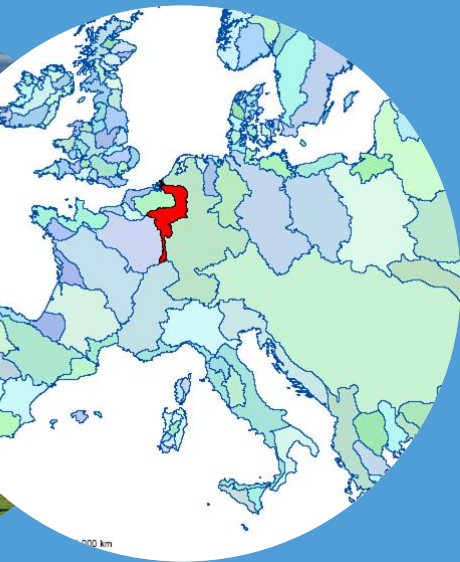
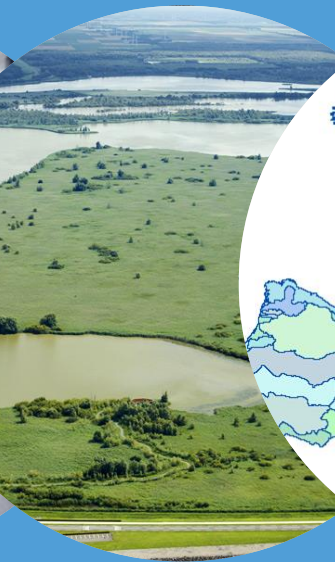
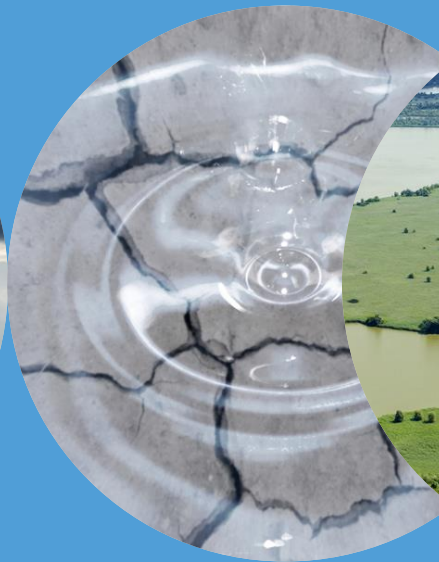
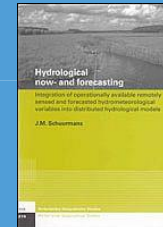
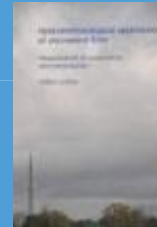


# Opportunistic sensing in hydrology:

cell phones, crowdsourced hobby meteorological stations,  
microwave links from cellular communication networks

Remko Uijlenhoet

Hydrology and Quantitative Water Management Group



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# Dedicated vs. opportunistic sensors



(Victoria Roberts, 2000)

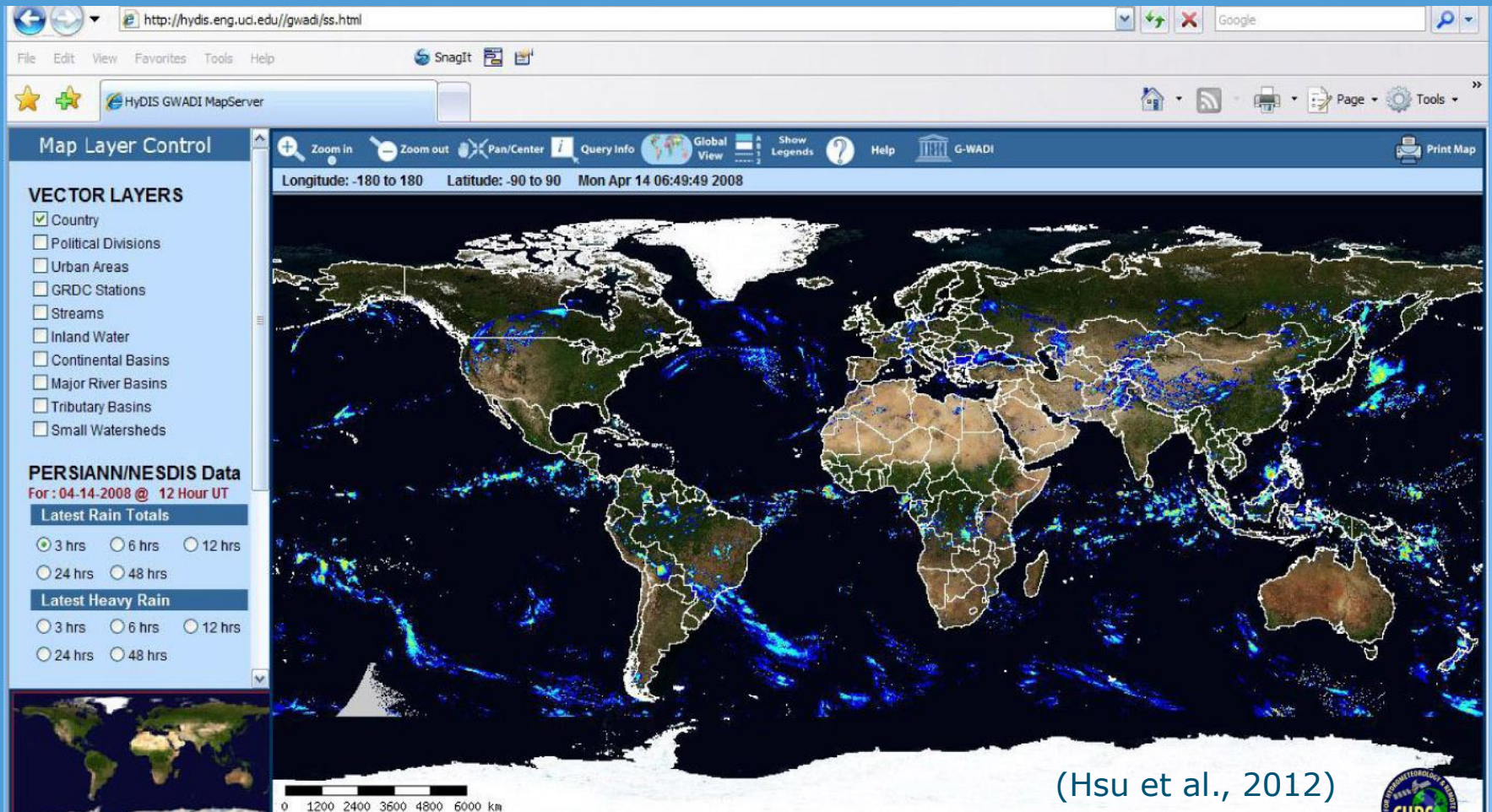


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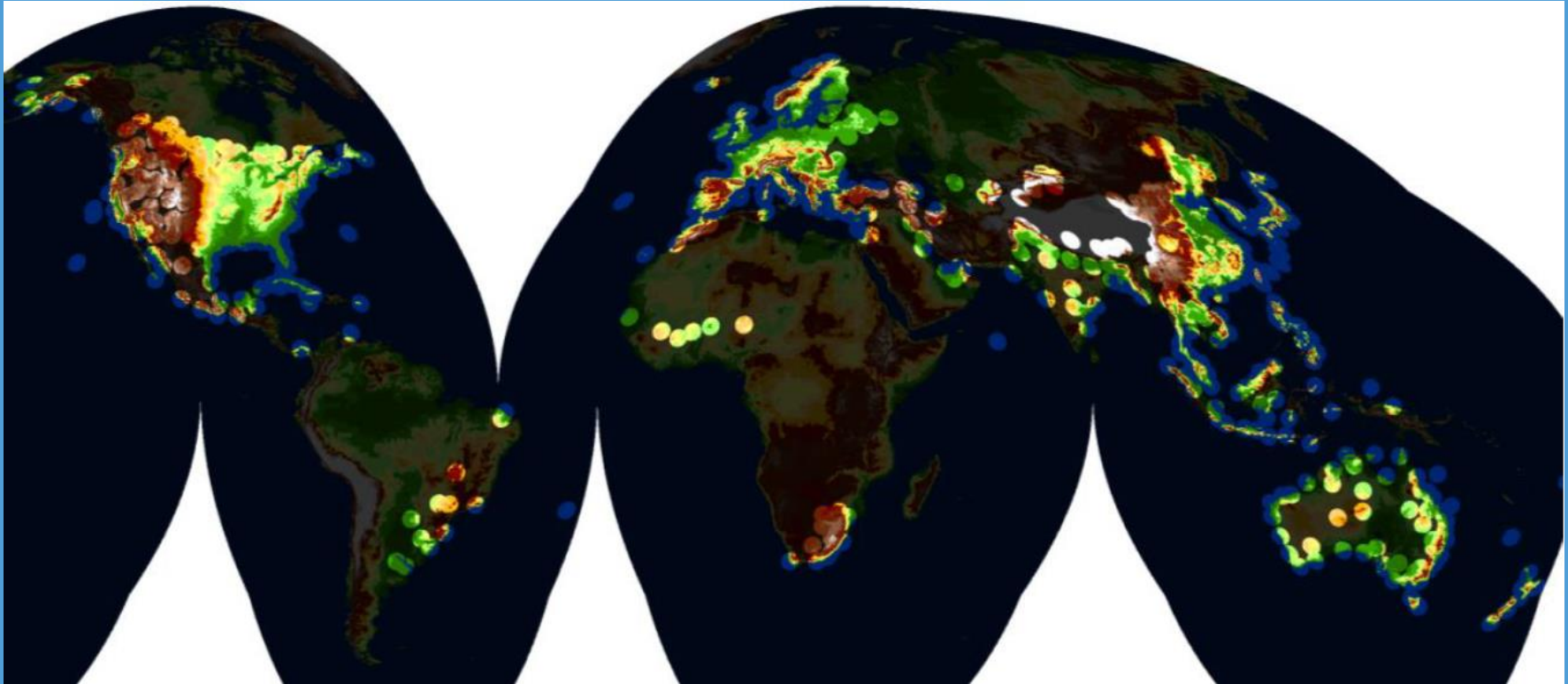
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# Satellites (need ground truthing)





# Global weather radar coverage (incomplete)



(Heistermann et al., 2012)

