Urban air temperature estimation from smartphone battery temperatures

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OpenSignal

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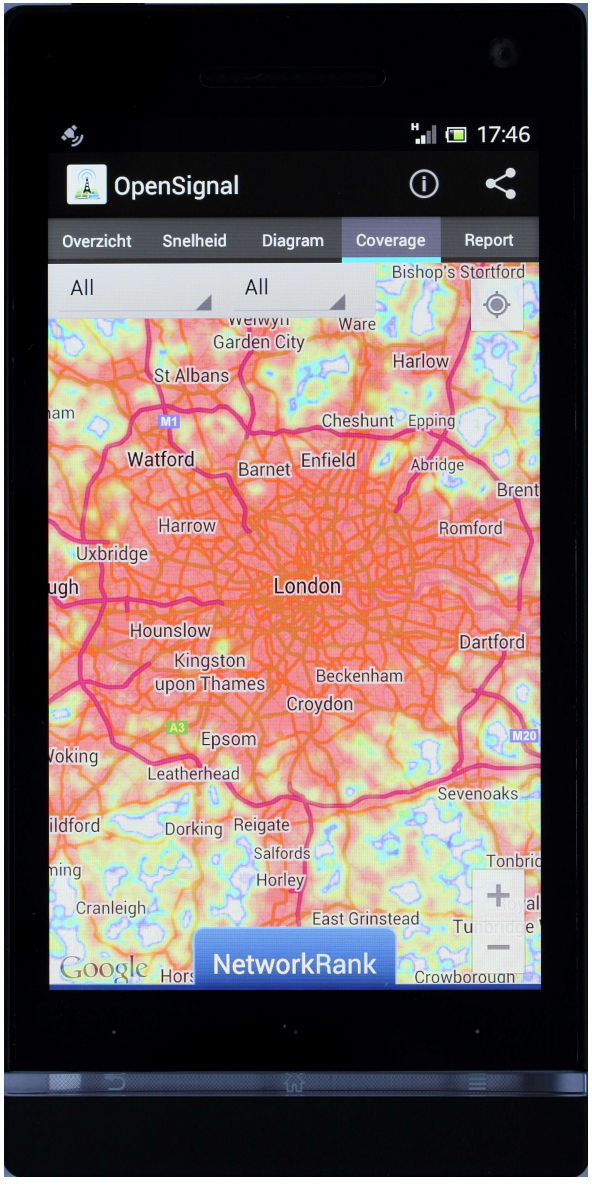
Outline

- Introduction
- Method: heat transfer model
- Results London, São Paulo, and The Netherlands
- Discussion
- Conclusions and outlook

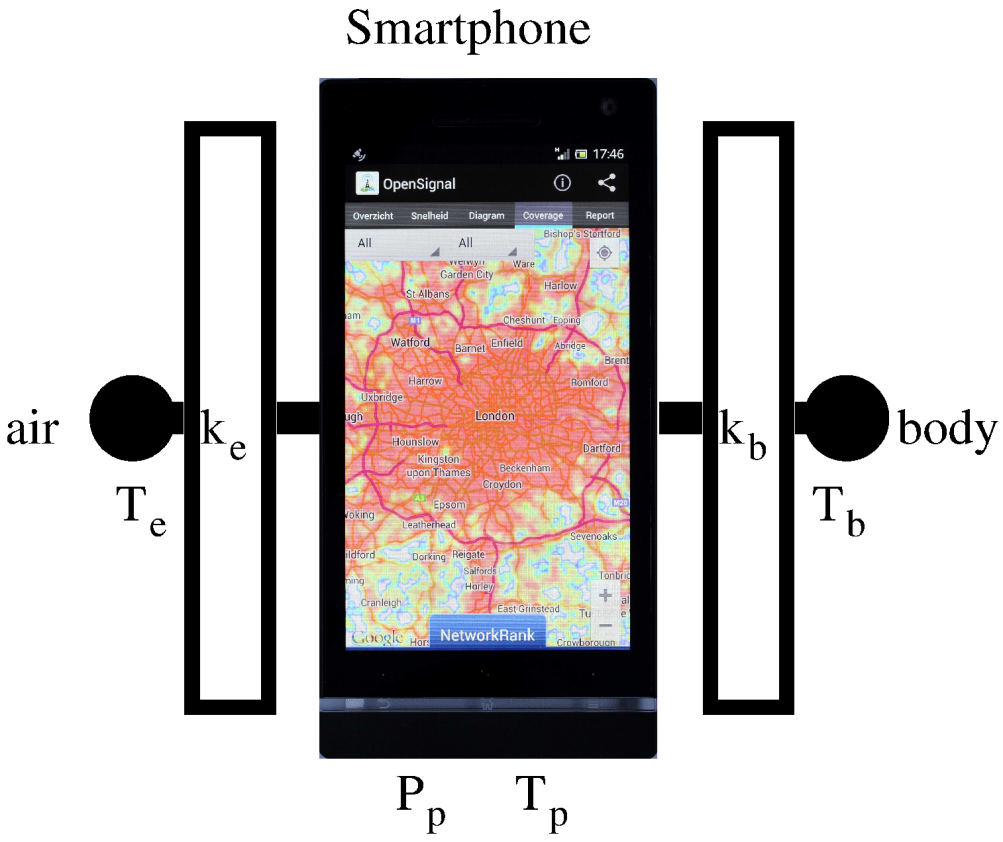
Introduction - Crowdsourcing air temperatures from smartphones



- OpenSignal: application for smartphones.
- Monitors signal strength of wireless networks.
- Free.
- Also stores battery temperatures.
- Originally not designed for estimating environmental variables.

Overeem *et al.* (2013)

