Air Quality sensing, an How To

# *MySense: together we measure*

## our focus: environmental pollution in an agricultural region

**how we do it**

**how we show it**

**lessons we learned**

*teus hagen*

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ver. Behoud de Parel

http://behouddeparel.nl

Koppelting WAR, 25th of January 2020

# MySense air quality sensing project
# Open and free: it's not a free beer

- **goal**:
  - know what is locally happening
  - develop and measure *together* with citizens, with farmers and scientists
  - focus on agricultural environments, e.g. bio-industry
- **how:**
  - sense pollutants, develop sensor kits, show results and technology
    - **info: http://behouddeparel.nl/samen-meten**
    - **technology: shttp://github.com/teusH/MySense**
  - where in Nld: east N-Brabant, south Gelderland and N-Limburg
  - MySense kits ca 25 operational, see **http://behouddeparel.nl/meetkits**
  - presentations, statistical overviews, Open data

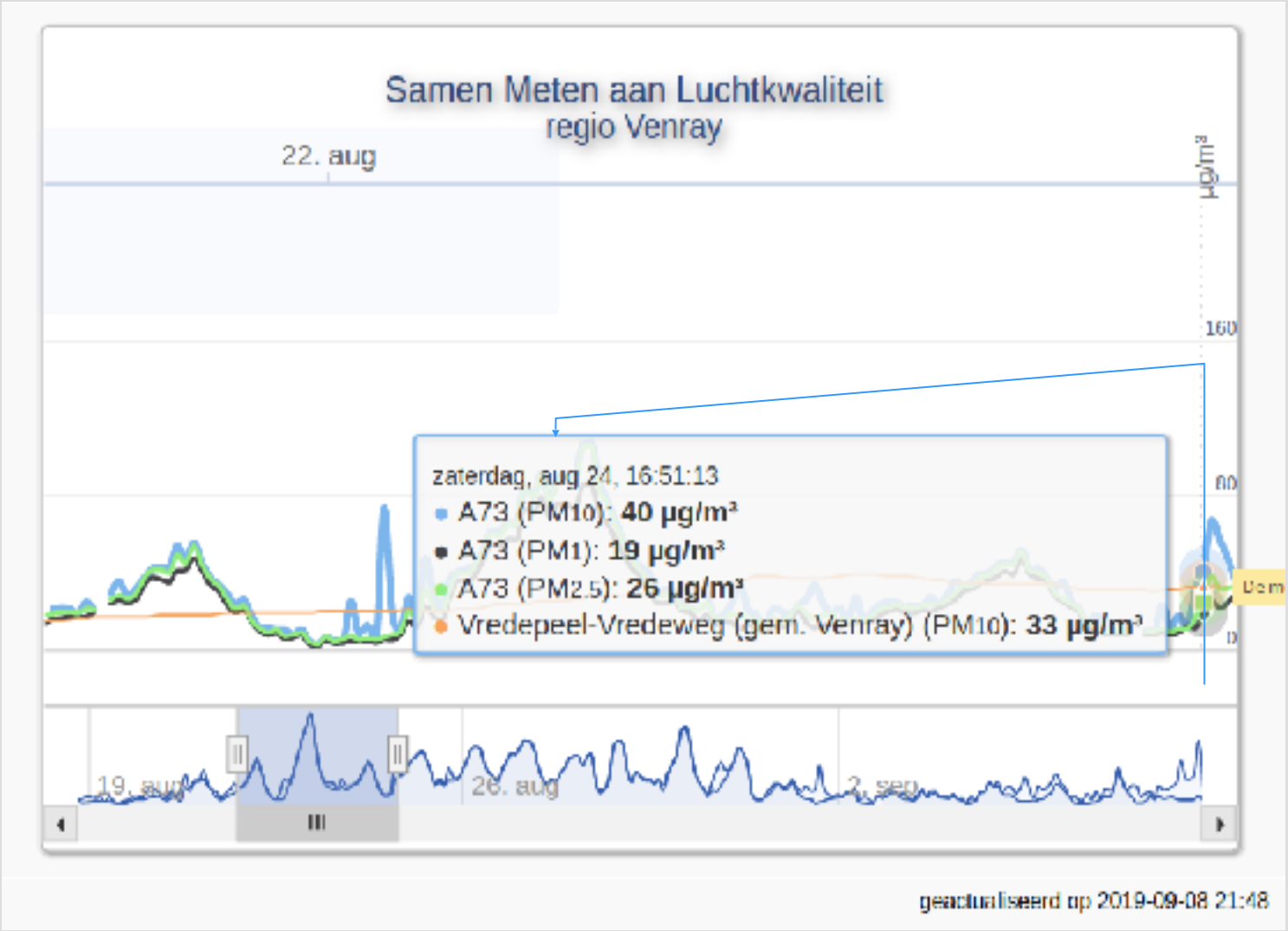
# **together we measure pollutants** (mainly dust particles) **local air quality, local differences**


