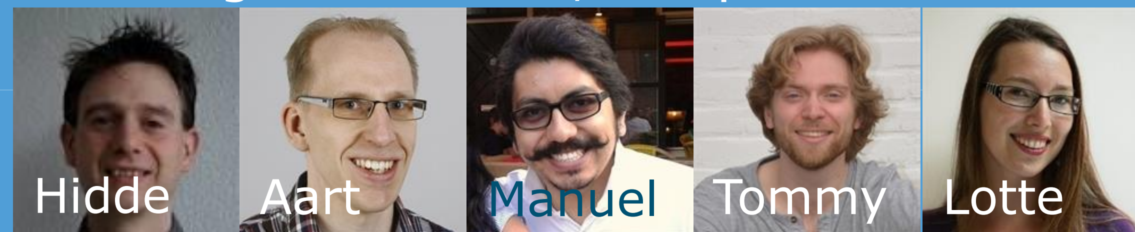
Opportunistic sensing in hydrology:

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



Remko Uijlenhoet

Hydrology and Quantitative Water Management Group

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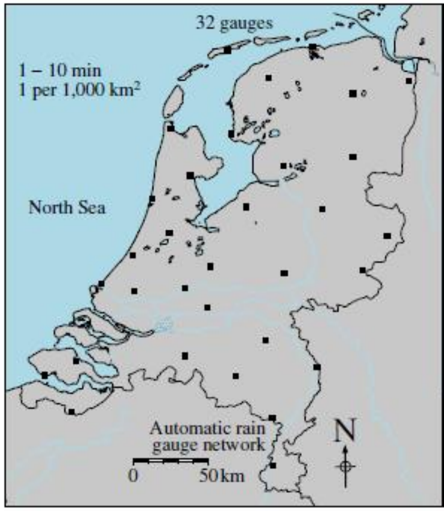
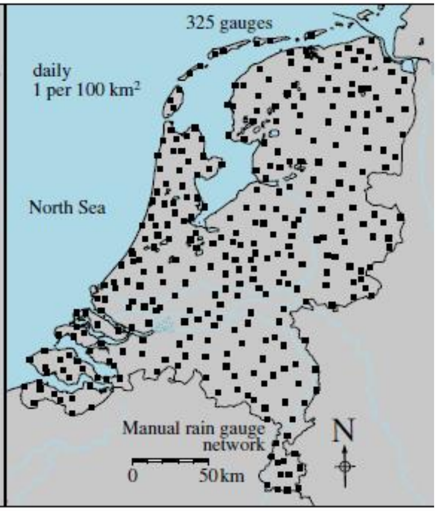
Dedicated vs. opportunistic sensors

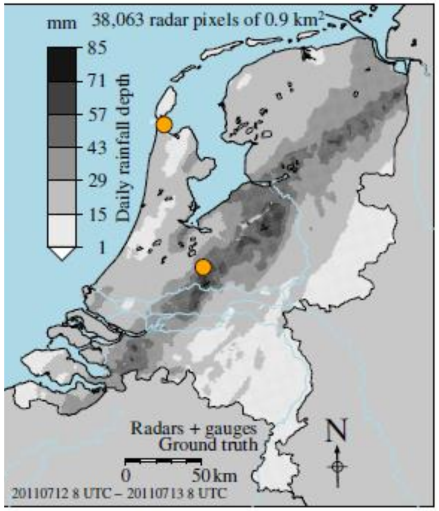
(Victoria Roberts, 2000)

Rainfall measurements in The Netherlands





Room for opportunistic sensors



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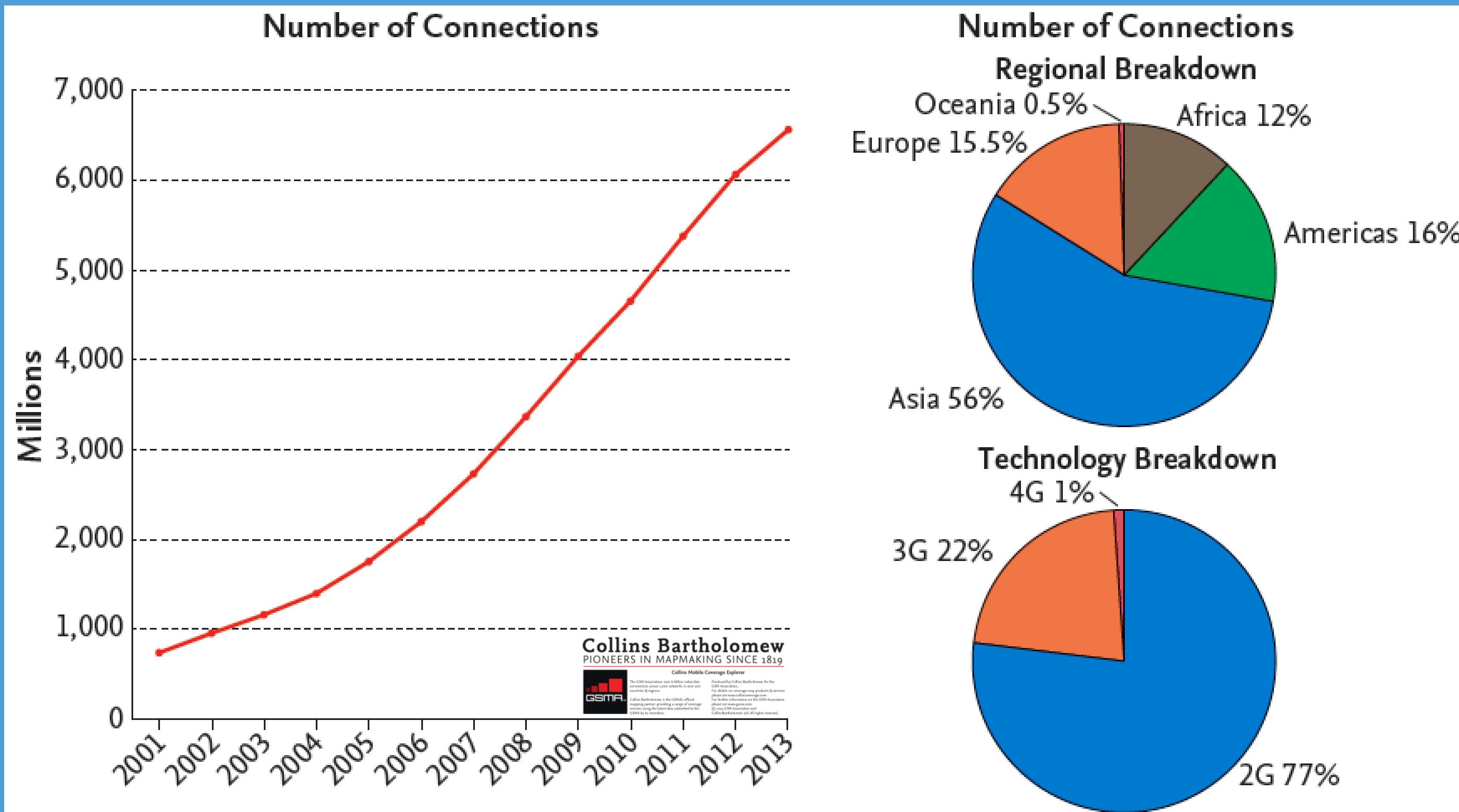
Rapid growth cellular telecommunication



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What are opportunistic sensors?

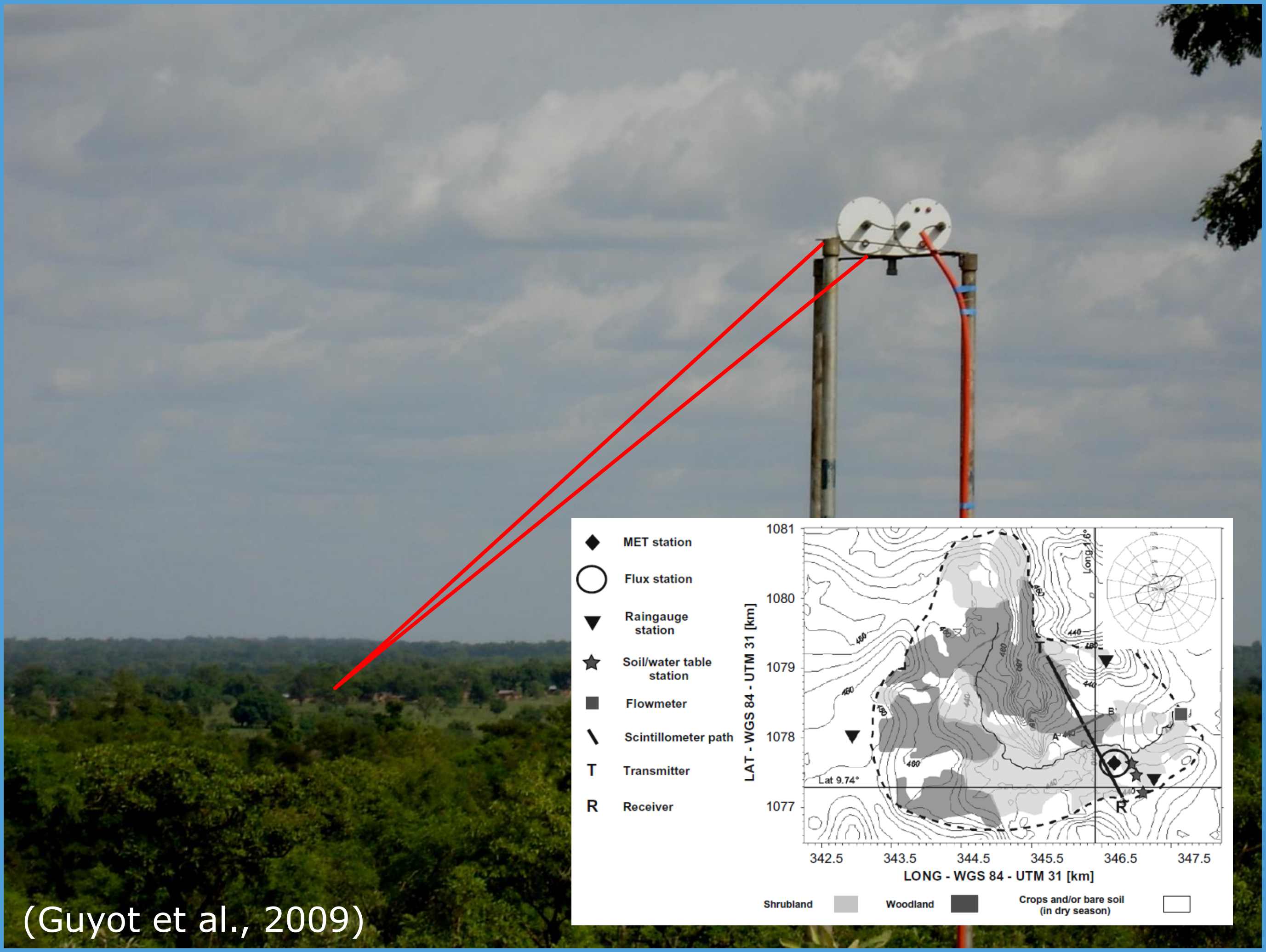
(Victoria Roberts, 2000)