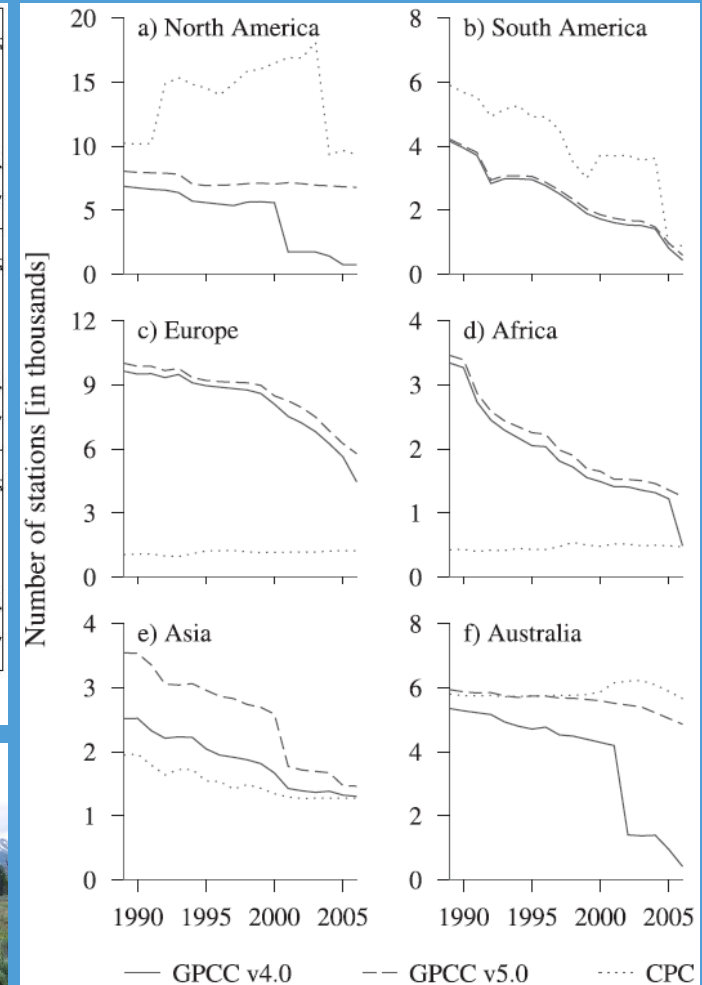
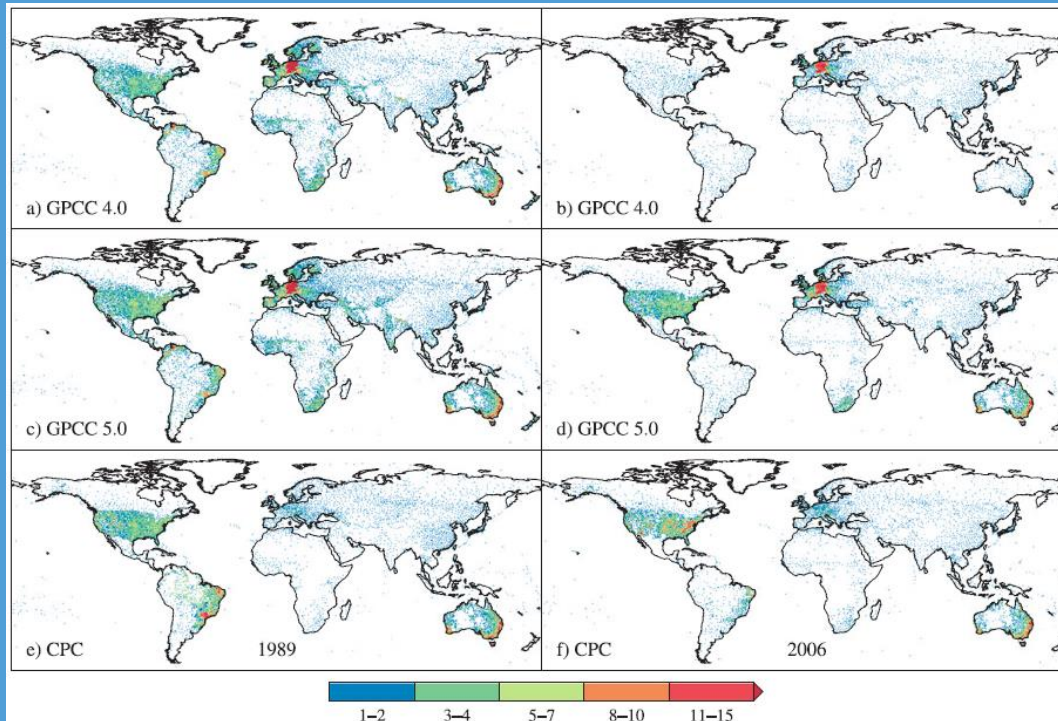


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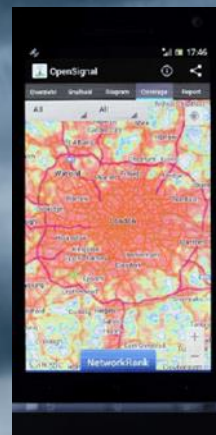
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# Number of rain gauges (rapidly declining)



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





(identim / Shutterstock)



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# Crowdsourcing air temperatures from cell phones



(Victoria Roberts, 2000)



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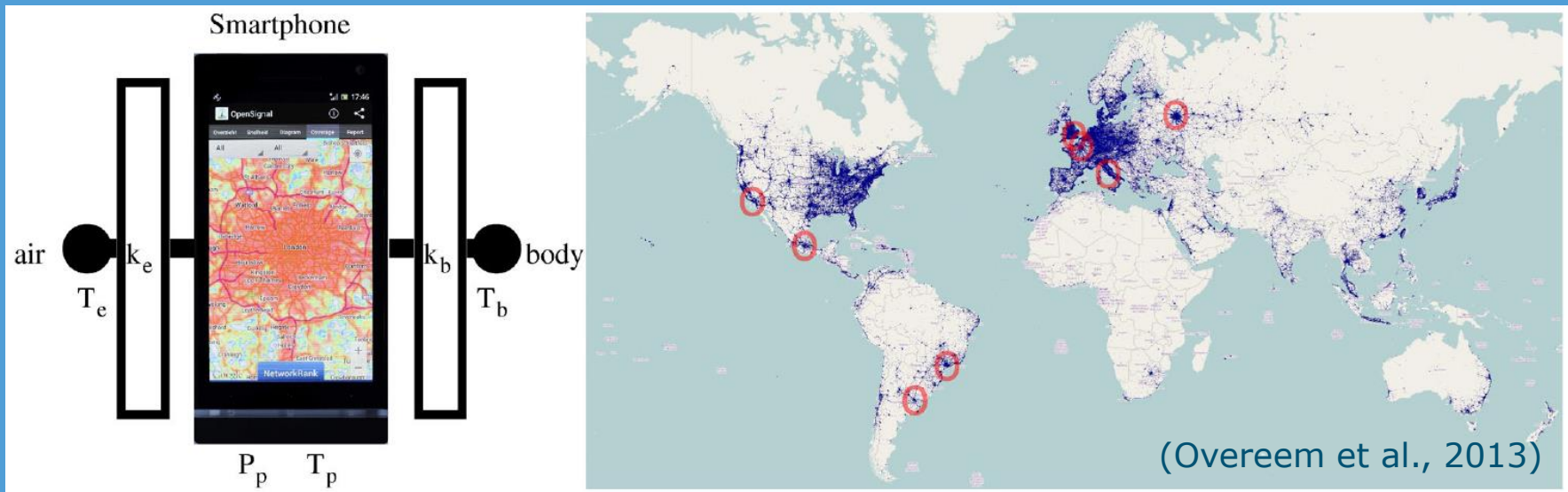
# Environmental monitoring using smartphones

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4081–4085, doi:10.1002/grl.50786, 2013

## Crowdsourcing urban air temperatures from smartphone battery temperatures

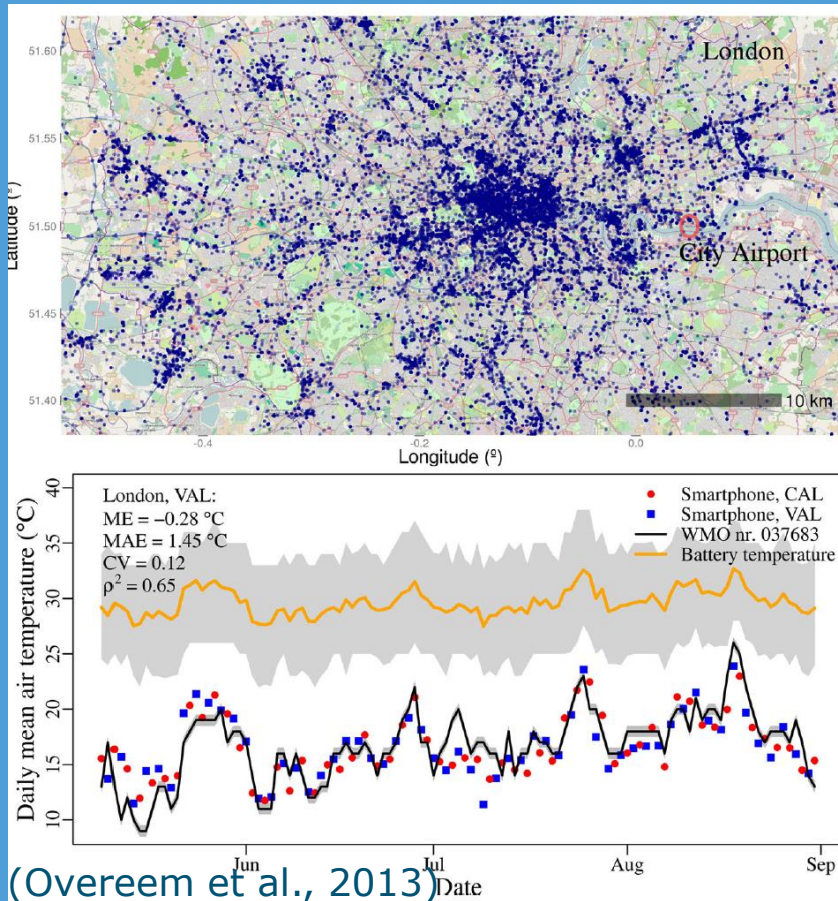
A. Overeem,<sup>1,2</sup> J. C. R. Robinson,<sup>3</sup> H. Leijnse,<sup>2</sup> G. J. Steeneveld,<sup>4</sup>  
B. K. P. Horn,<sup>5</sup> and R. Uijlenhoet<sup>1</sup>

Received 21 June 2013; revised 18 July 2013; accepted 22 July 2013; published 14 August 2013.



