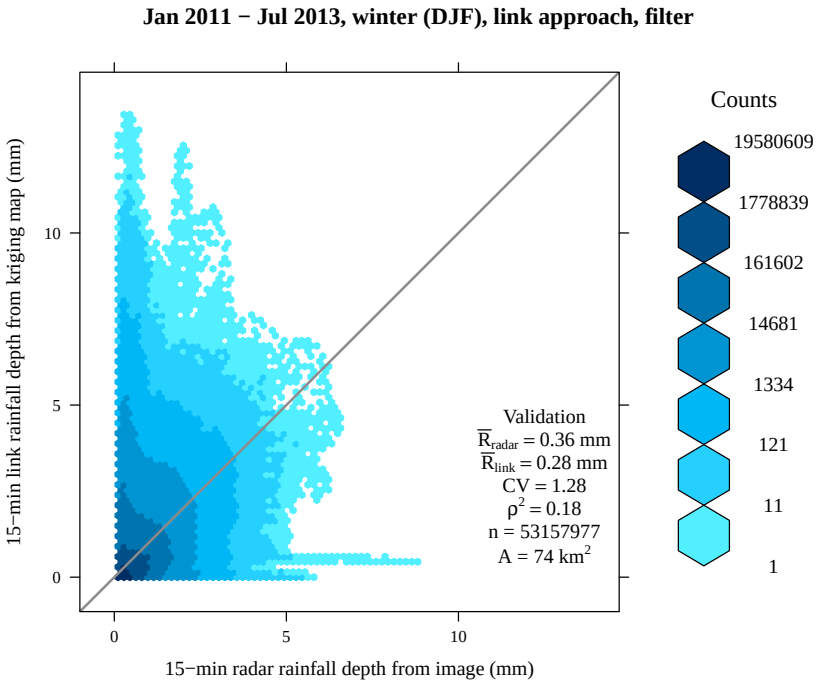
Automatic rain gauges:



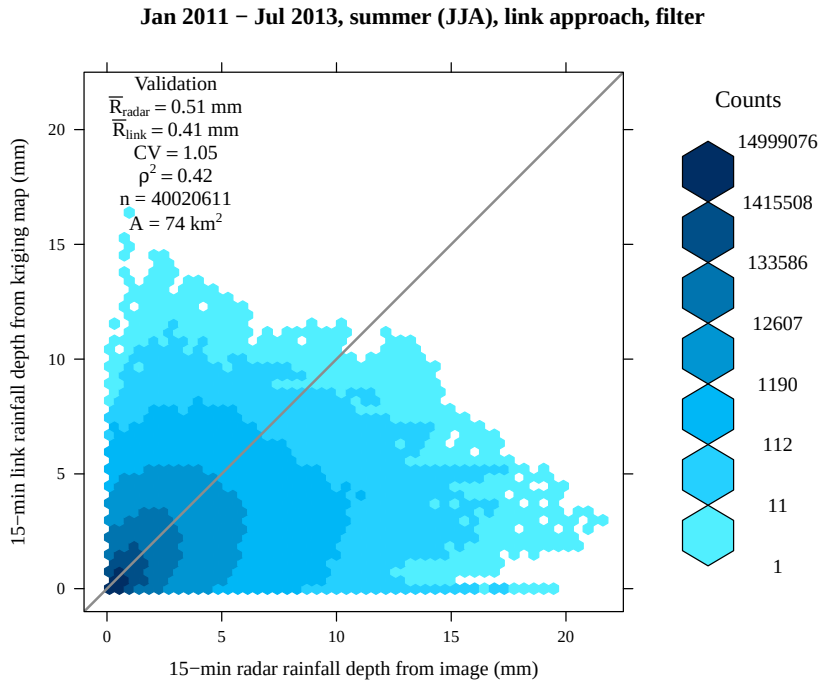
- Summer months.
- Verification against gauge-adjusted radar rainfall maps.