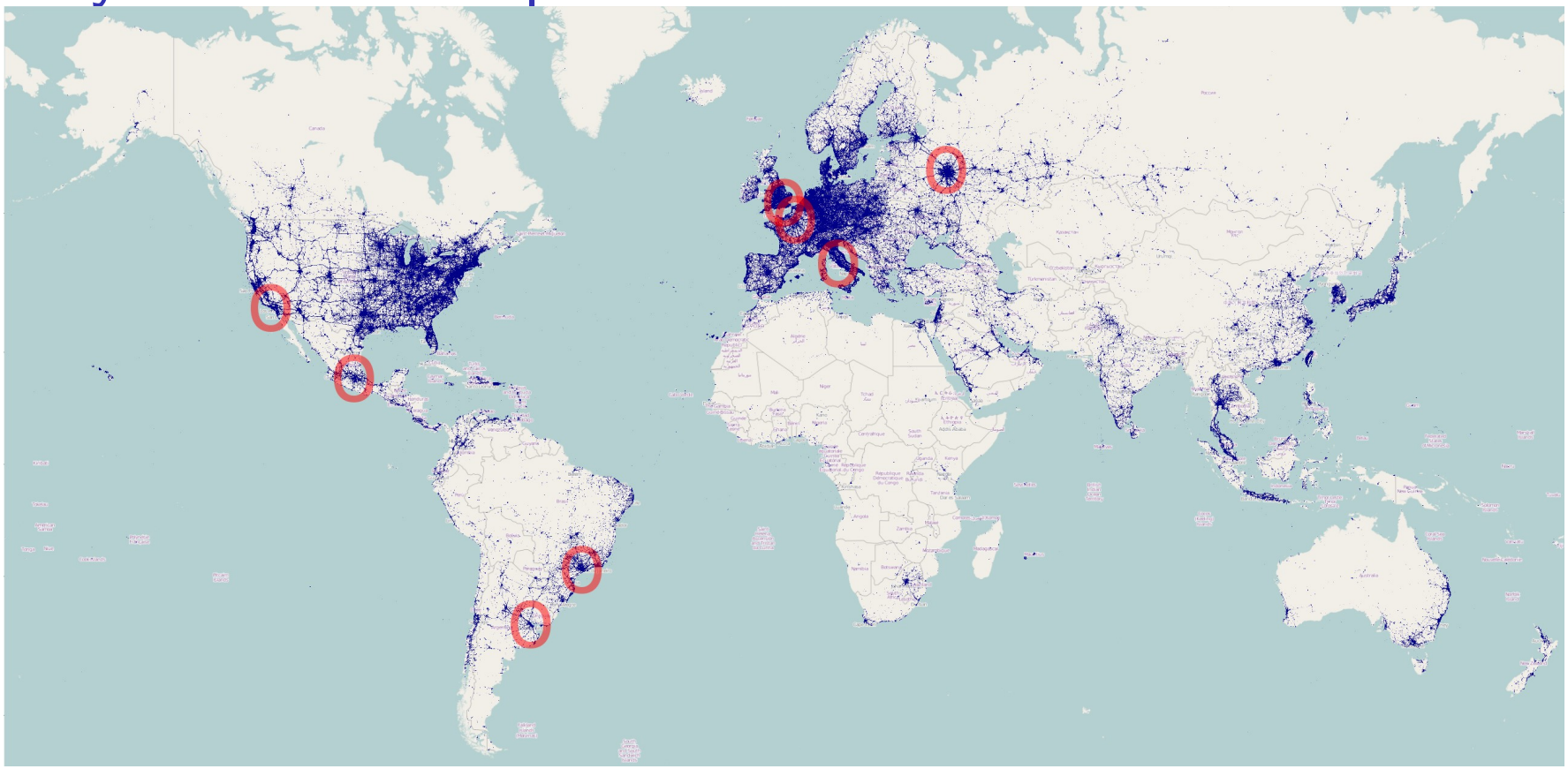
Method - Heat transfer model



(Overeem *et al.*, 2013)

- Assumption: smartphone close to user's body.
- Thermal energy generated by smartphone in equilibrium with heat outflow to body and environment.
- The conductive heat flow between two adjacent systems is proportional to temperature difference between systems.
- Convection, radiation and external heat sources are neglected.
- Basic principle: air temperature will influence battery temperature.

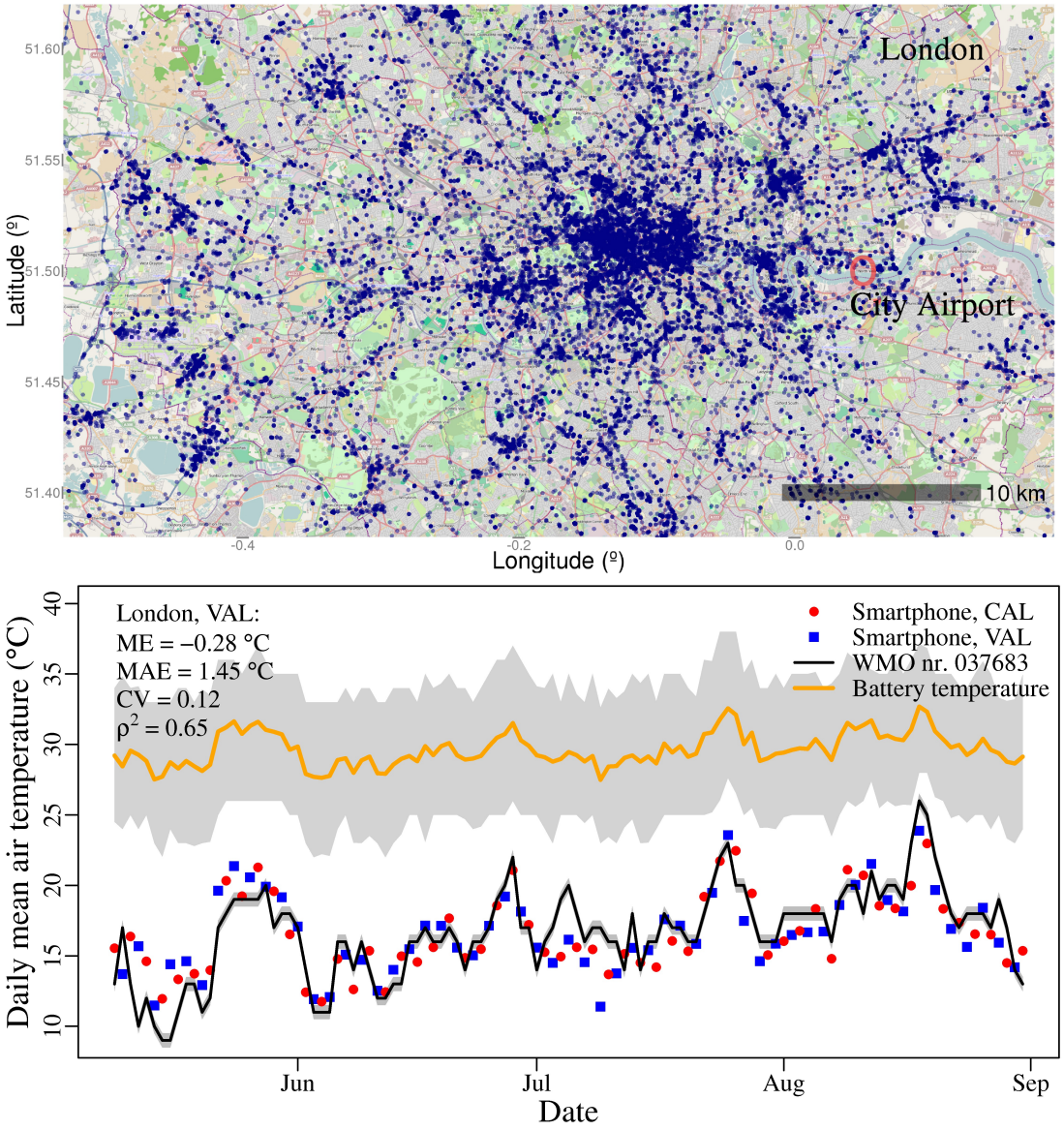
Daily mean air temperature for 8 cities



World map (openstreetmap.org) with locations of battery temperatures for one year (Overeem *et al.*, 2013).
Compute daily mean air temperature from daily mean battery temperature:

$$\bar{T}^{\mathrm{A,day}}_{\mathrm{e},j,d} = m_j(\bar{T}^{\mathrm{A,day}}_{\mathrm{p},j,d} - T_0) + T_0 + \epsilon_{j,d}. \qquad (1)$$