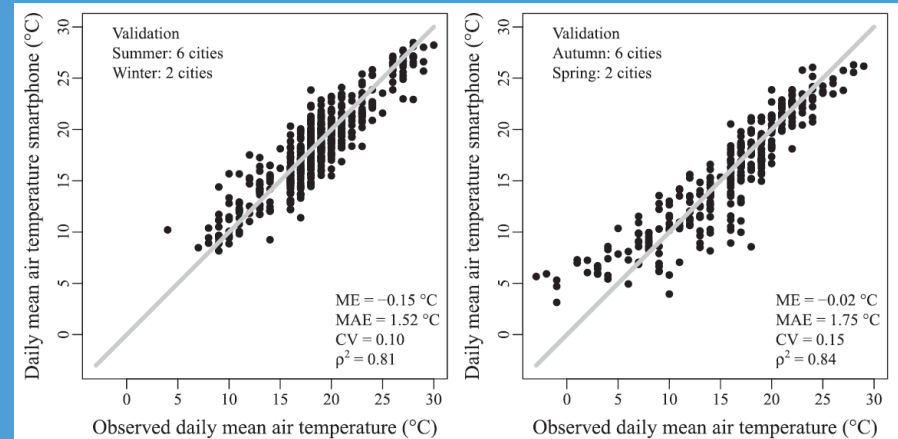


# Daily mean urban air temperatures from smartphone battery temperatures

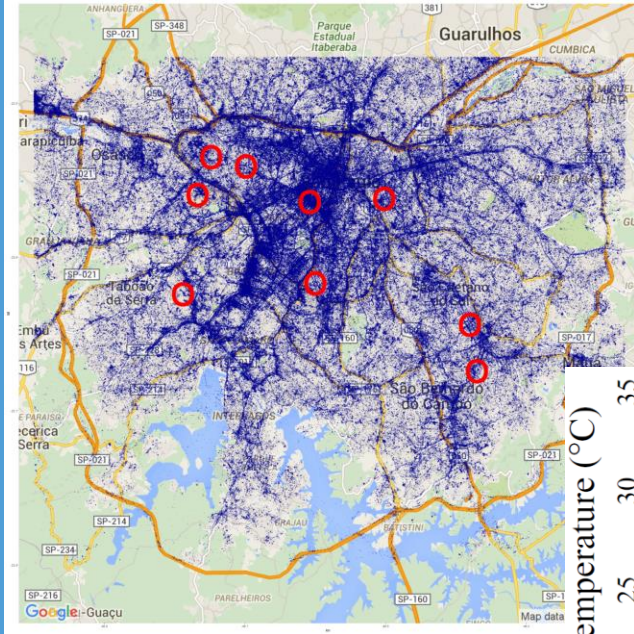


$$P_p = P_e + P_b = k_e(T_p - T_e) + k_b(T_p - T_b)$$

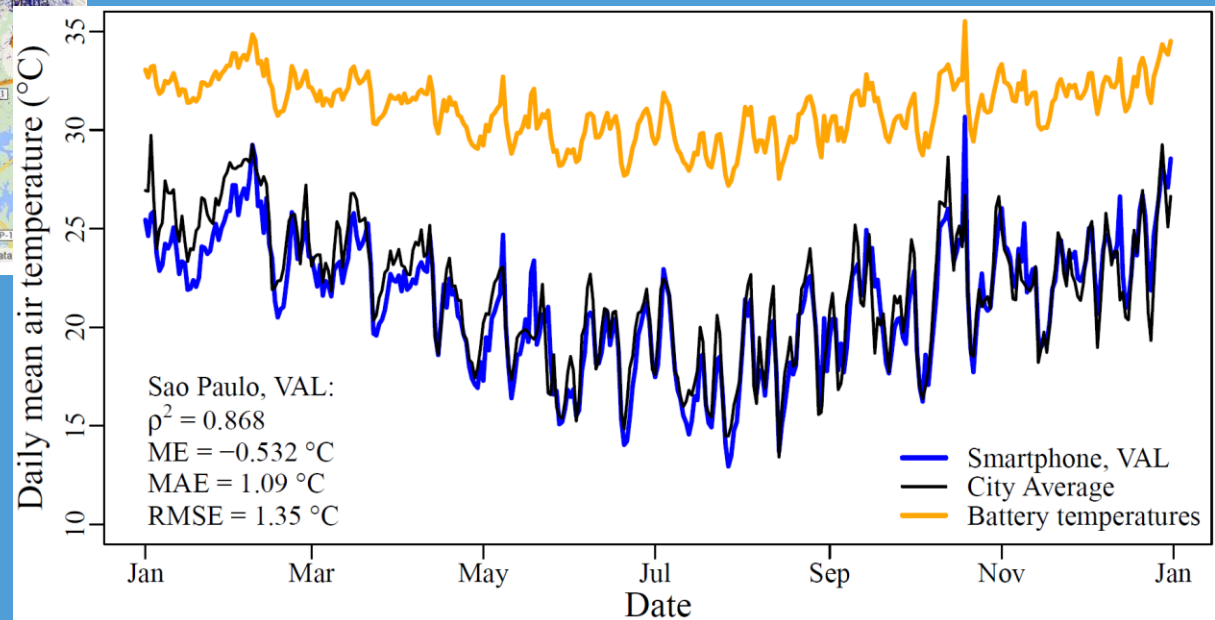
$$T_e = \left(1 + \frac{k_b}{k_e}\right) T_p - \left(\frac{k_b}{k_e} T_b + \frac{P_p}{k_e}\right)$$



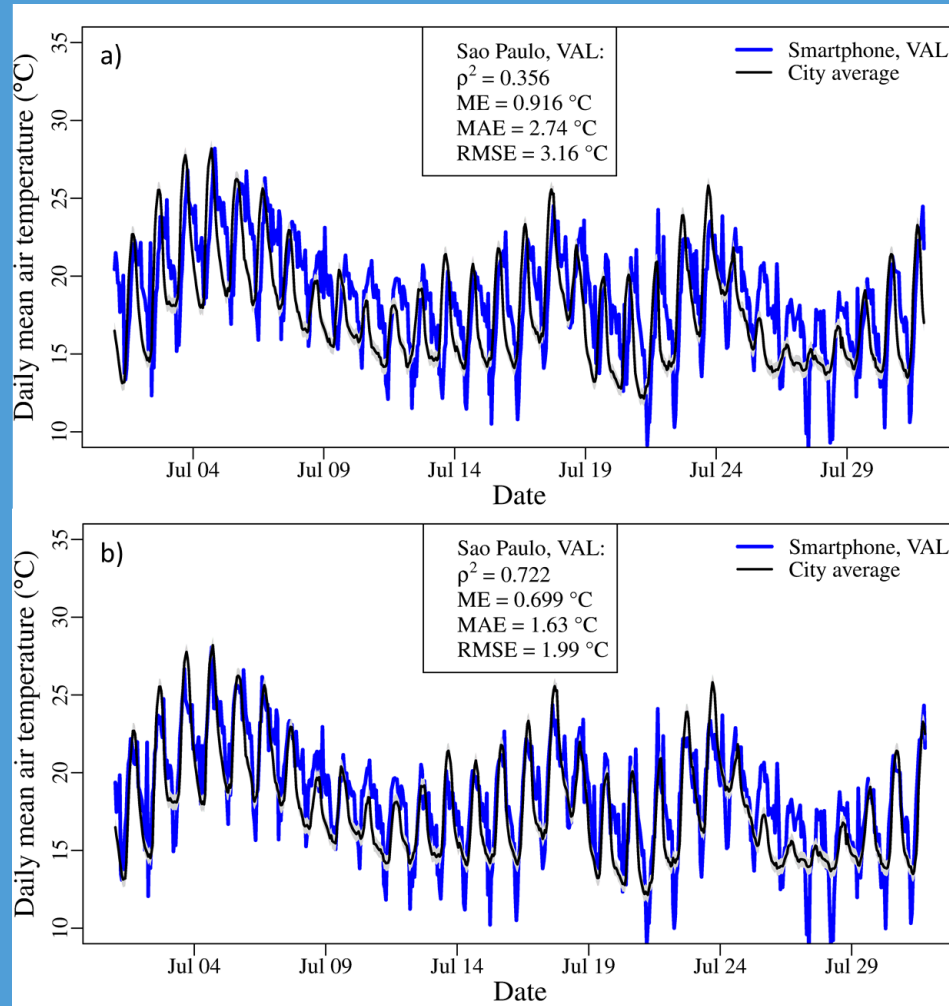
# Improved resolution for São Paulo



(Droste et al., 2016)



# Hourly mean air temperature estimates



(Droste et al., 2016)



# Crowdsourcing urban rainfall from personal weather stations



(Victoria Roberts, 2000)

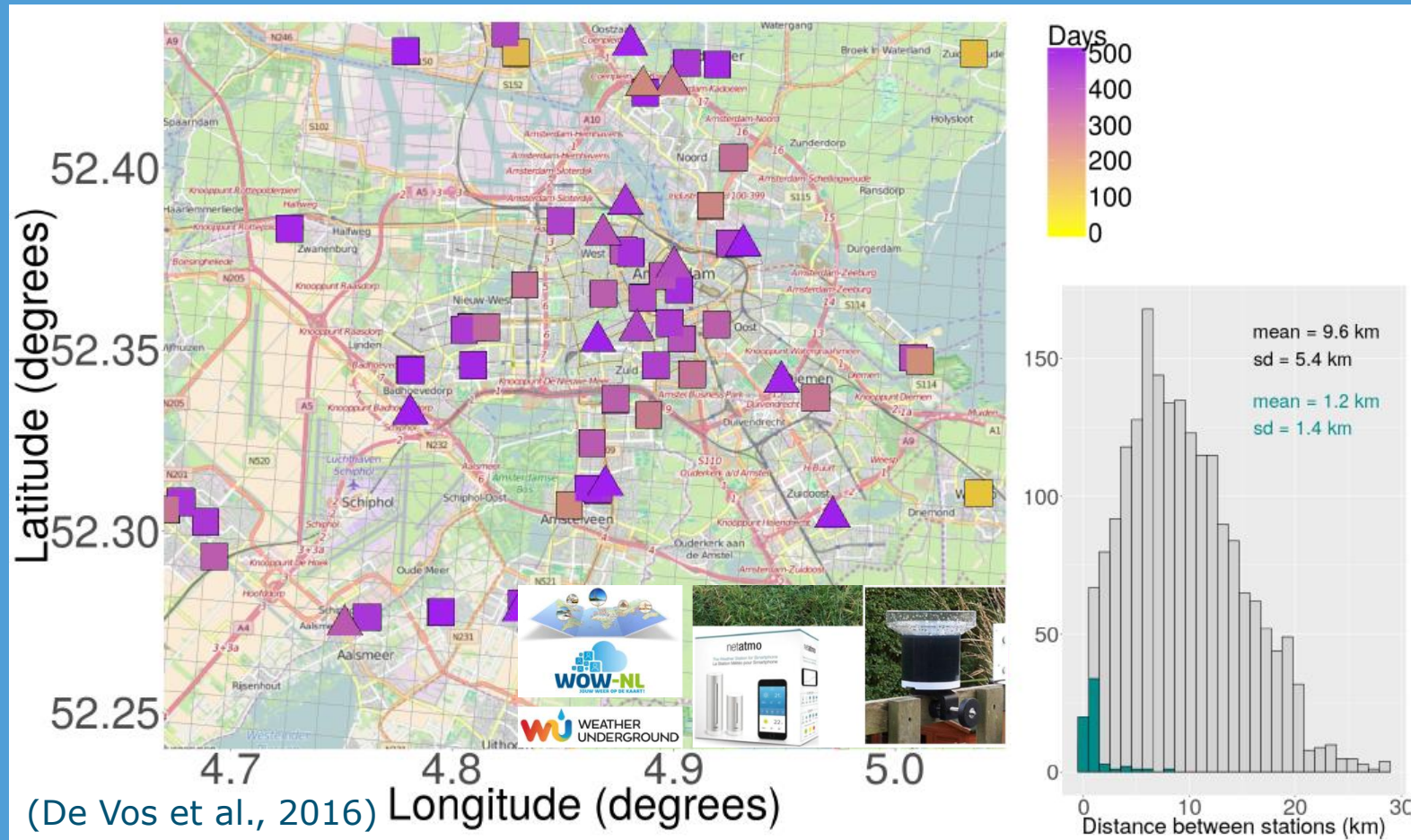


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# Personal weather stations in Amsterdam