Results - Scatter density plots 15-min rainfall map

Winter:

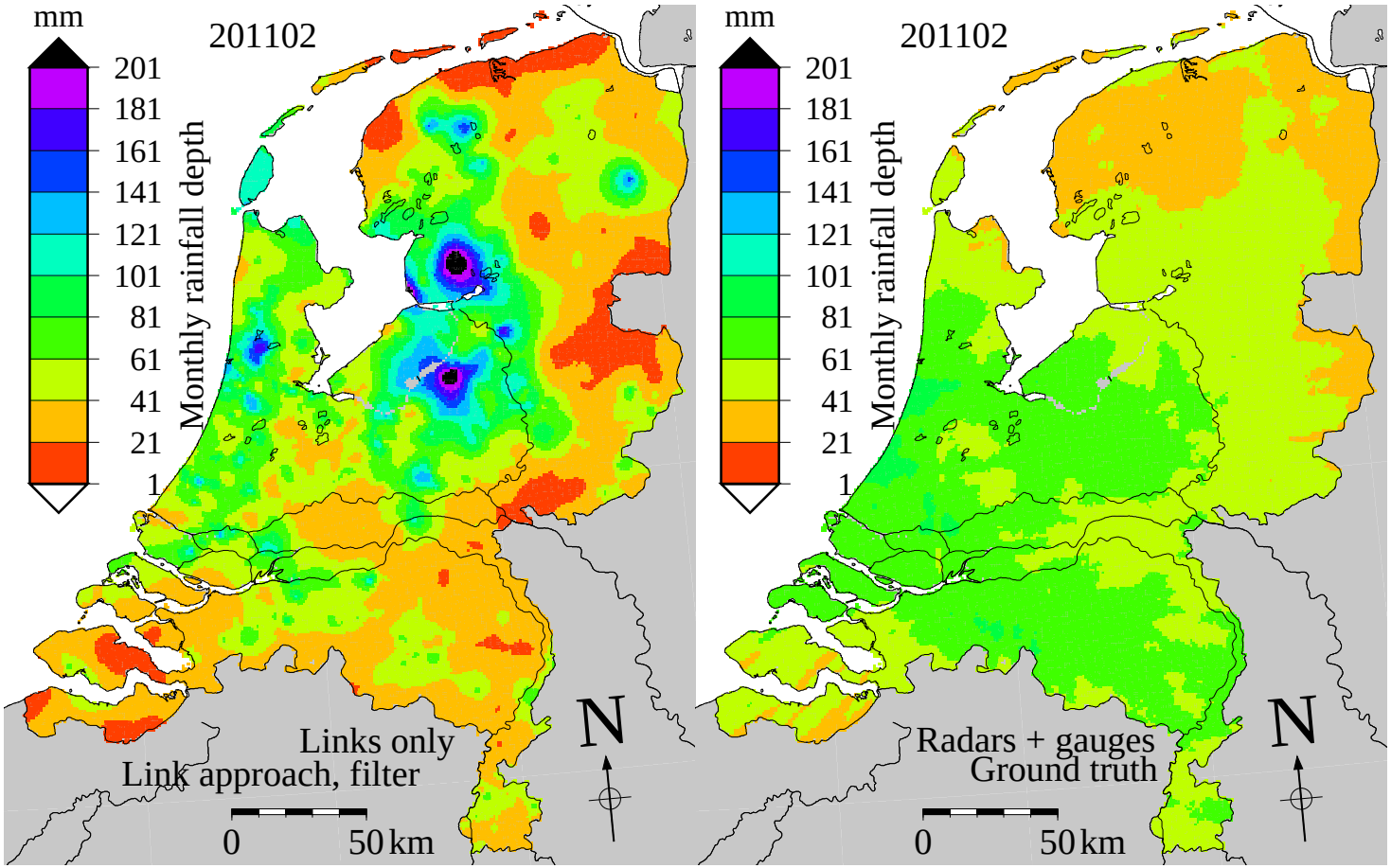


Summer:



- Verification against gauge-adjusted radar rainfall maps.