Sensible heat flux causes fluctuations in refractive index of air (scintillations)

(Source: Wetenschap in Beeld)

(Photo: Ron Poot)

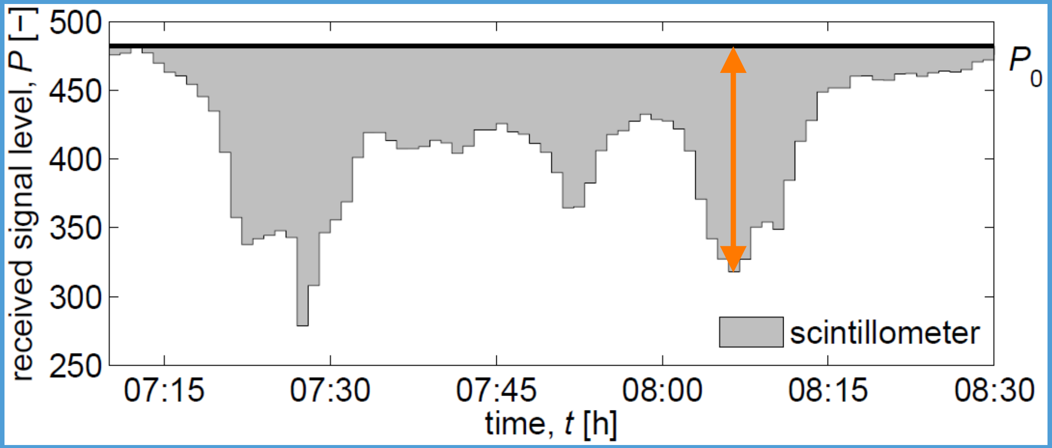
Scintillometer in Benin



(Guyot et al., 2009)

Optical extinction caused by rainfall

From optical extinction to rain rate



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

$$\langle k\rangle = \frac{10}{L}\log\left(\frac{P_0(L)}{P(L)}\right)$$

$$\langle R\rangle = \left(\langle k\rangle / c\right)^{1/d}$$

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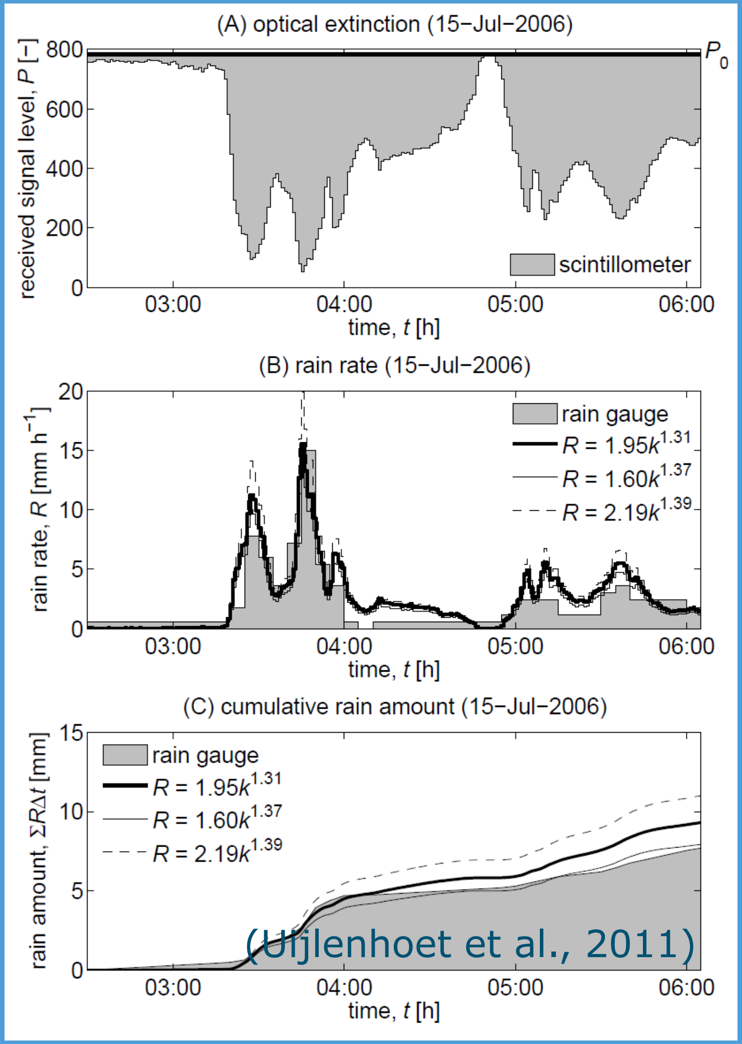
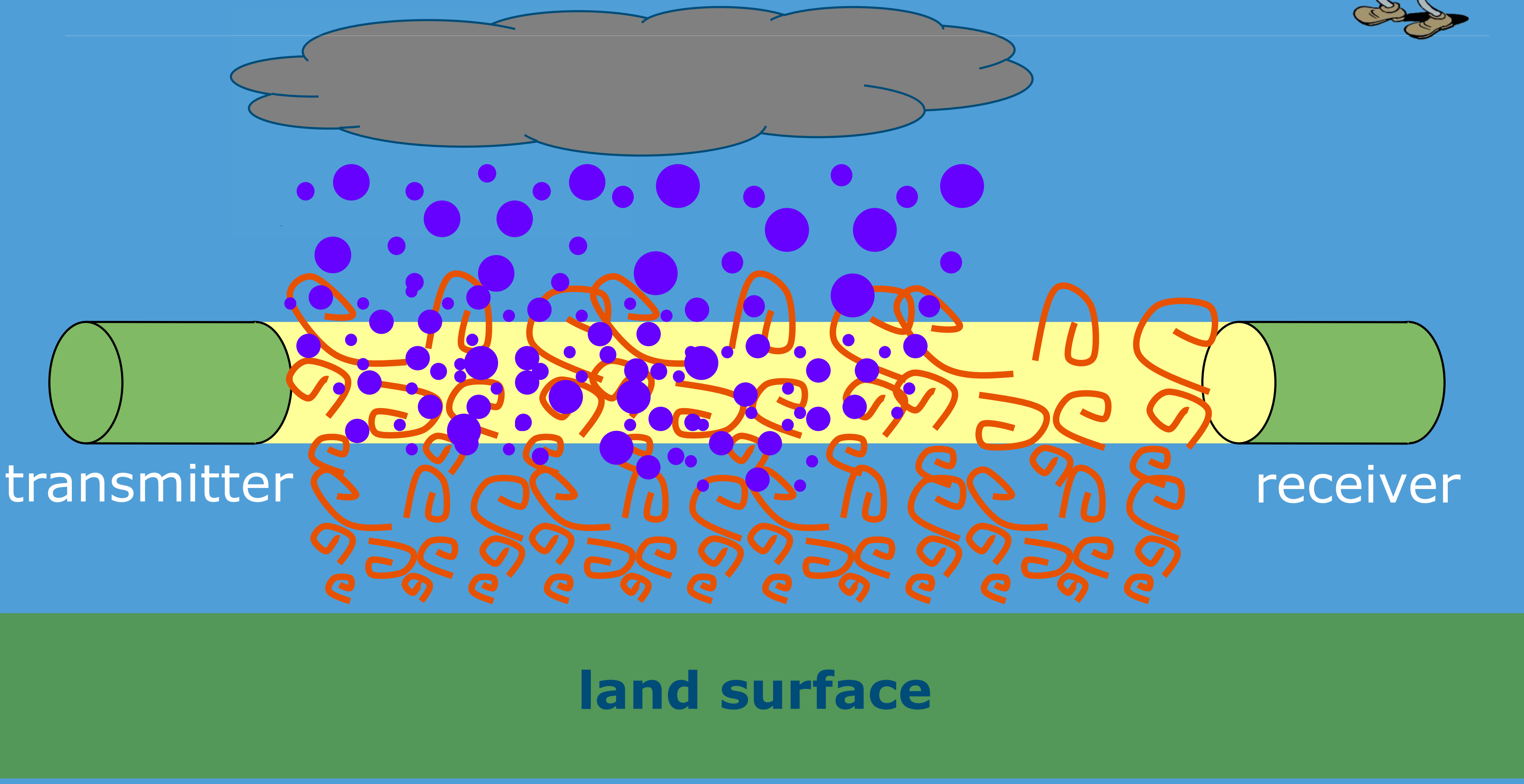
Proof of concept