**local** on-line measurements since 2017

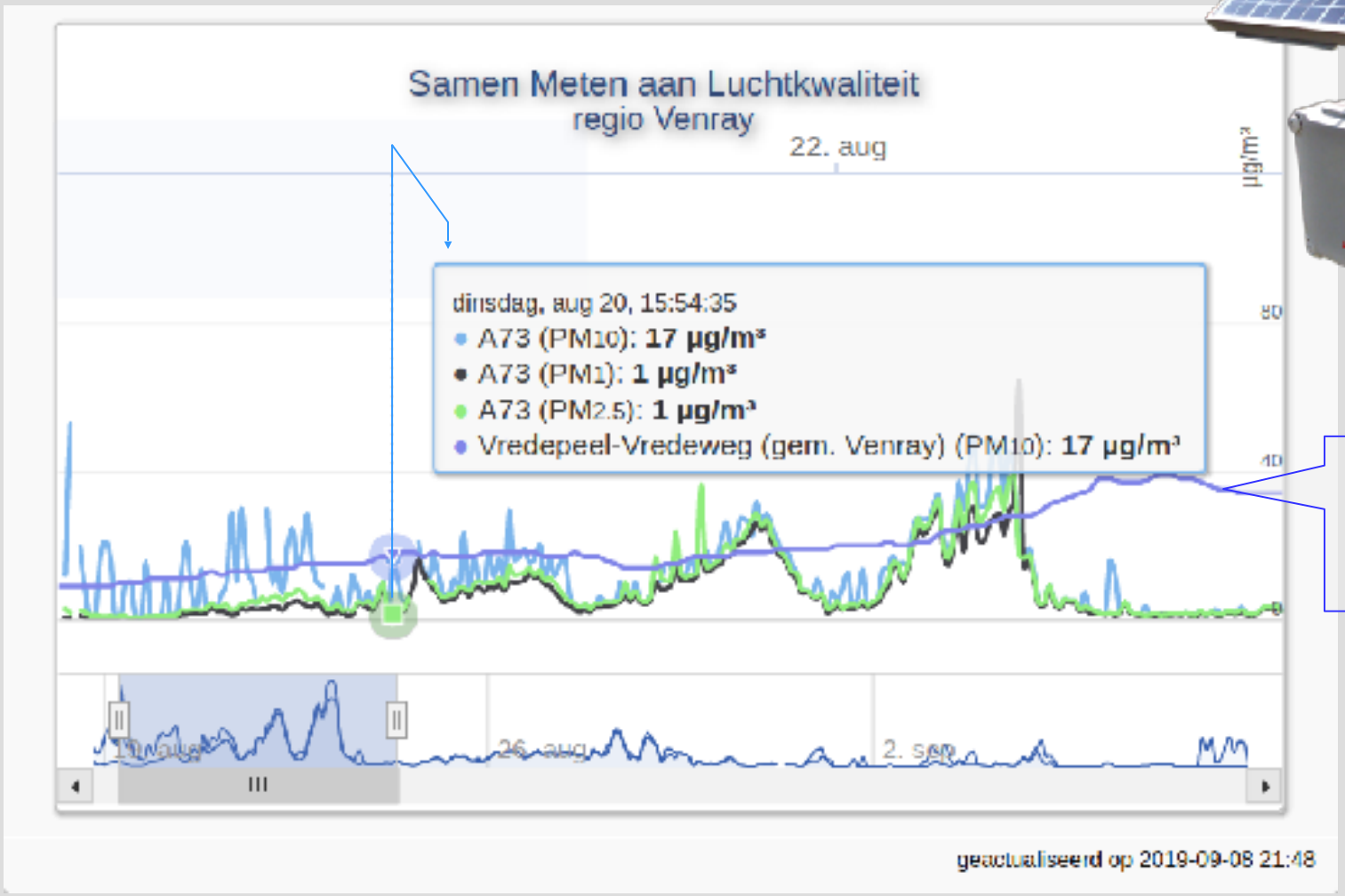

- gives insight in very local air quality, e.g. near farms
- focus on pollutant emissions e.g. bio industry and farms
- together with a farmer and animal welfare to optimize the problem triangle:
  dust emissions, animal welfare, and production economics
- today: Yes We Can
  IoT, affordable sensors, controllers and 3D printing