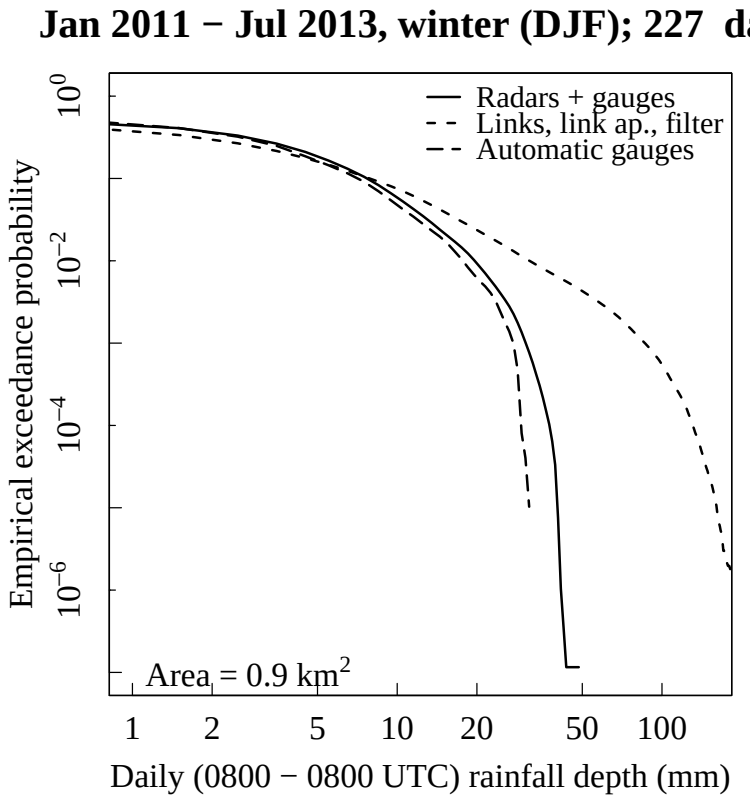
Results - Monthly rainfall maps Feb 2011 - Jul 2013

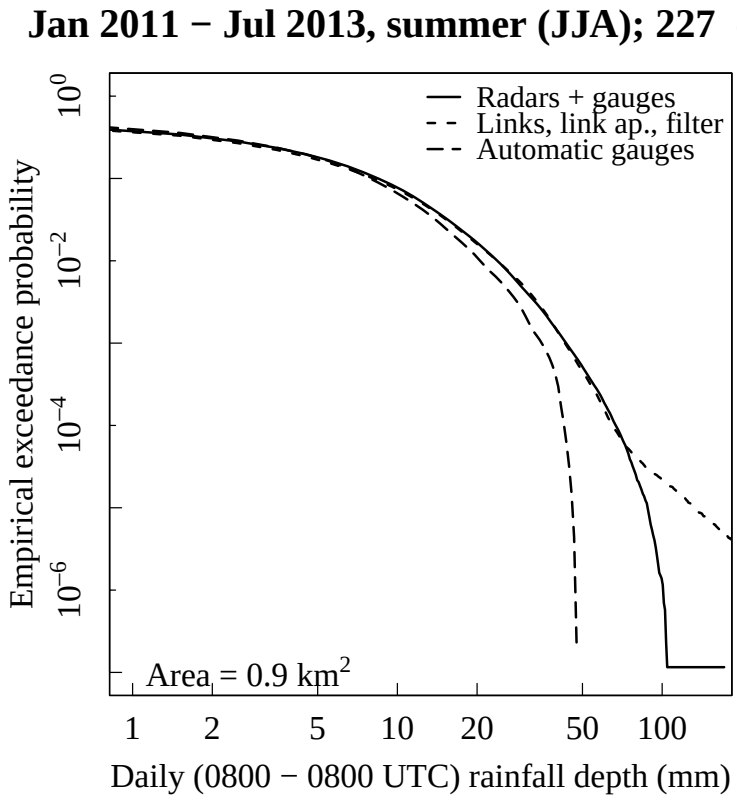


Links only (kriged map)