"aha-moment": measuring evaporation and precipitation with one instrument



Rainfall monitoring using microwave links

(Victoria Roberts, 2000)

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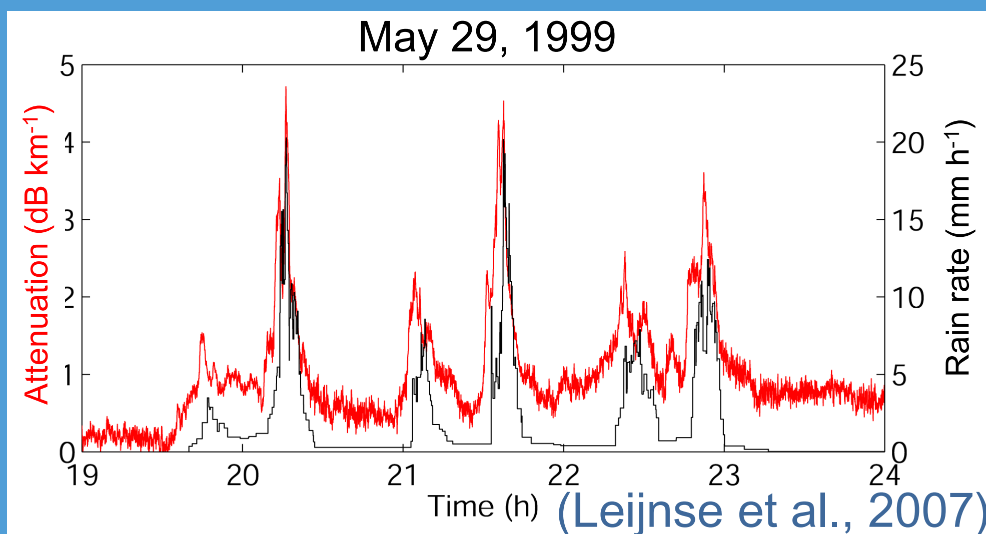
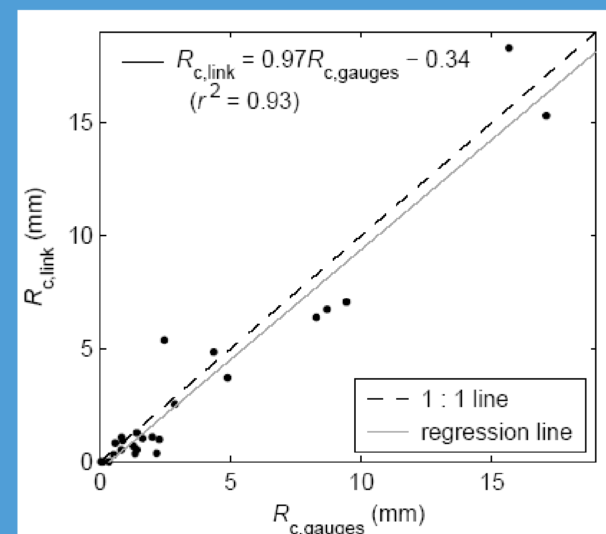
Research link Wageningen, 1999





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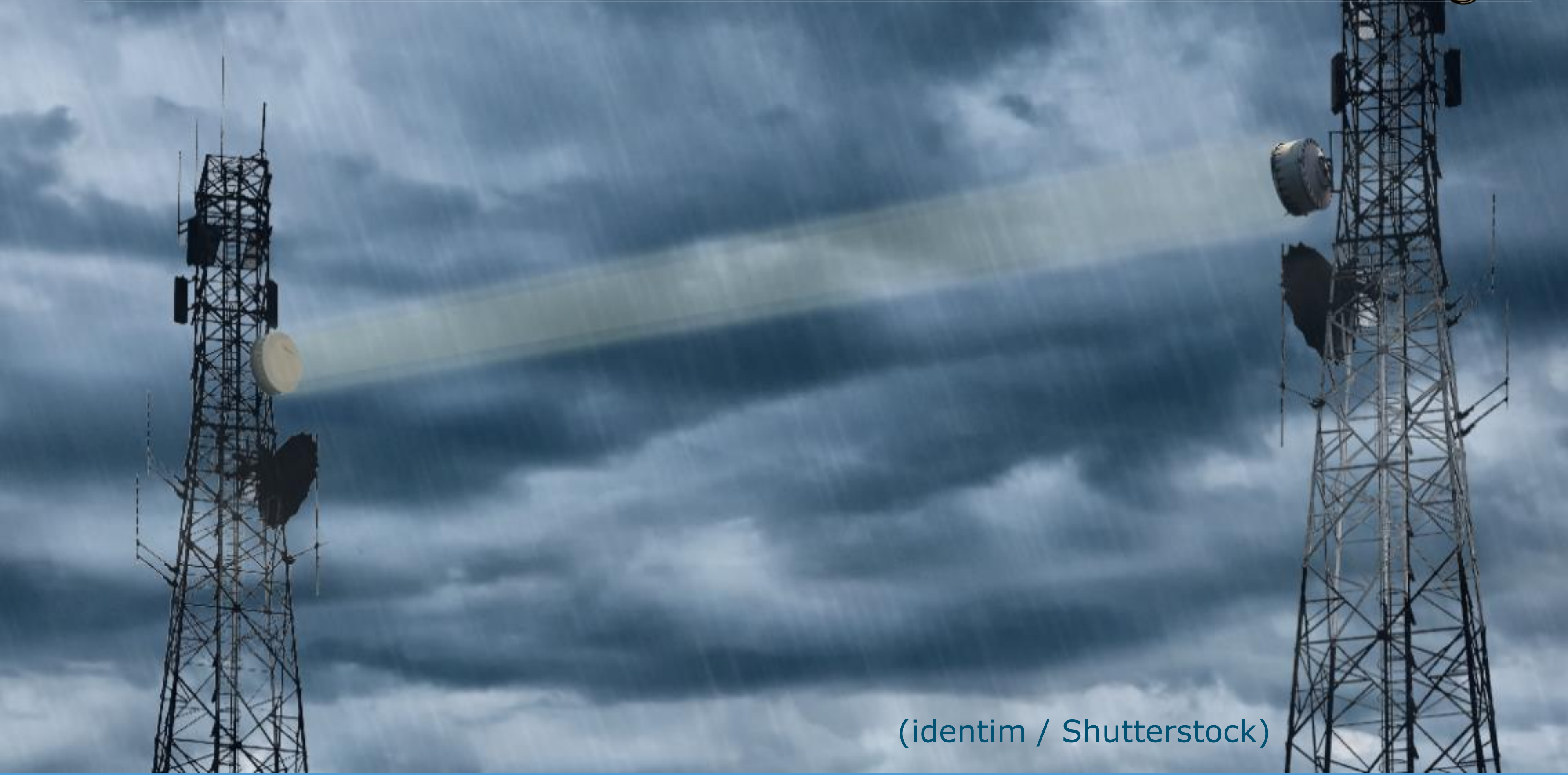
“aha-moment”: there are (commercial) microwave links (nearly) everywhere



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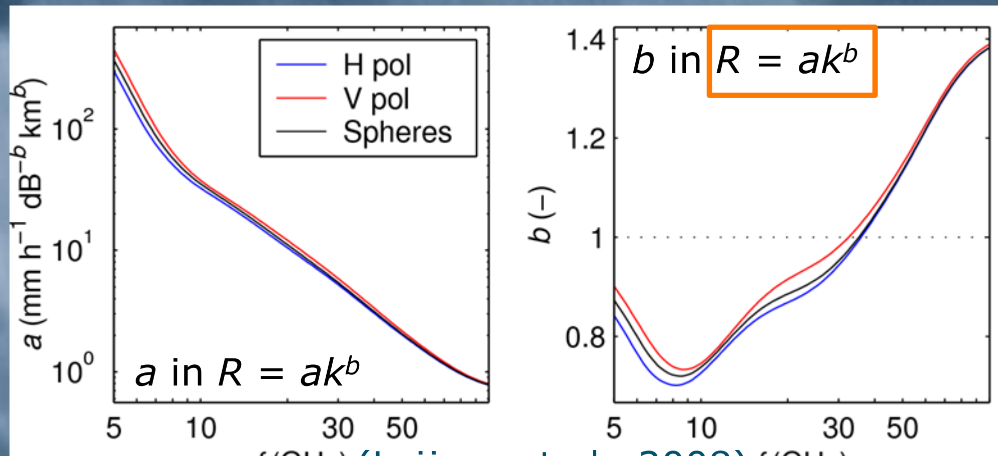
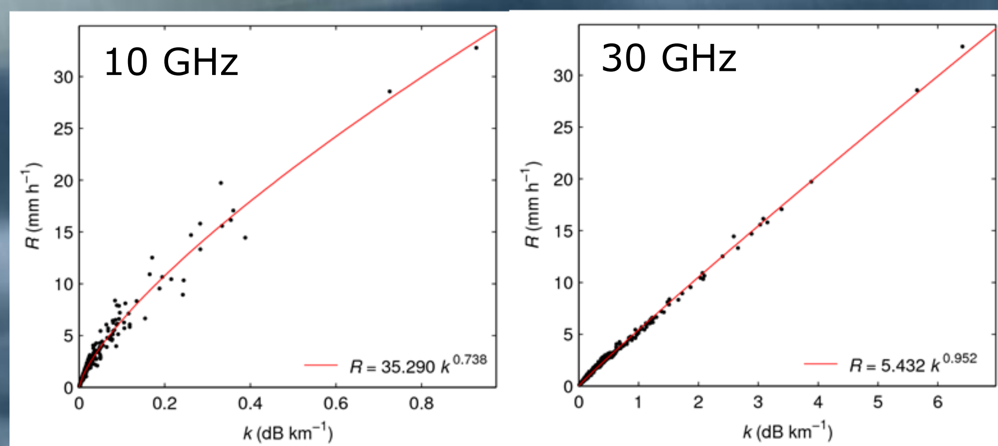
(Power-law R–k relations)



(Leijnse et al., 2008)



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1960s and 70s

- Rainfall attenuates radio wave communication signals at millimeter wavelengths

(Hogg, 1968)

Reprinted from
SCIENCE
January 5, 1968, Vol. 159, No. 3810, pages 39-46

COWEETA RAINFALL DATA COLLECTED
BY UNIV. ILLINOIS RAINDROP CAMERA
AT MOONEY GAP. COOP. STUDY DATA
USED ON PG H-5

Millimeter-Wave Communication through the Atmosphere

The known and unknown features in propagation of short radio waves are discussed.