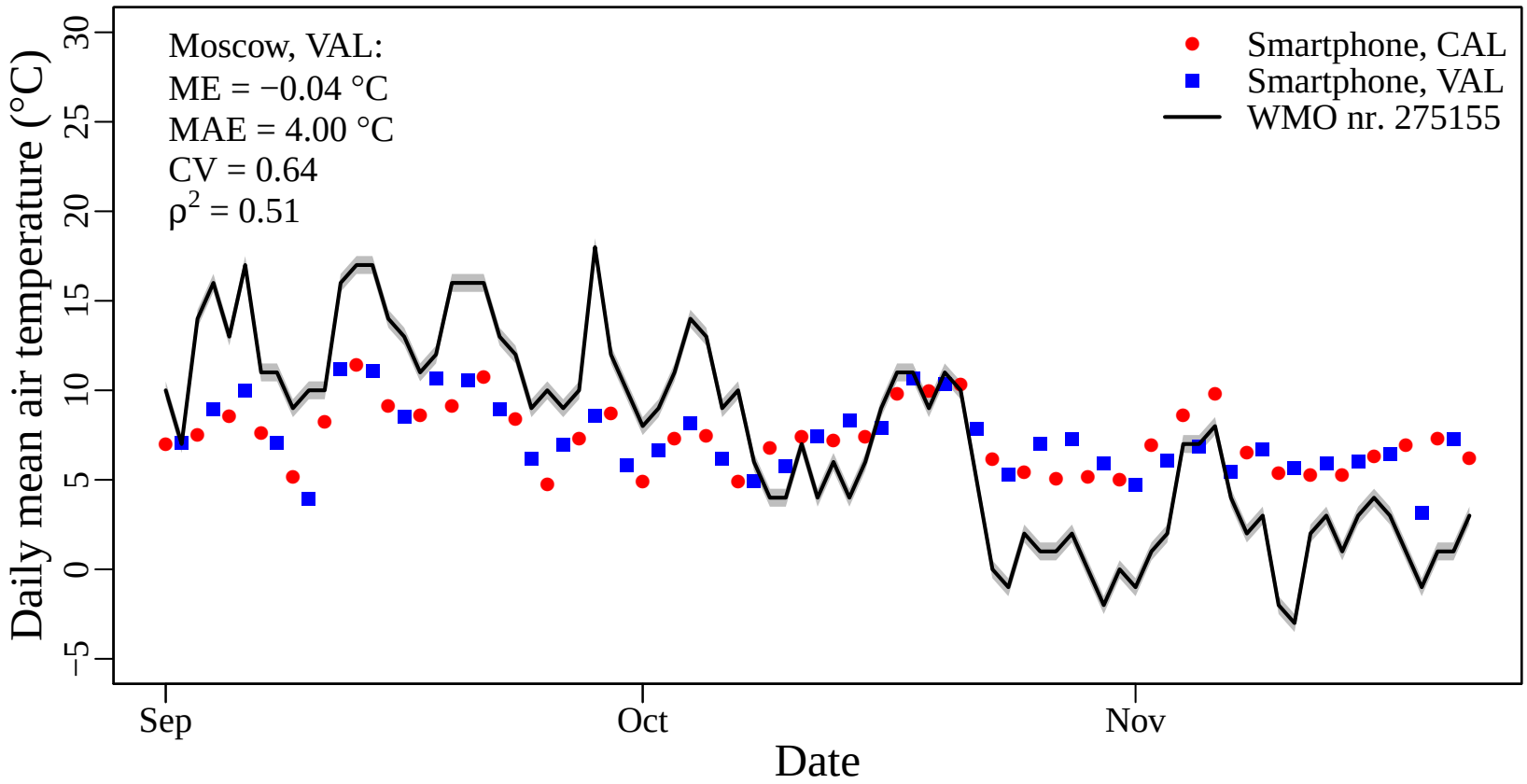
Daily mean temperature London



Overeem *et al.* (2013)

Map of London (openstreetmap.org) with locations of battery temperatures (upper panel). Daily mean battery and air temperatures London (lower panel).