Radars + gauges

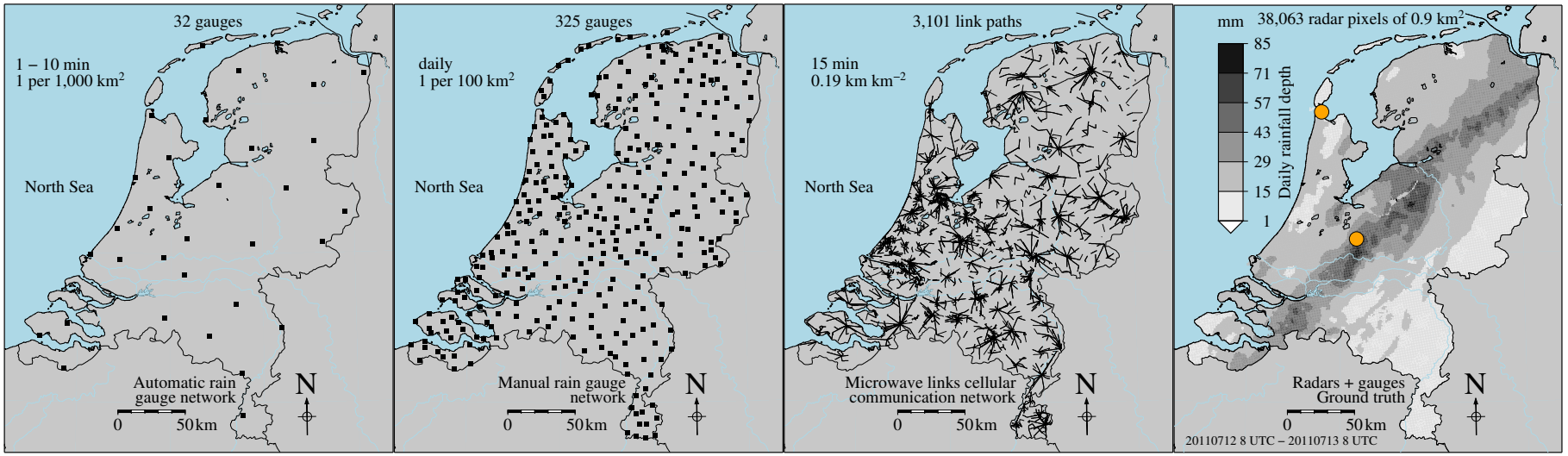
Results - Empirical exceedance probabilities daily rainfall