D. C. Hogg

In spite of the fact that we have had coherent radio sources with significant amounts of millimeter-wave power for many years, these wavelengths have not been used for communication. Why do ...

components for utilization of the millimeter-wave band. Steadily, over the past two decades, invention and improvement have given us equipment equal in quality to that used in the ...

atmosphere. My present intent, then, is to reexamine the problems of transmission through the atmosphere. Much is known, but we do not yet know, or do not know surely, some things necessary for the engineering design of reliable, useful millimeter-wave systems.

Absorption by the Clear Atmosphere

Transmission of waves along the earth's surface through a clear atmosphere is subject to attenuation due to absorption by oxygen and water vapor. This attenuation is ordinarily plotted in decibels per kilometer, as shown in Fig. 1. The theoretical curve *(2)* agrees satisfactorily with the measured data *(3)*, provided suitable values are taken for the pressure broadening constants —namely, the frequency widths—of the oxygen and water-vapor lines *(4)*. There are many thousands of mega- ...

(Olsen et al., 1978)

The efficiency measurements [1, table II] gave $H_0 = 1.74$ mm for the total gravitational deformations. The total should not be smaller than its astigmatic part; but both agree if we allow a 15-percent error for the efficiency value. The large value of (16) means that the astigmatic deformation is by far the largest part of the total deformation, and that deformations of higher order can be neglected in the design of a deformable subreflector.

ACKNOWLEDGMENT

It is a pleasure to thank R. Fisher for the elongated feed horn and for his assistance during the observations.

REFERENCES

[1] S. von Hoerner and W. Y. Wong, "Gravitational deformation and astigmatism of tiltable radio telescopes," *IEEE Trans. Antennas Propagat.*, vol. AP-23, pp. 689-695, 1975.
[2] S. von Hoerner, "The design of correcting secondary reflectors," *IEEE Trans. Antennas Propagator.*, vol. AP-24, pp. 336-340, 1976.
[3] —, "Design and improvement of tiltable radio telescopes," in *Vistas in Astronomy*, to be published.
[4] G. Feix, "Focus broadening by astigmatism of large microwave paraboloid antennas," *Appl. Opt.*, vol. 8, pp. 1631-1634, 1969.
[5] J. R. Cogdell and J. H. Davis, "Astigmatism in reflector antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-21, pp. 565-567, 1973.
[6] J. Ruze, "Axial astigmatic fields in the focal region," *IEEE Trans. Antennas Propagat.*, vol. AP-23, pp. 734-735, 1975.

The aR^b Relation in the Calculation of Rain Attenuation

RODERIC L. OLSEN, MEMBER, IEEE, DAVID V. ROGERS, MEMBER, IEEE, AND DANIEL B. HODGE, SENIOR MEMBER, IEEE

Abstract—Because of its simplicity, the empirical relation $A = aR^b$ between the specific attenuation A and the rainrate R is often used in the calculation of rain attenuation statistics. Values for the frequency-dependent parameters a and b are available, however, for only a limited number of frequencies. Some of these values, furthermore, were obtained experimentally, and may contain errors due to limitations in the experimental techniques employed. The aR^b relation is shown to be an approximation ...

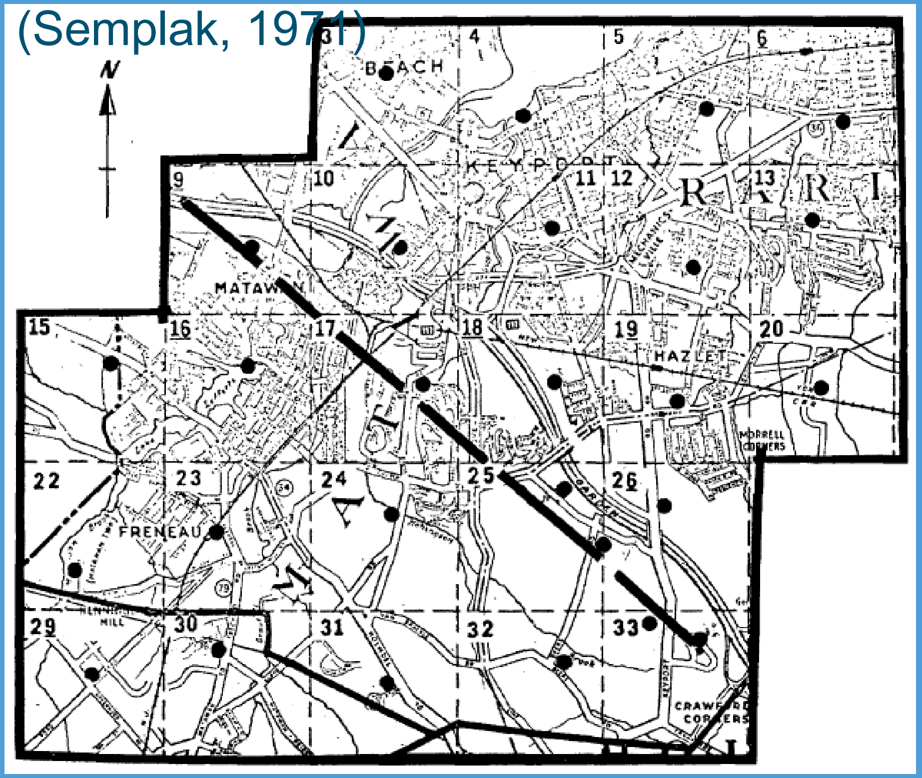
theoretical method employing a uniformly random distribution of raindrops modelled as water spheres or more complex shapes, and 2) an empirical procedure based on the approximate relation between A and the rainrate R,

$$A = aR^b \quad (1)$$

Holmdel, New Jersey, US (Bell Labs)

- High-resolution rain gauge network (96 gauges over 130 km^2 area; mean intergauge distance 1.3 km; time resolution 10 s)
- 18.5 GHz microwave link of ~5 km length

(Semplak, 1971)



ACKNOWLEDGMENT

The suggestion of D. C. Hogg that people additional to wave propagationists may be interested in these data is appreciated.

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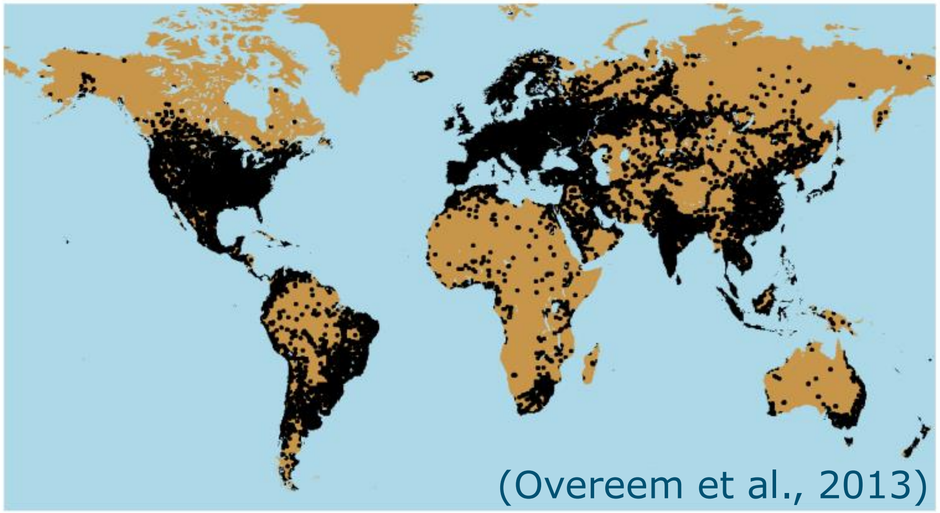
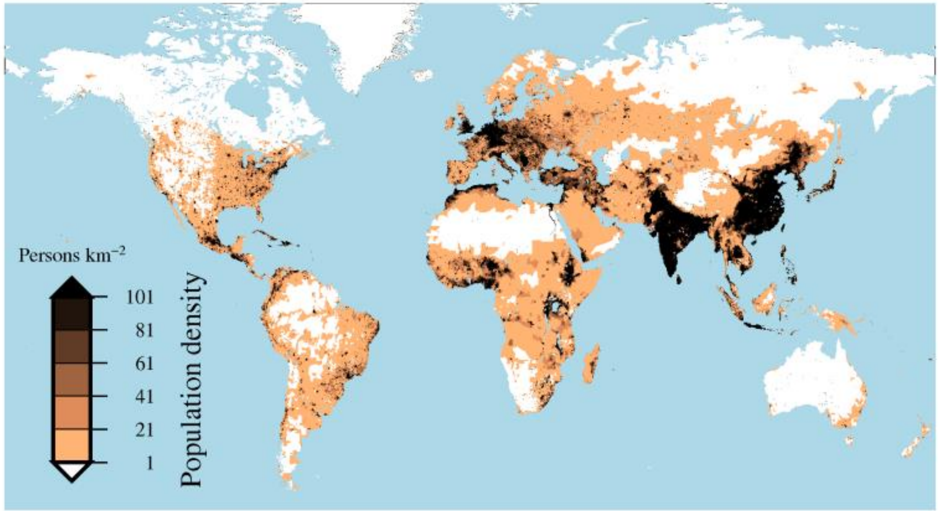
Microwave links from cell. comm. networks