# Netatmo rain gauge

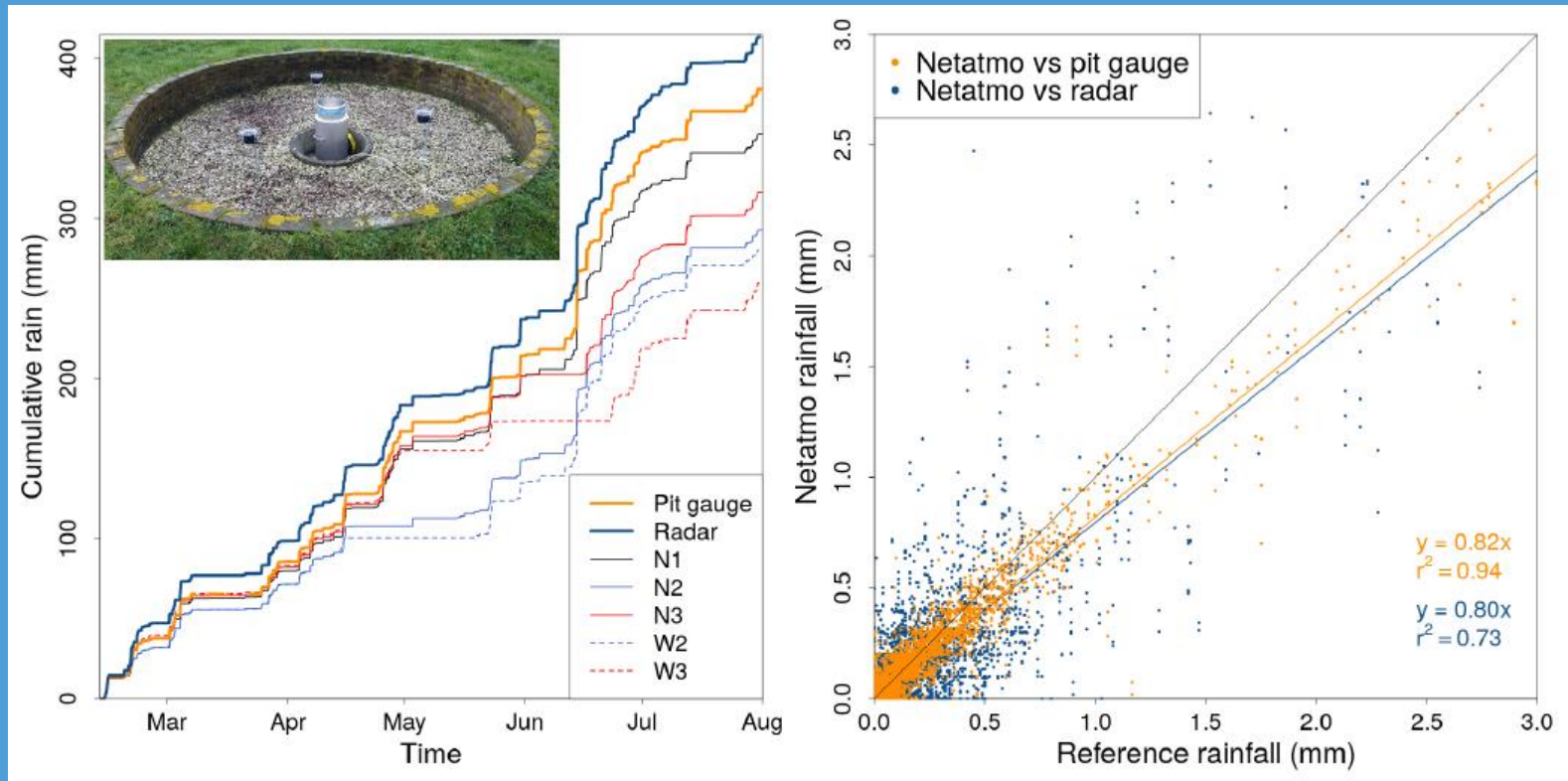


(De Vos et al., 2016)



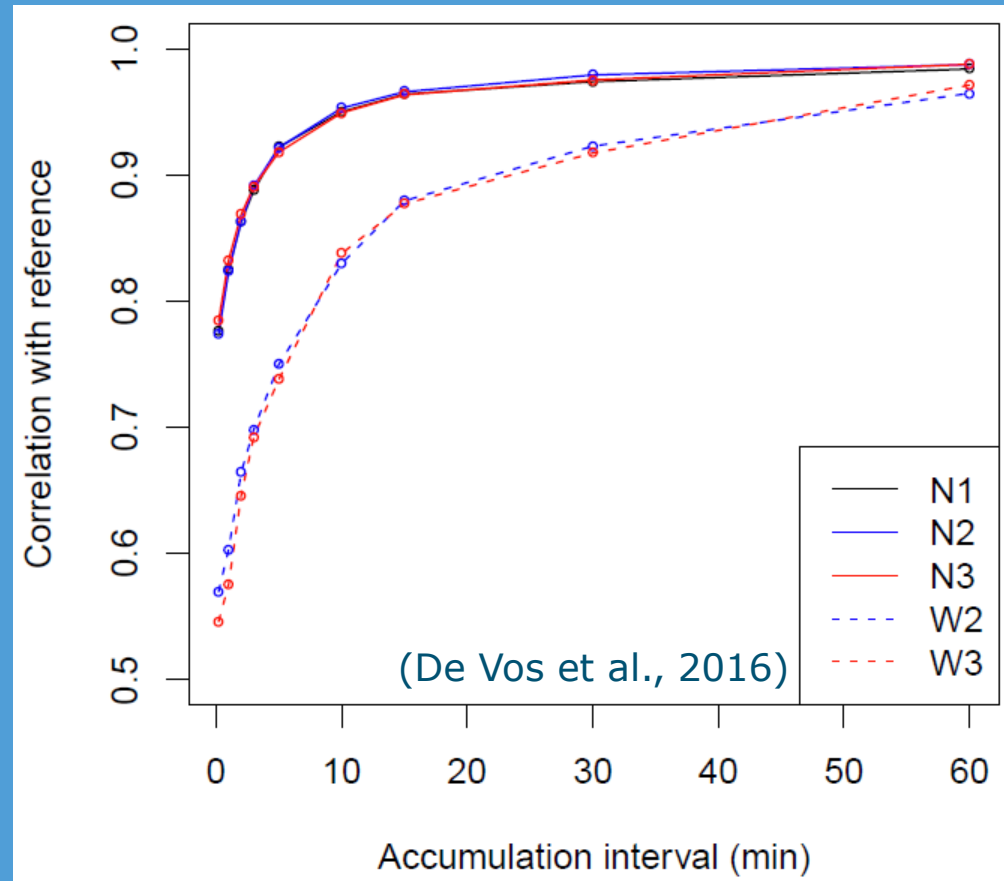


# Validation of Netatmo stations at Cabauw

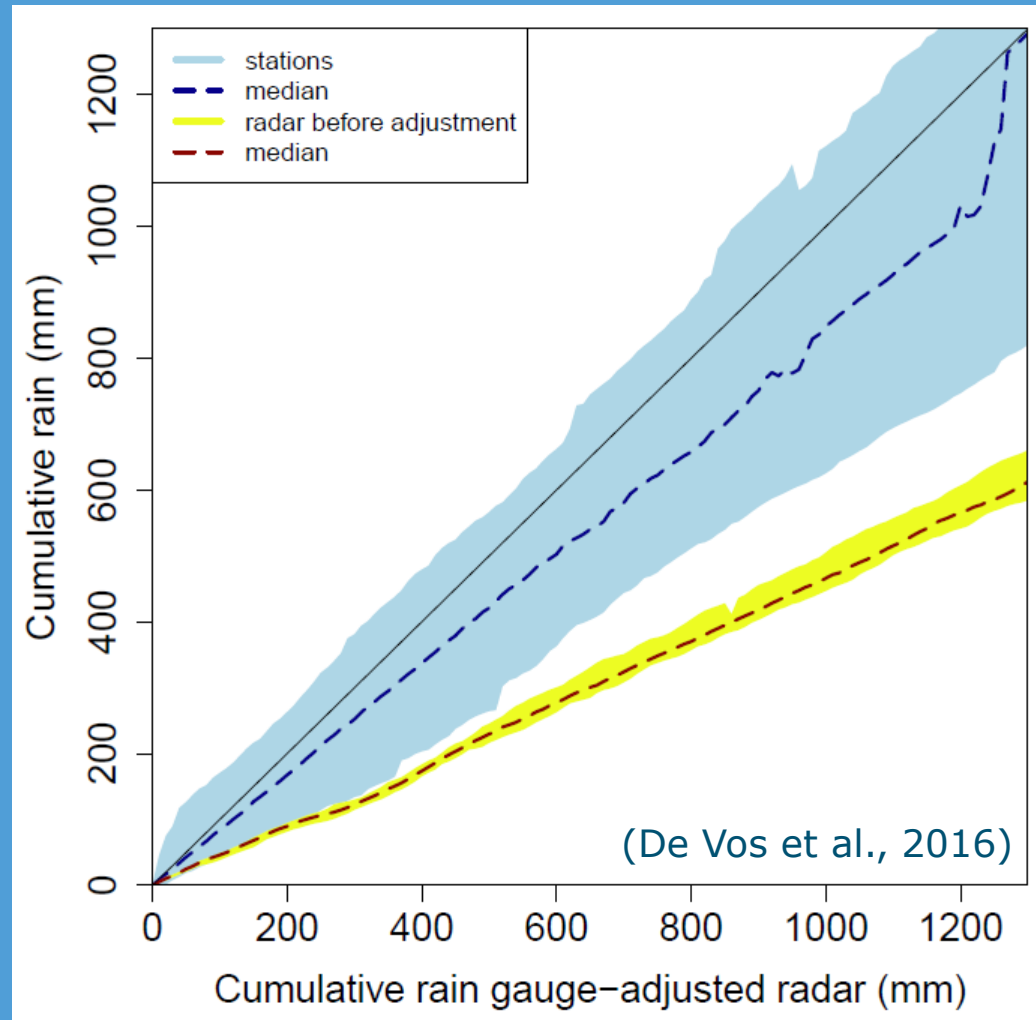


(De Vos et al., 2016)

