Ground-based remote sensing of precipitation for hydrological applications

Remko Uijlenhoet

Hydrology and Quantitative Water Management Group

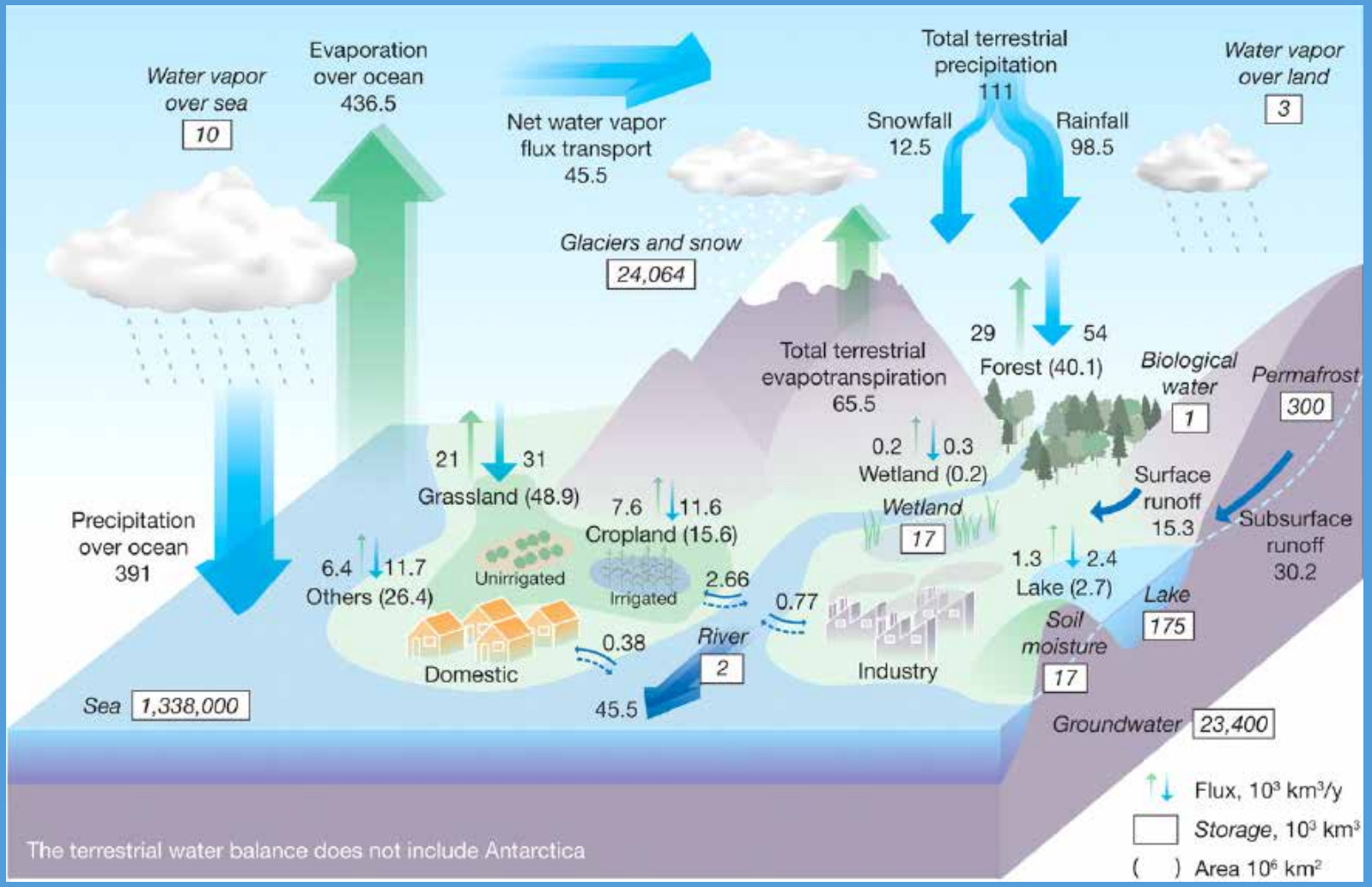
WAGENINGEN UNIVERSITY
WAGENINGEN UR

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

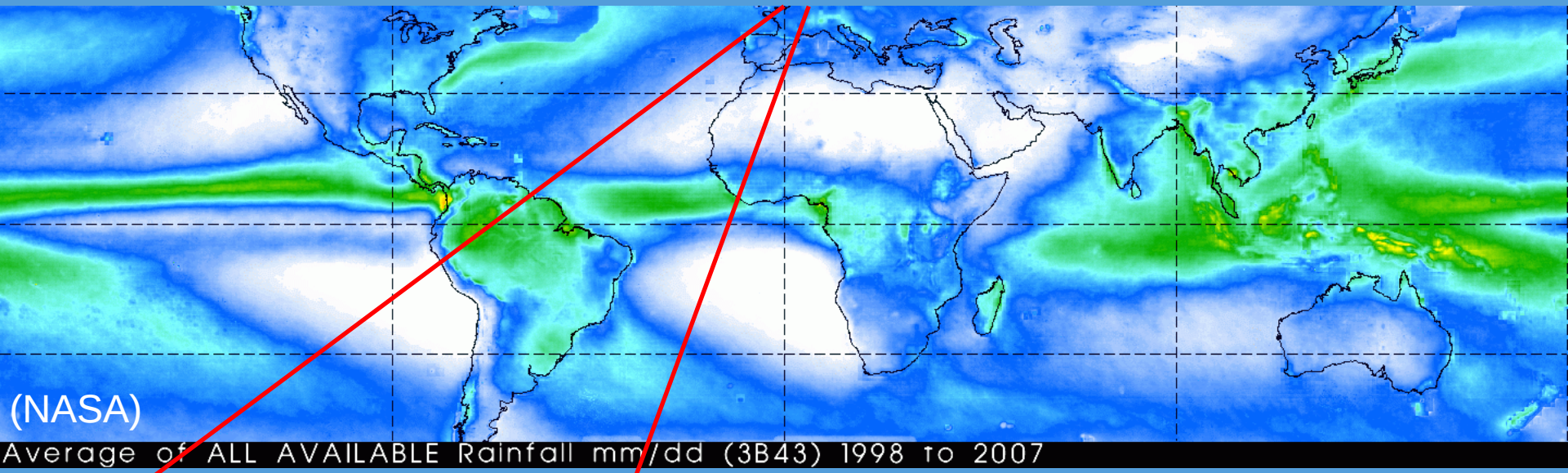
Why should hydrologists care about rainfall in the first place?

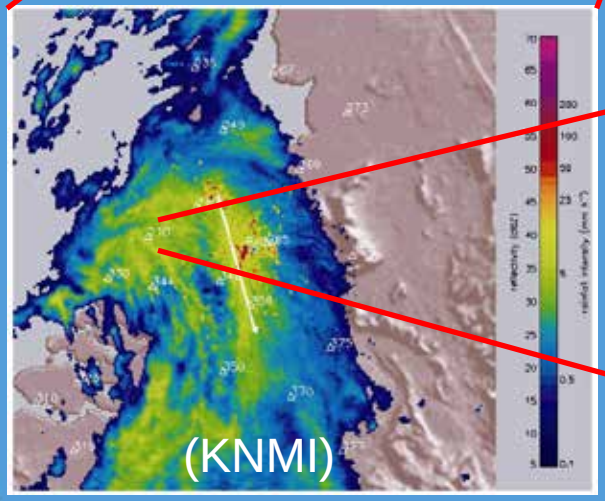
(Victoria Roberts, 2000)

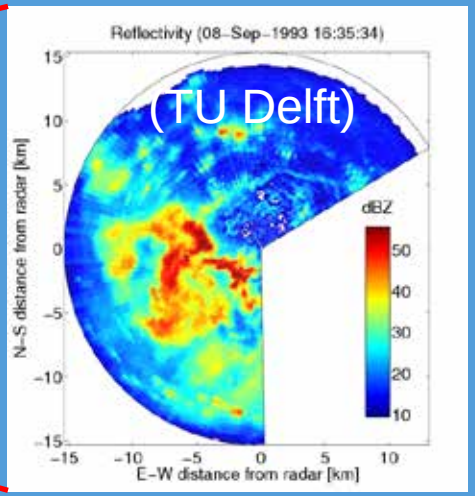
Stores and fluxes of water on earth



Rainfall variability over a range of scales



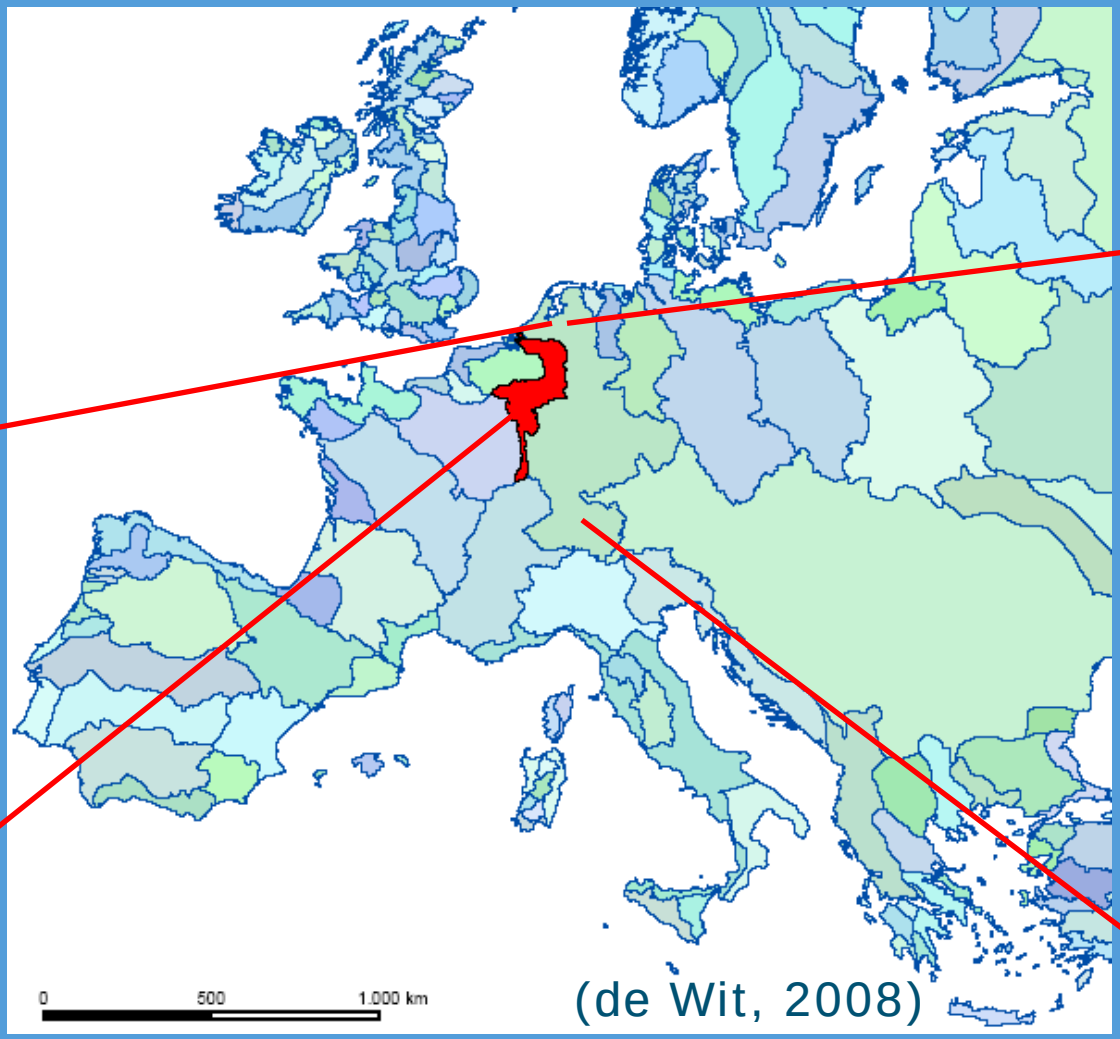


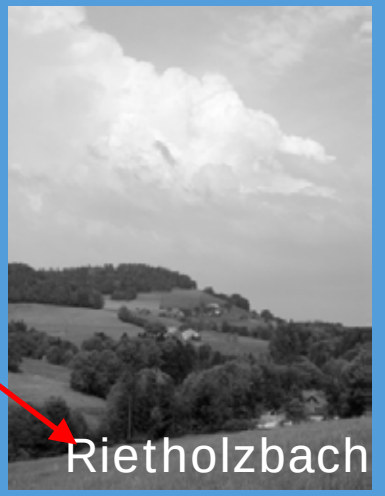


WAGENINGEN UNIVERSITY
WAGENINGEN UR

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

Map of Europe – according to hydrologists



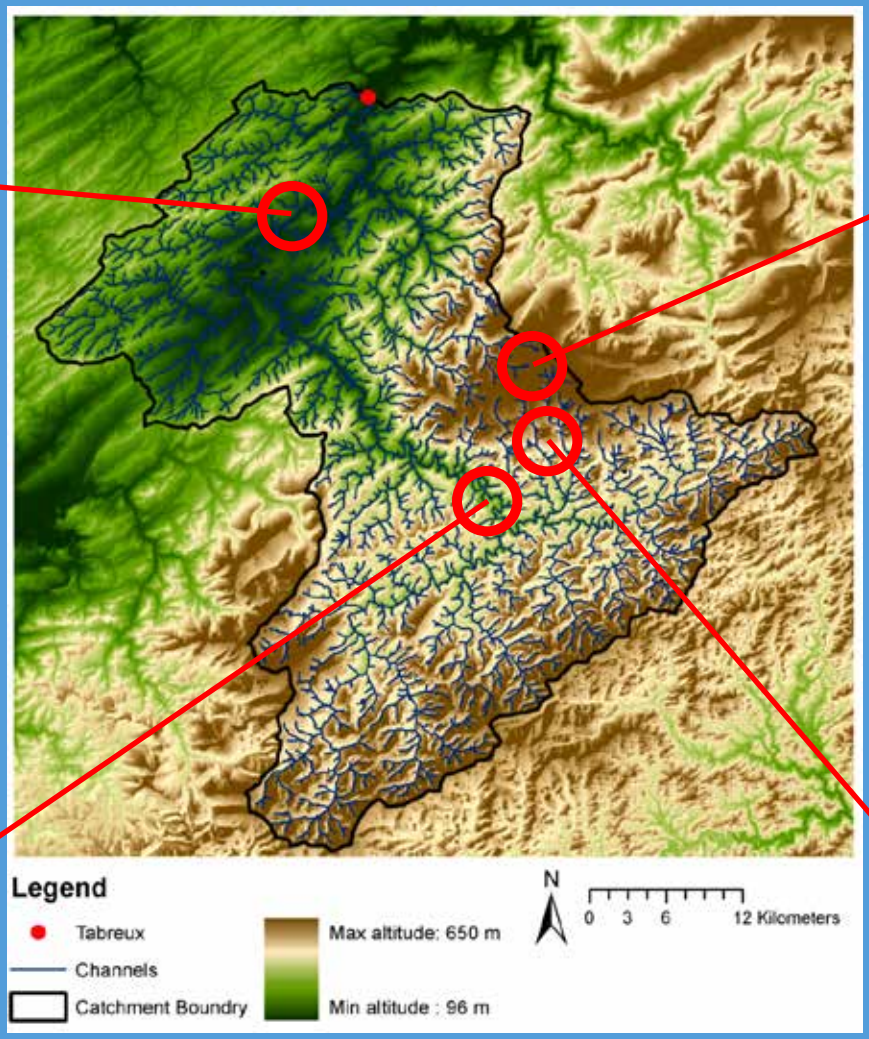


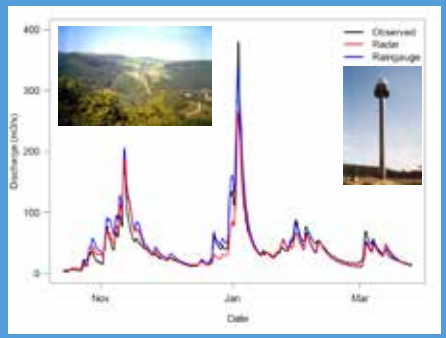
WAGENINGEN UNIVERSITY
WAGENINGEN UR

STW

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

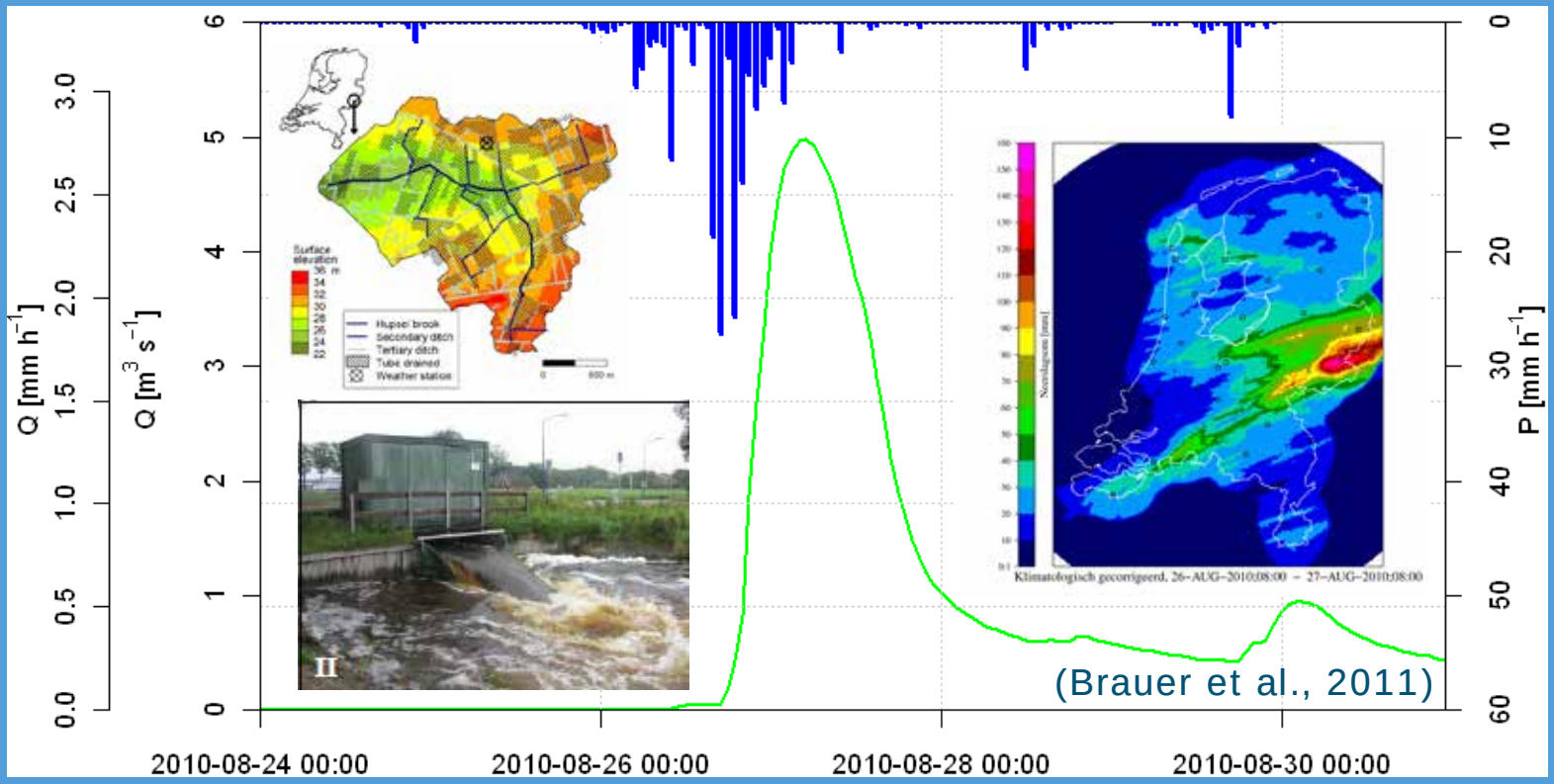
Close-up of a river catchment





(~1600 km^2 Ourthe catchment, tributary of Meuse)

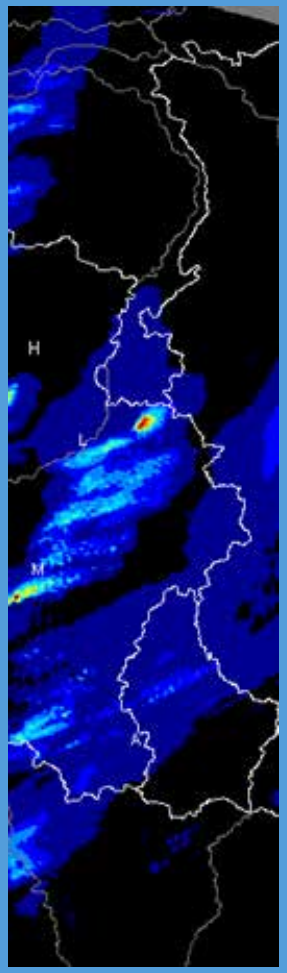
Rainfall-runoff processes; design/planning