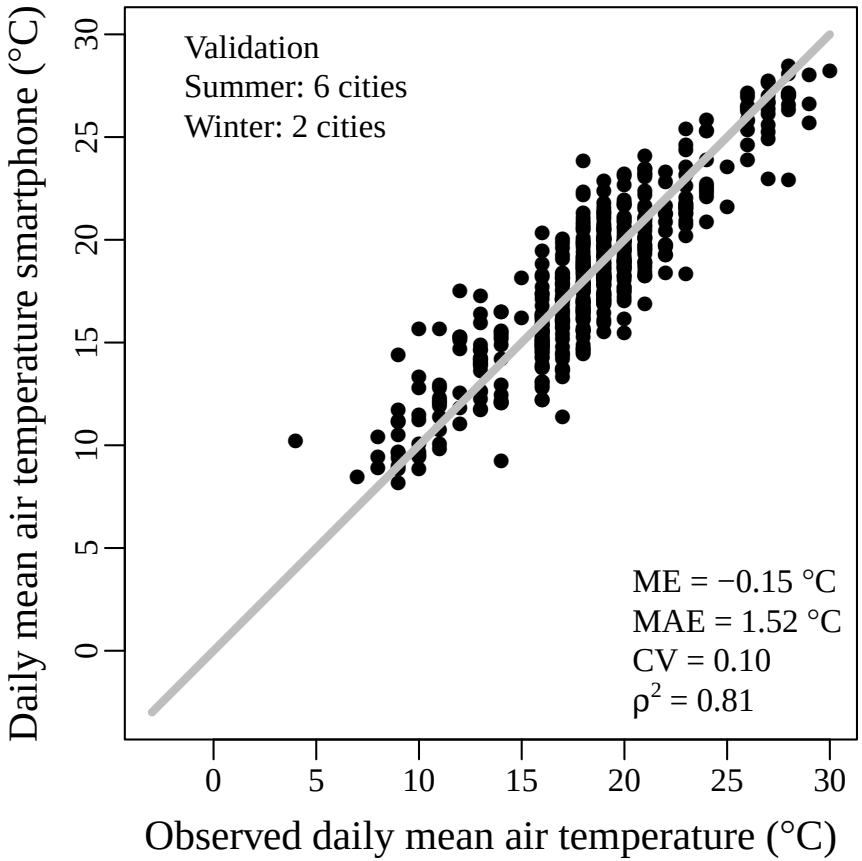
Daily mean temperature Moscow

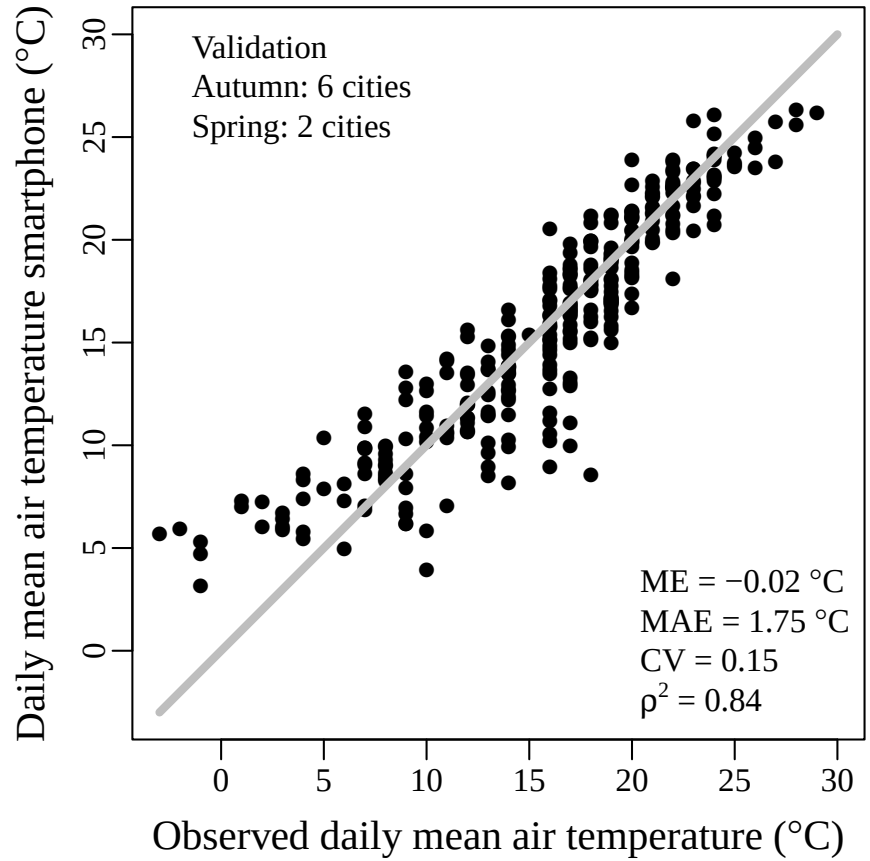


(Overeem *et al.*, 2013)

- Daily mean observed and estimated air temperatures Moscow.
- Poor performance probably related to large range of observed air temperatures within period (i.e., value of m_j is not optimal for entire period).

Daily mean temperature 8 cities

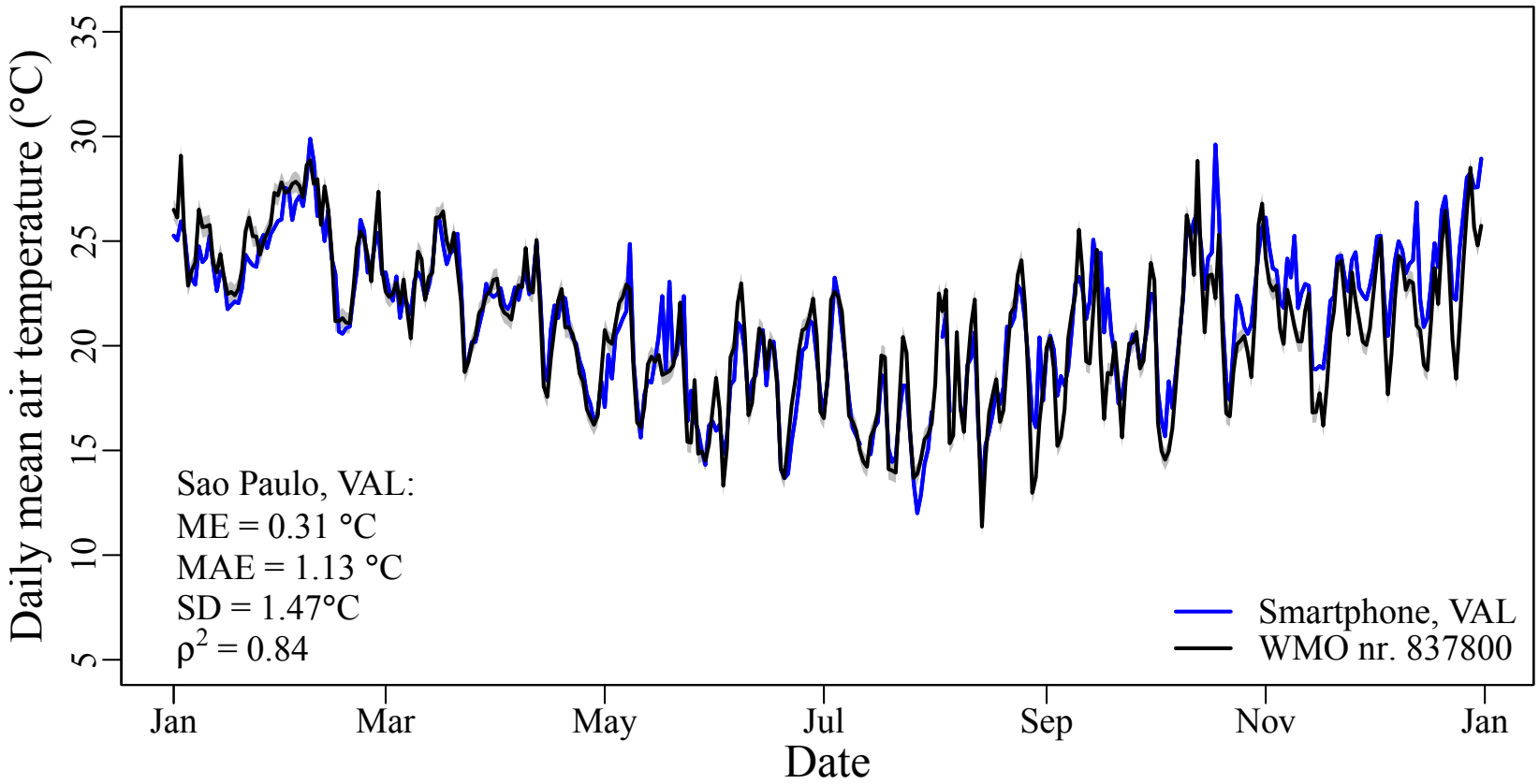




(Overeem *et al.*, 2013)