# Correlation with pit gauge reference

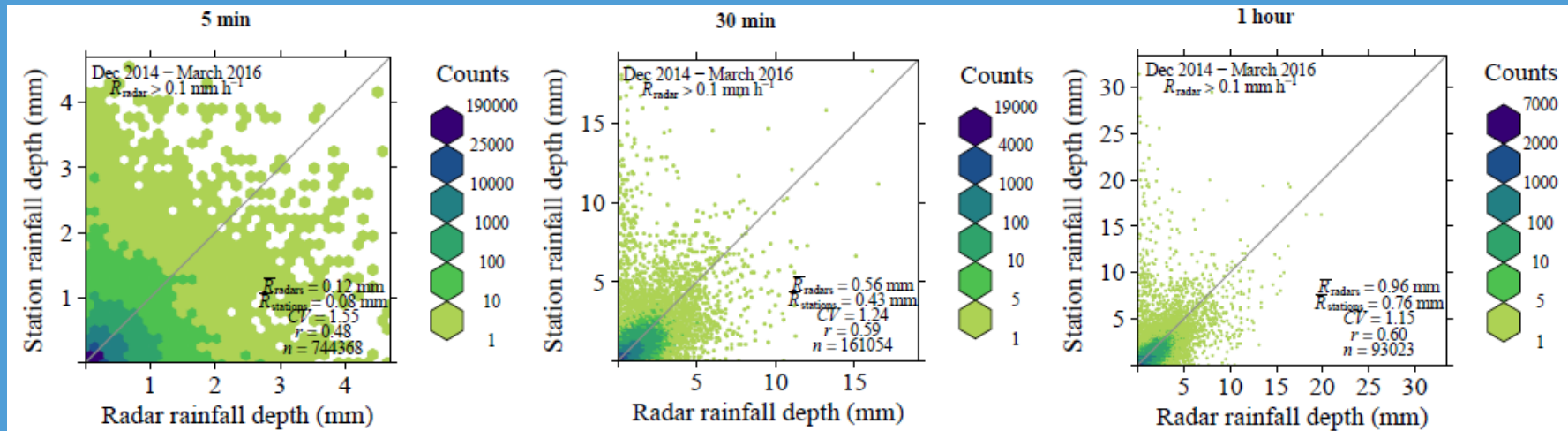


# Double mass plots (PWS versus radar)



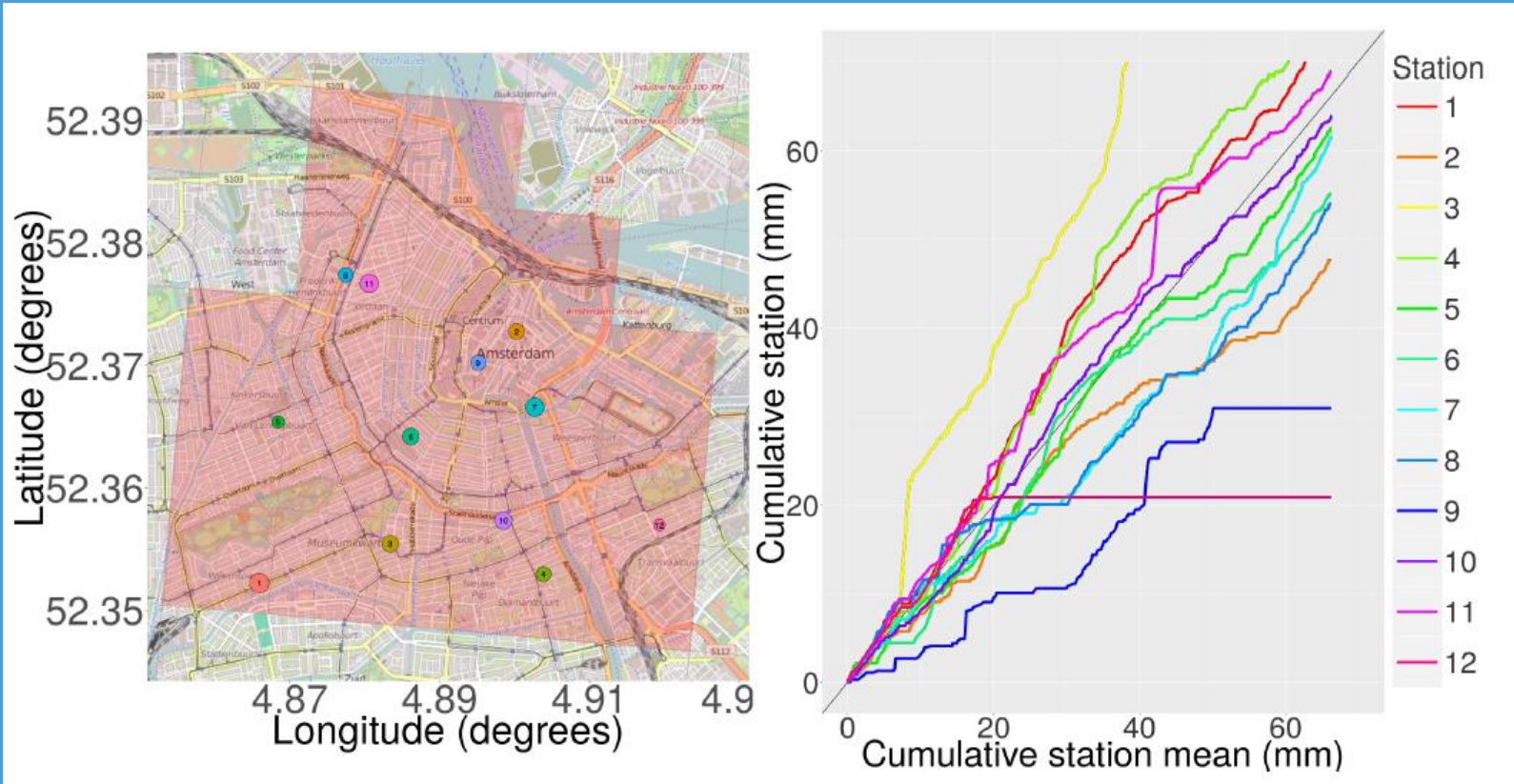


# Scatter density plots (PWS versus radar)



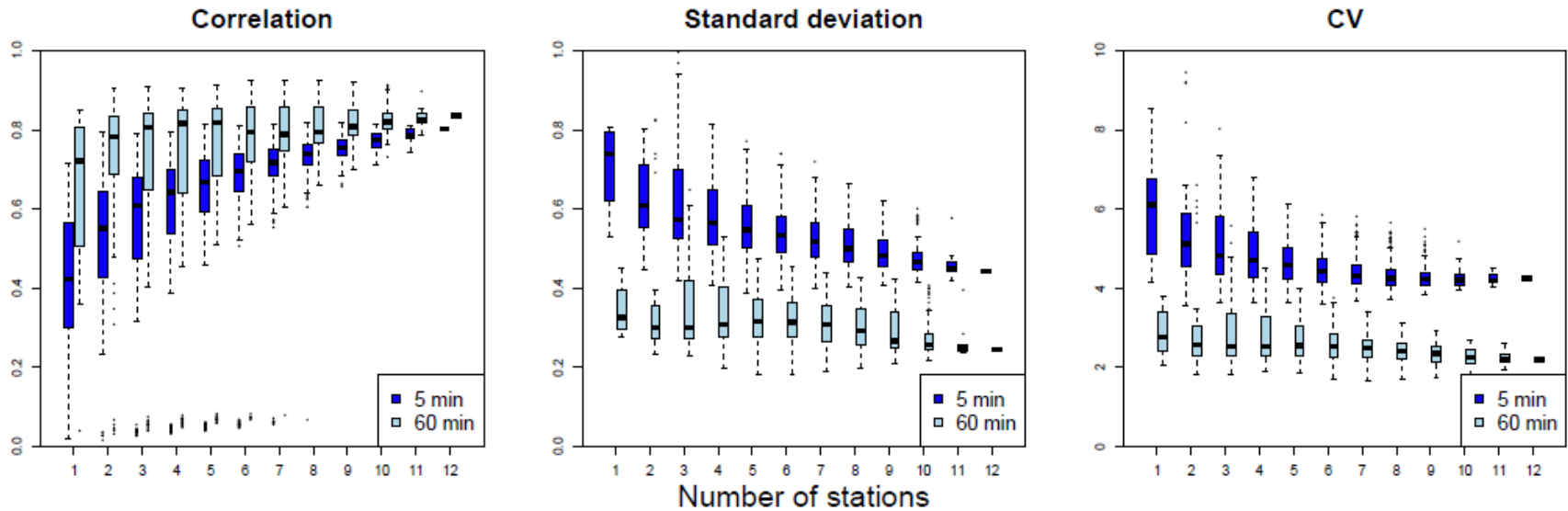
(De Vos et al., 2016)

# Analysis for Amsterdam city center



(De Vos et al., 2016)

# Mean rainfall over Amsterdam city center



(De Vos et al., 2016)



# Rainfall monitoring using microwave links



(Victoria Roberts, 2000)



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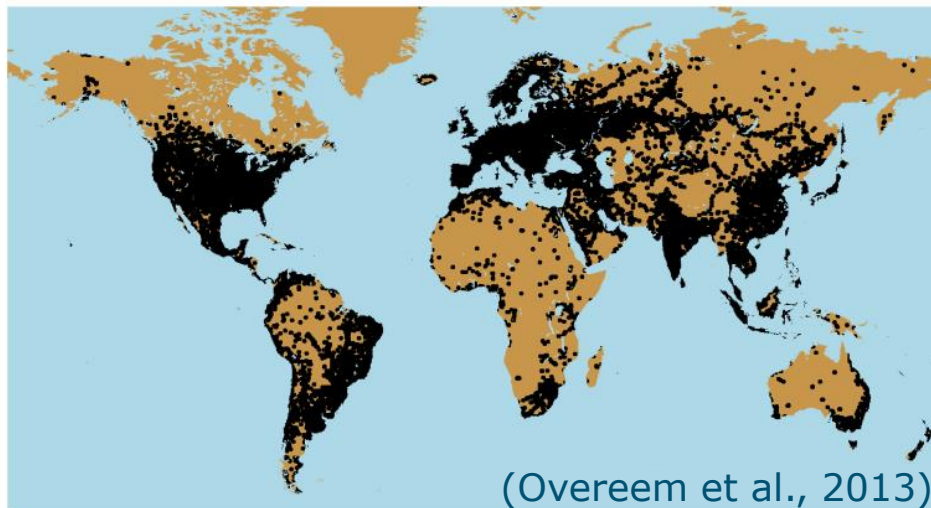


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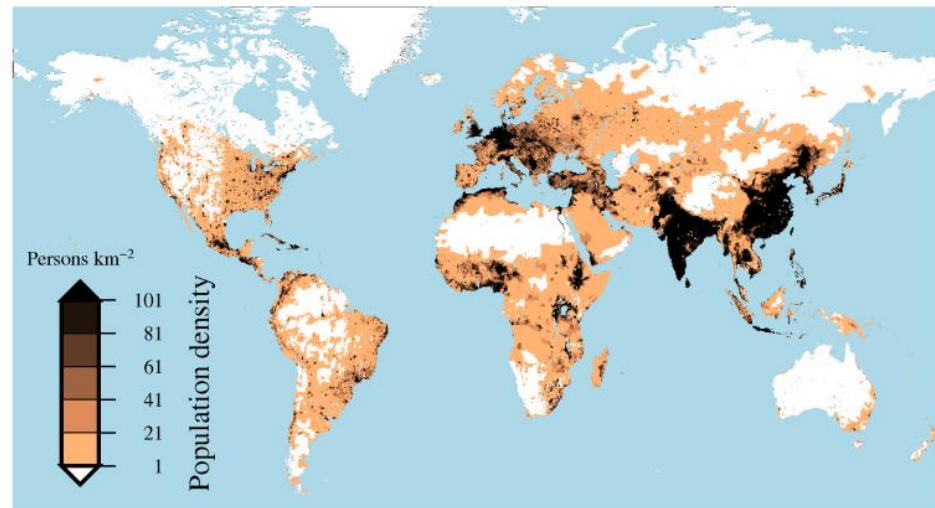
# Microwave links from cell. comm. networks

- Potential over poorly gauged regions / continents
- Urban areas poorly gauged, but high cell phone density

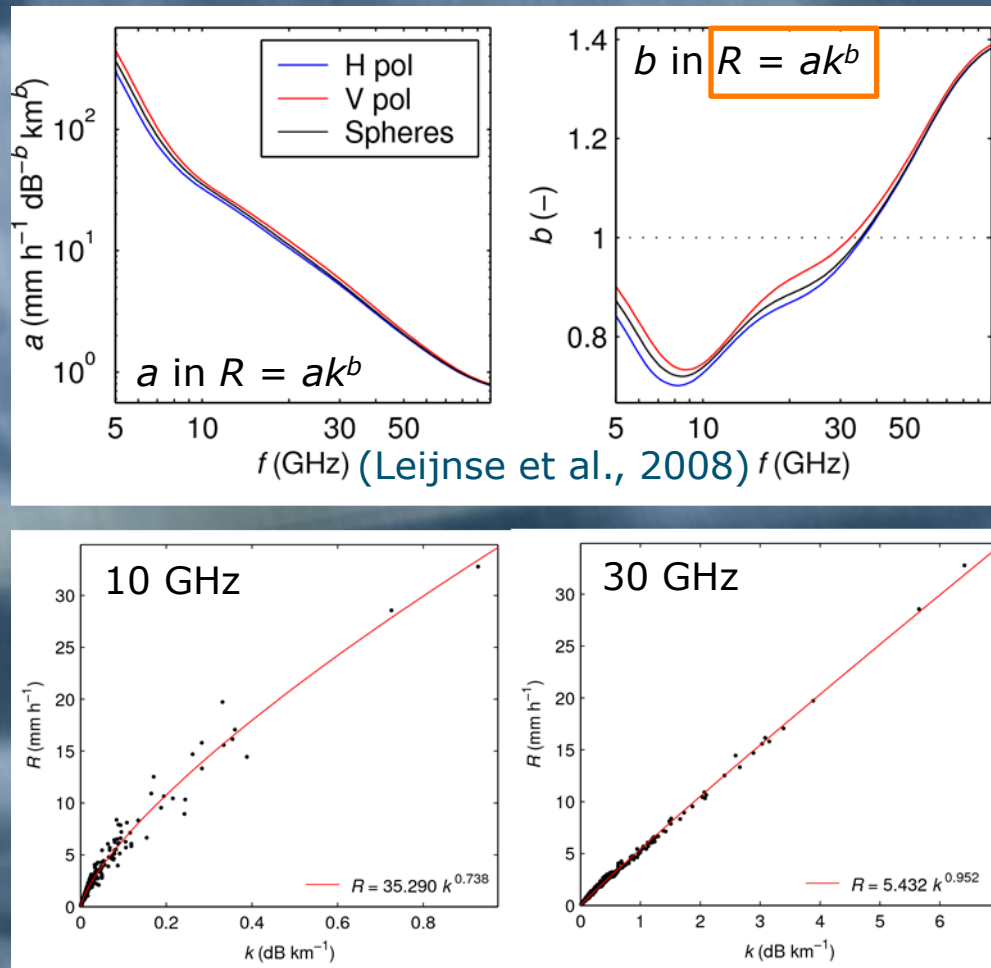
(identim / Shutterstock)