§ Hupsel Brook (6.5 km^2), 26 August 2010: nearly 160 mm of rainfall in 24 h (T > 1000 y)

Flash flood early warning systems

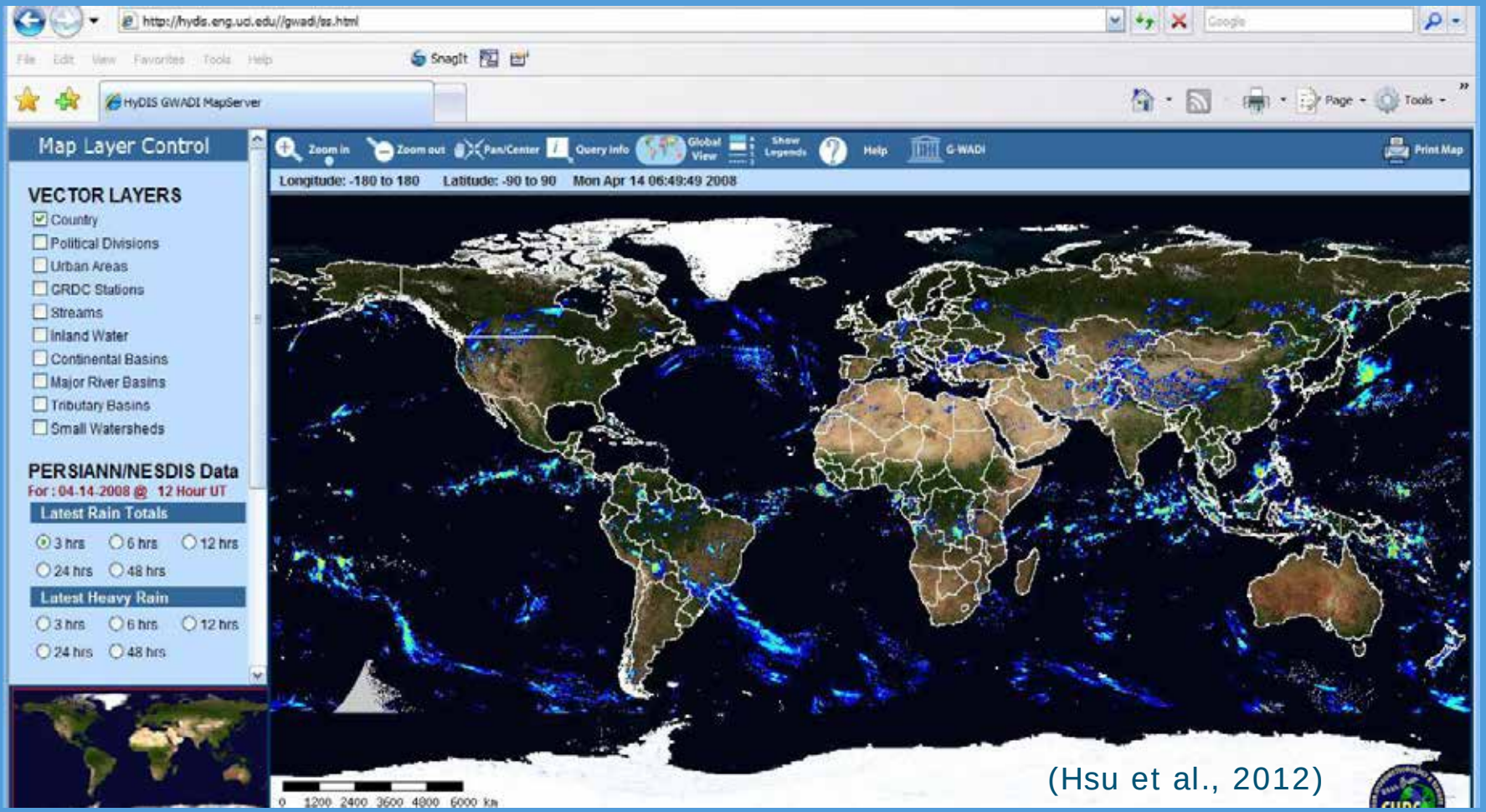
(Slenaken flash flood 28–29 July 2012)



Rainfall measurements for hydrology and meteorology

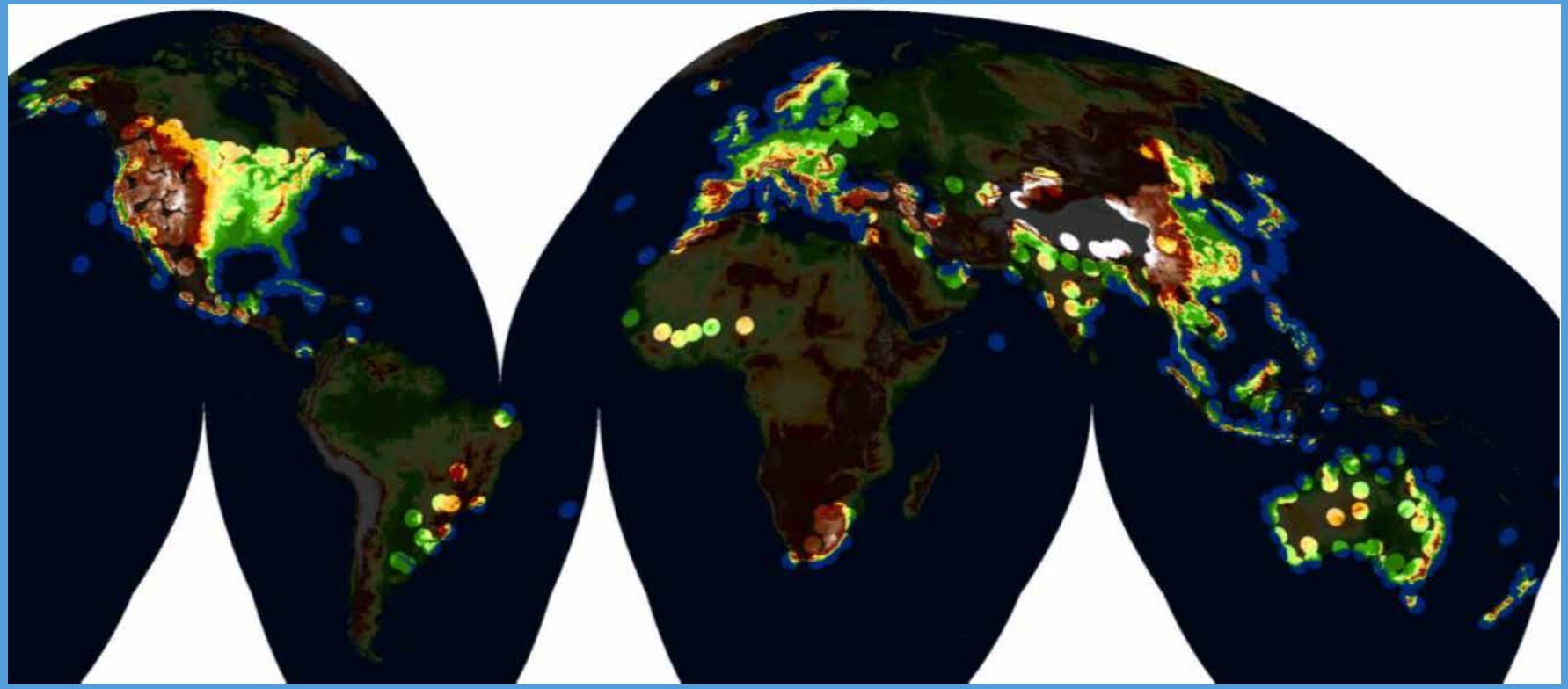
(Victoria Roberts, 2000)

Satellites need ground truthing



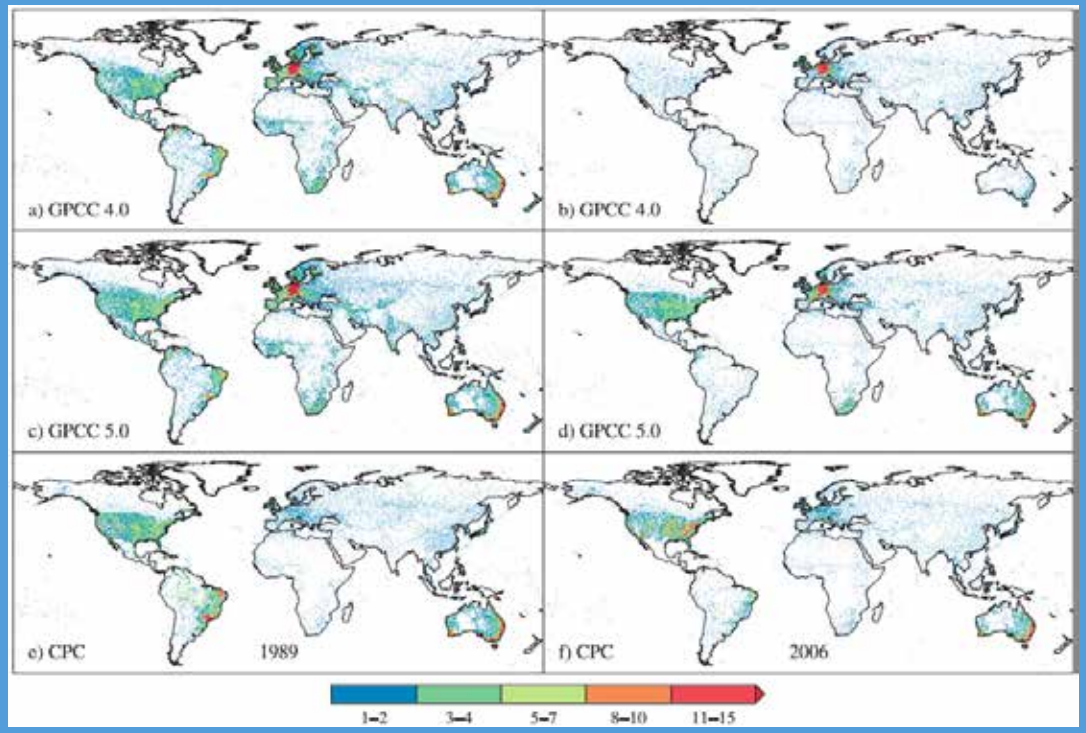
(Hsu et al., 2012)

Global weather radar coverage incomplete

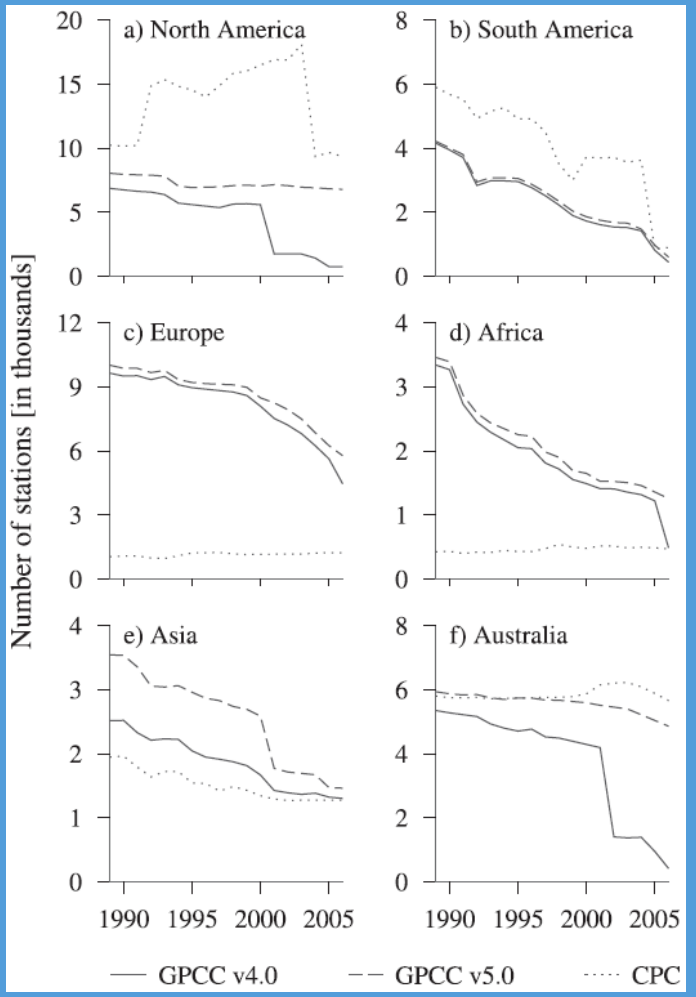


(Heistermann et al., 2012)

Number of rain gauges rapidly declining



(Lorenz and Kunstmann, 2012; NY Times green blog, 2 July 2012)

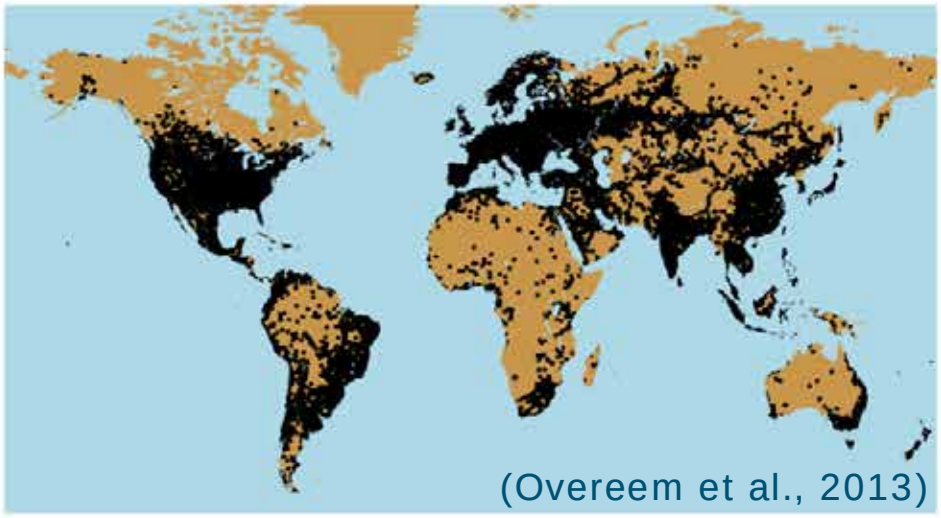


Microwave links from cell. comm. networks

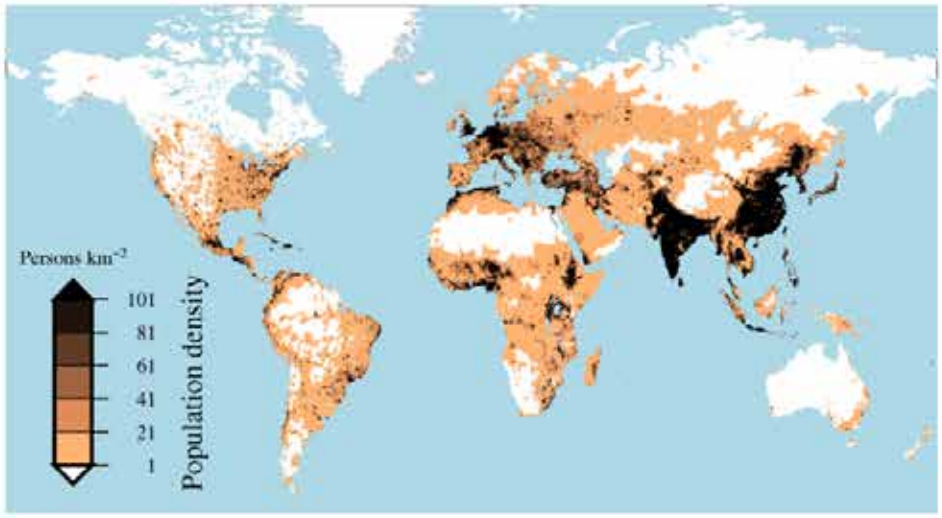
§ Potential over poorly gauged regions / continents

§ Urban areas poorly gauged, but high cell phone density

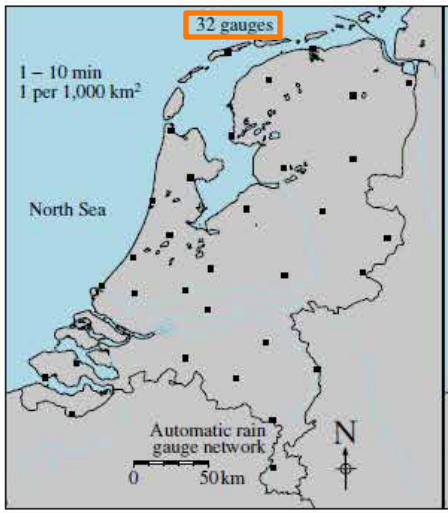
(identim / Shutterstock)

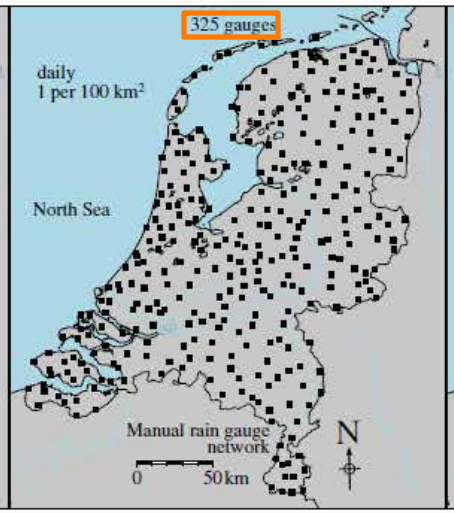


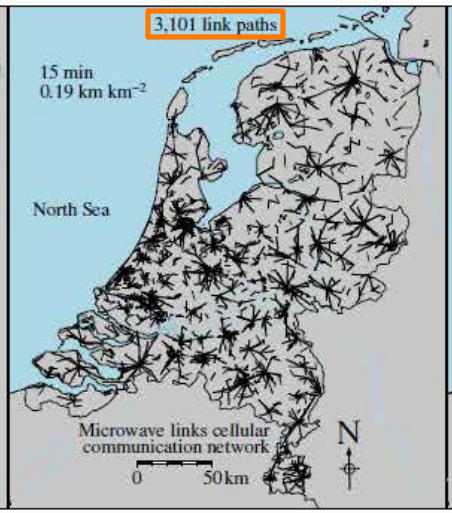
(Overeem et al., 2013)