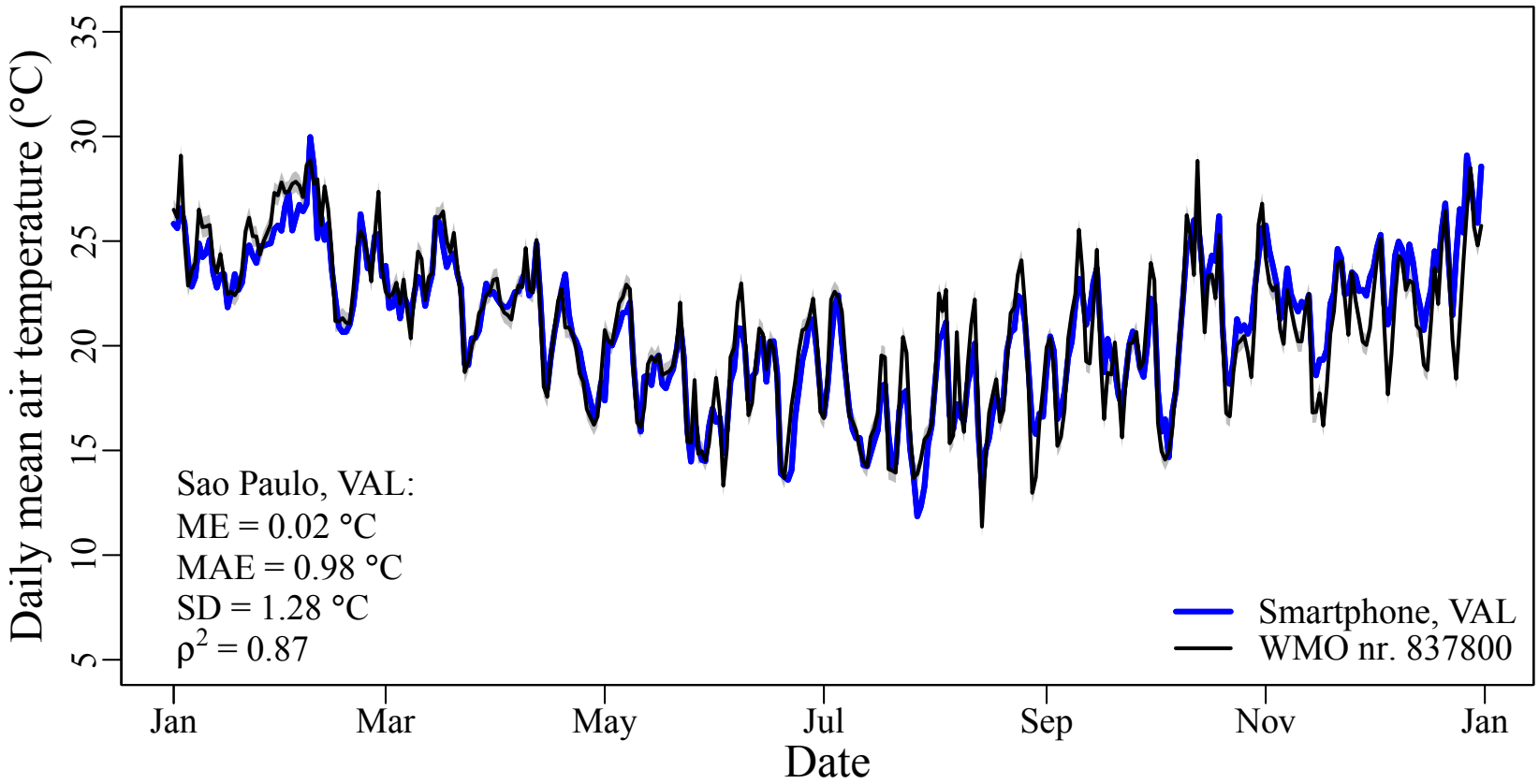
- Scatter plots: daily air temperatures for 8 cities and 2 seasons.

Daily mean temperature São Paulo



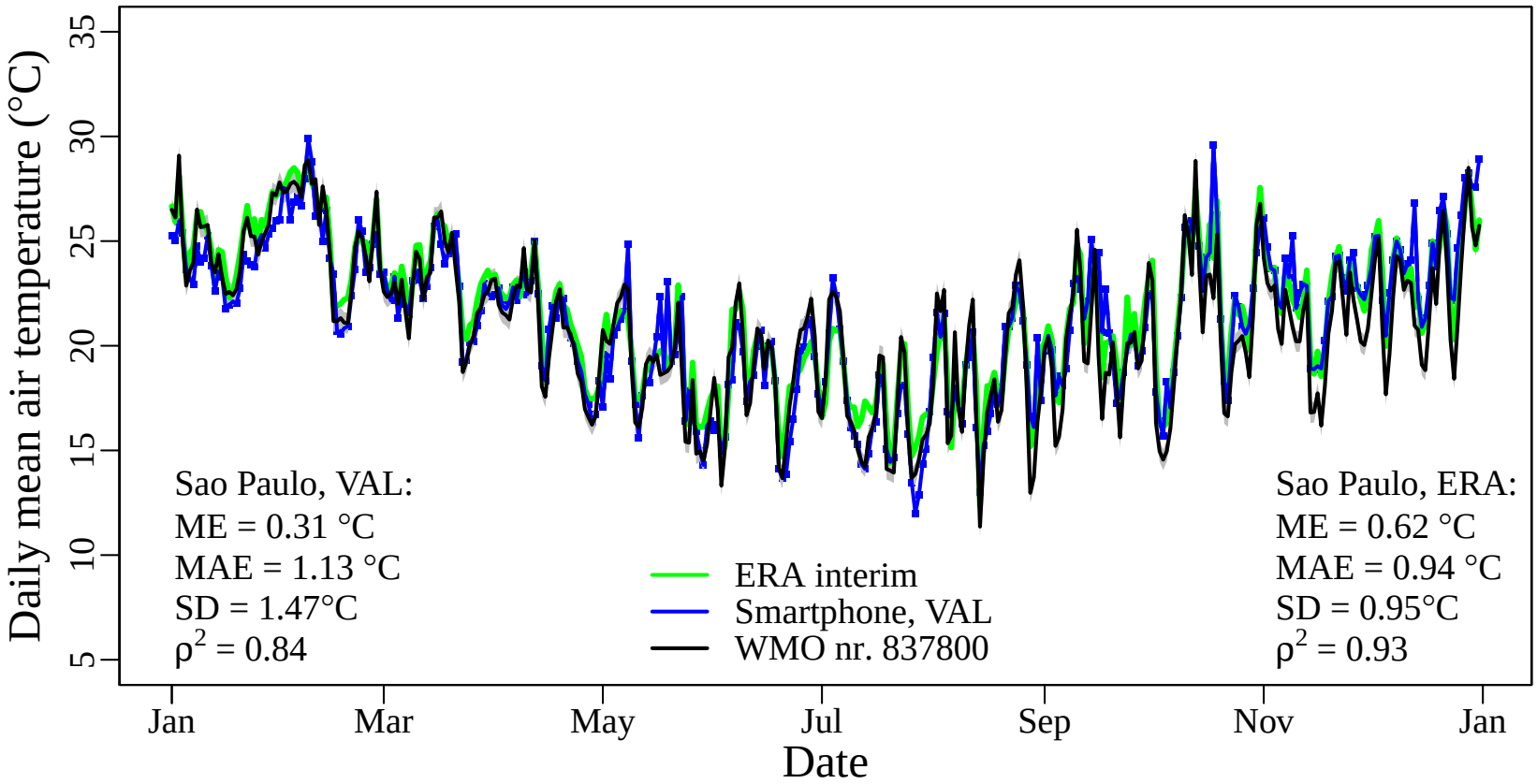
- Daily mean observed and estimated air temperatures São Paulo.
- Roughly 15000 battery temperature readings per day.
- 1 year calibration; 1 year validation.