(Overeem et al., 2013)



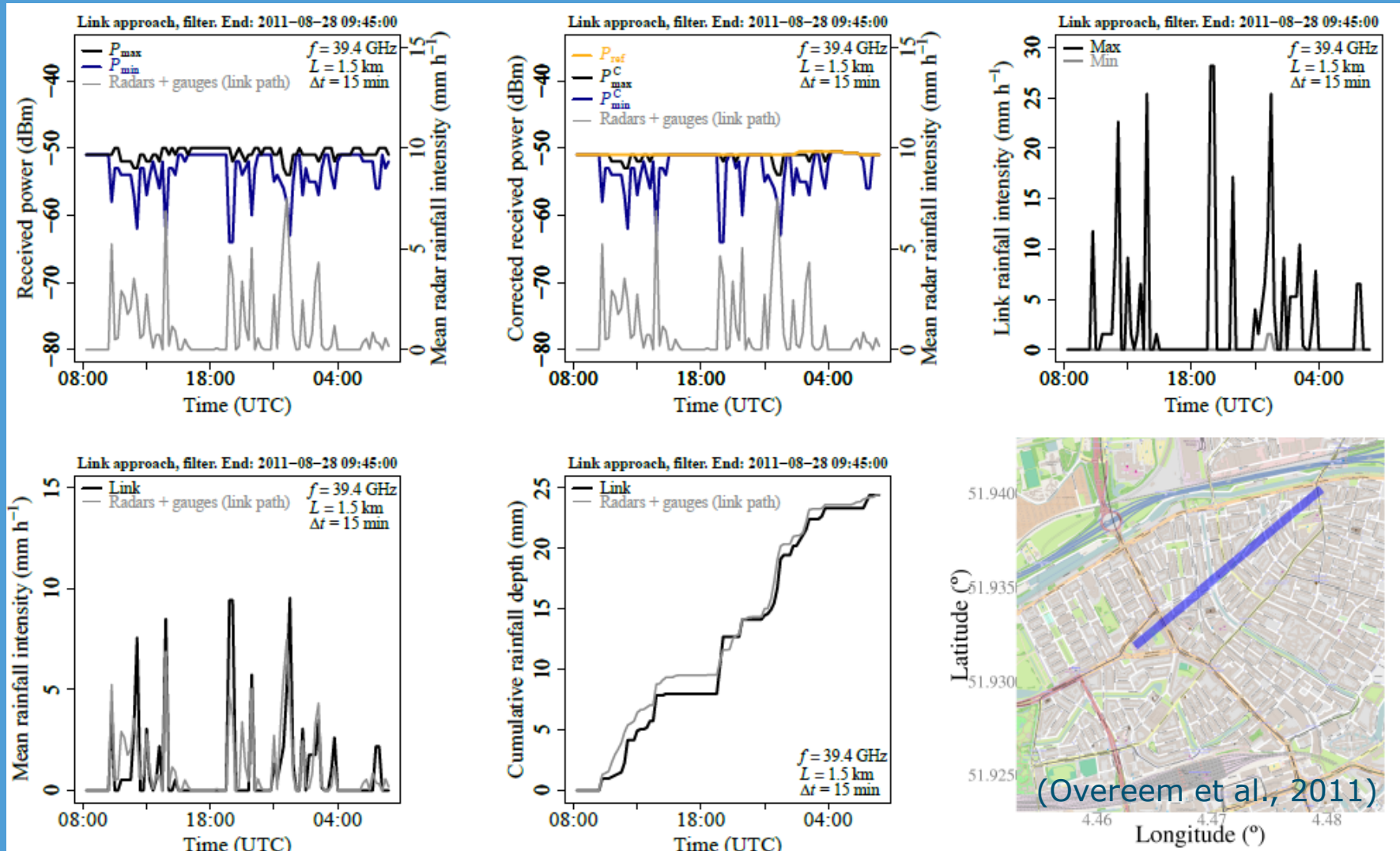
(Power-law  $R$ - $k$  relations)



(identim / Shutterstock)