‘**WE**’ is citizens, farmers,
poly technical university, national health institute, agri-consulting

# MySense sensing $PM_1$, $PM_{2.5}$, and $PM_{10}$ inside (canteen, packing department) of an open chicken farm



# MySense sensing $PM_1$, $PM_{2.5}$, and $PM_{10}$ measure around an open chicken farm at 4 locations




official air sensing
**station Vredepeel**
distance 14 km
on wind: <1 m/sec

# http://BehoudDeParel.nl/MySense
# what is MySense about?

dust particles
$PM_1$ $PM_{2.5}$
$PM_{10}$

nitrogen oxides
$NO_x$

ammonium
$NH_3$

carbon dioxide
$CO_2$

sulfur dioxide
$SO_2$

ozone
$O_3$

odor

rain fall

wind

GPS location

sound

temperature

air pressure

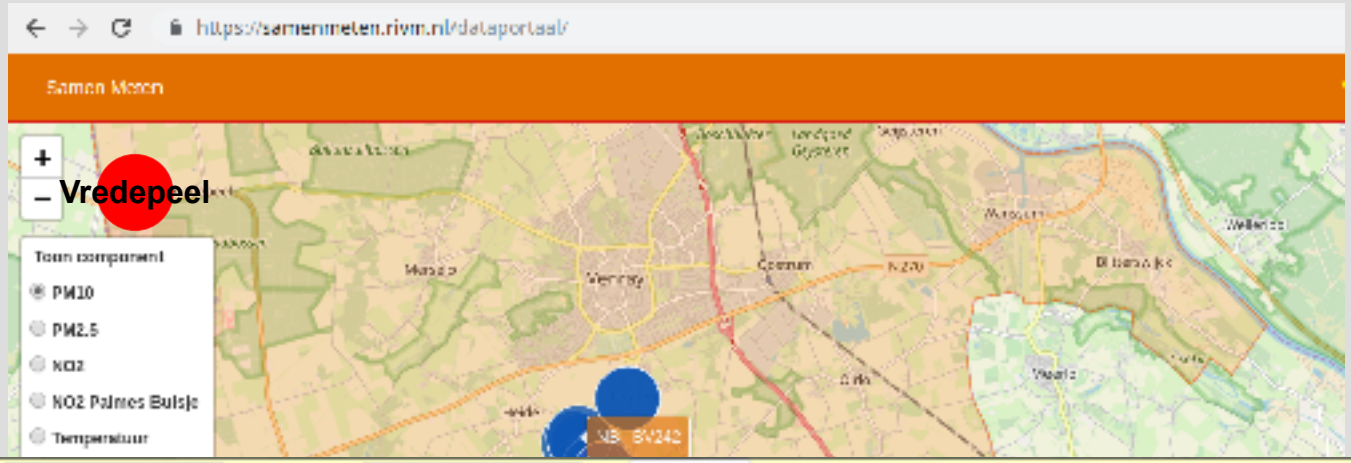
VOC gas

rel. humidity

red bulleted slides are not presented

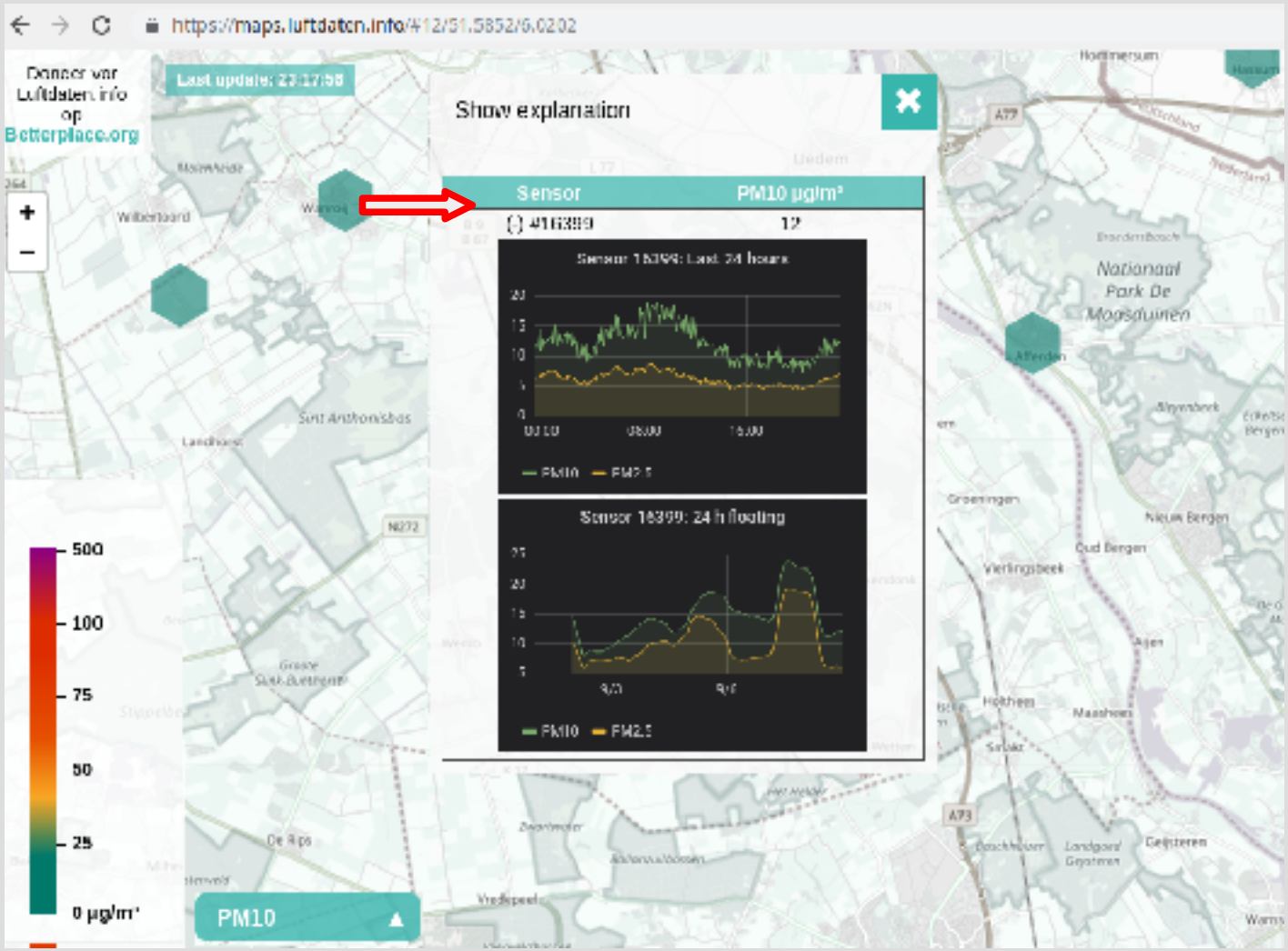
# en Buren' project (Venray)