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

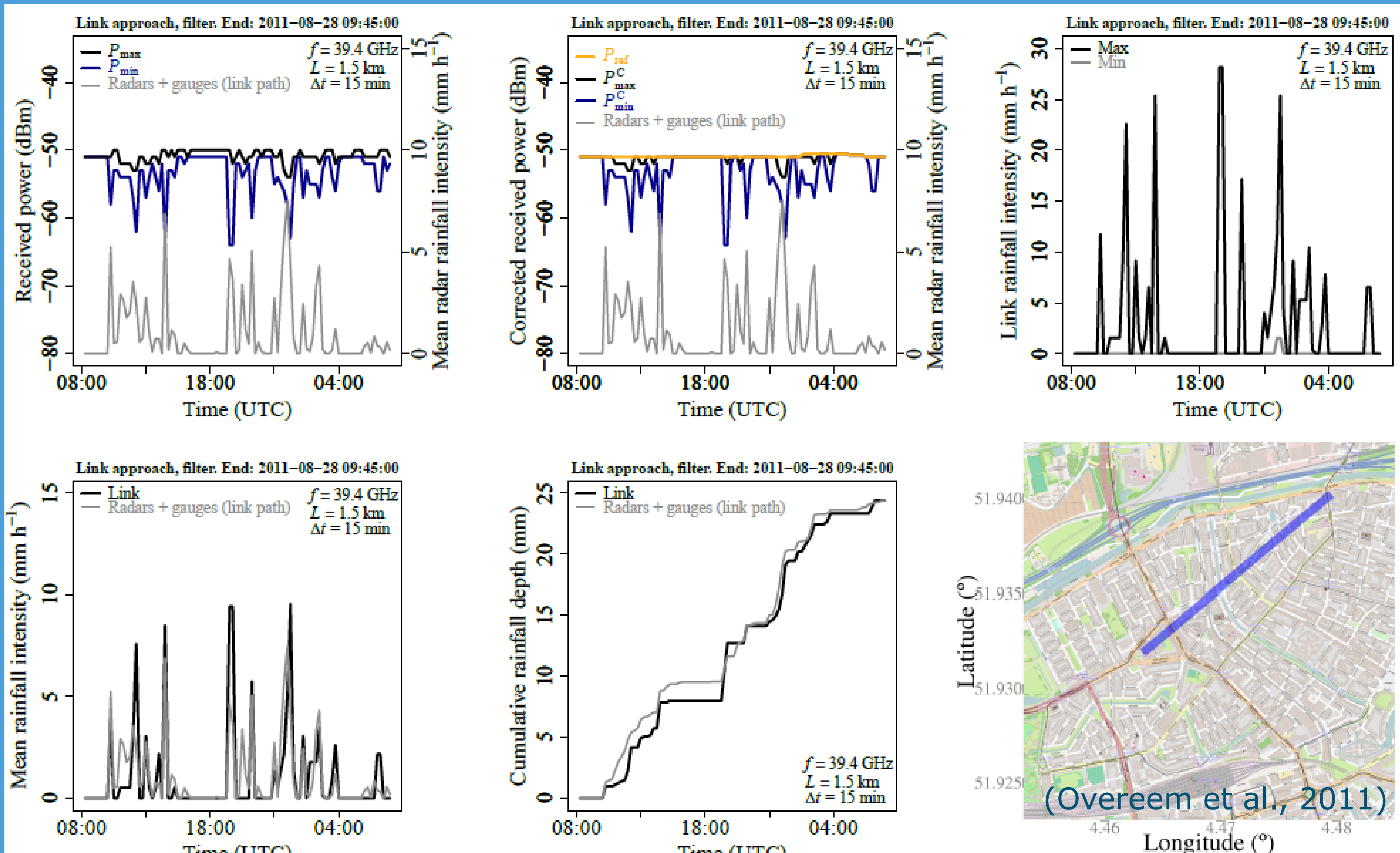
(identim / Shutterstock)



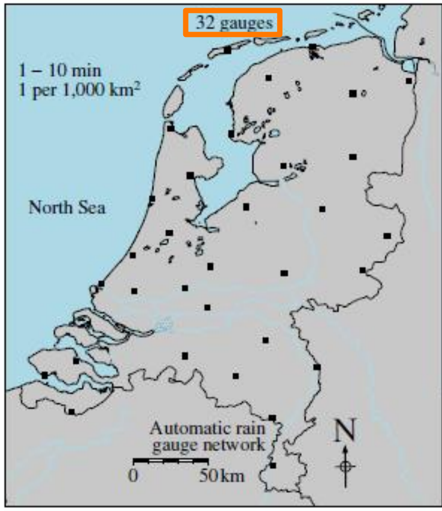
(Overeem et al., 2013)