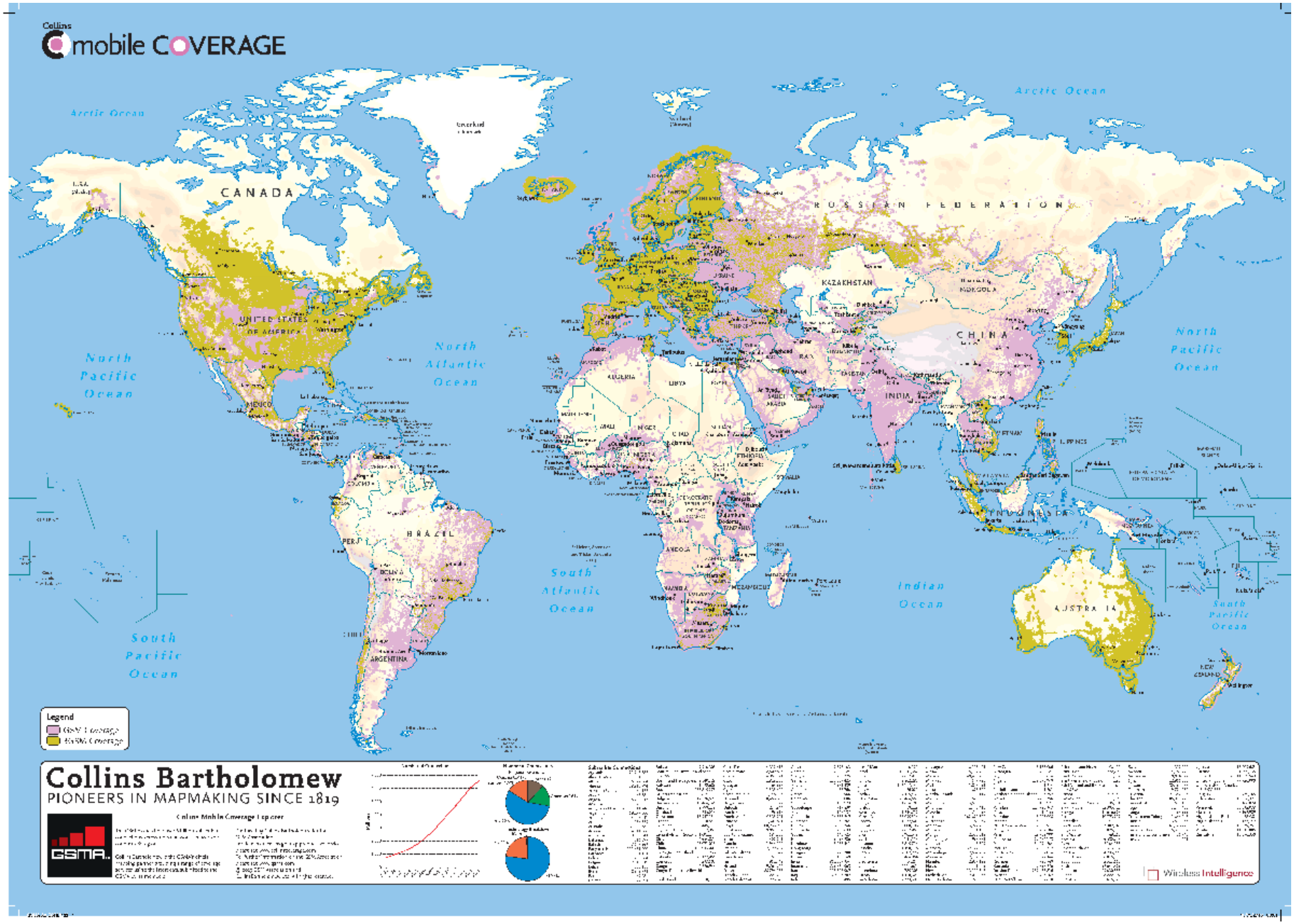


- Up to tens of mm quite good correspondence for links in winter with respect to radars + gauges. Large deviations for higher thresholds.
- Good correspondence for links in summer with respect to radars + gauges. Better than rain gauges, probably because of higher network density.

Applicability - Number of rain gauges, links, and radars



Applicability - World map of cellular telephone coverage



Conclusions

- Cellular communication network not originally designed to measure rainfall!
- Rainfall maps from microwave links often correspond quite well with radar-based maps.
- In summer: Quality comparable to maps from automatic rain gauges (1 gauge per 1000 km^2).
- Potential for improving flood early warning, validation of satellite QPE, et cetera.
- Application to long time series for other networks and climates necessary.
- Improve understanding and algorithm (e.g. by experimental research; EMS2015-158).