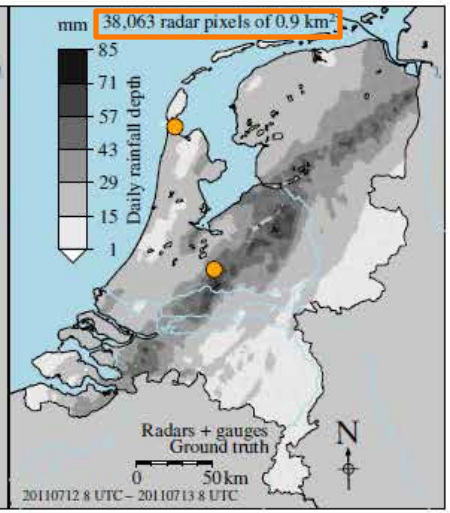


Many more microwave links than gauges







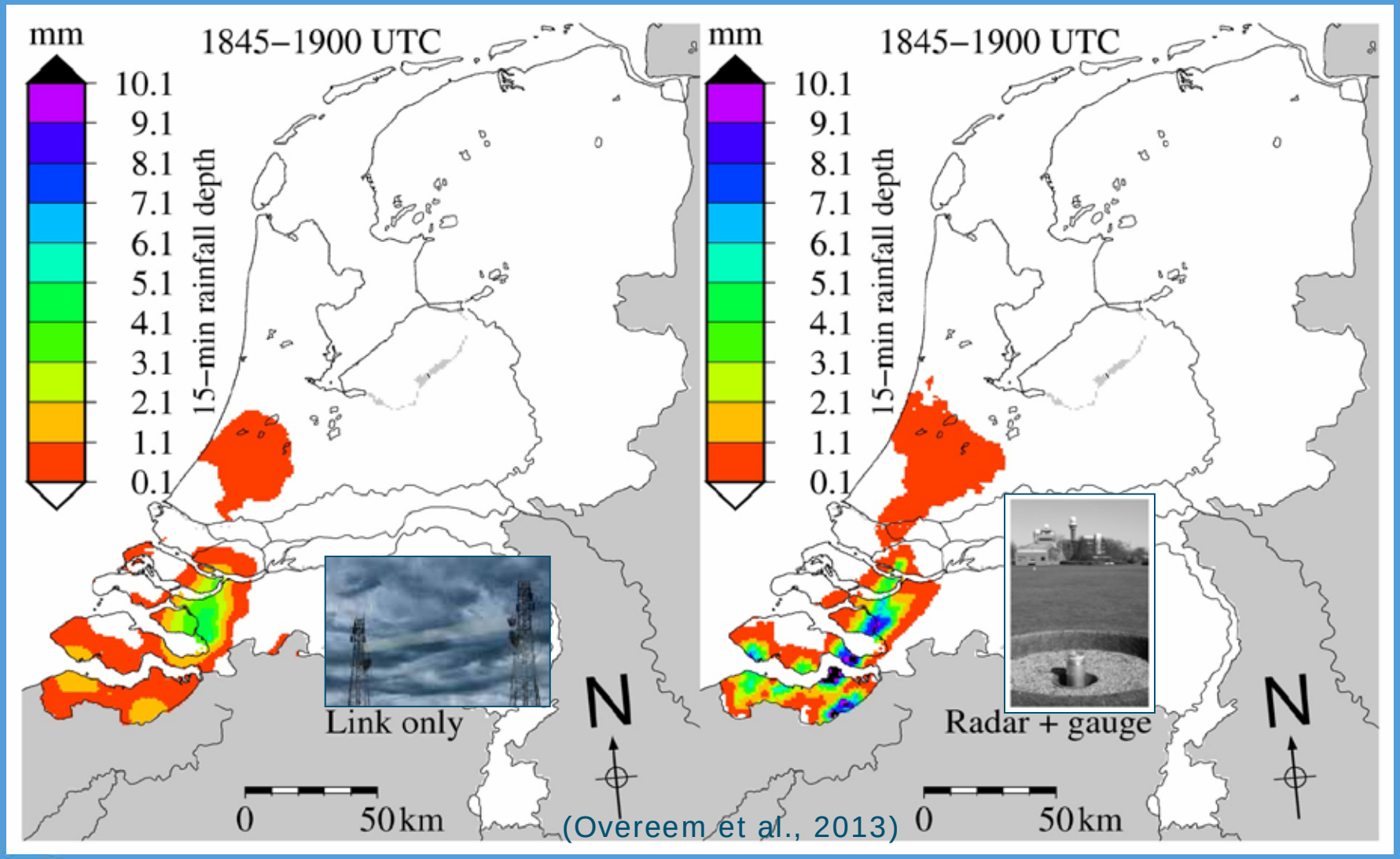


WAGENINGEN UNIVERSITY
WAGENINGEN UR

STW

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

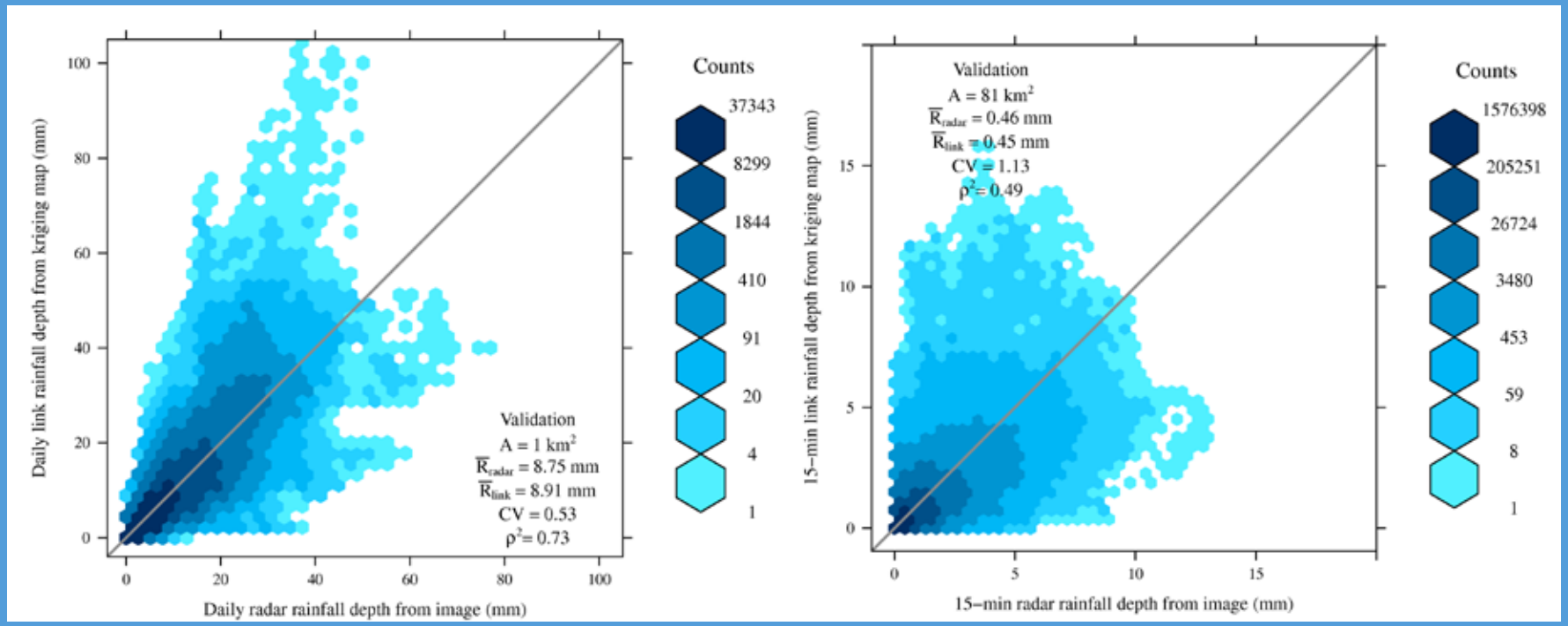
Microwave links versus radar + gauges



(Overeem et al., 2013)

Microwave links versus radar + gauges

§ Daily local (left) and 15-min regional (right) comparison



(Overeem et al., 2013)

Principle of rain estimation using microwave links

(Victoria Roberts, 2000)

(Beer-Bouguer-Lambert law of extinction)

$$\frac{P(L)}{P_0(L)} = \exp\left[-\frac{\ln 10}{10}\int_0^L k(s)ds\right]$$

$$\bar{k} = \frac{10}{L}\log\left[\frac{P_0(L)}{P(L)}\right]$$

(identim / Shutterstock)

(specific attenuation coefficient, dB km^{-1})

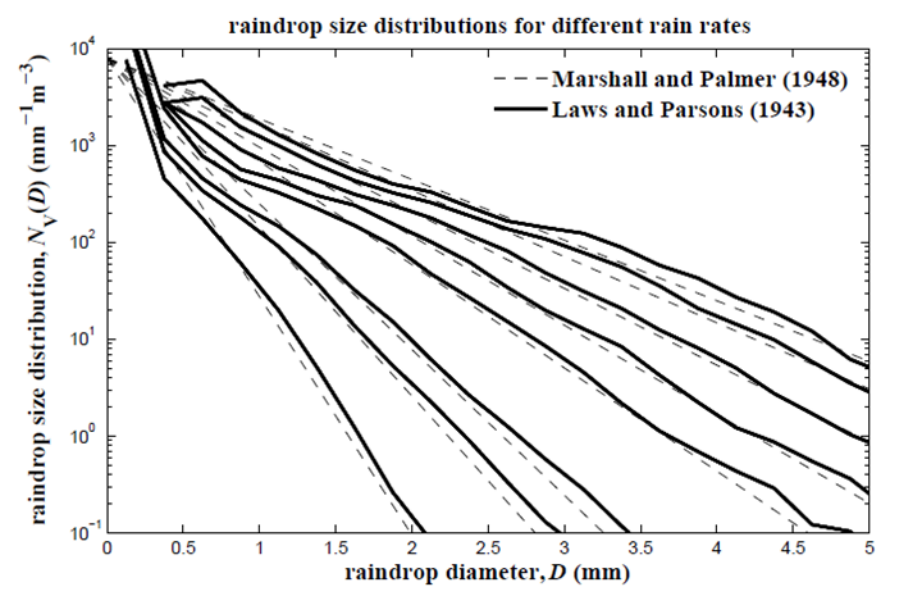
$$k = \frac{1}{\ln 10}\int_0^\infty \sigma_E(D) N_V(D) dD$$

(rainfall rate, mm h^{-1})

$$R = 6\pi \times 10^{-4}\int_0^\infty D^3 v(D) N_V(D) dD$$

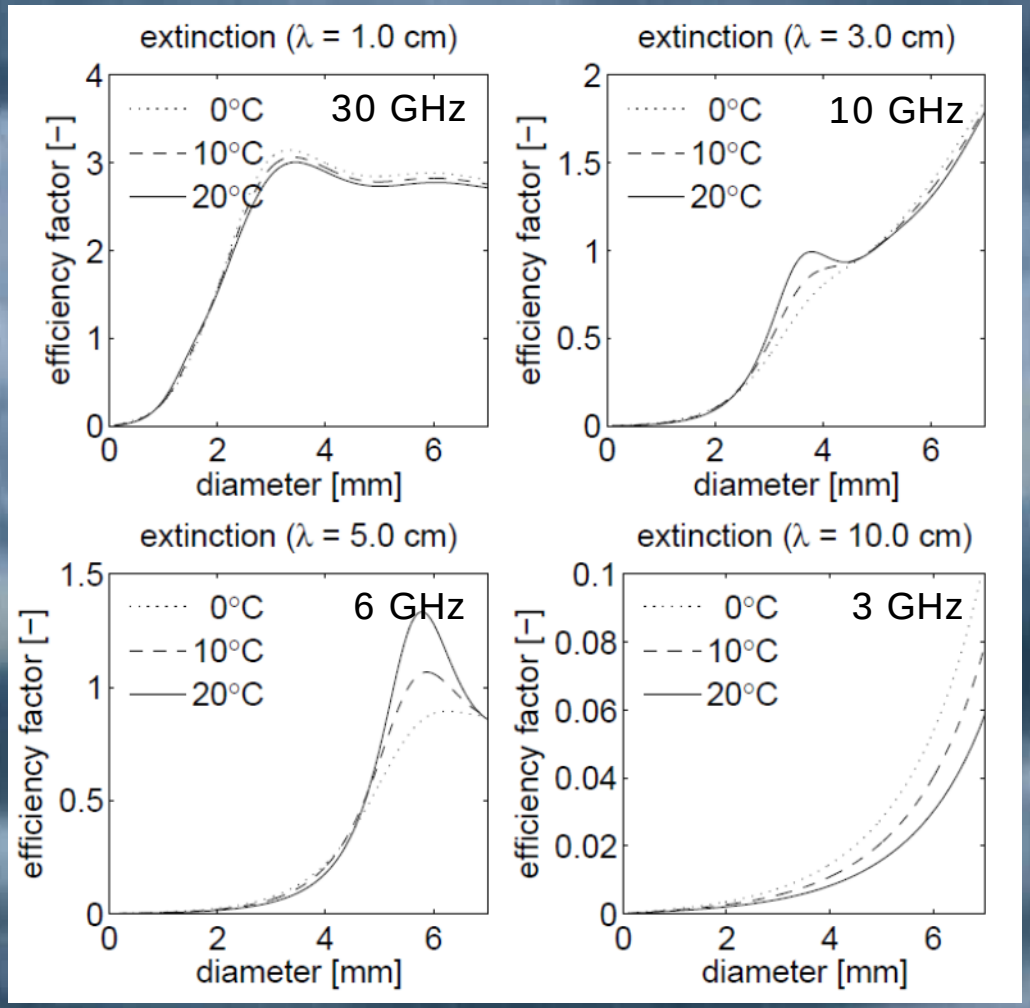
(identim / Shutterstock)

(drop size distribution – DSD)



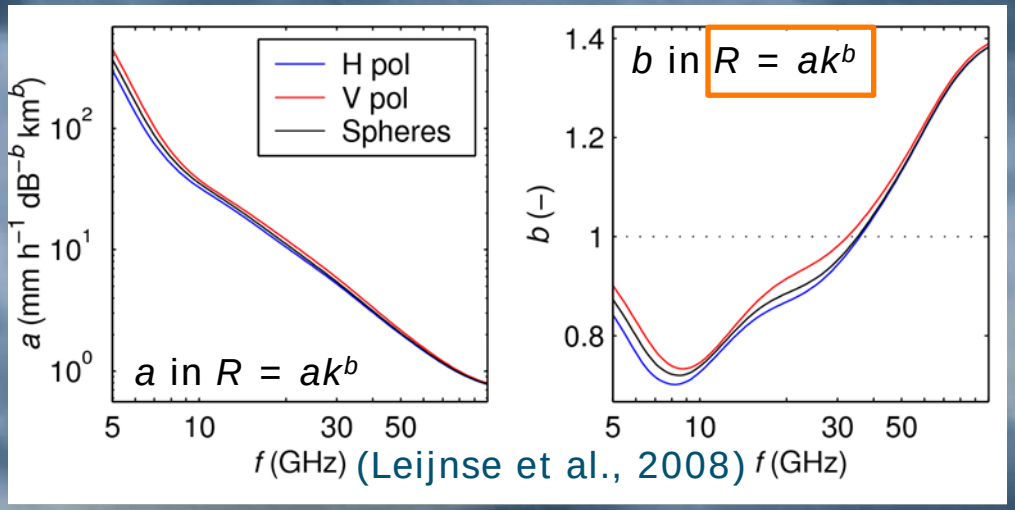
(identim / Shutterstock)

(Mie scattering cross-sections)

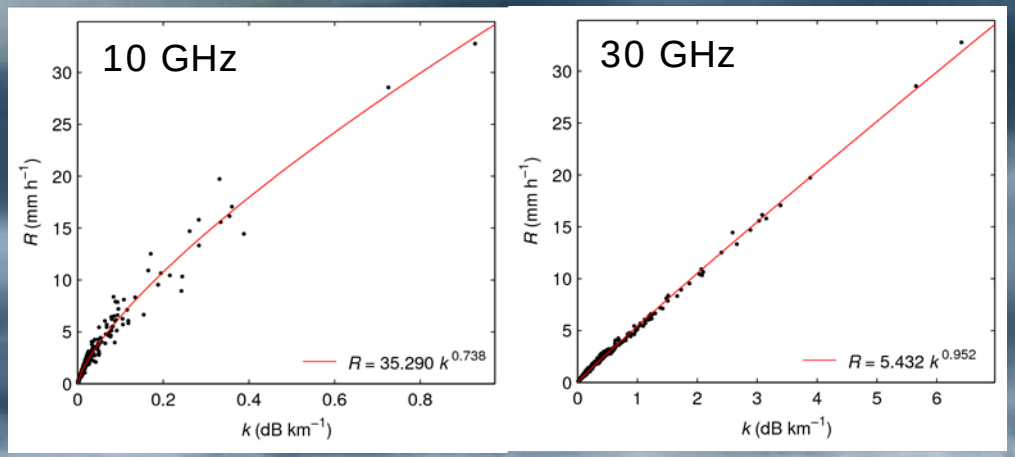


(identim / Shutterstock)

(Power-law R–k relations)



(Leijnse et al., 2008)



(identim / Shutterstock)

Basic principle: power law R–k relation

Method

$$R_{gsm} = ak^b$$

$$A_m = \int_0^L k(s)\mathrm{d}s = L\langle k \rangle = P_{ref} - P$$

$$\langle R_{gsm} \rangle \approx a \cdot \left[\frac{(P_{ref} - P)}{L}\right]^b$$ Reasonable approximation because $b \approx 1$.

- $\langle R_{gsm} \rangle$: Path-averaged link rainfall intensity (mm h^{-1})
- A_m: Attenuation over link path (dB)
- P: Received power (dBm)
- P_{ref}: Reference signal level (dBm)
- L: Link length (km)
- a, b: Coefficients
- k: Specific attenuation (dB km^{-1})
- $\langle k \rangle$: Path-averaged specific attenuation (dB km^{-1})
- s: Distance at link path (km)

(Overeem et al., 2011)

Rainfall retrieval algorithm

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

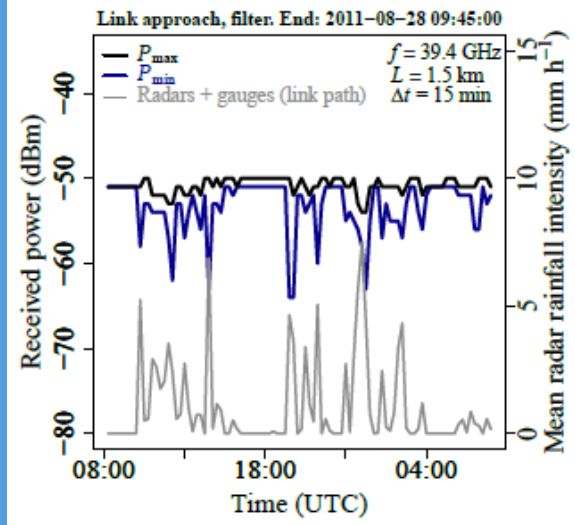
$\alpha = 0.335$

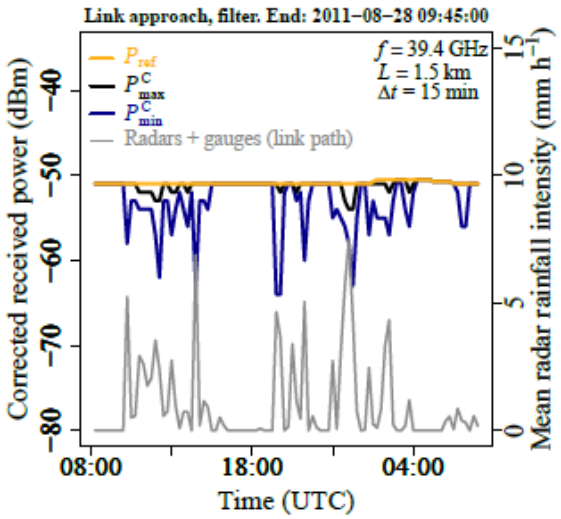
$b = 0.79$ - 1.03 (13-40 GHz)

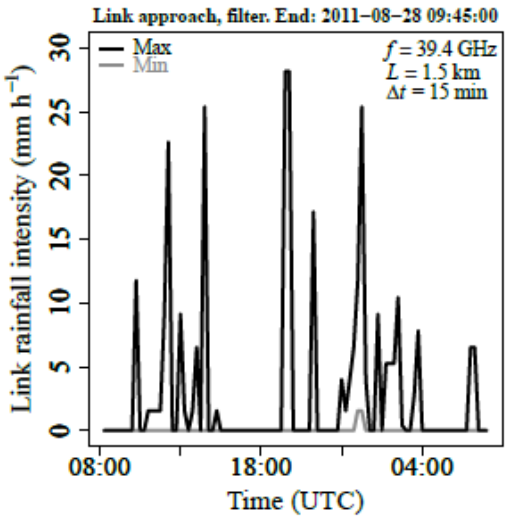
12-day calibration dataset

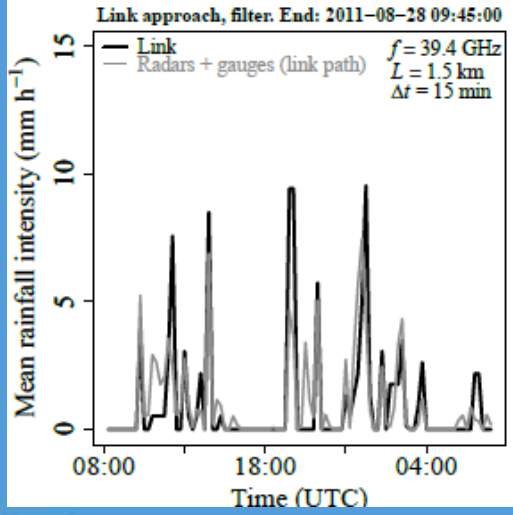
(Overeem et al., 2013; 2015)