Daily mean temperature São Paulo



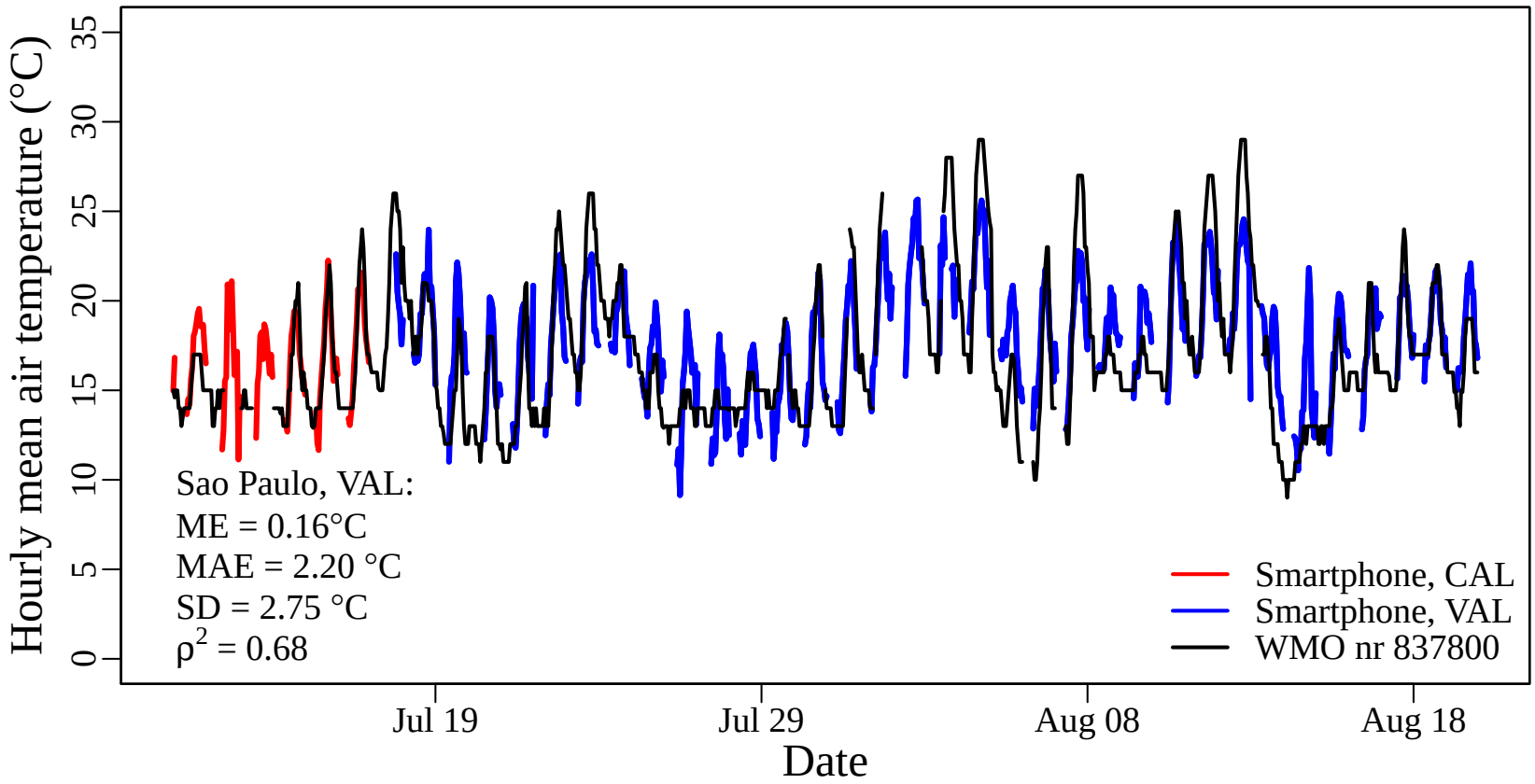
- Daily mean observed and estimated air temperatures São Paulo
- Only battery temperatures from Samsung GTI series.
- 1 year calibration; 1 year validation.

Daily mean temperature São Paulo



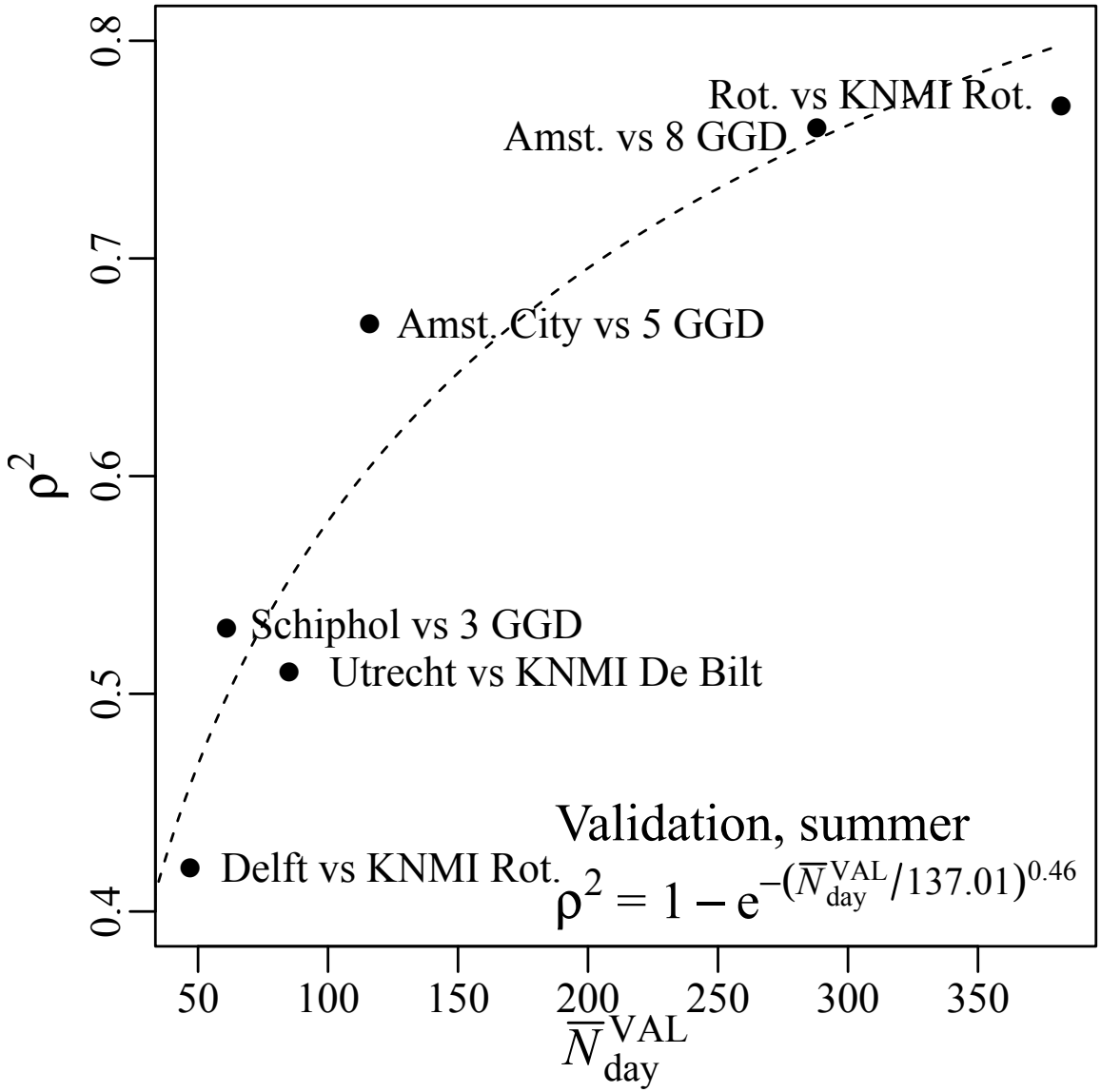
- Daily mean observed and estimated air temperatures São Paulo.
- Roughly 15000 battery temperature readings per day.
- Performance of ERA-interim re-analysis is also given.