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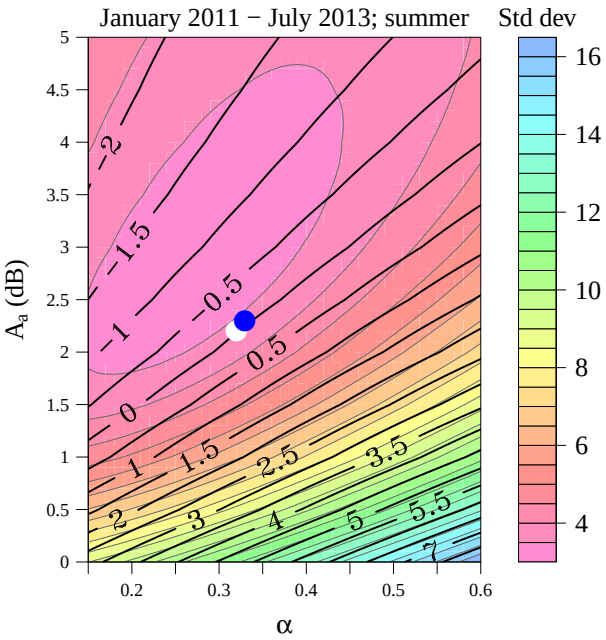
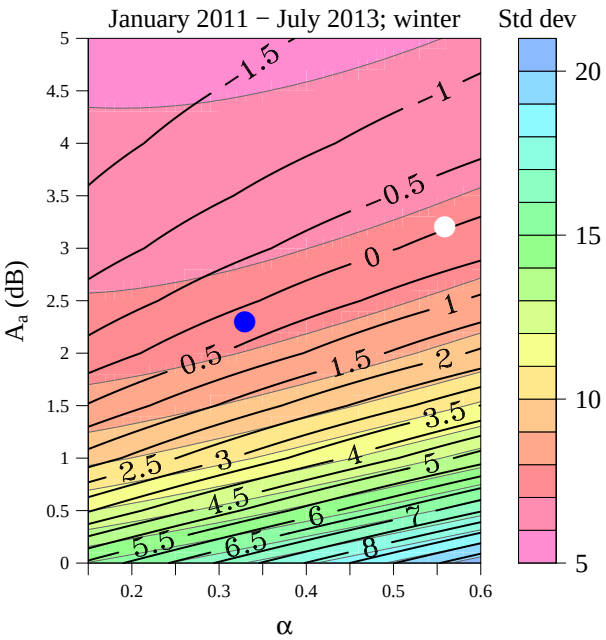
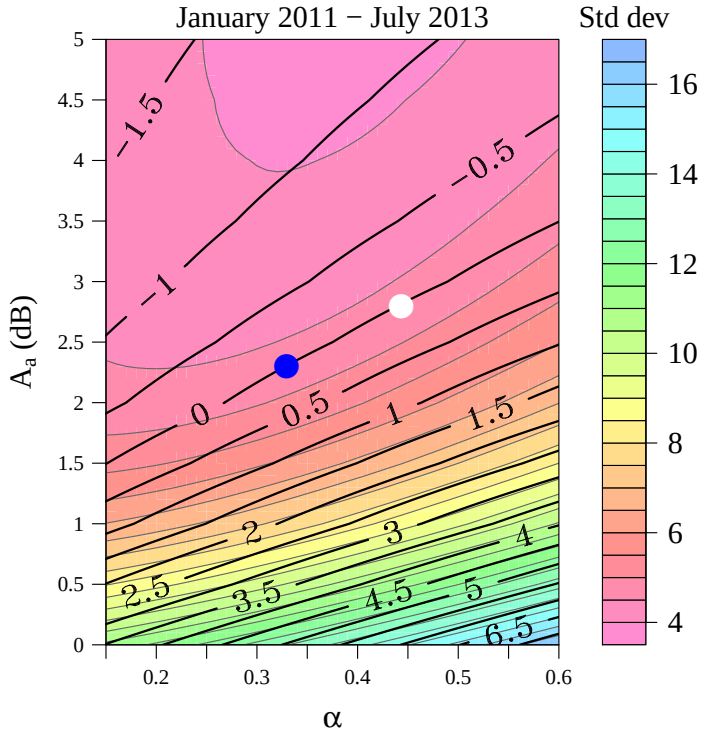
- H. Leijnse, R. Uijlenhoet, J.N.M. Stricker, 2007. Rainfall measurement using radio links from cellular communication networks, *WRR*.
- H.A. Messer, A. Zinevich, P. Alpert, 2006. Environmental monitoring by wireless communication networks, *Science*.
- A. Overeem, H. Leijnse, R. Uijlenhoet, 2013. Country-wide rainfall maps from cellular communication networks, *PNAS*.
- A. Overeem, H. Leijnse, R. Uijlenhoet, 2015. Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, *AMTD*.

Sensitivity analysis coefficients A_a and α







- Blue dot: values for 12-day data set. Red dot: optimal value for entire period.
- Performance rainfall retrieval algorithm relatively insensitive to chosen values for α and A_a.