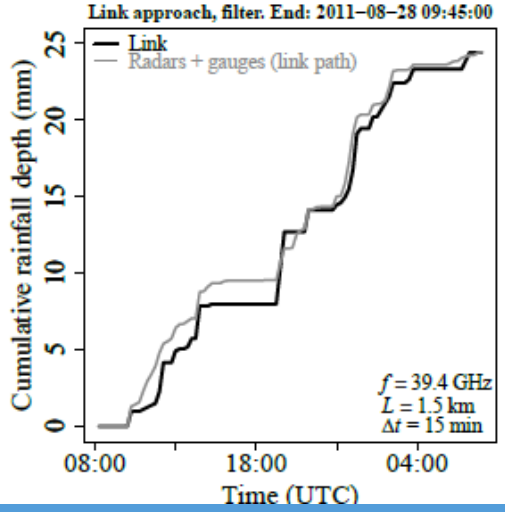
Rainfall retrieval in Rotterdam

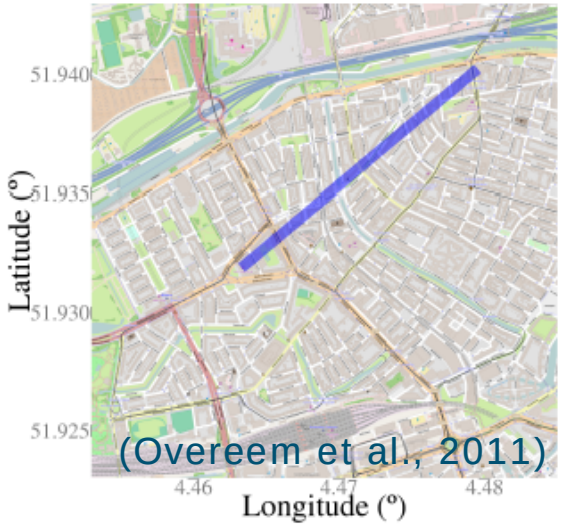








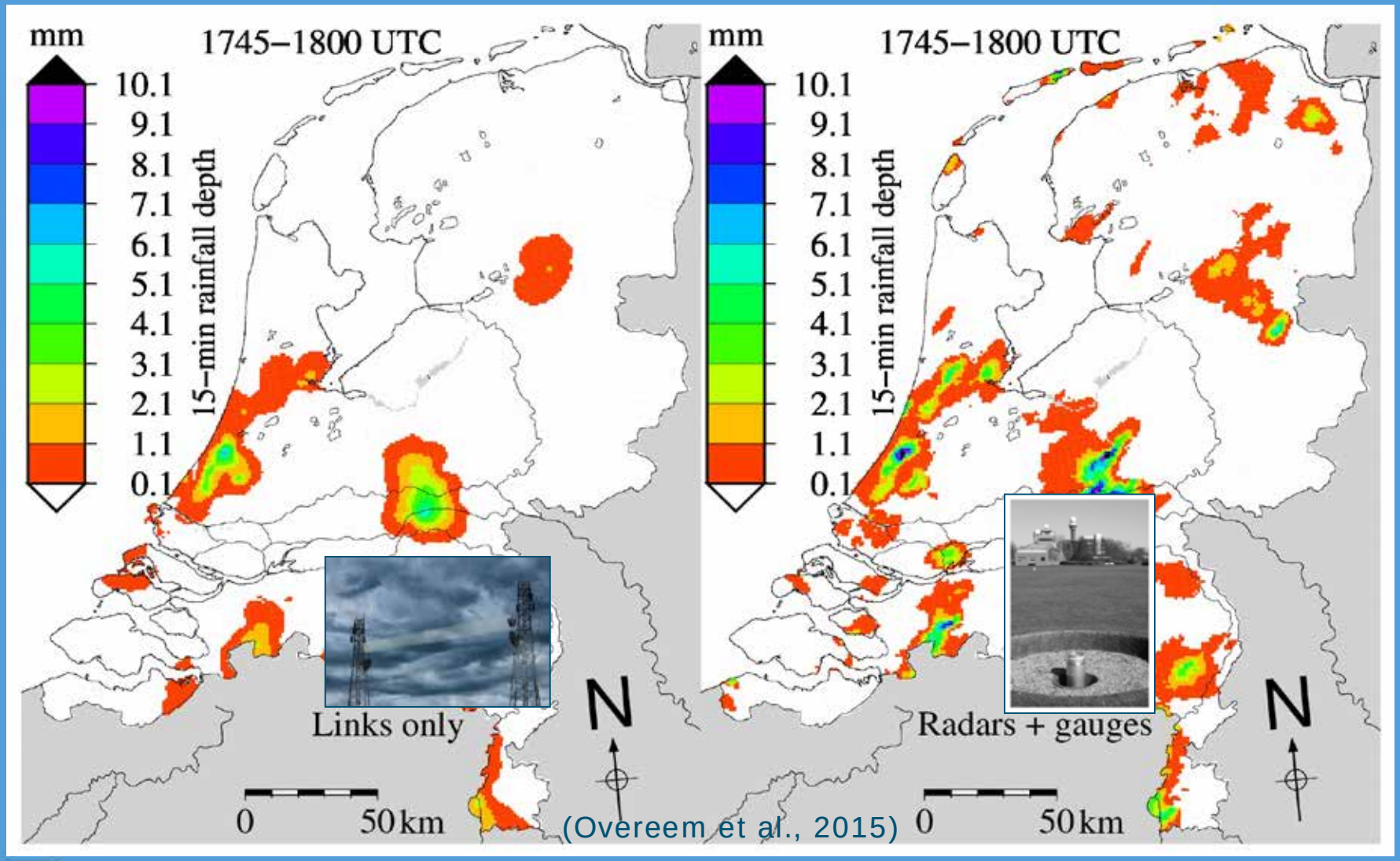




WAGENINGEN UNIVERSITY
WAGENINGEN UR

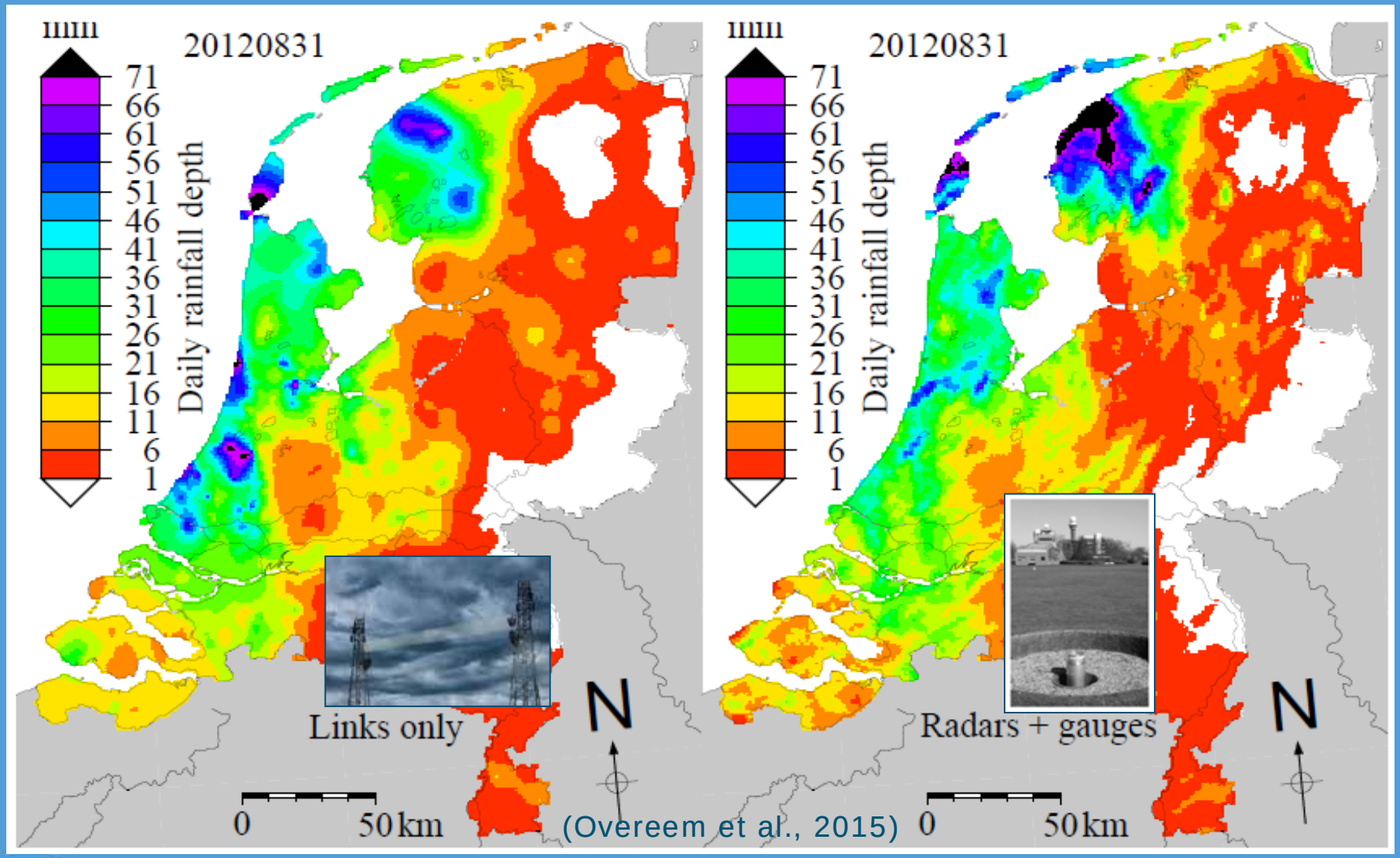
Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

Microwave links versus radar + gauges



(Overeem et al., 2015)

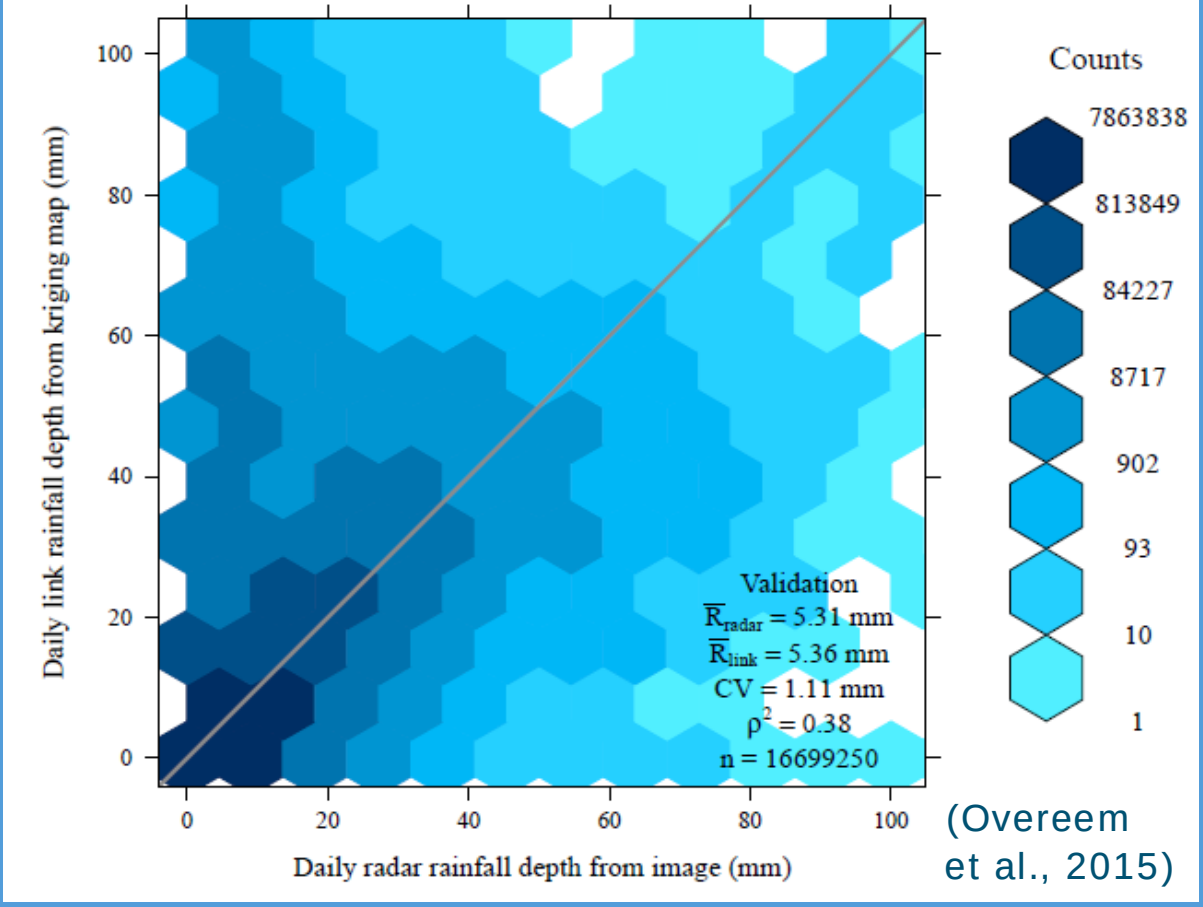
Microwave links versus radar + gauges



(Overeem et al., 2015)

Microwave links versus radar + gauges

- Daily rainfall
- 1086 days
- Validation
- Bias close to 0
- Correlation > 0.6

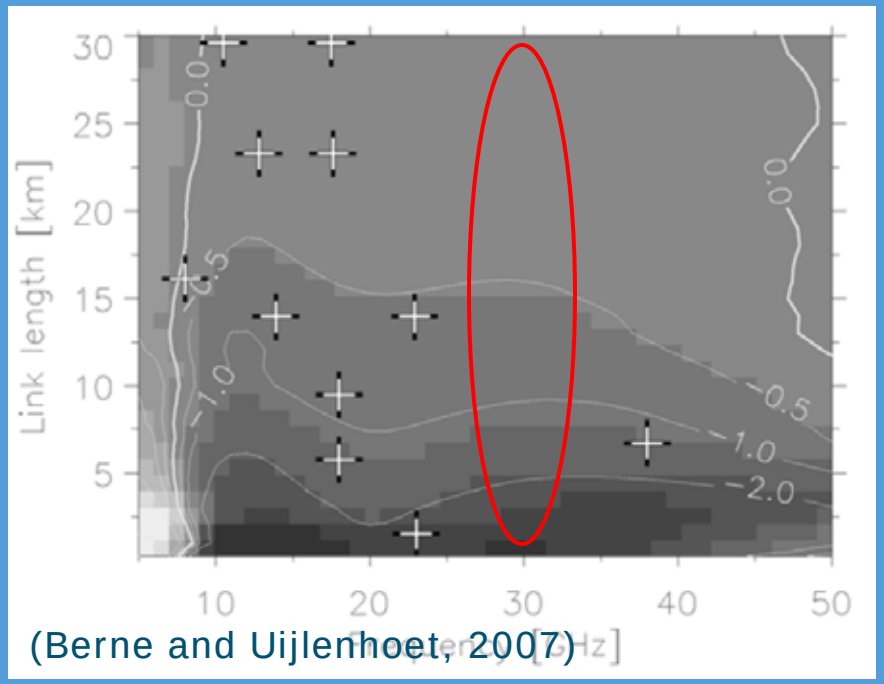


(Overeem et al., 2015)

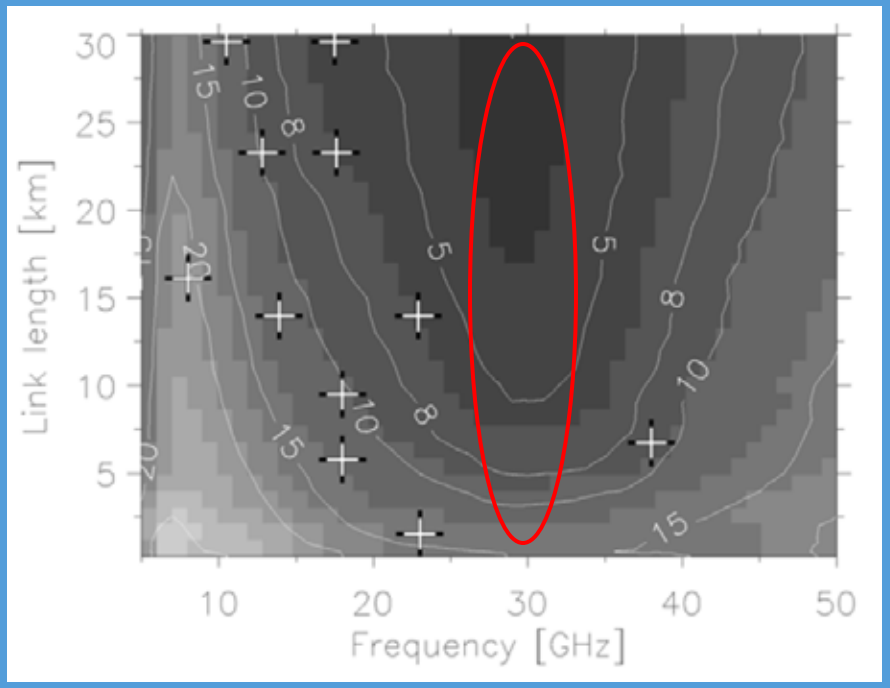
Uncertainties in rain estimates by microwave links

(Victoria Roberts, 2000)

Uncertainty in mw link rainfall estimation

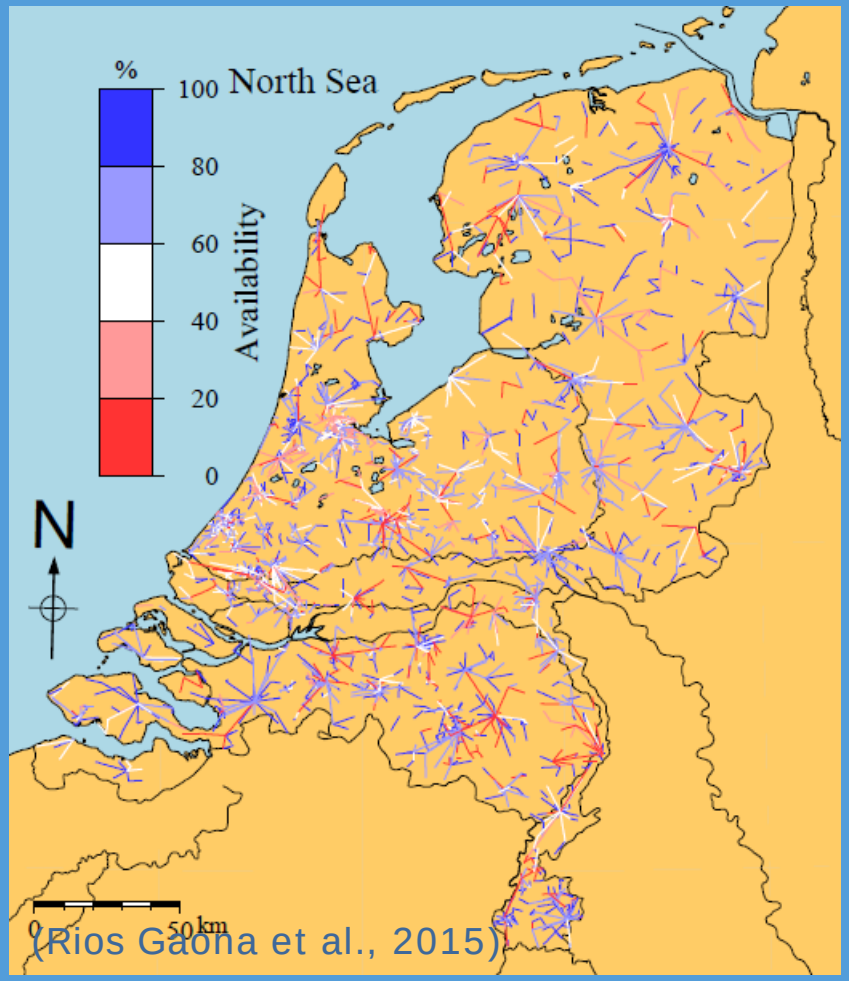


(Berne and Uijlenhoet, 2007)

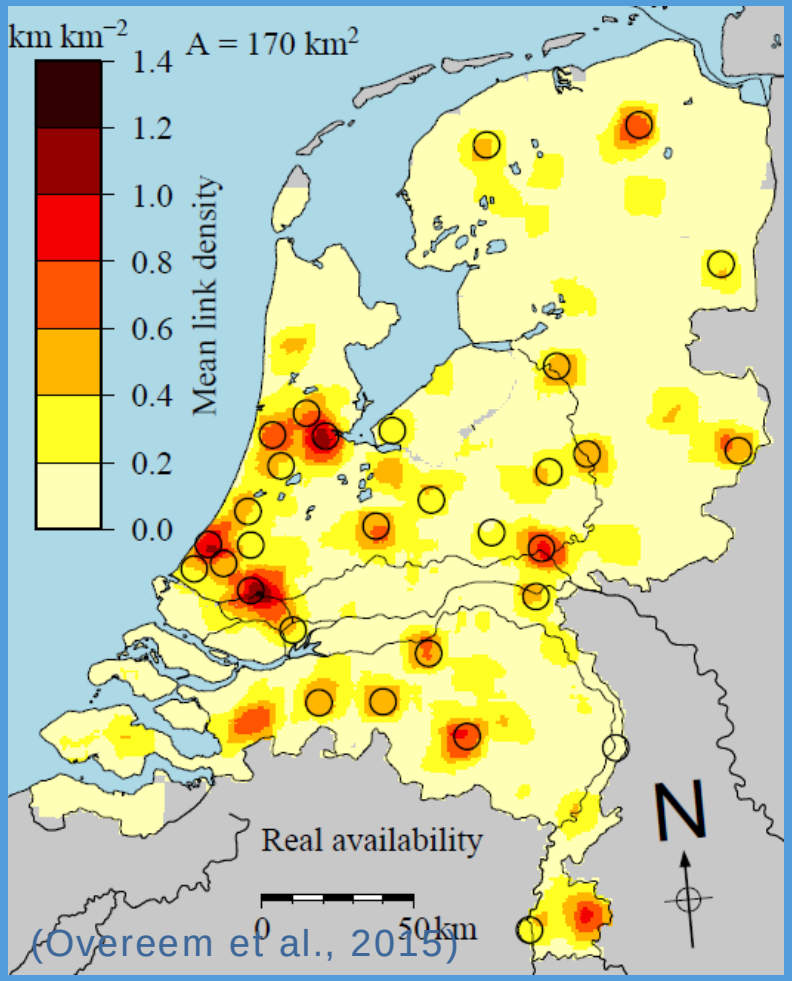


Mean relative error (in %, left panel) and associated uncertainty (in %, right panel) between the estimated and the true path-averaged rain rate (the "+" signs correspond to real microwave links)