## RIVM data portal: https://samenmeten.rivm.nl/dataportaal



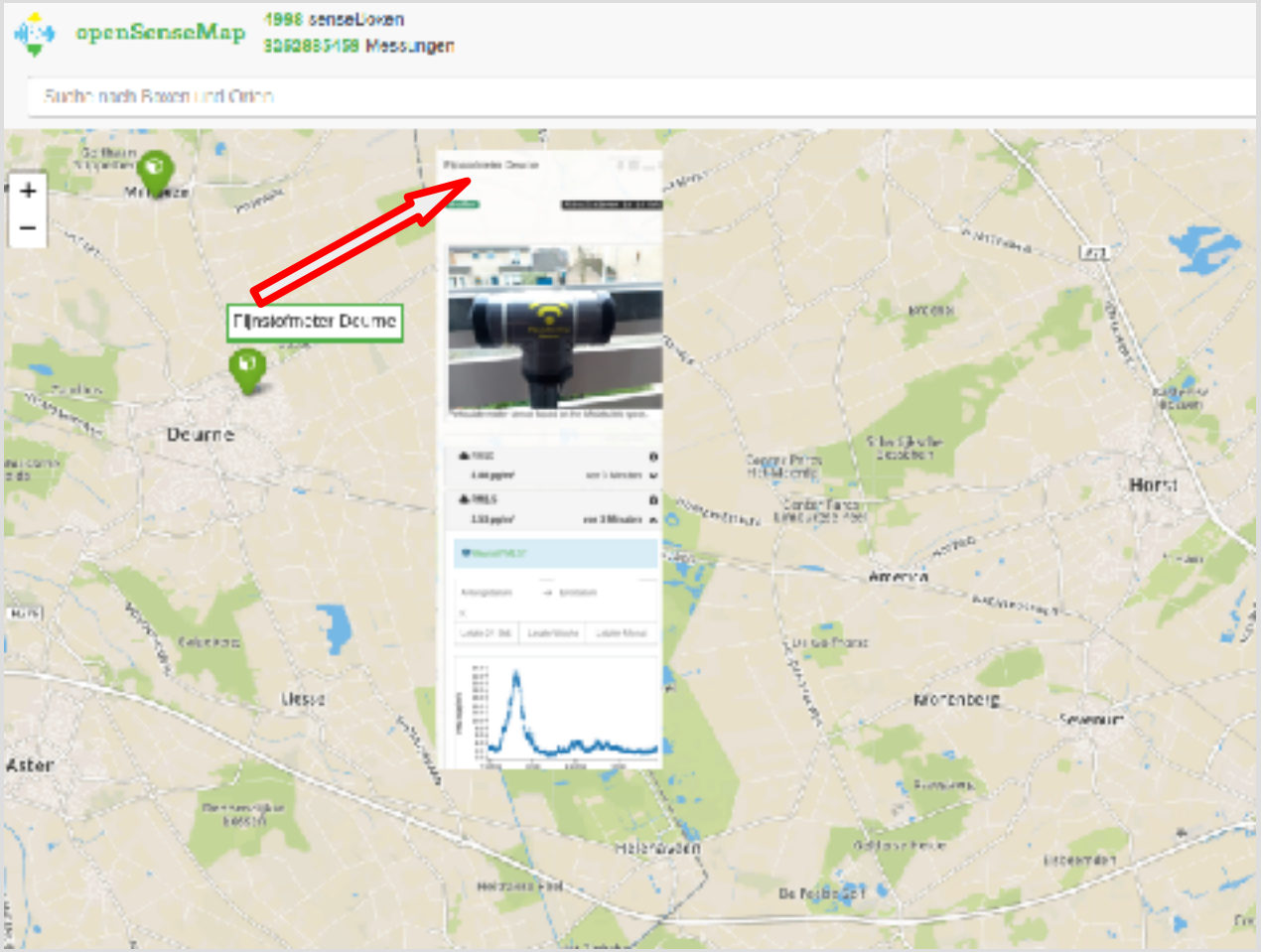

# Luftdaten.info  project (Stuttgart)

**Open