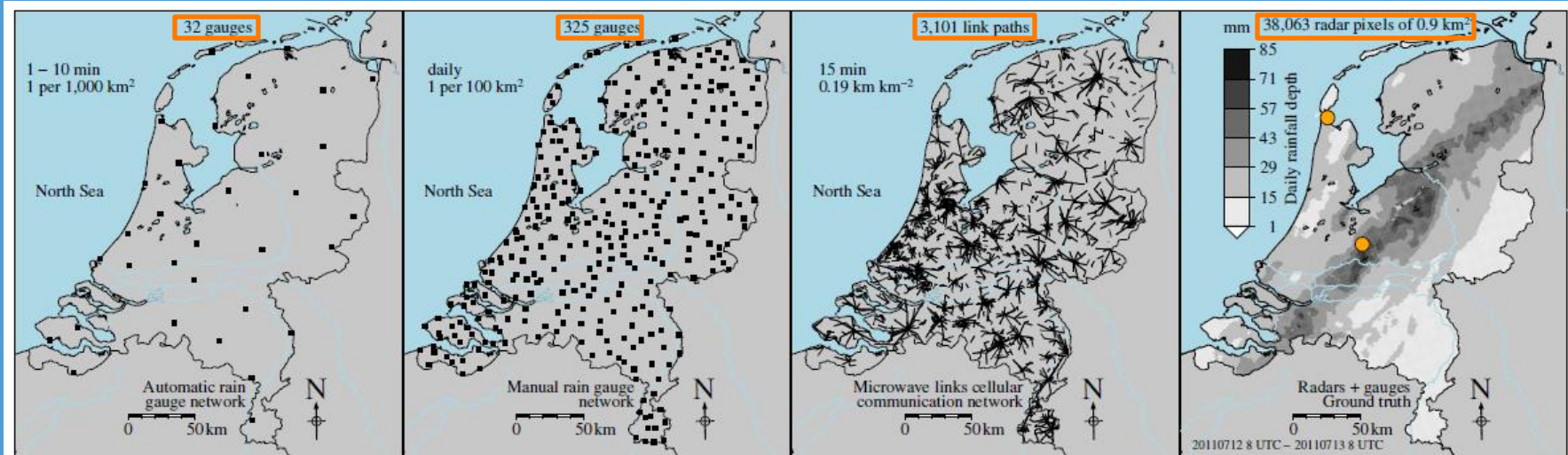


# Rainfall retrieval in Rotterdam

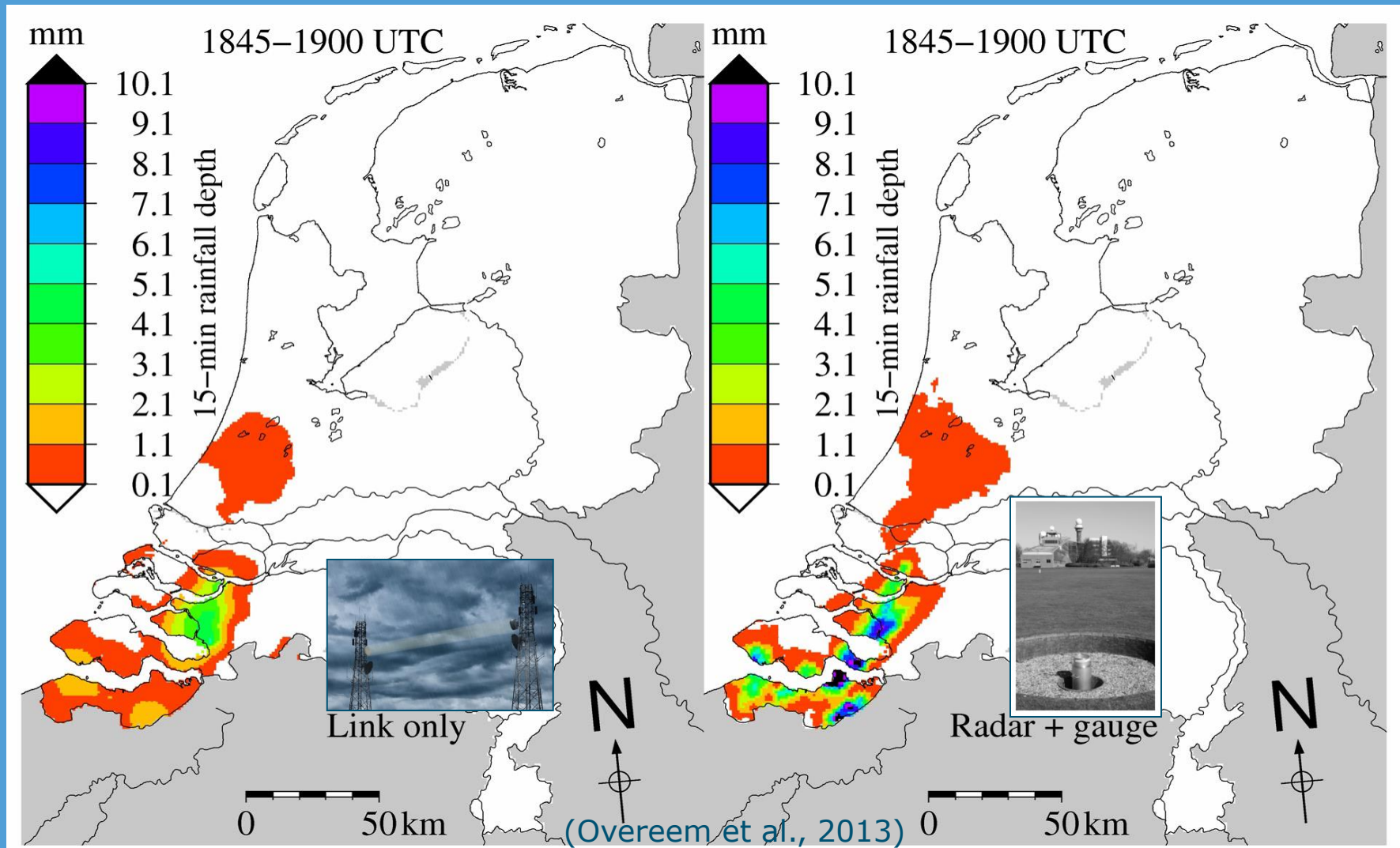




# Many more microwave links than gauges

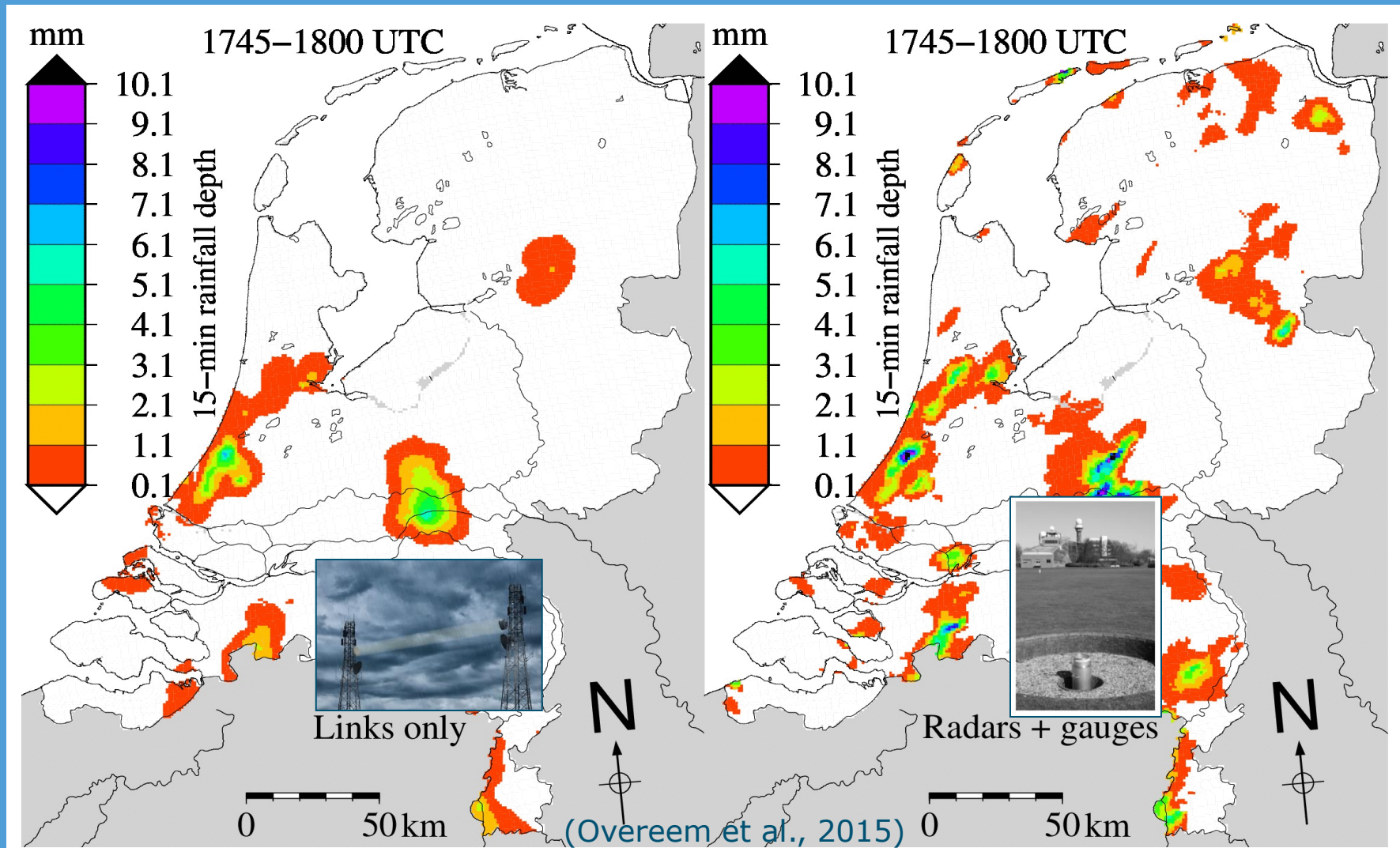


# Microwave links versus radar + gauges



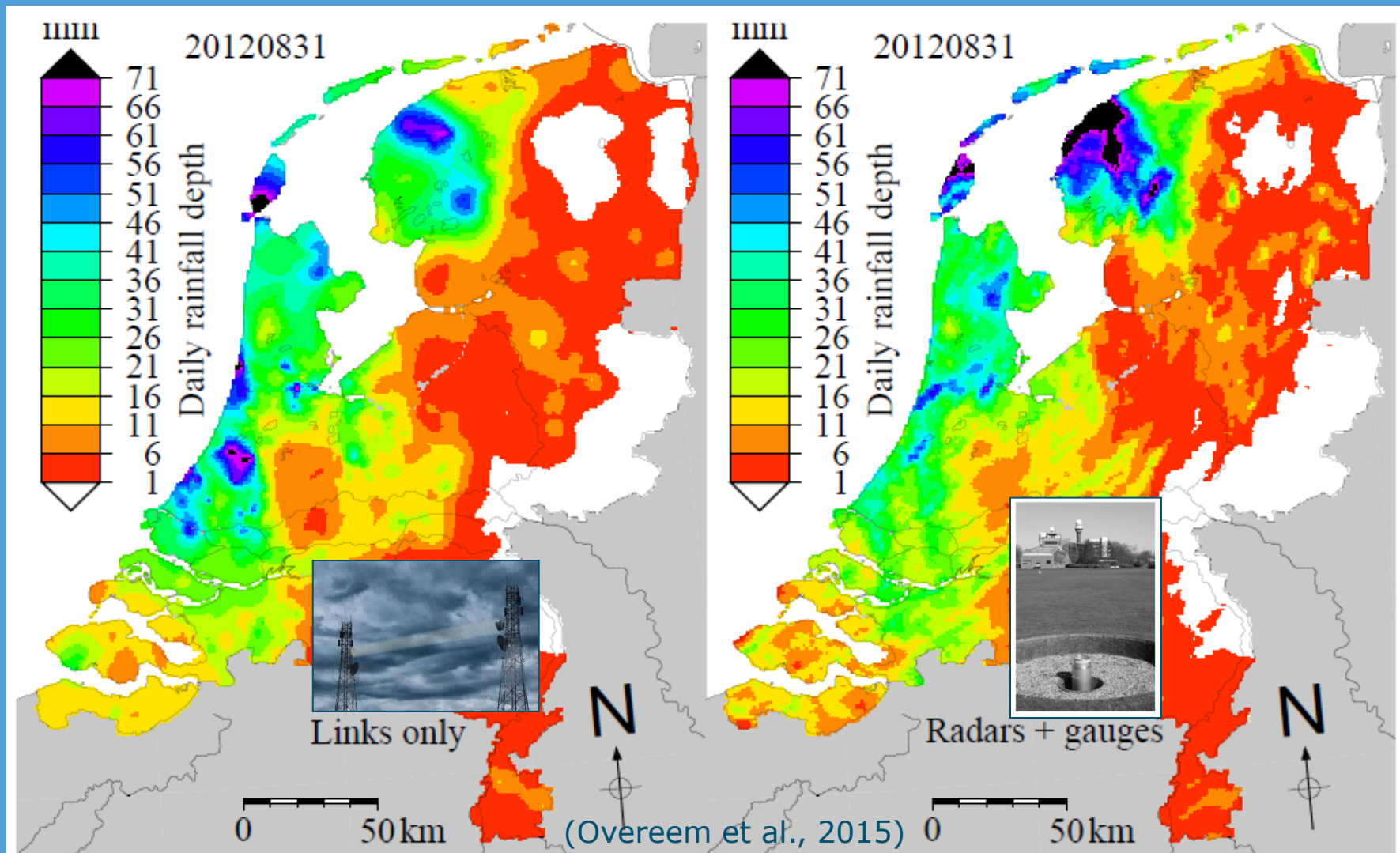


# Microwave links versus radar + gauges



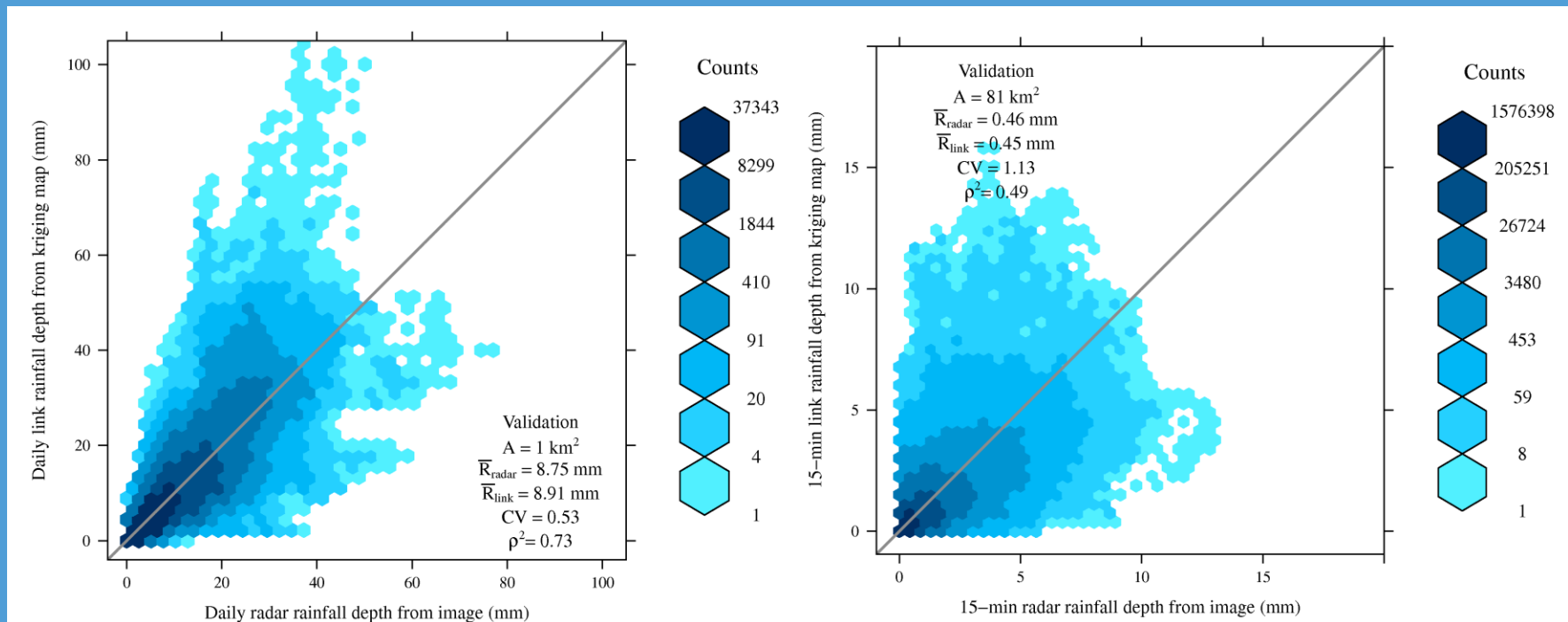


# Microwave links versus radar + gauges



# Microwave links versus radar + gauges

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



(Overeem et al., 2013)

# Opportunities and challenges



(Victoria Roberts, 2000)