Density and availability of link network

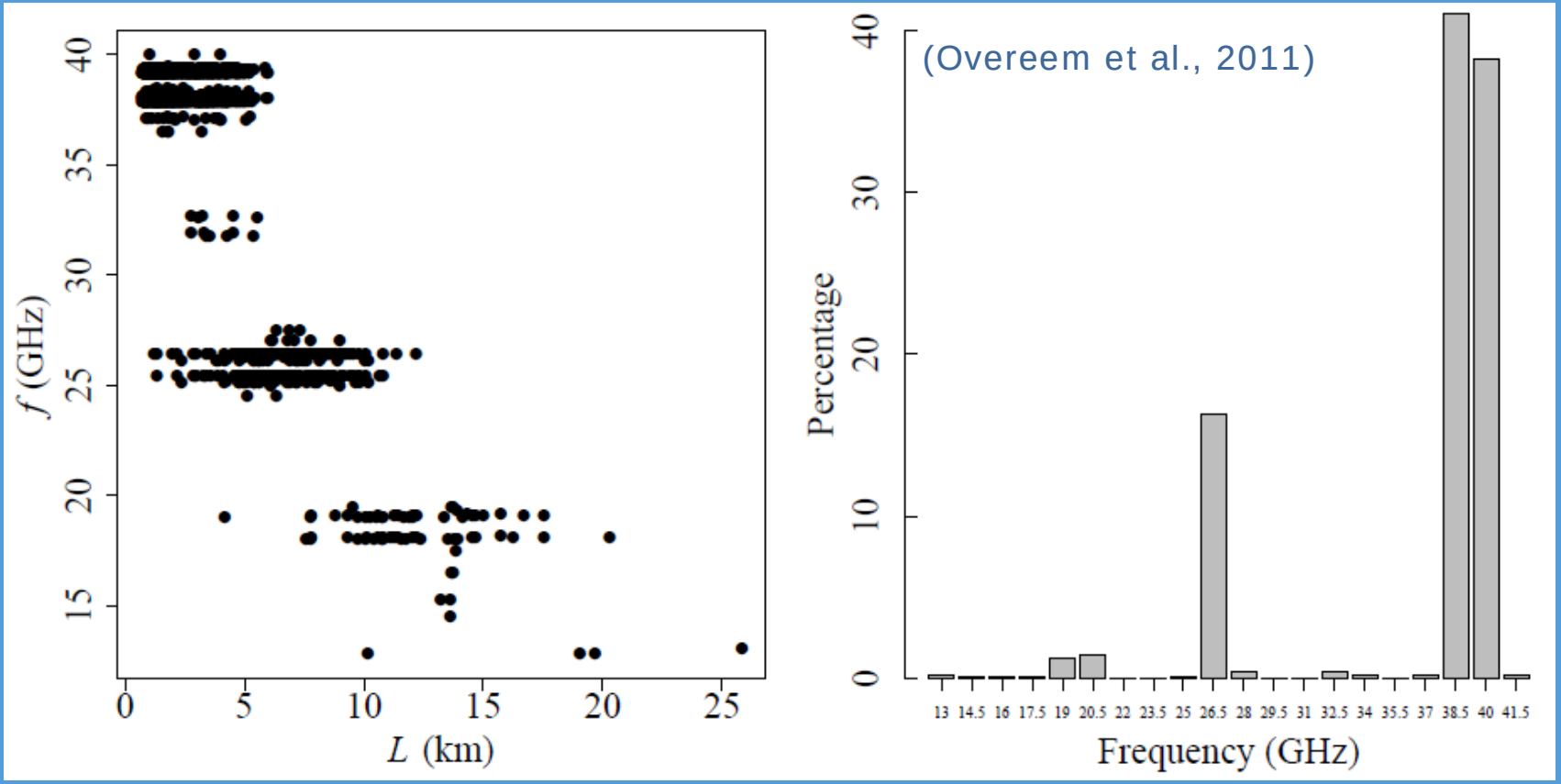


(Rios Gaona et al., 2015)

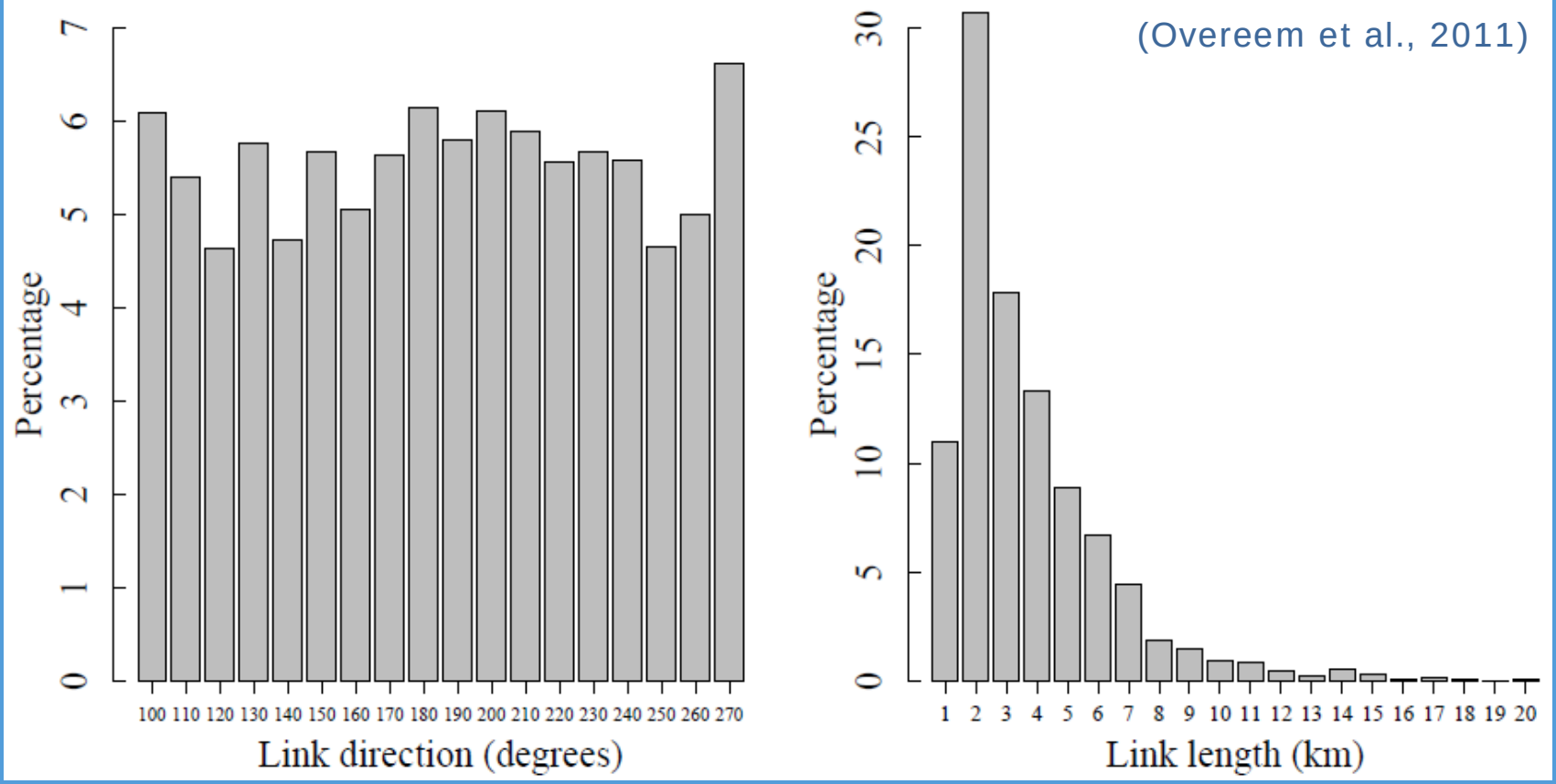


(Overeem et al., 2015)

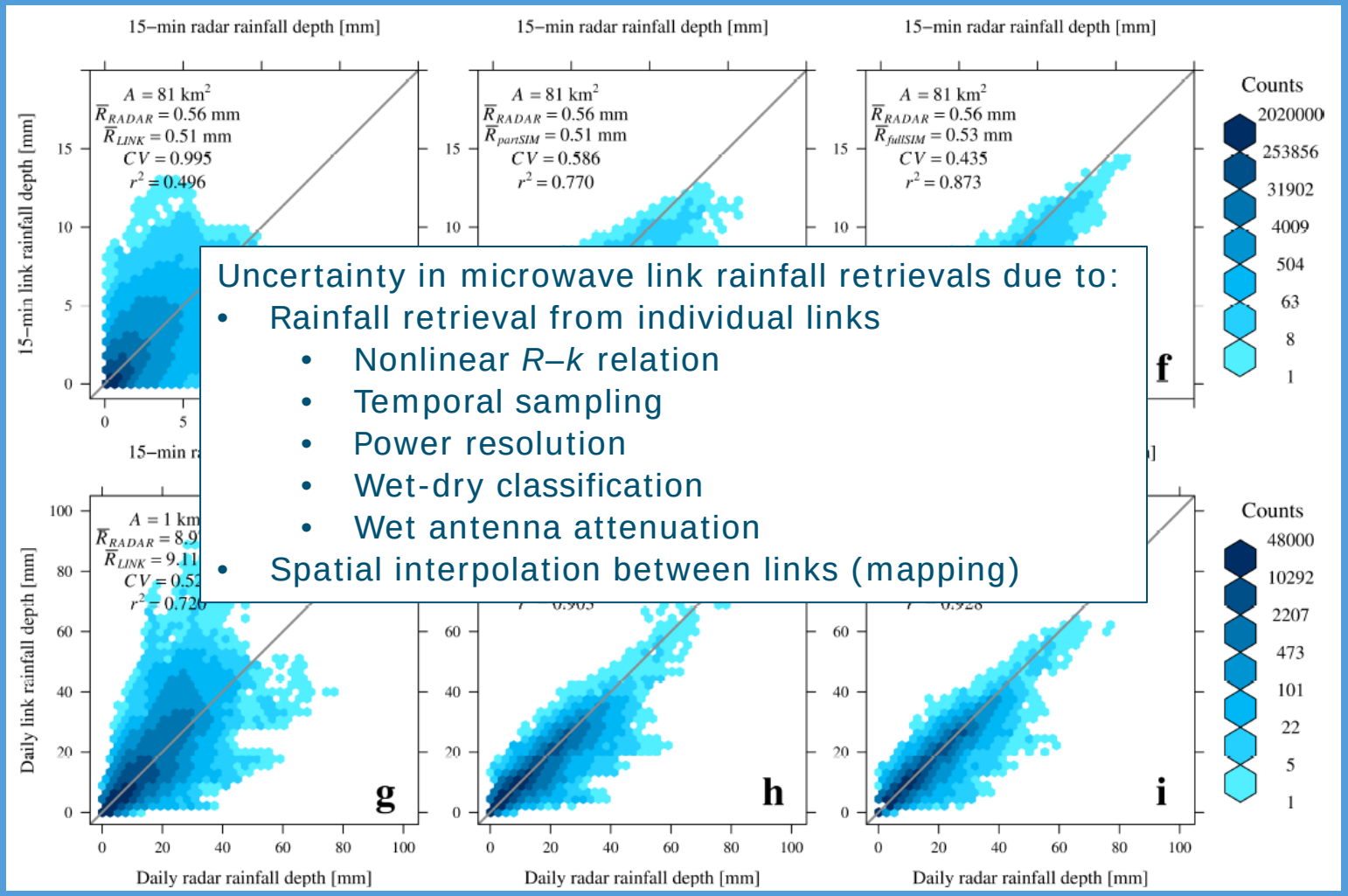
Link lengths and frequencies



Link orientations and lengths



Actual and simulated microwave links



Uncertainty in microwave link rainfall retrievals due to:

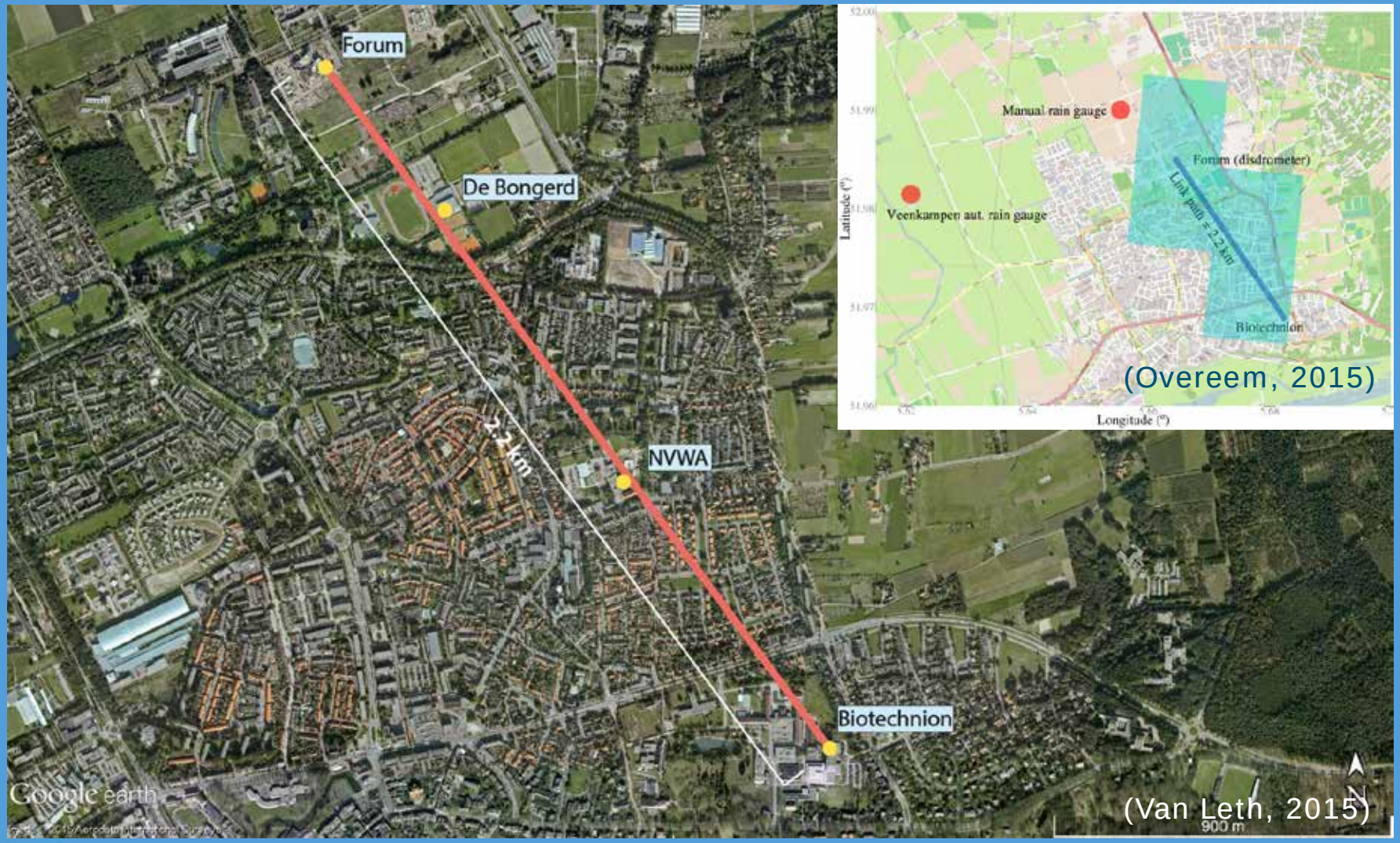
- Rainfall retrieval from individual links
  - Nonlinear *R–k* relation
  - Temporal sampling
  - Power resolution
  - Wet-dry classification
  - Wet antenna attenuation
- Spatial interpolation between links (mapping)

(Rios Gaona et al., 2015)

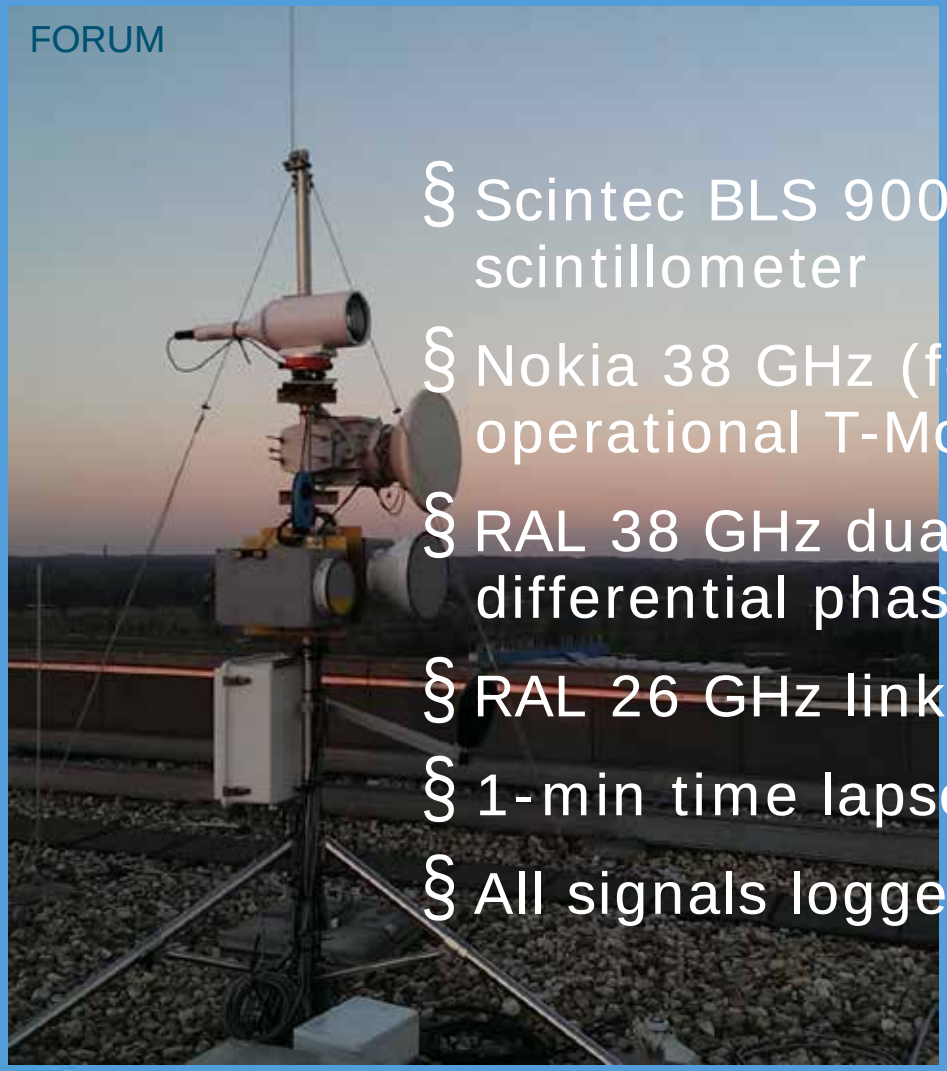
WURex14–15: Experimental setup and first results

(Victoria Roberts, 2000)

Wageningen Urban Rainfall Experiment



Backbone: 2.2 km multi-frequency link



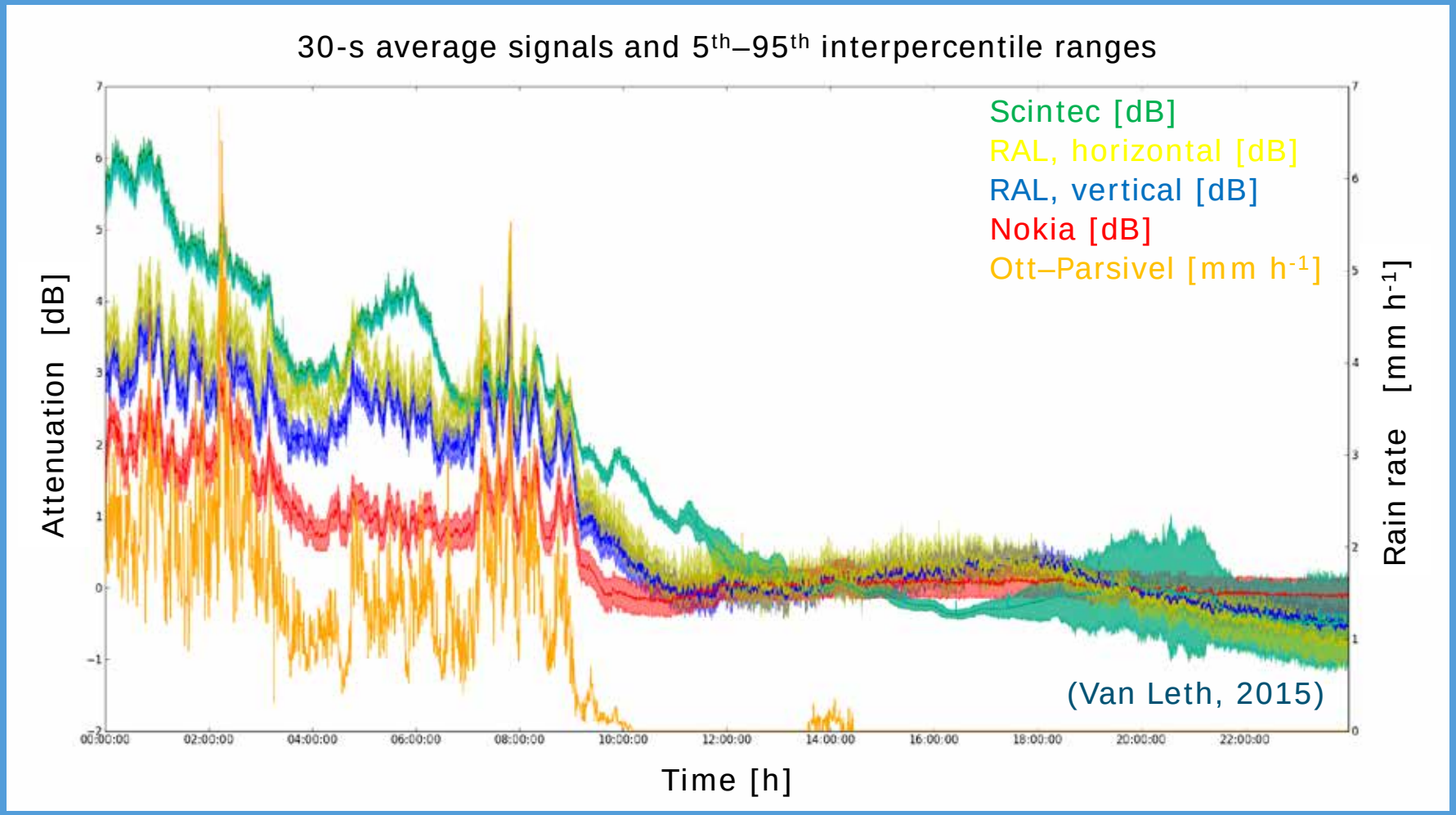
- Scintec BLS 900 NIR scintillometer
- Nokia 38 GHz (former operational T-Mobile link)
- RAL 38 GHz dual-pol differential phase link
- RAL 26 GHz link
- 1-min time lapse cameras
- All signals logged at 20 Hz