Data Germany:  https://www.luftdaten.info/#12/51.5852/6.0202**



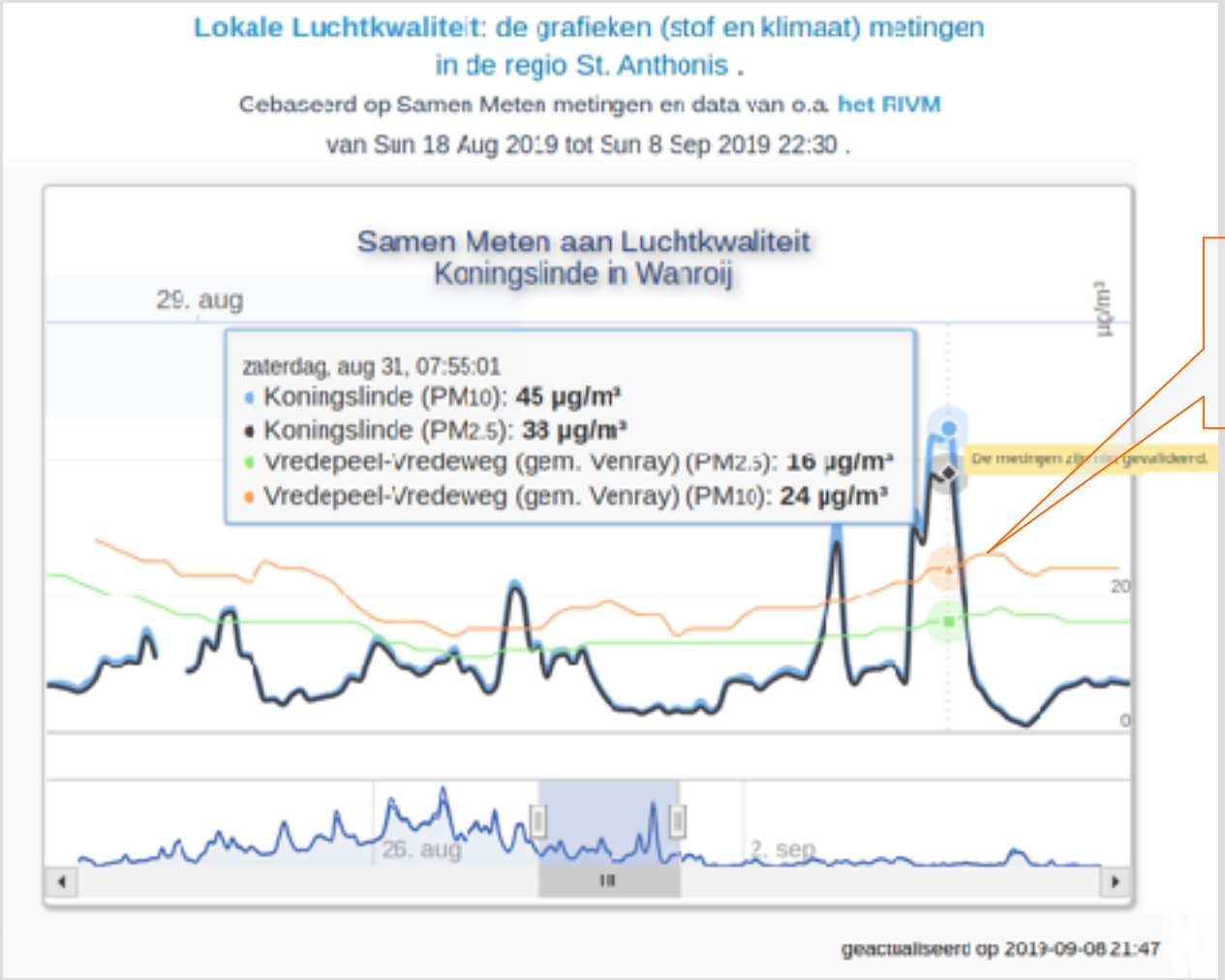
# OpenSense  project (uni van Munster)