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

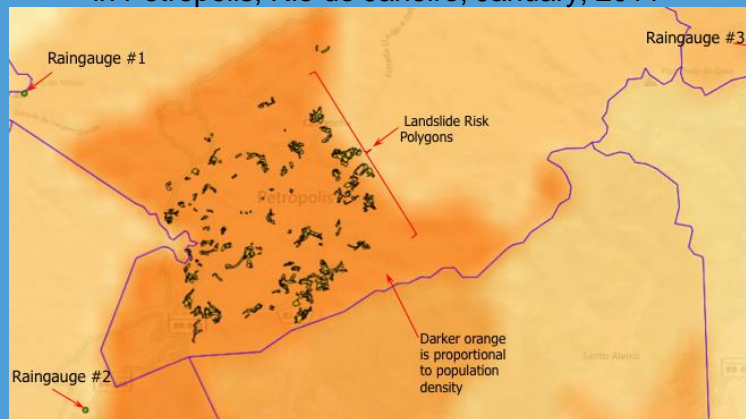
**Sparse coverage** of automated rain-gauges in Brazil, January, 2011



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

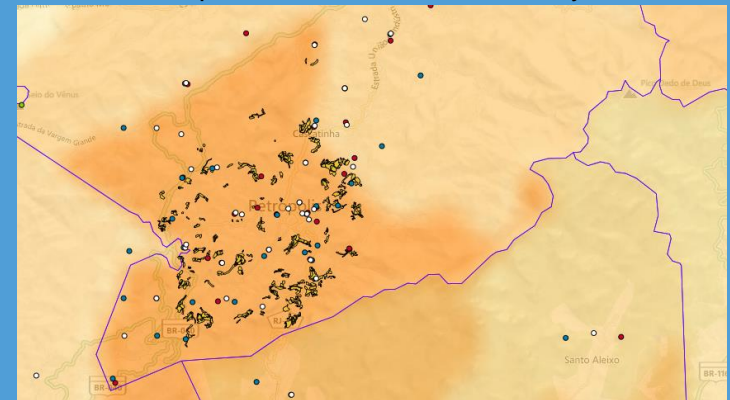


**Sparse coverage** of automated rain-gauges\* in Petropolis, Rio de Janeiro, January, 2011



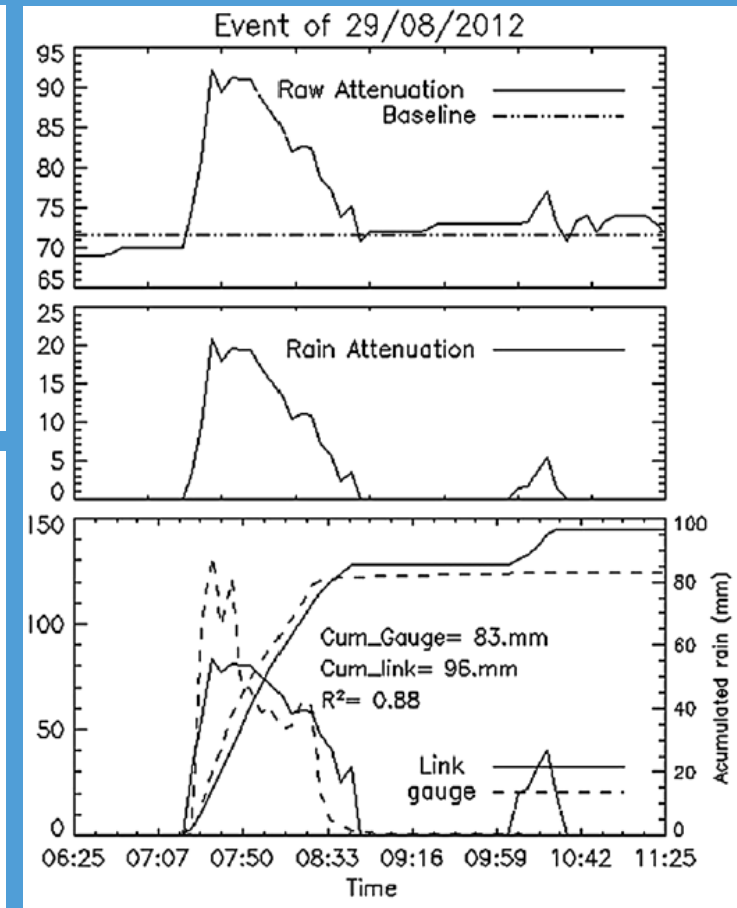
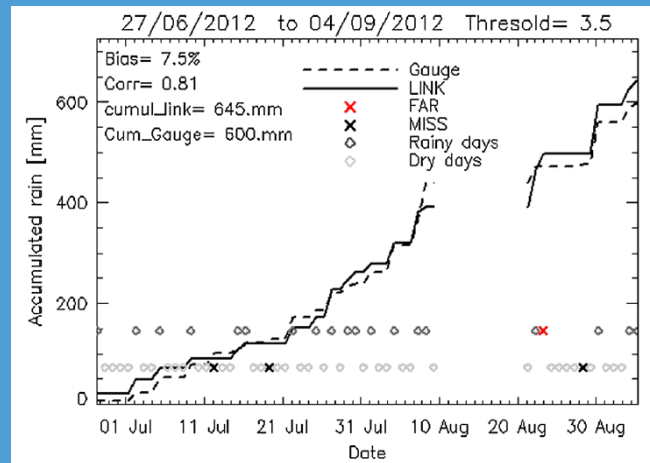
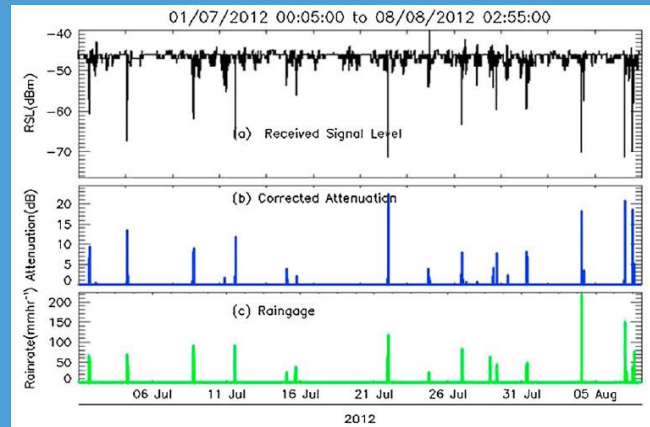
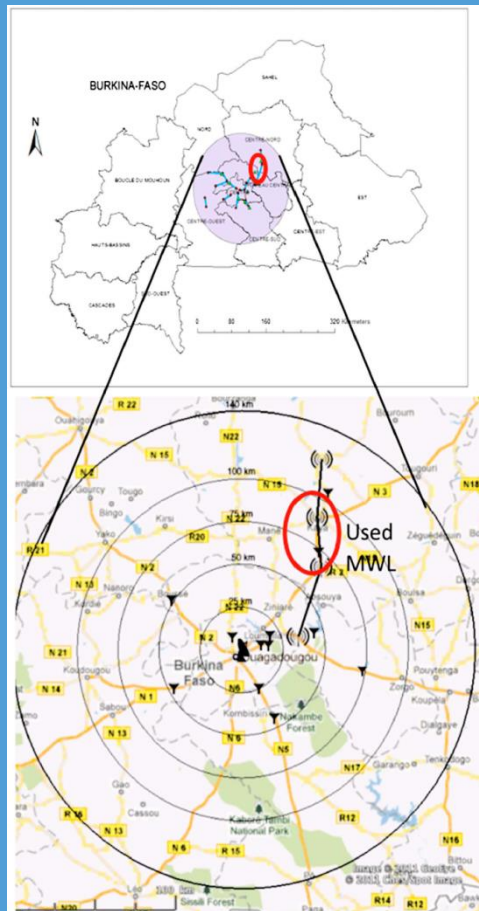
\*Petropolis region has 130 automatic raingauges by 2014

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





# First measurements on African continent



■ Doumounia et al. (2014, GRL)

# Raincell Africa Training School



30 trainees from universities, water and weather agencies, and telecom operators were introduced to the Rain Cell principles and learned to utilise freeware to process the raw data and produce rainfall maps based on cell phone networks.



<http://raincell01.sciencesconf.org/>

©2013 GSM Association and CollinsBartholomew Ltd.

(Gosset et al., 201)

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

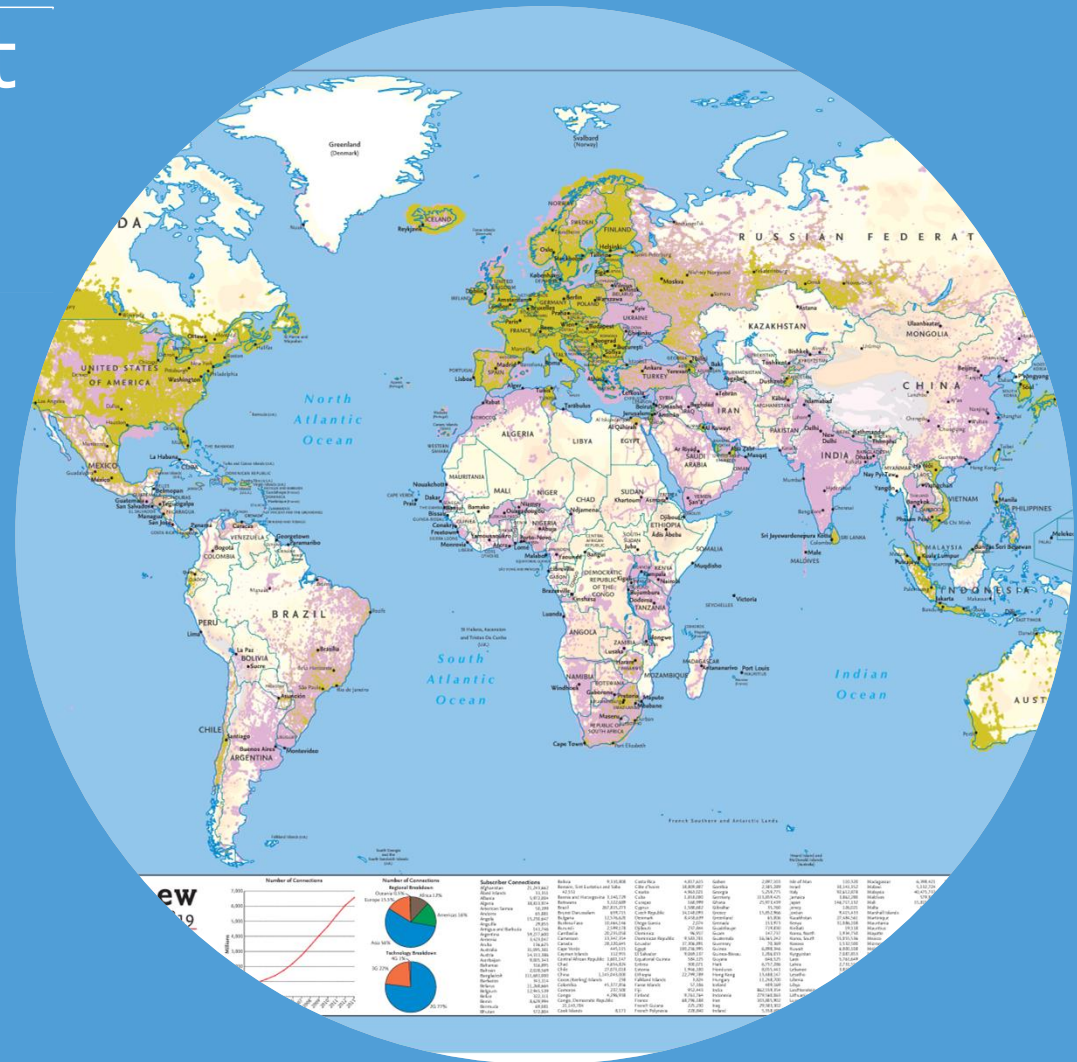


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# Remko.Uijlenhoet @wur.nl



(Collins Bartholomew / GSMA, 2015)



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