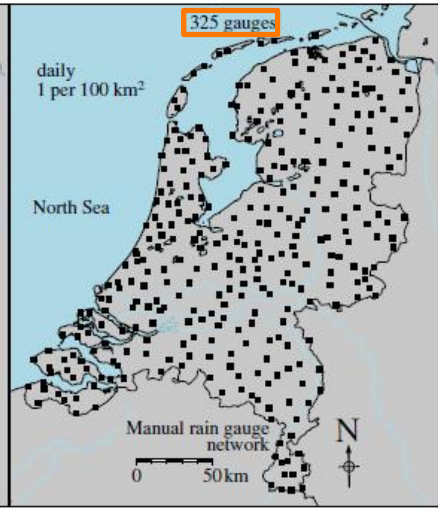


Rainfall retrieval in Rotterdam

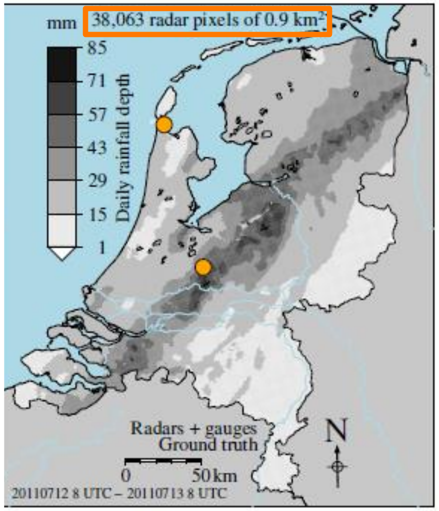


Many more microwave links than gauges

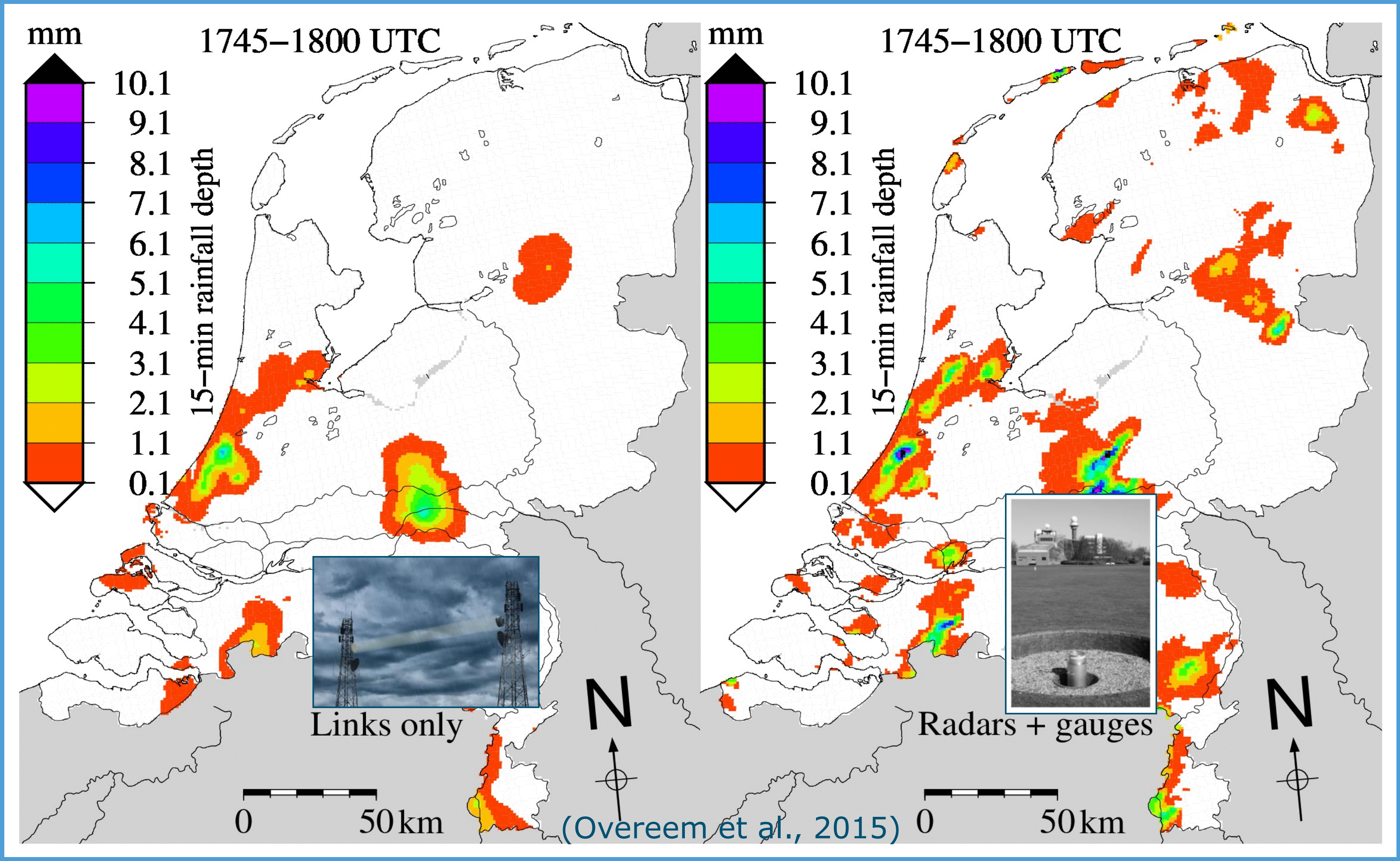




Room for opportunistic sensors

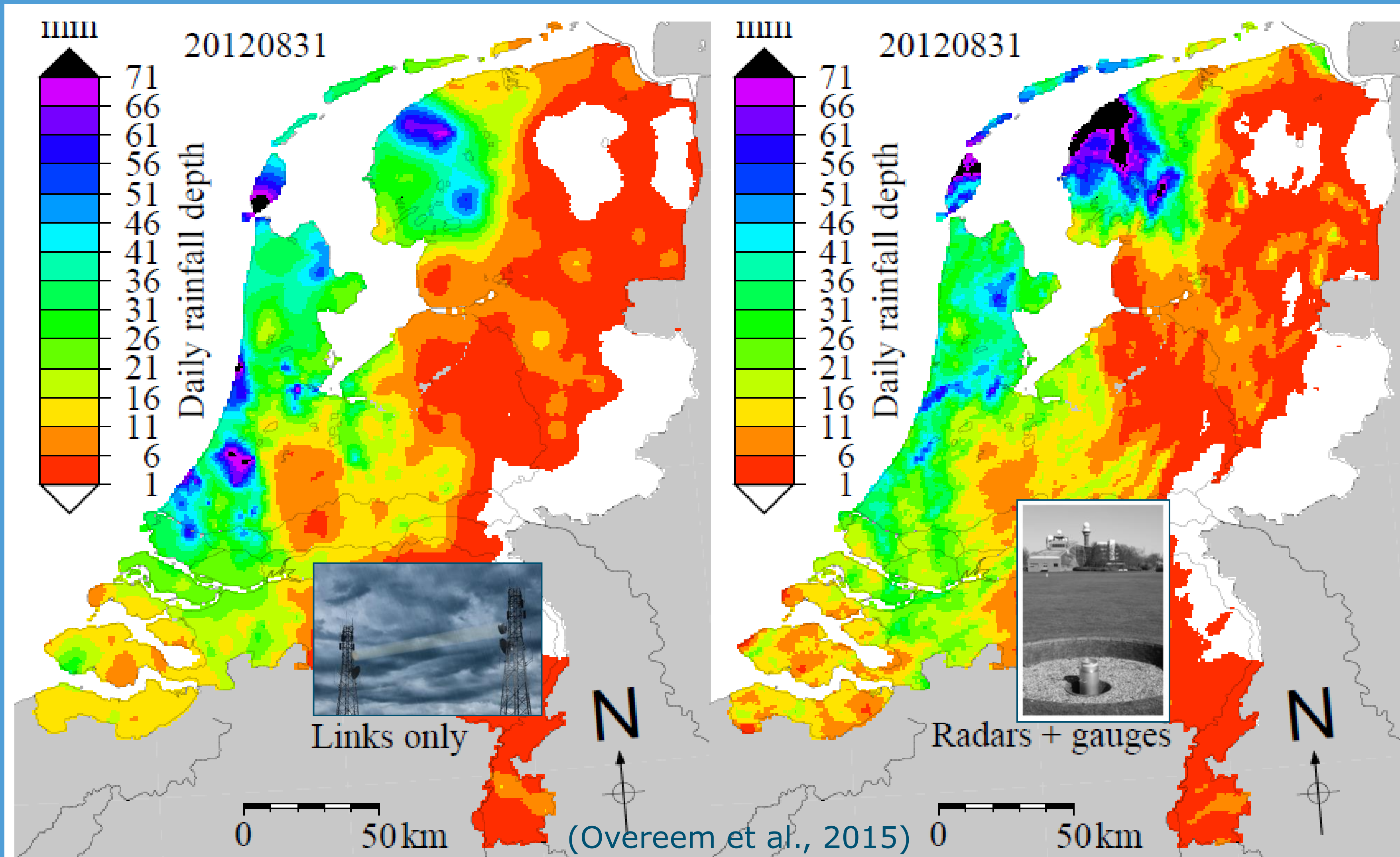


Microwave links versus radar + gauges



(Overeem et al., 2015)

Microwave links versus radar + gauges



(Overeem et al., 2015)

Crowdsourcing urban rainfall from personal weather stations

(Victoria Roberts, 2000)

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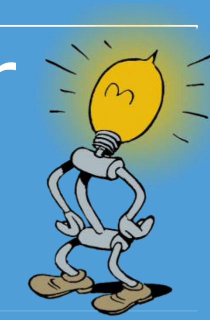
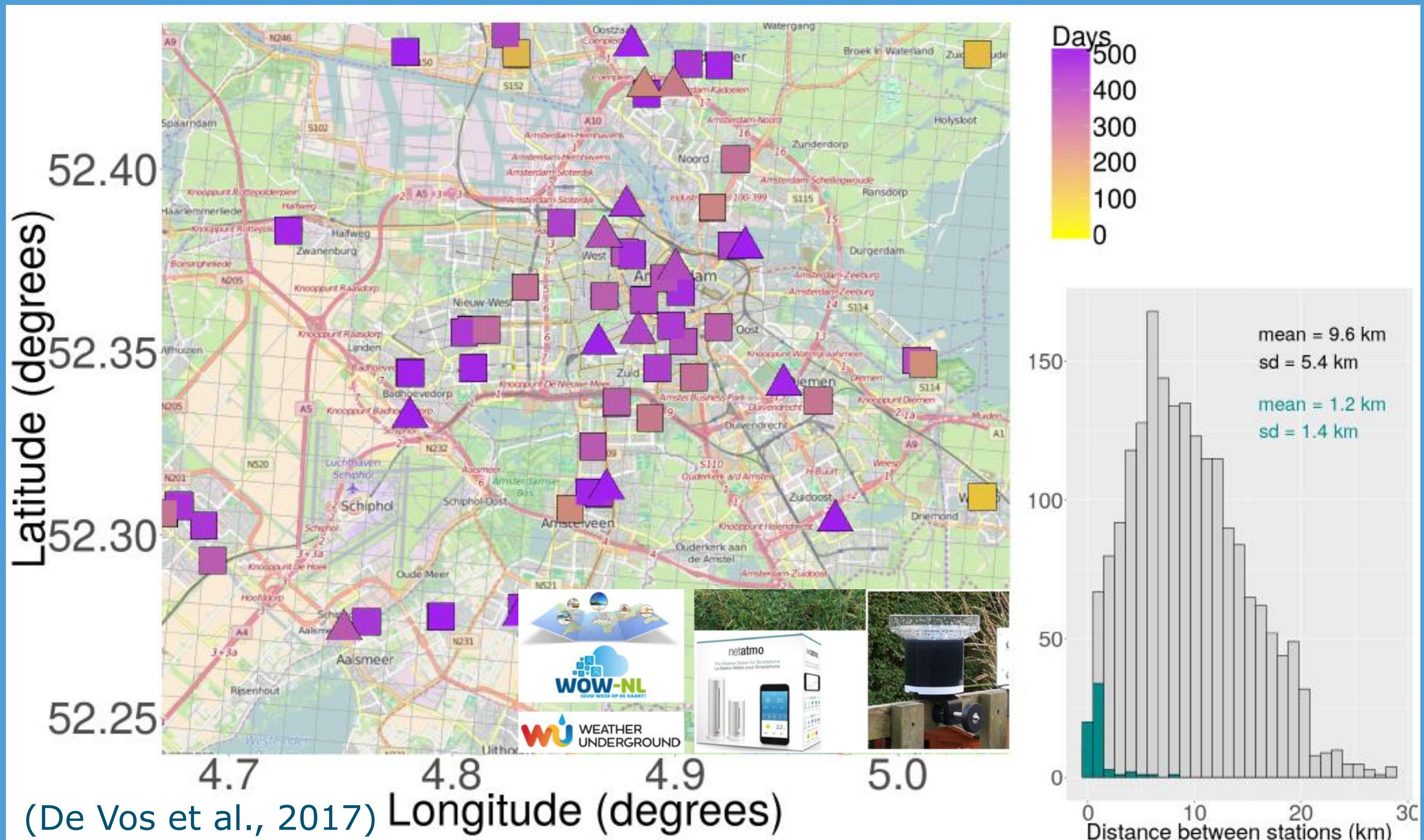
“aha-moment”: more personal weather stations than official rain gauges