Hourly mean temperature São Paulo



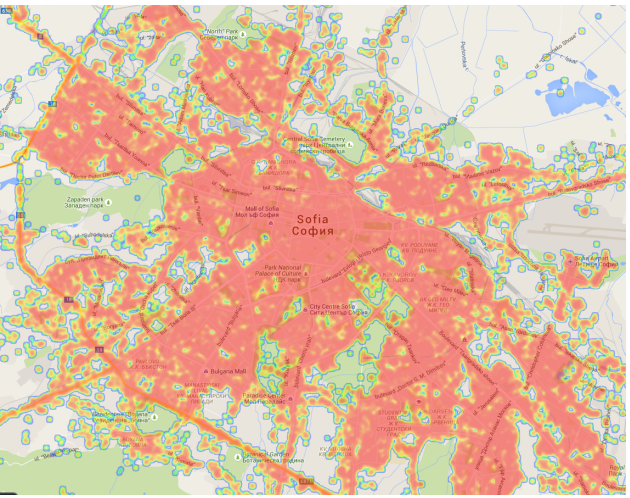
- Hourly mean observed and estimated air temperatures São Paulo.
- Only battery temperatures from Samsung GTI series.
- Calibration coefficient for each hour.

Performance as function of number of readings



- Daily mean battery and air temperatures for some Dutch cities.

Discussion



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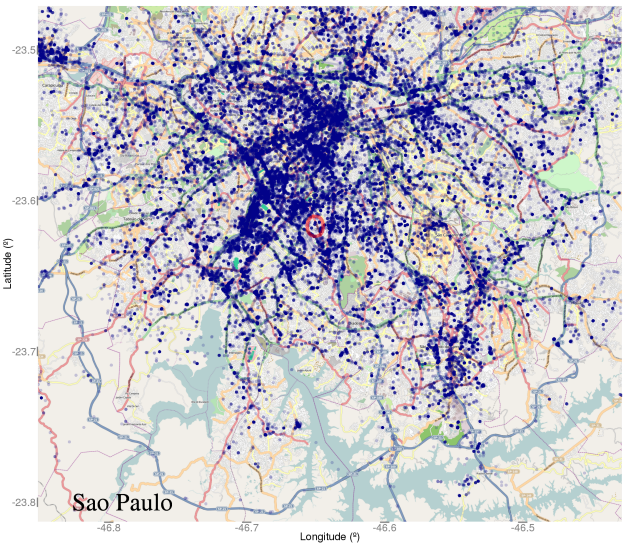
- Method works because of averaging over many battery temperature readings.
- Many readings will be representative for indoors, not outdoors.
- Smartphones: often not in pocket.
- Representativity of weather station and readings: which air temperature is observed?
- Lower number of readings during night and probably less outdoor readings during cold periods.
- Accuracy of reading: roughly 40% within 300 m.
- ..., ..., ...

Conclusions and outlook



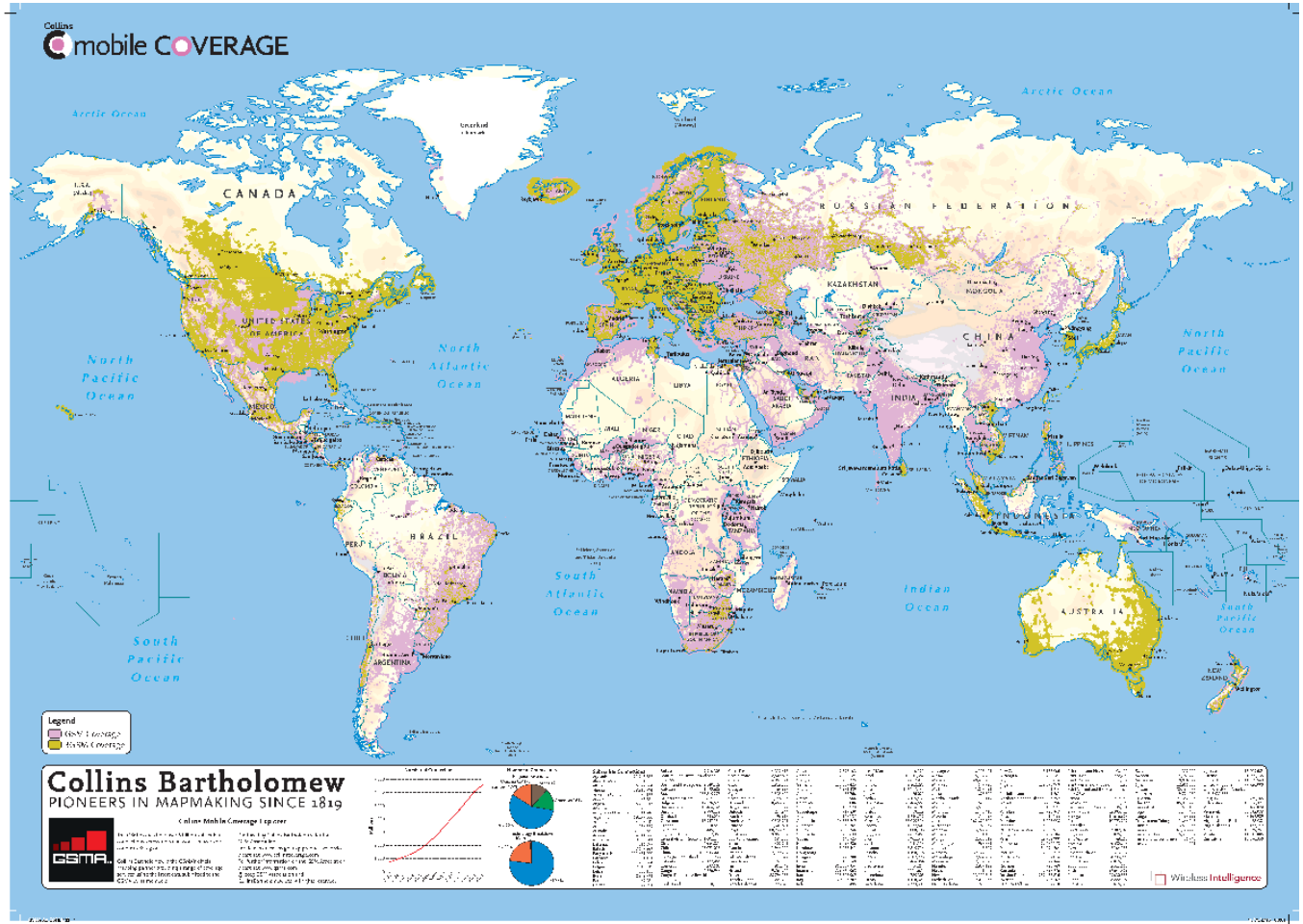
- Fairly accurate daily air temperature from smartphones.
- Crowdsourcing using smartphone sensors is promising.
- Battery temperatures: interesting illustration.
- Meant as additional source of temperature information.