(Van Leth, 2015)

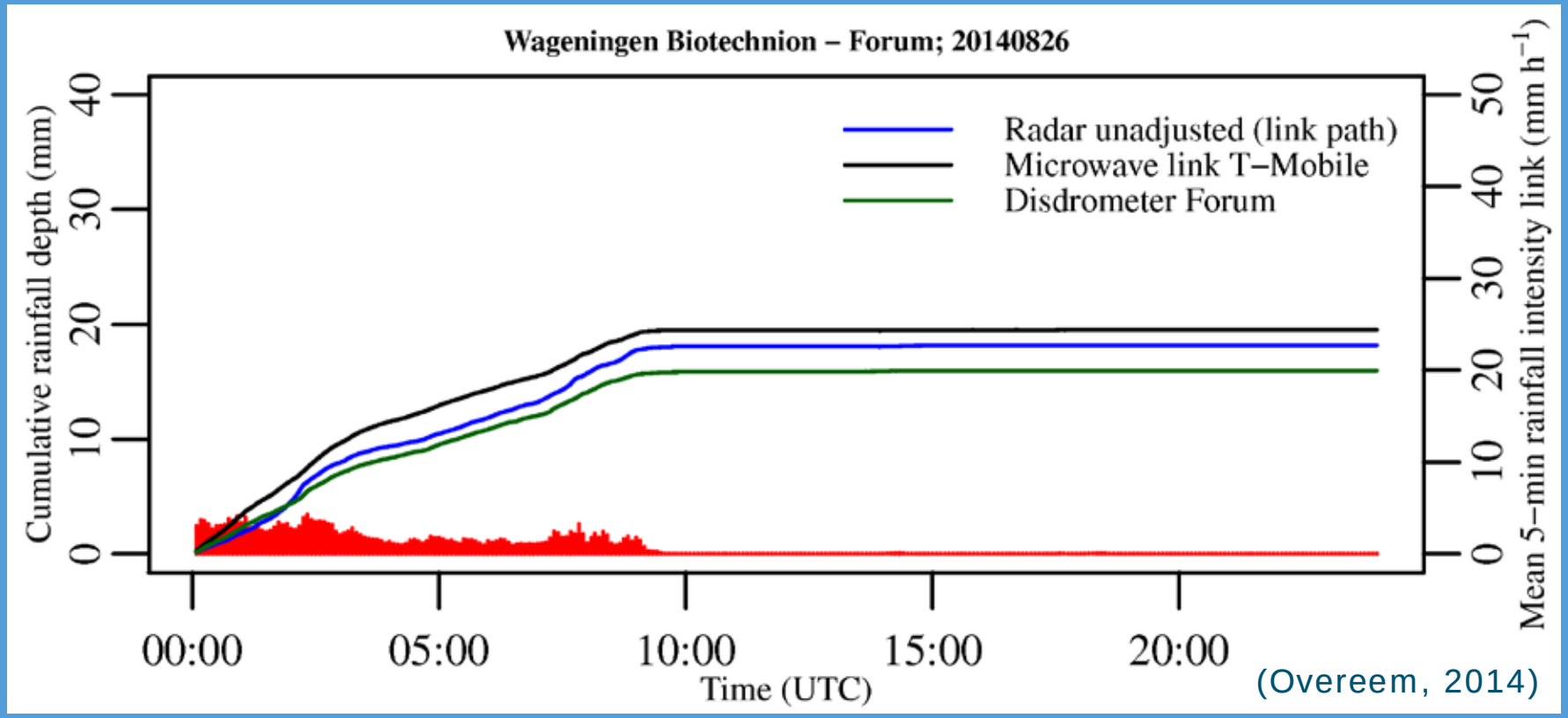
Ground truth: 5 Parsivel disdrometers*

*courtesy of A. Berne, EPFL

Rainfall event on August 26th, 2014

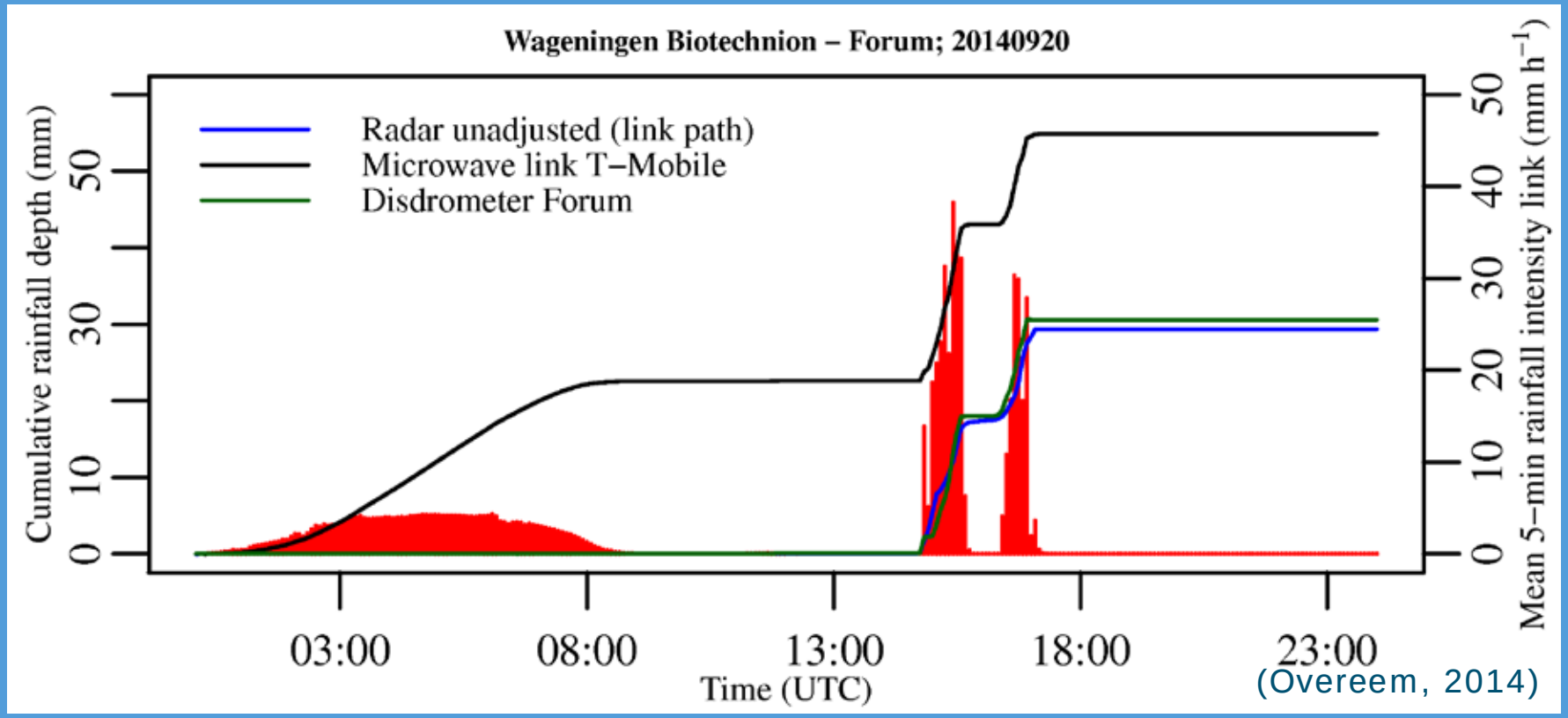


Rainfall rates and cumulative rain amounts



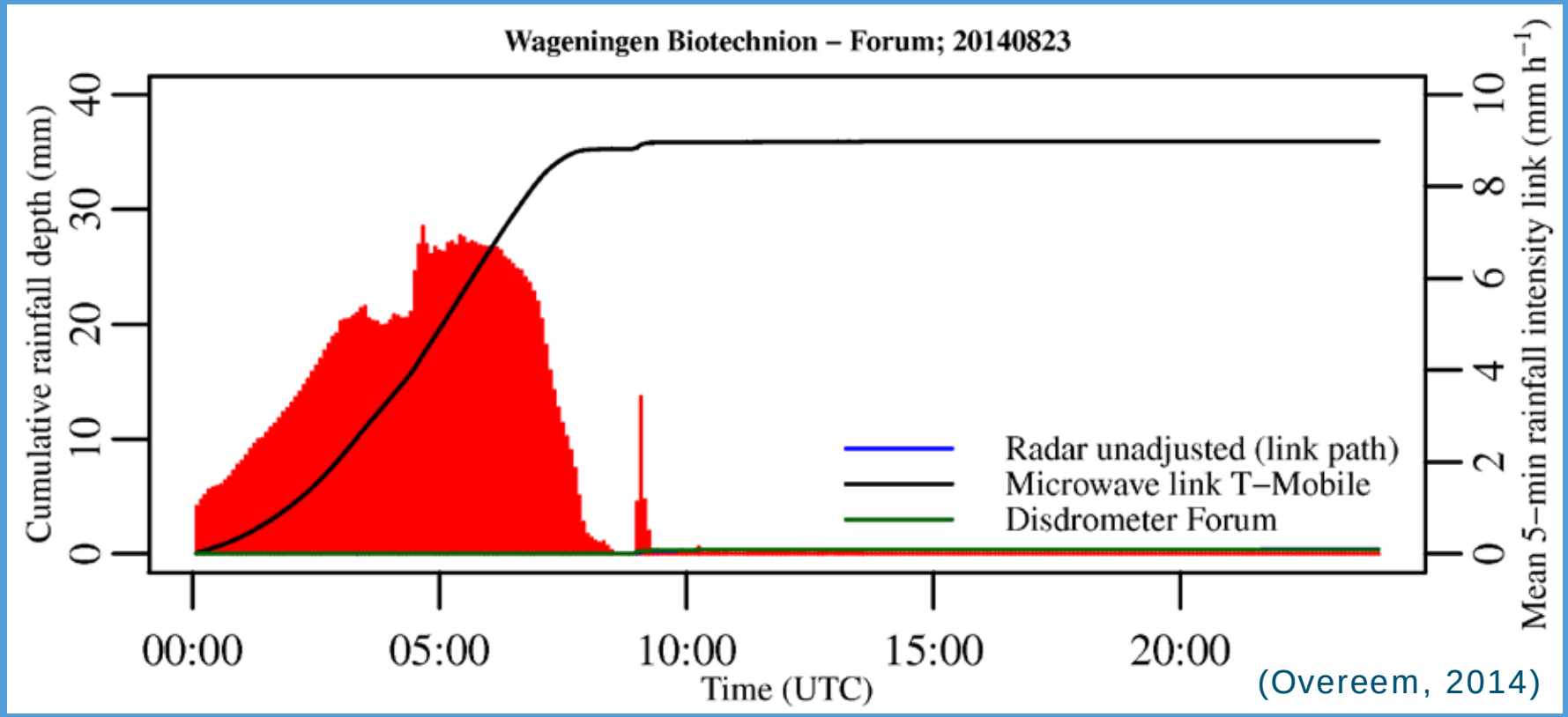
(Overeem, 2014)

Dew on antennas and rainfall events



(Overeem, 2014)

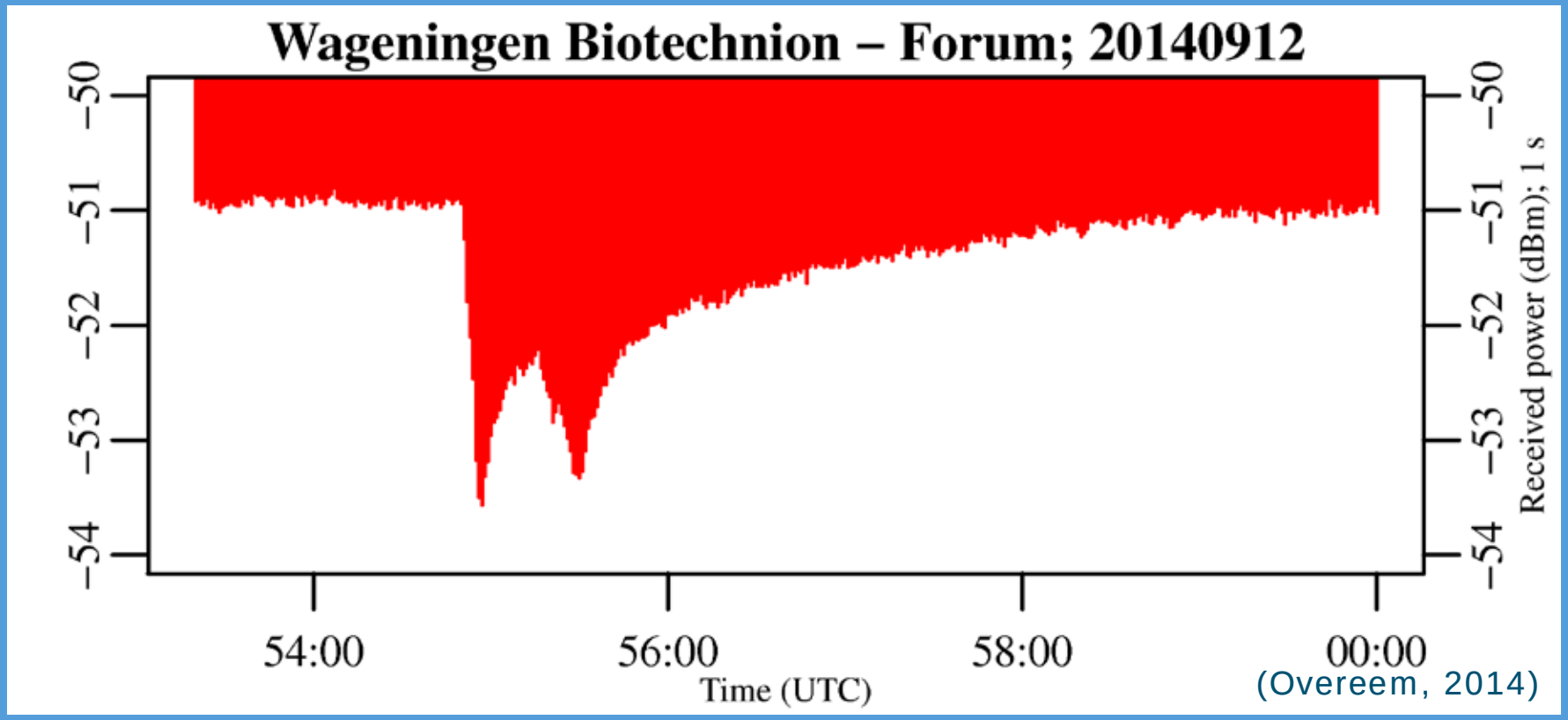
Dew on antennas and a few droplets



(Overeem, 2014)

Wet antenna experiment

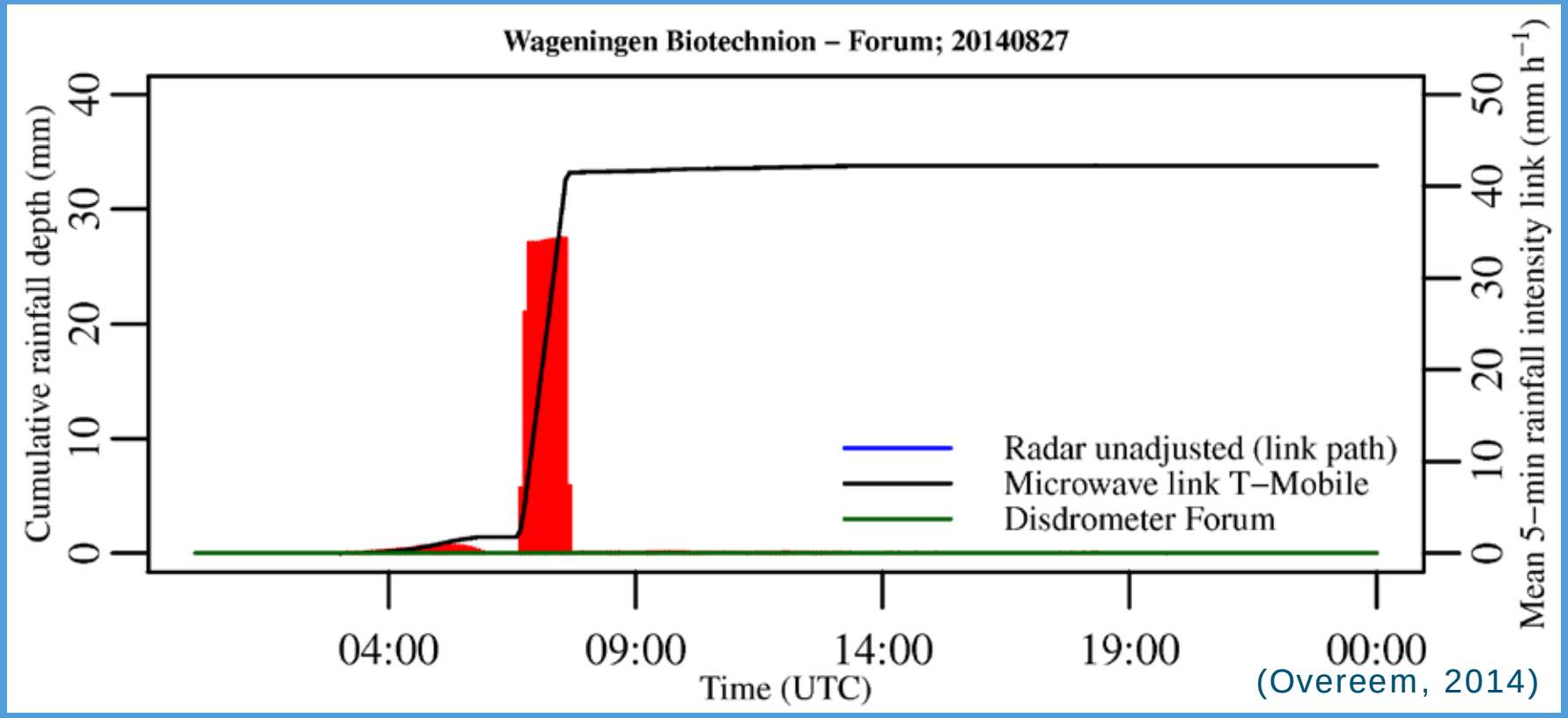
Wet antenna experiment – results



(Overeem, 2014)

Time lapse cameras to monitor antennas

What is going on here ??!!



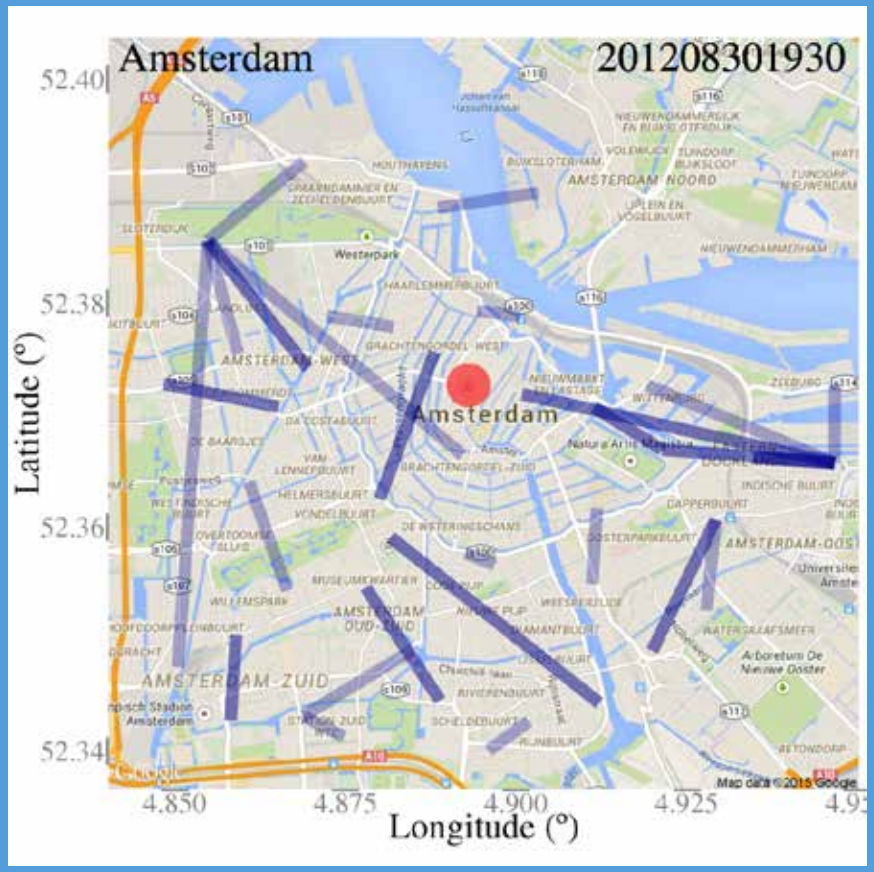
(Overeem, 2014)

OK, that explains ...