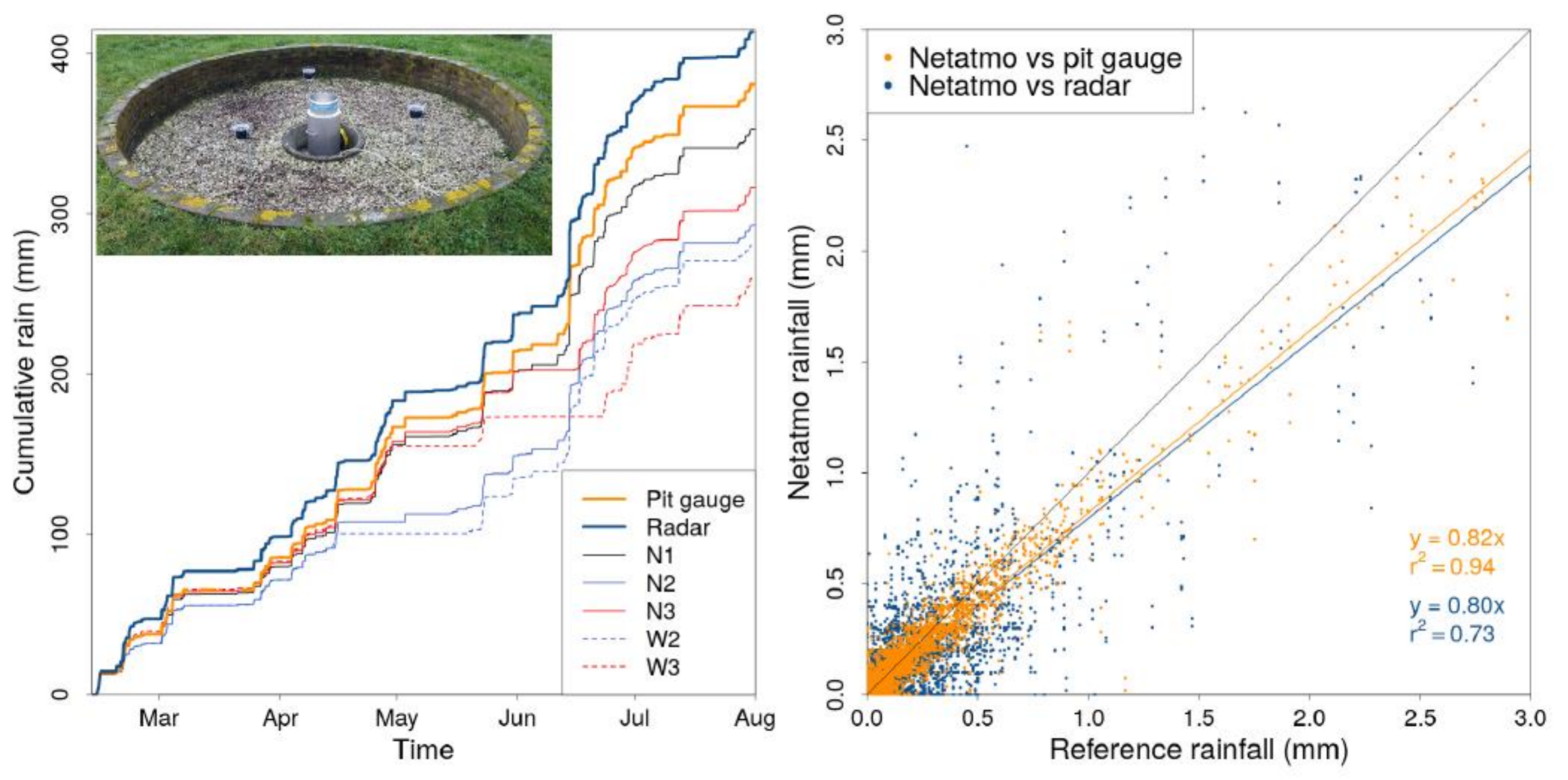


(De Vos et al., 2017)

Netatmo tipping bucket rain gauge

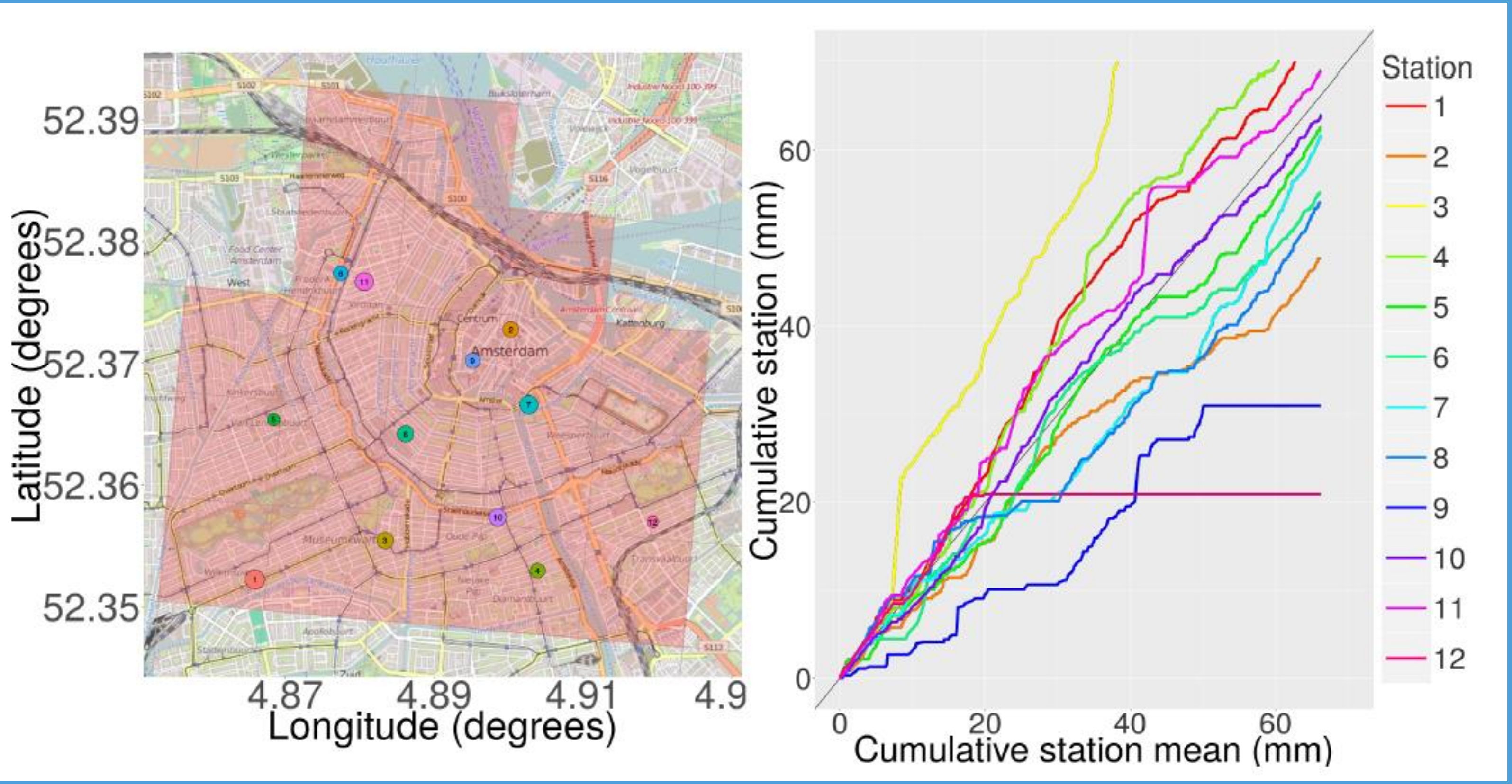
(De Vos et al., 2017)

Validation of Netatmo stations at Cabauw



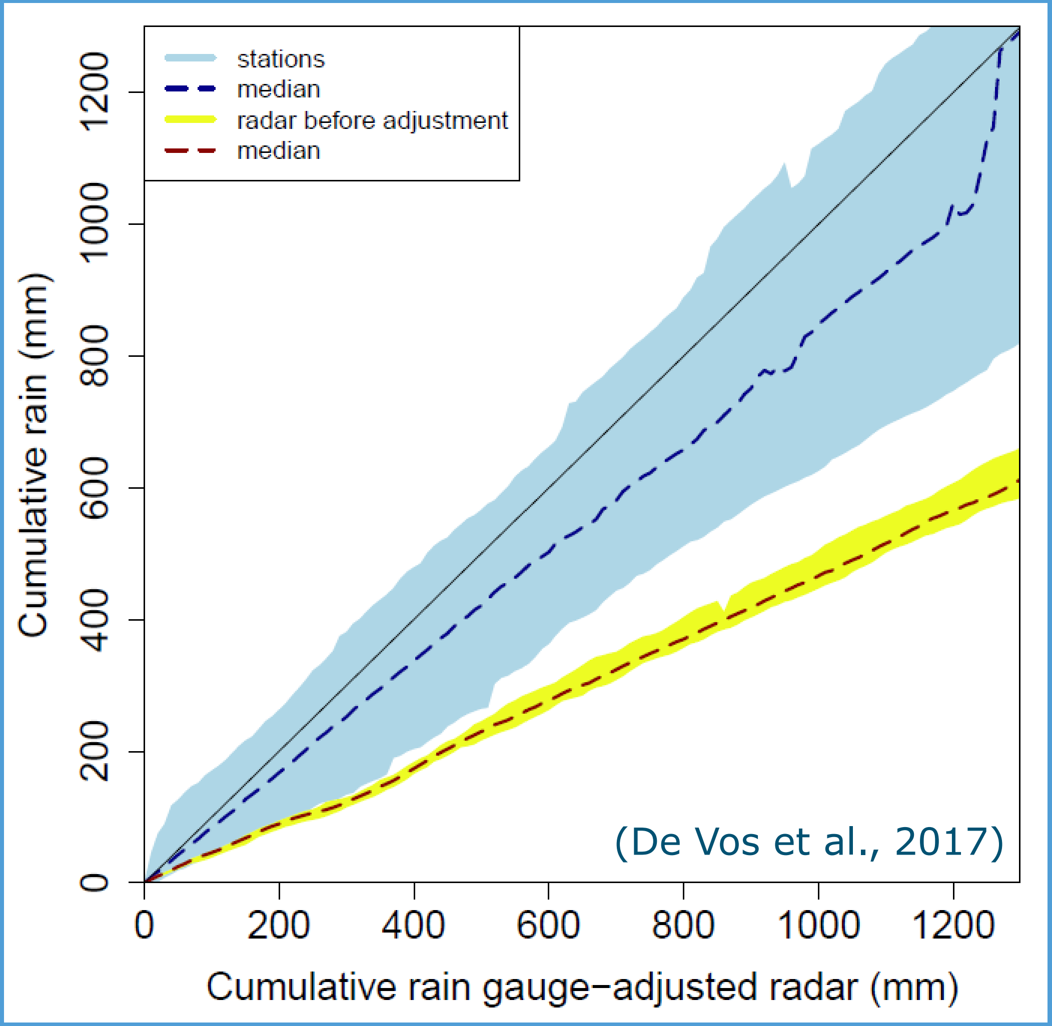
(De Vos et al., 2017)