Open Sense map Dld: https://www.opensensemap.org/explore/5c3915a74c2f300199ebbfa

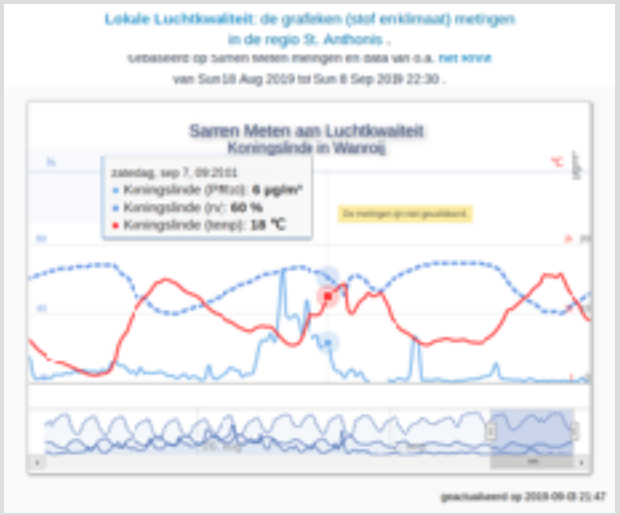


# Stichting Burgerwetenschappers Land van Cuijk

## started a MySense project with 11 kits (end of Feb 2020: 30 kits)
## region: St Anthonis (Boxmeer)




official air sensing
**station Vredepeel**
distance 16 km
on wind: < 1 m/sec



# Smart Village: the farmers wisdom
# MySense technology base

- **hardware**: modular, device connections with wires, plug & play
- **programs/scripts** Open Source, modular, scalable
- **software** and **documentation** freely available

  **https://github.com** and **http://behouddeparel.nl/samen-meten**
- **(website and statistical) tooling**:

  standard, free for none commercial use
- **data**:

  standard exchange format

  standard storage in a standard open database
- **communication**: Internet of Things (IoT) wireless

  WiFi (too fragile, too expensive)

  LoRa (the Things Network)