Opportunities and challenges

(Victoria Roberts, 2000)

Rainfall retrieval in Amsterdam



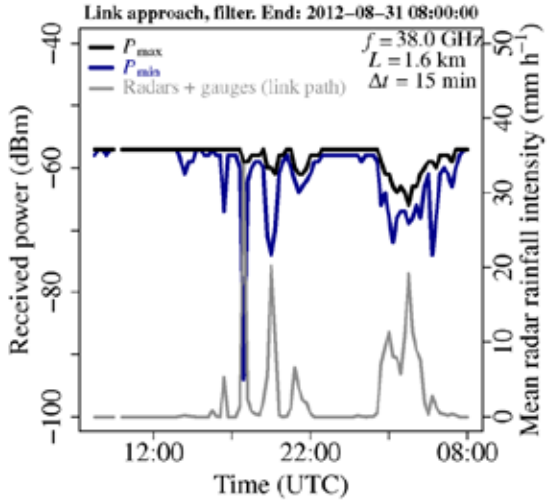
AMS
AMSTERDAM INSTITUTE FOR
ADVANCED METROPOLITAN SOLUTIONS

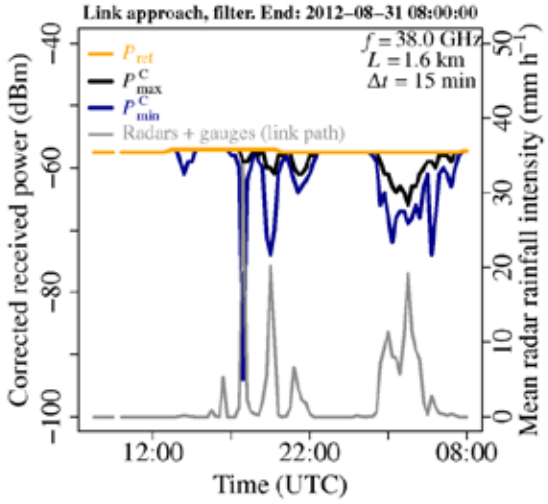
WAGENINGEN UNIVERSITY
WAGENINGEN UR

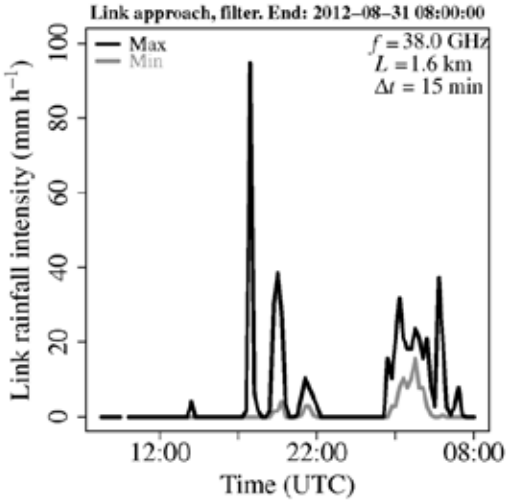
STW

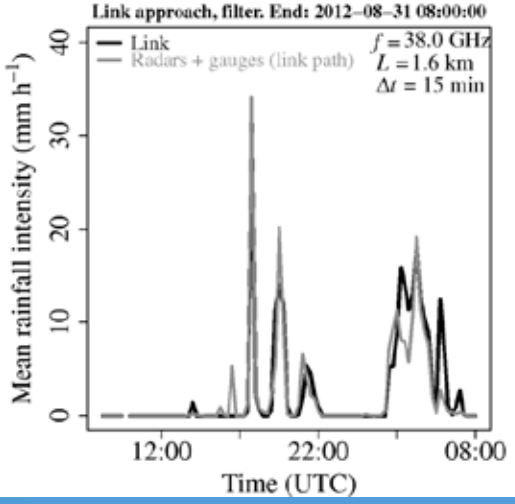
Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

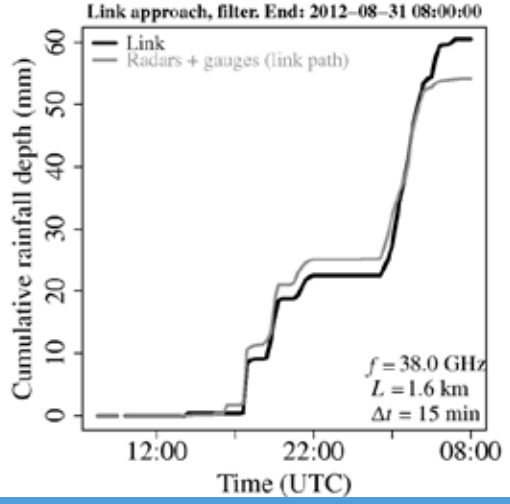
August 30st, 2012

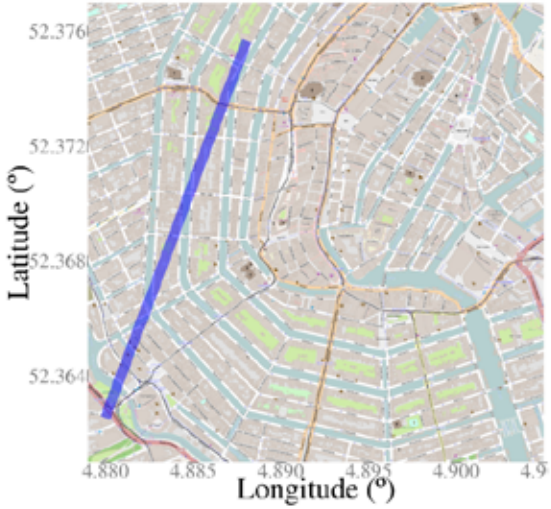








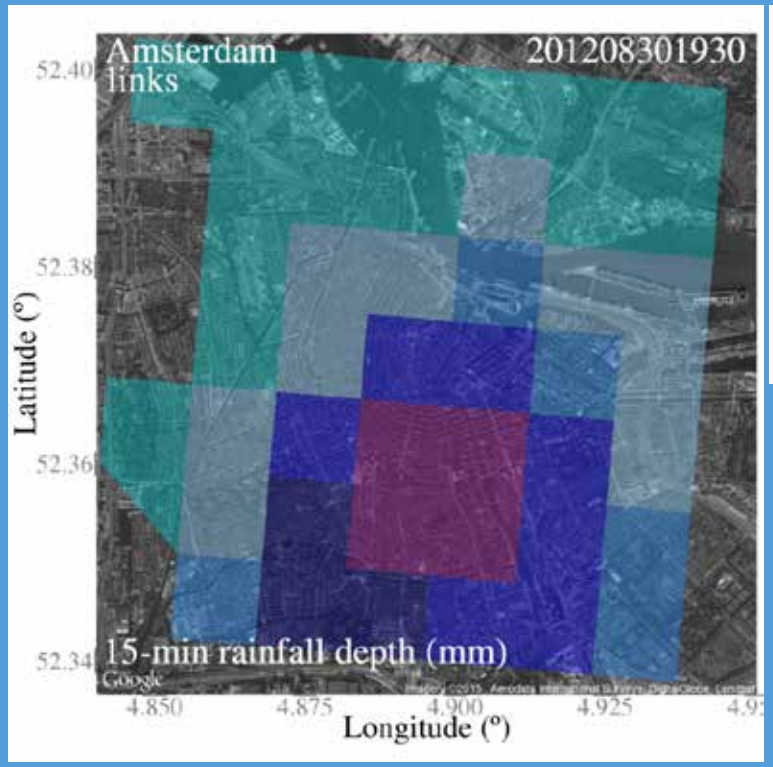


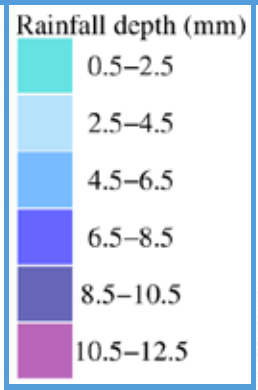


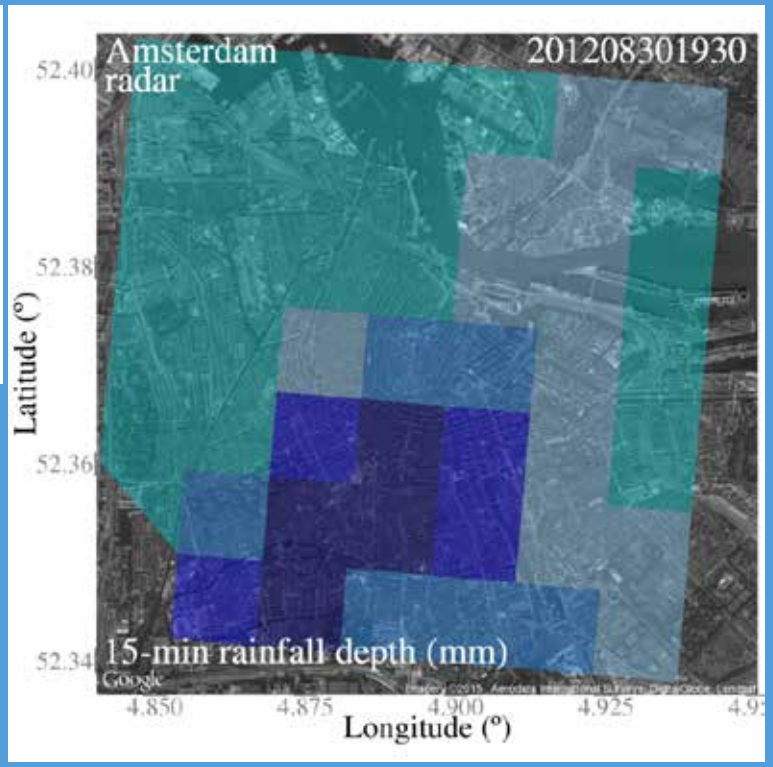
WAGENINGEN UNIVERSITY
WAGENINGEN UR

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

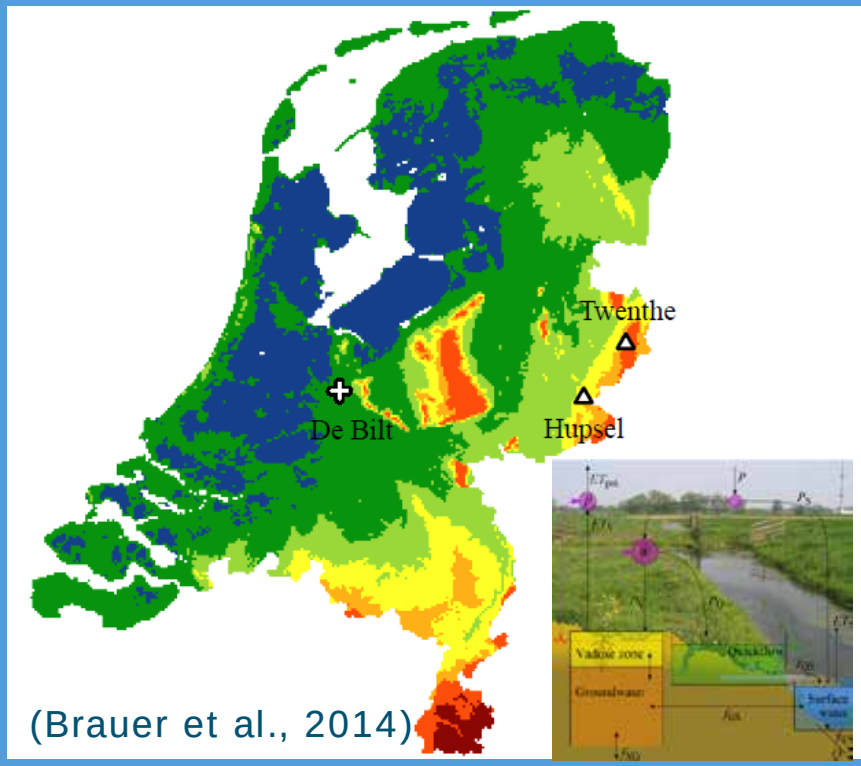
August 30th, 2012, 19h30



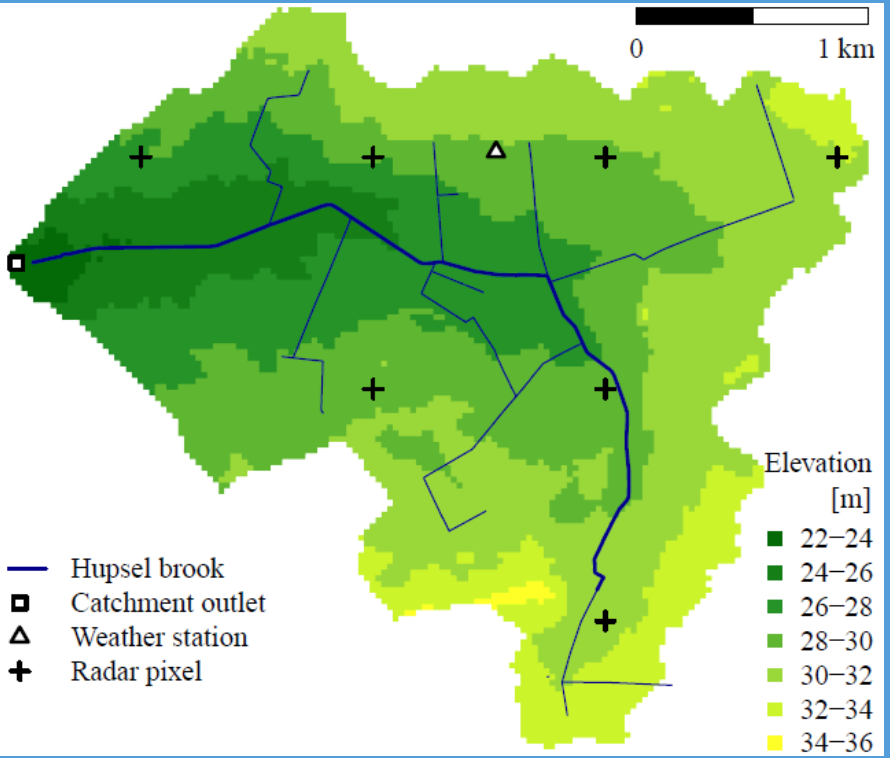




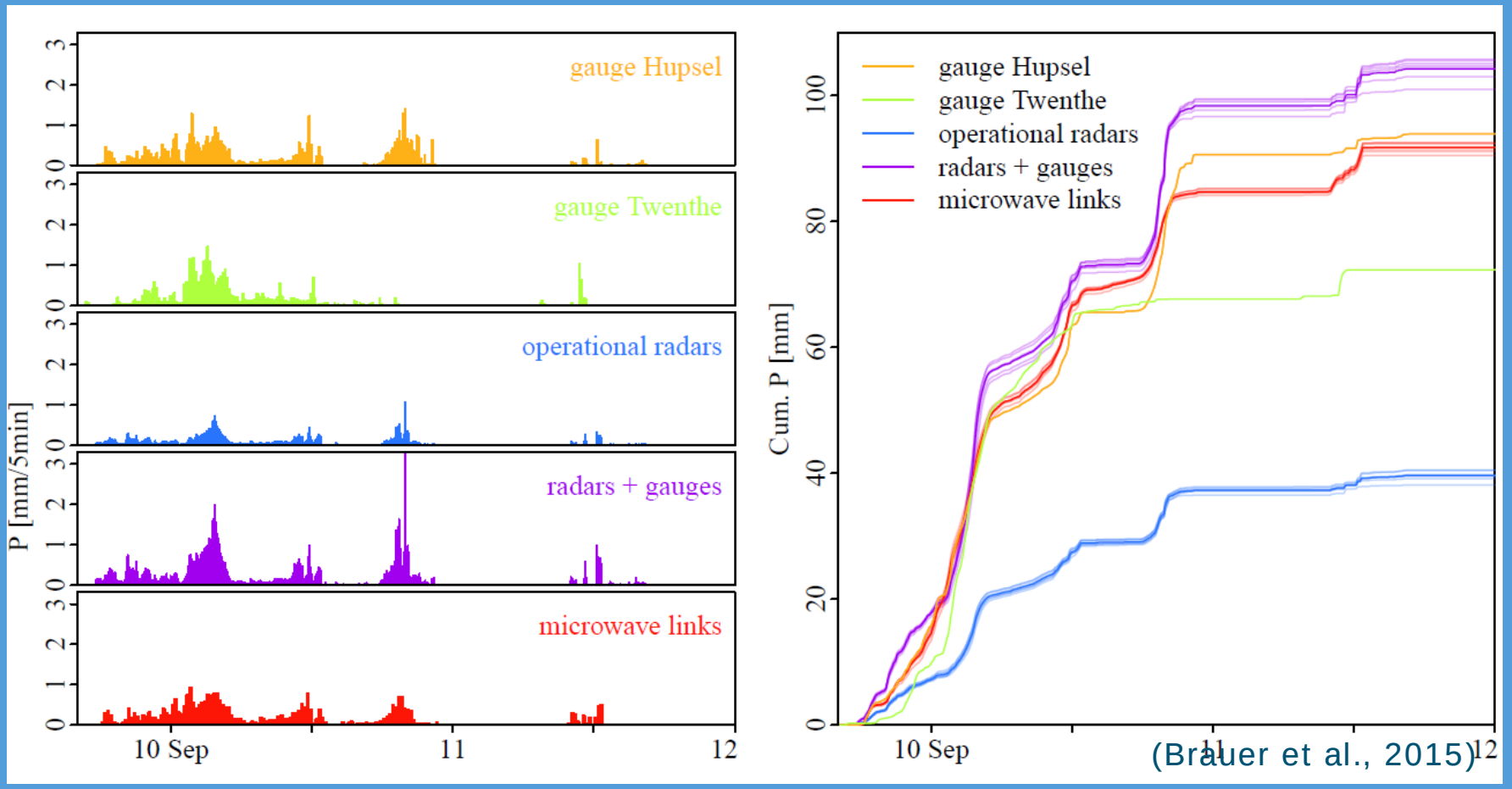
Comparison of different rainfall sensors as forcing for Wageningen Lowland Runoff Simulator (WALRUS)



(Brauer et al., 2014)