Analysis for Amsterdam city center



(De Vos et al., 2017)

Double mass plots (PWS versus radar)



Crowdsourcing air temperatures from cell phones

(Victoria Roberts, 2000)

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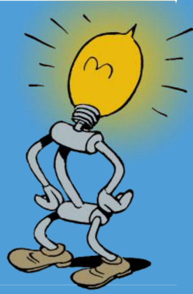
"aha-moment": smartphones can be used as (urban) thermometers

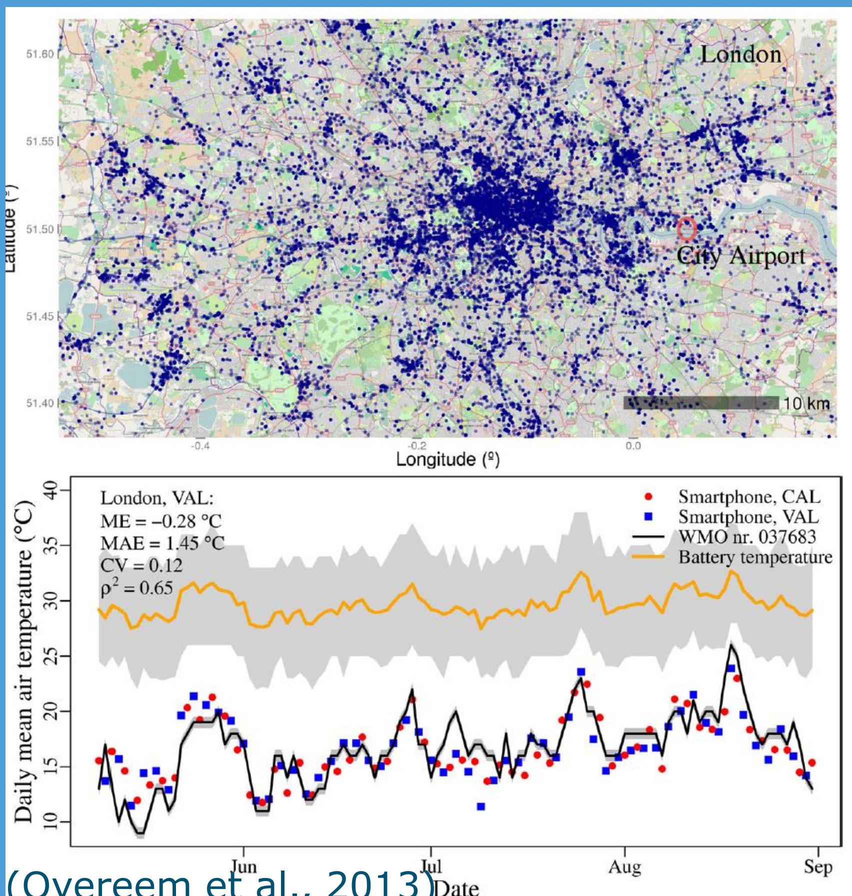


(Overeem et al., 2013)

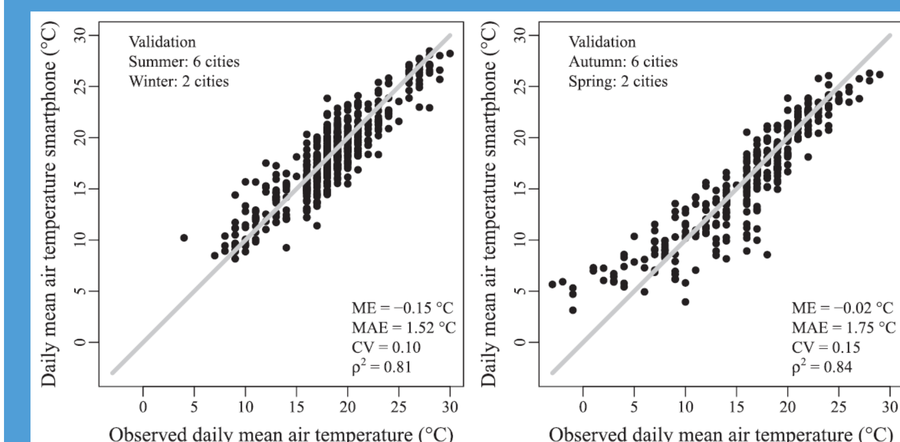
Daily mean urban air temperatures from smartphone battery temperatures

$$P_{\mathrm{p}} = P_{\mathrm{e}} + P_{\mathrm{b}} = k_{\mathrm{e}}(T_{\mathrm{p}} - T_{\mathrm{e}}) + k_{\mathrm{b}}(T_{\mathrm{p}} - T_{\mathrm{b}})$$

$$T_{\mathrm{e}} = \left(1 + \frac{k_{\mathrm{b}}}{k_{\mathrm{e}}}\right) T_{\mathrm{p}} - \left(\frac{k_{\mathrm{b}}}{k_{\mathrm{e}}} T_{\mathrm{b}} + \frac{P_{\mathrm{p}}}{k_{\mathrm{e}}}\right)$$



(Overeem et al., 2013)



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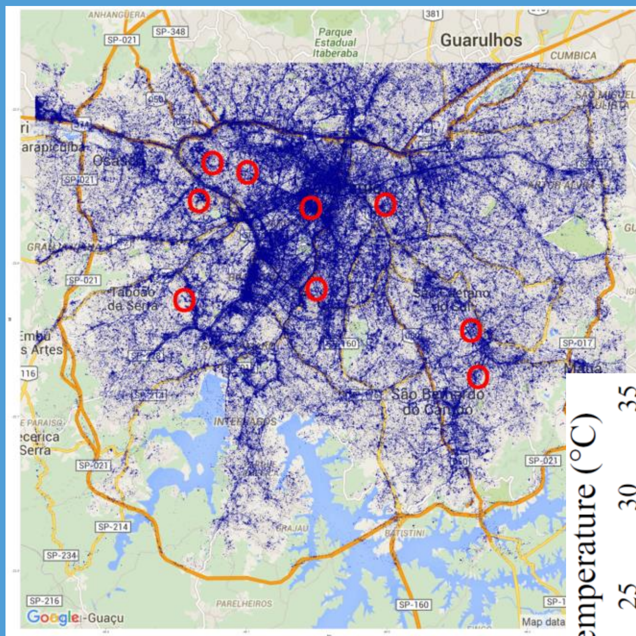
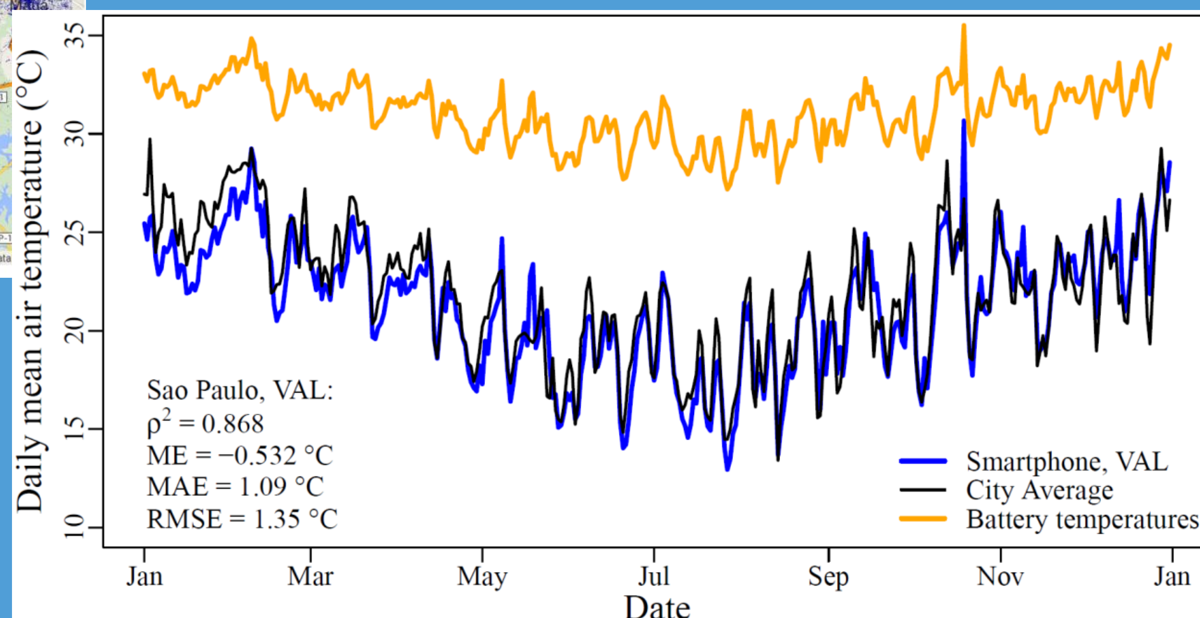
Improved resolution for São Paulo



(Droste et al., 2017)



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