Recommendations:

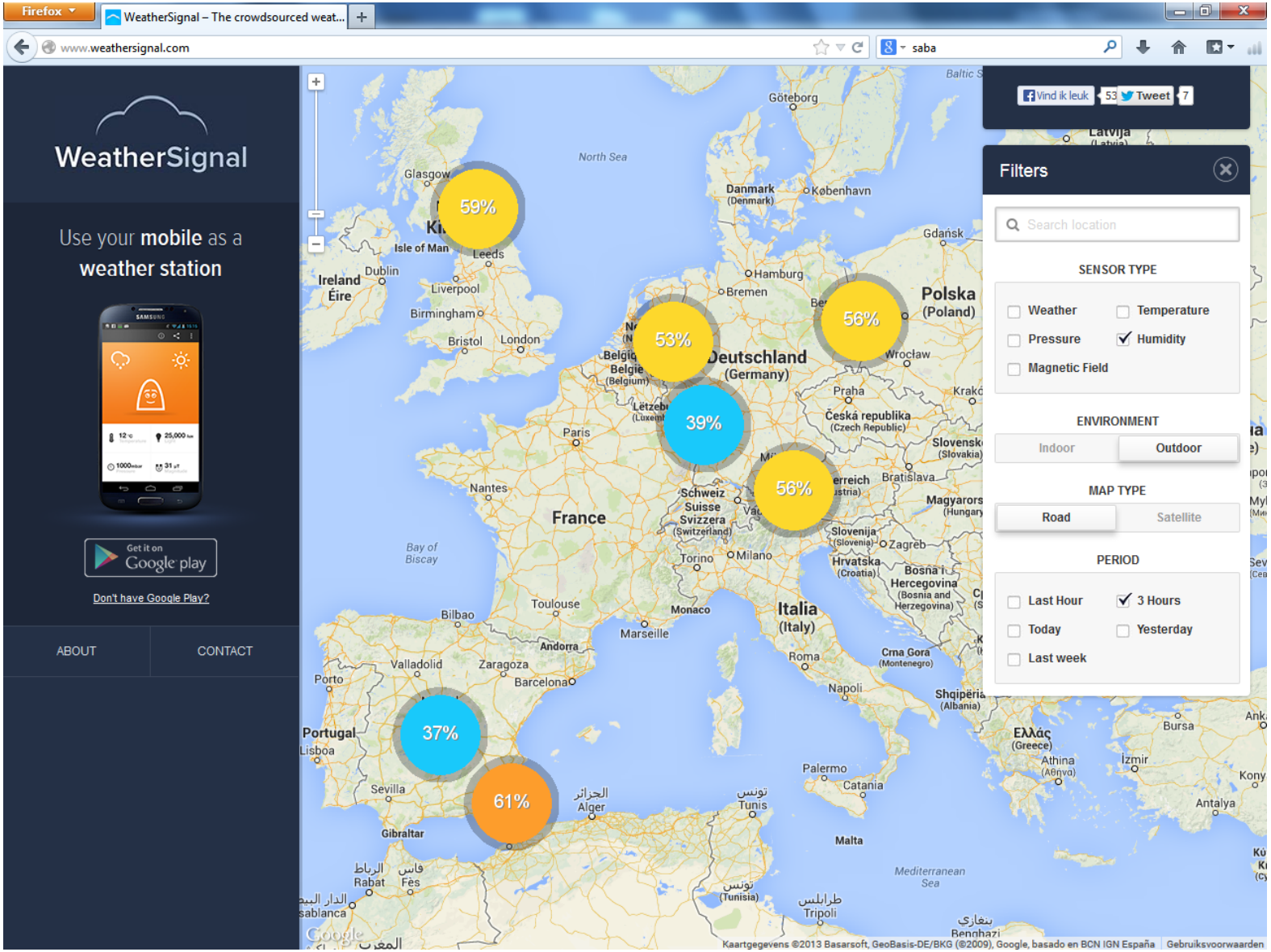
- Use a dense urban meteorological network for validation purposes.
- Apply algorithm for cities with thousands of readings.
- Remove indoor readings (light sensor?).
- Air temperature maps (requires many readings).

World map of cellular telephone coverage

- 20% of earth's land surface has coverage.
- Hundreds of millions of Android smartphones.
- Many potential measurements + "free" transmission.
- Application and smartphone have originally not been designed for air temperature estimation.



Another application: WeatherSignal



New smartphones may have air pressure, humidity or temperature sensors.

Questions?

- Overeem, A., Robinson, J.C.R., Leijnse, H., Steeneveld, G.J., Horn, B.K.P, Uijlenhoet, R., 2013. Crowdsourcing urban air temperatures from smartphone battery temperatures, *Geophys. Res. Lett.*.
- Muller, C.L., Chapman, L., Johnston, S., Kidd, C., Illingworth, S., Foody, G., Overeem, A. and Leigh, R.R., 2015. Crowdsourcing for climate and atmospheric sciences: current status and future potential, *Int. J. Climatol.*.

Some other recent work:

- Mass, C.F., Madaus, L.E., 2014: Surface Pressure Observations from Smartphones: A potential revolution for high-resolution weather prediction?, *BAMS*.
- Elmore, K.L., Flamig, Z.L., Lakshmanan, V., Kaney, B.T., Farmer, V., Reeves, H.D., Rothfusz, L.P., 2014: MPING: Crowd-sourcing weather reports for research, *BAMS*.