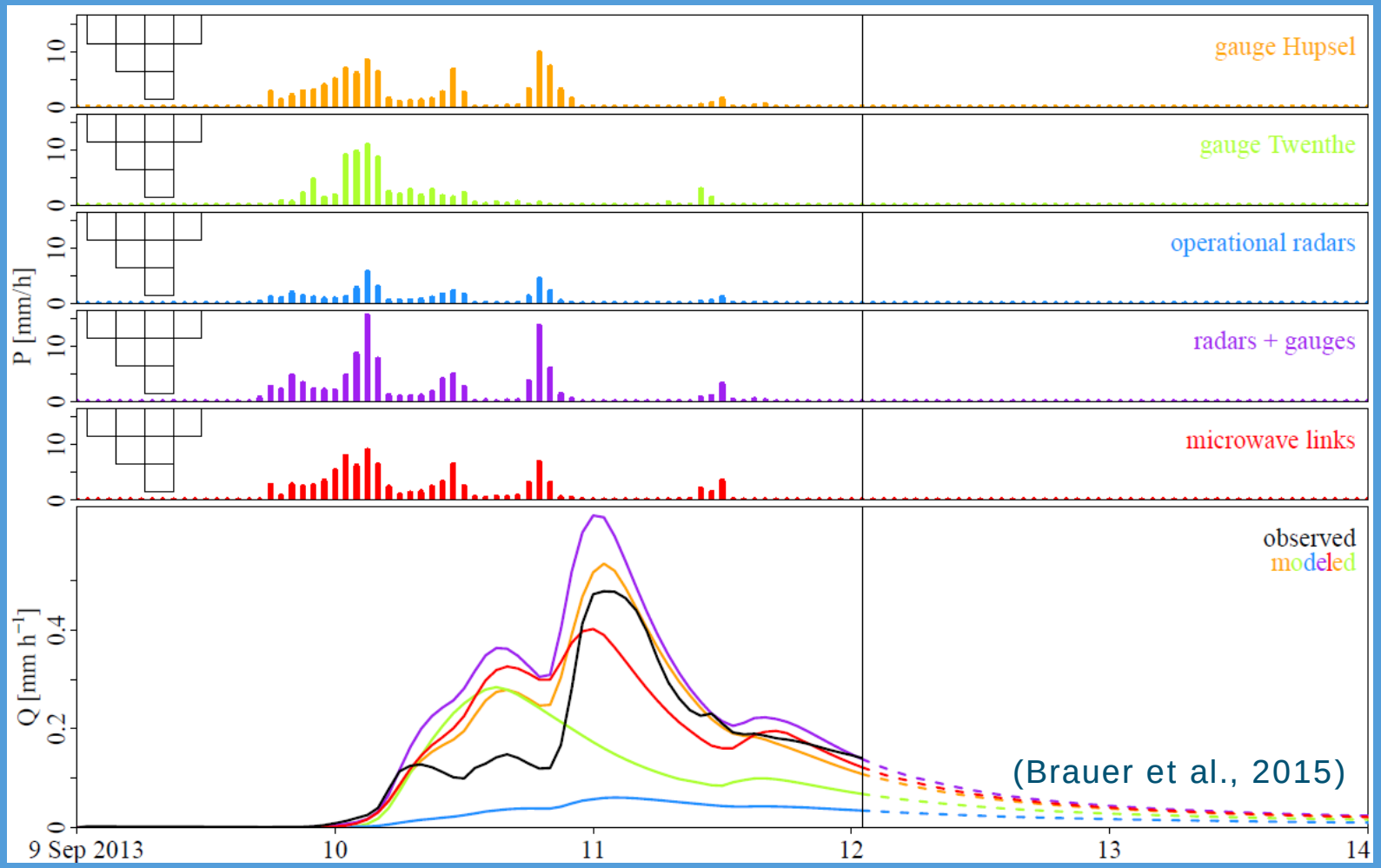


Rainfall observations 9–11 Sep 2013

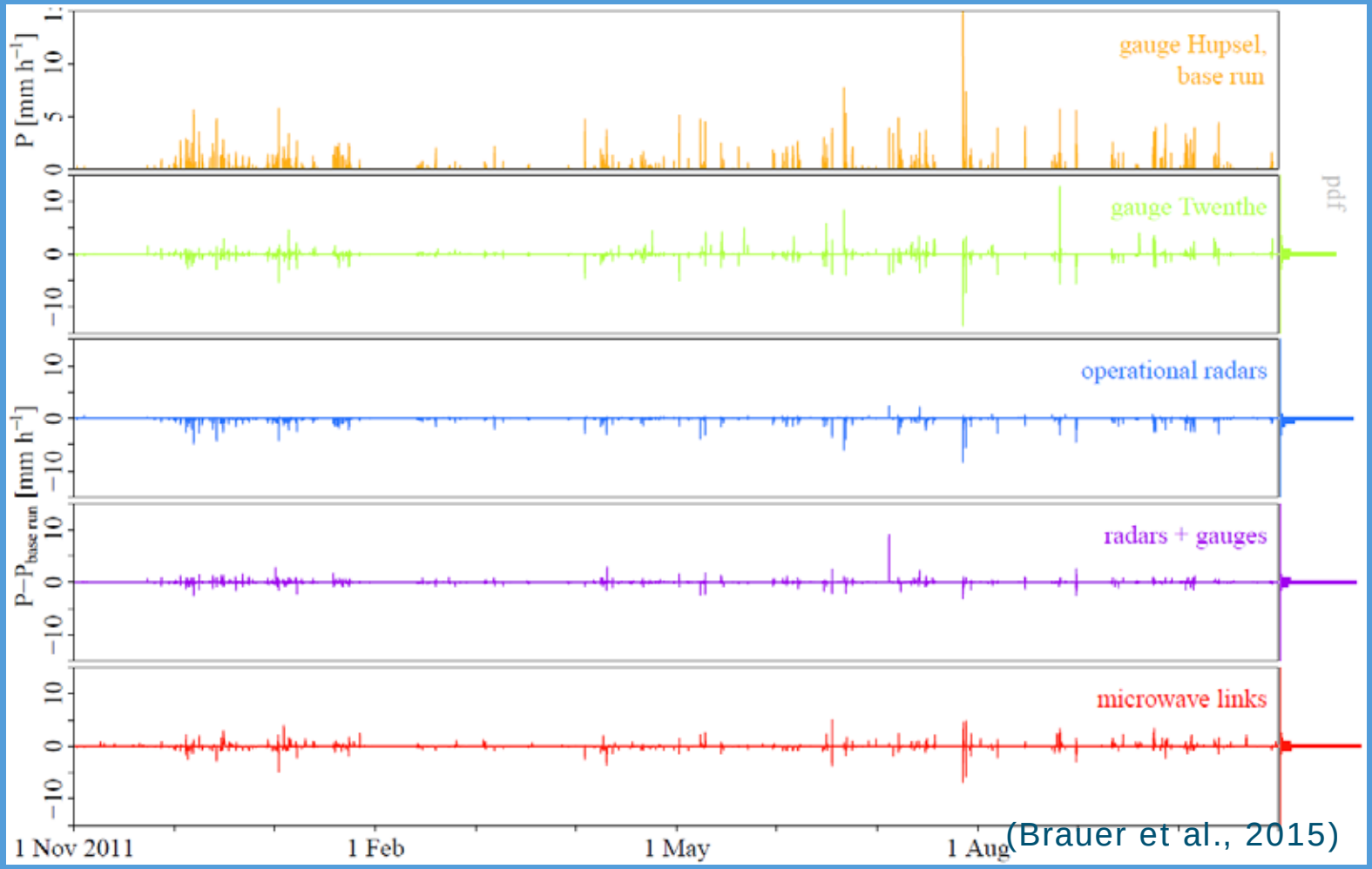


(Brauer et al., 2015)

Hydrological impact Hupsel Brook

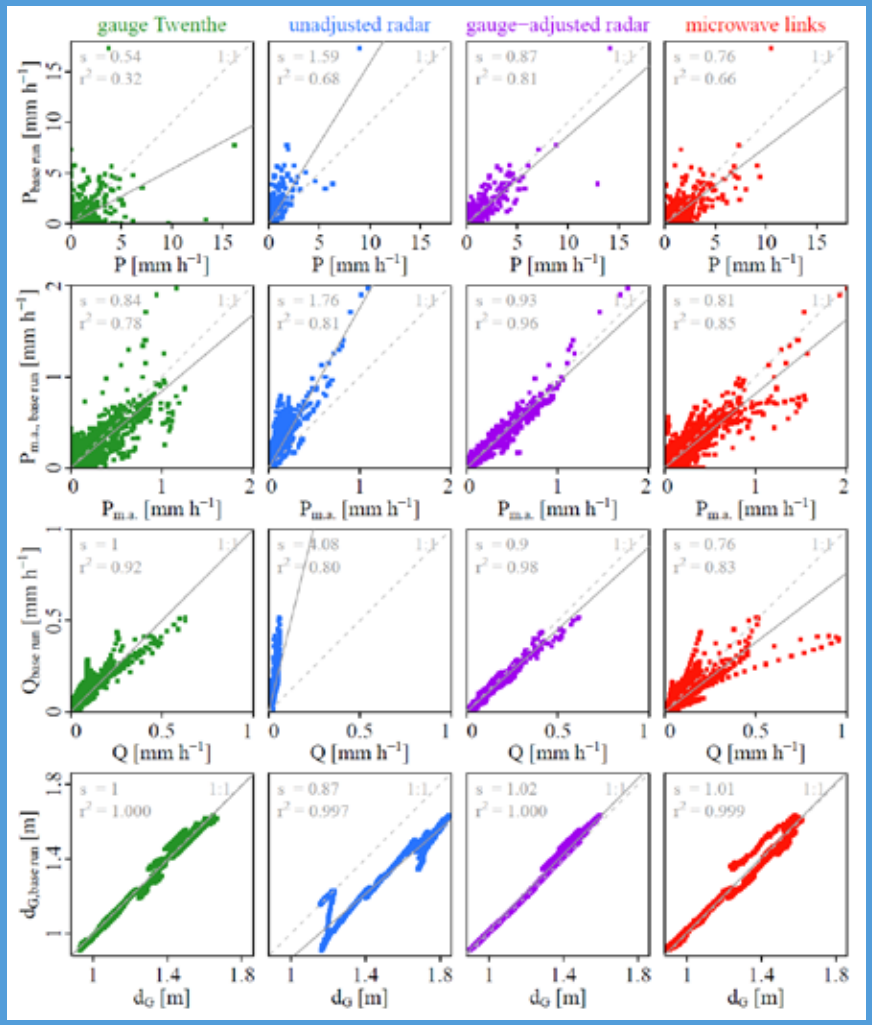


Hourly catchment rainfall for one full year



(Brauer et al., 2015)

Propagation of rainfall errors in catchment



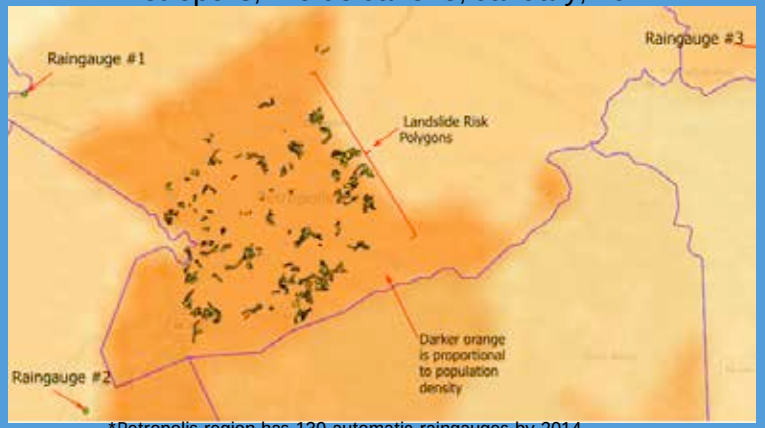
(Brauer et al., 2015)

R&D Partnership to develop a 'National Virtual Weather Station' starting in Brazil with a view to replicate across Emerging Markets

Sparse coverage of automated rain-gauges in Brazil, January, 2011

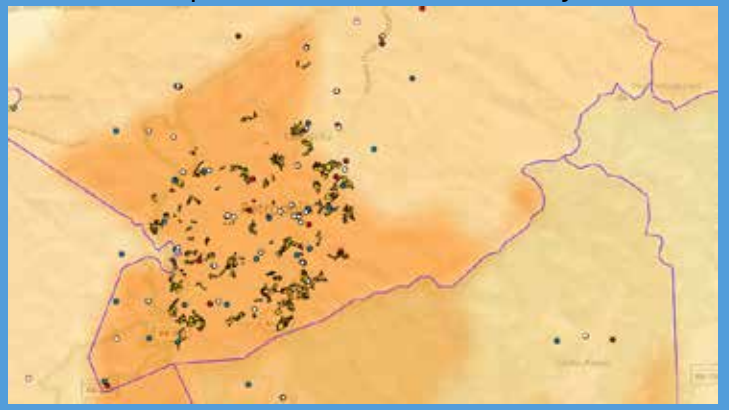
Dense coverage of cellular radio base stations in Brazil , January, 2011

Sparse coverage of automated rain-gauges* in Petropolis, Rio de Janeiro, January, 2011



*Petropolis region has 130 automatic raingauges by 2014

Dense coverage of cellular microwave links in Petropolis, Rio de Janeiro, January, 2011



WAGENINGEN UNIVERSITY
WAGENINGEN UR

PLANETARY SKIN INSTITUTE
Sense, Predict, Act

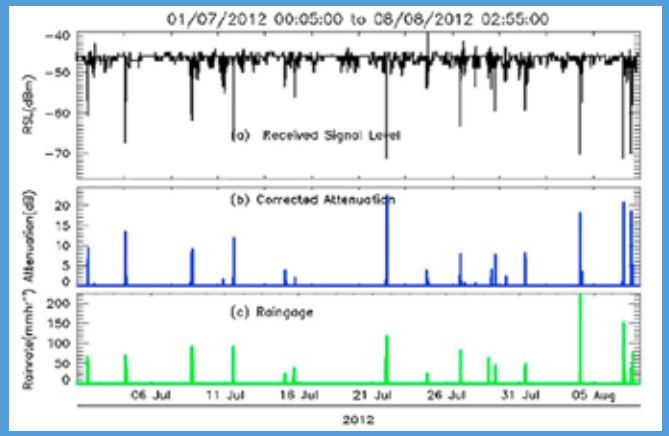
KNMI

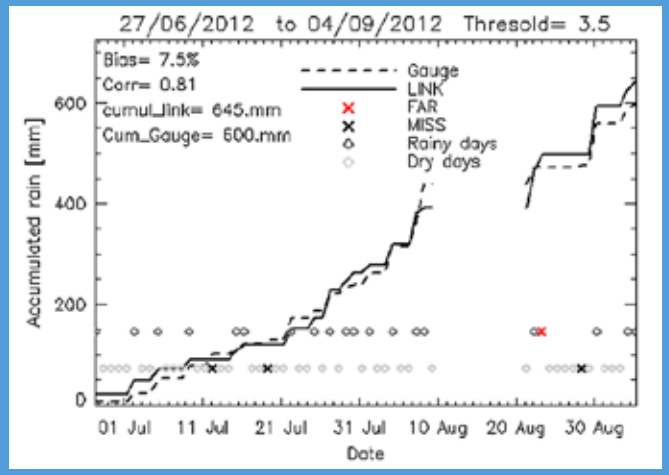
Ministério da Ciência, Tecnologia e Inovação

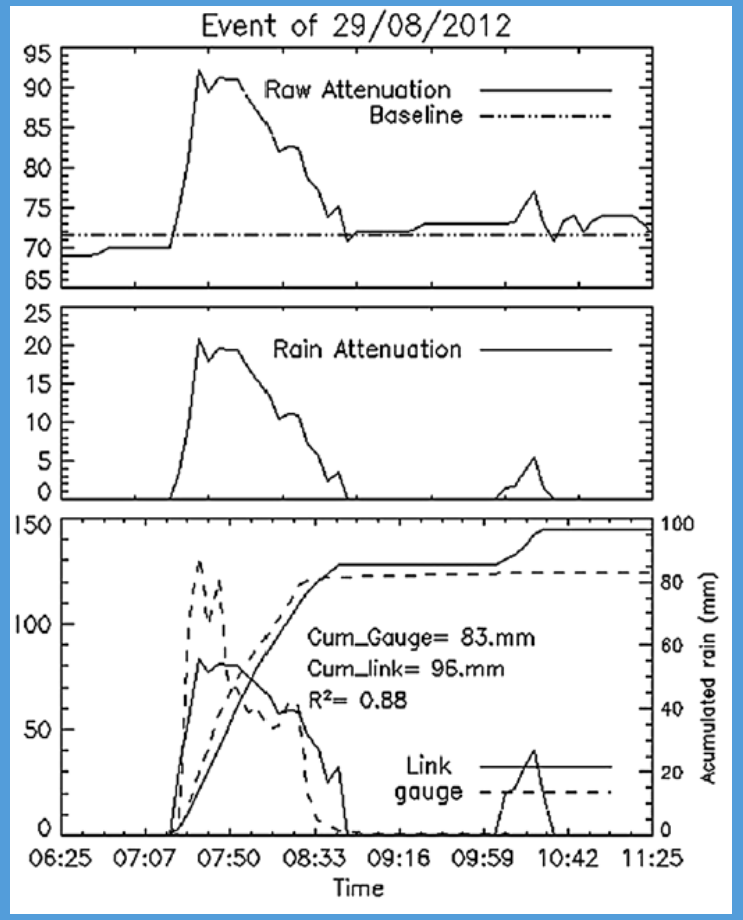
BRASIL
PAÍS RICO É PAÍS SEM POBREZA

Cemaden

First measurements on African continent

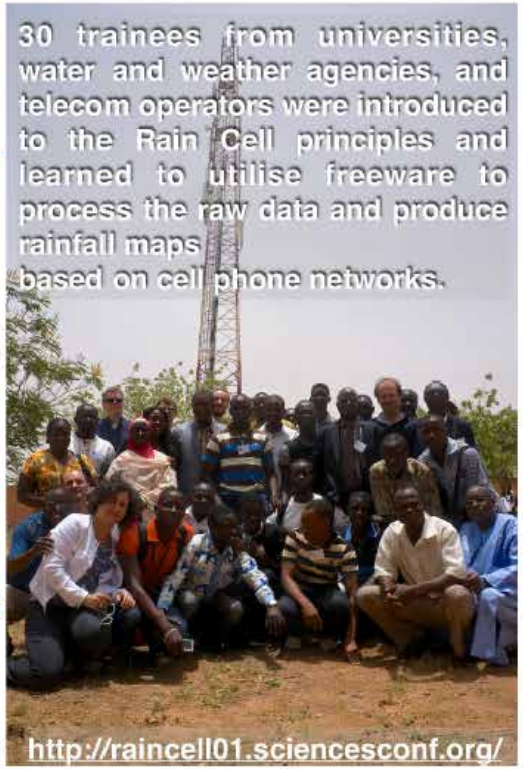






§ Doumounia et al. (2014, GRL)

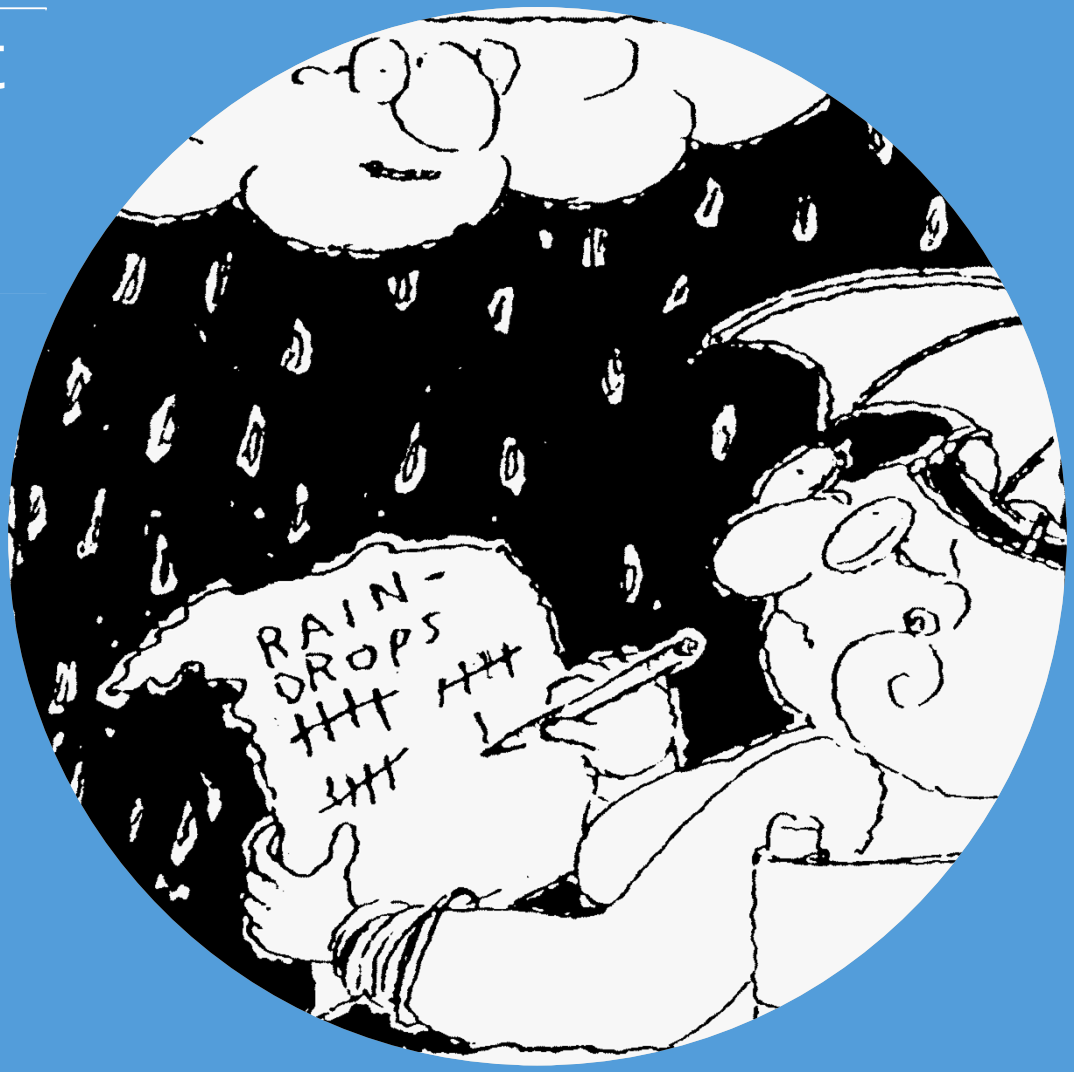
Raincell Africa Training School



(Gosset et al., 2015)

§ Ouagadougou, Burkina Faso, 30 March – 2 April 2015

Remko.Uijlenhoet
@wur.nl



(Victoria Roberts, 2000)