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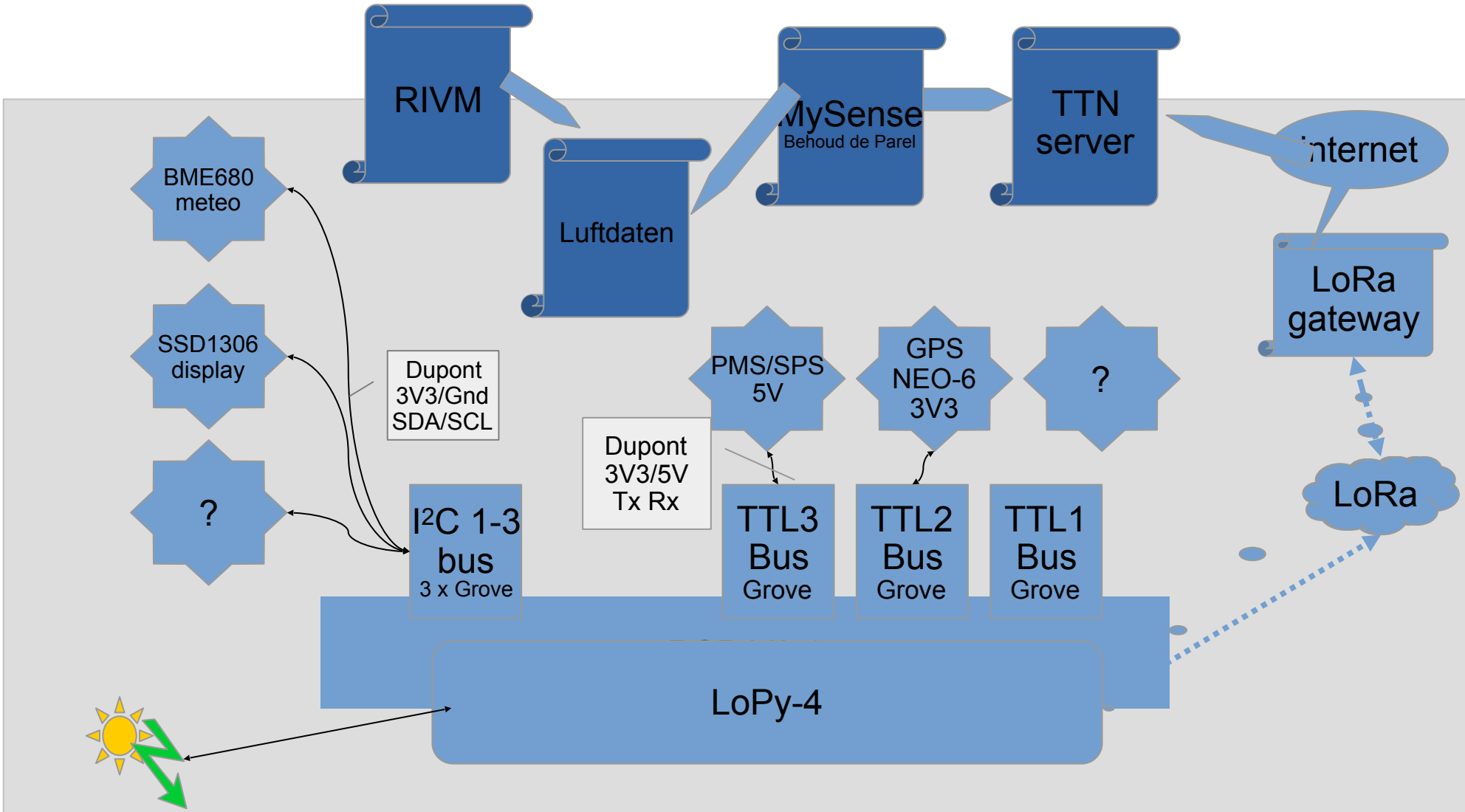
# Smart Village: wisdom on the countru site
# MySense technology base
# Open Source is not a free beer

- **hardware**: I2C-bus, serial TTL, LoRa and ESP8266 (PyCom LoPy-4)
- **embedded** as less as possible, use plug & play
- **Open Source** (Micro) Python software, modular
- all software and **documentation** freely available via github
- **PyCom LoPy**, Adafruit libraries and Atom/PyMakr with microPython
- **website tooling**: Drupal CMS, php, java script, RRD graph images, interactive HighCharts
- **data**: MySQL, Mosquitto, InfluxDB, JSON, HTML/XML, statistical packages (Python), NextCloud
- **communication**: internet/security, WAN/wifi, IoT/LoRa

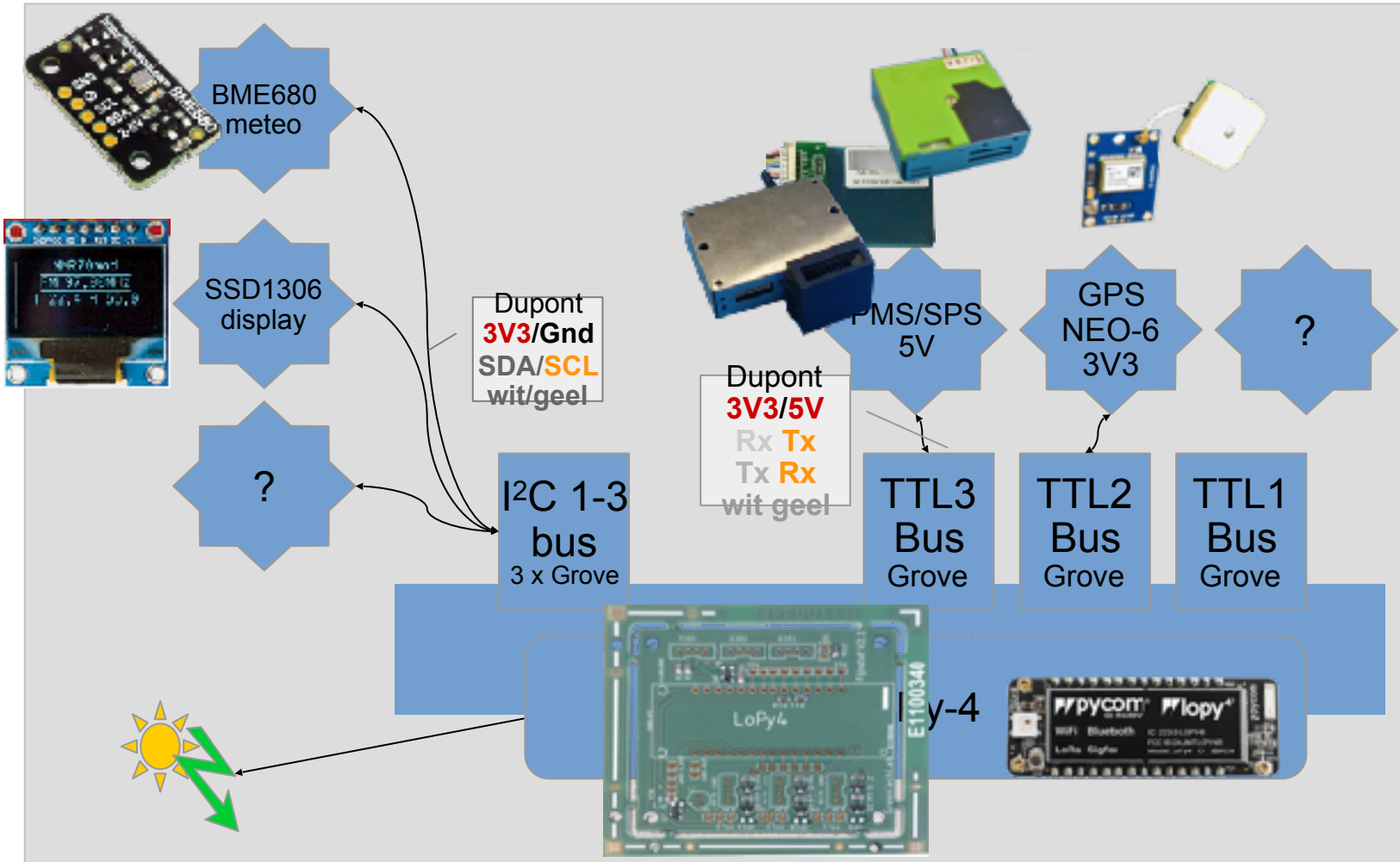
# hardware shopping list
## (as of April 2019, priority ordered lists)

- On-line shops:
  - AliExpress, Banggood (less as €25 per order)
  - Antratek, Kiwi Electronics, TinyElectronics, Ideetronics, and others
- LoRa measurement kit components (break out) (kits total ca € 125-250):
  - dust: **PMSx003** > Sensirion > PMS7003 > SDS011, UART
  - meteo: **BME680** > BME280 > SHT31, I2C!
  - GPS: **Neo-6**, UART
  - display: **SSD1306** (yellow/blue, 128X64), I2C!
  - PyCom **LoPy-4** + pigtail + 868 MHz antenna
  - connecting board Fontys **PCB V2.1** or **PCB St BWLvC** + 12 pins, 2 chip sockets, 6 Grove connectors
  - 4 4-wired **Grove-Dupont cables**, heat shrink tubing, (micro USB socket breakout), M4/M3 nylon bolts
  - **V5 DC adapte**r + 2.5m adapter cable (micro USB)
  - **air roof outlet sewer pipe PVC** 80mm + 70mm rain pipe
  - white paint and plastic primer, pvc en 2-component glue, small piece of plexiglas
  - mosquitto net, 60 mm non static plastic tube for air inlet
- LoRa gateway: eg RAK7258 micro gateway (has RAK833, OpenWRT) indoor (ca €140 + € 20 import tax)

# hardware architecture
## based on PyCom LoPy-4



# hardware components




# sockets and connections sensors via PCB

- color scheme connectores, use Grove/Adafruit standard:
  **red, black, white (dev Tx/SDA), and yellow (dev Rx/SCL)**
- type UART/TTL: red **5V of 3V3**, black **Gnd**

  **yellow** device Tx - controller **Rx**, **white** device Rx – controller **Tx**
- type I2C: red 3V3, black Gnd

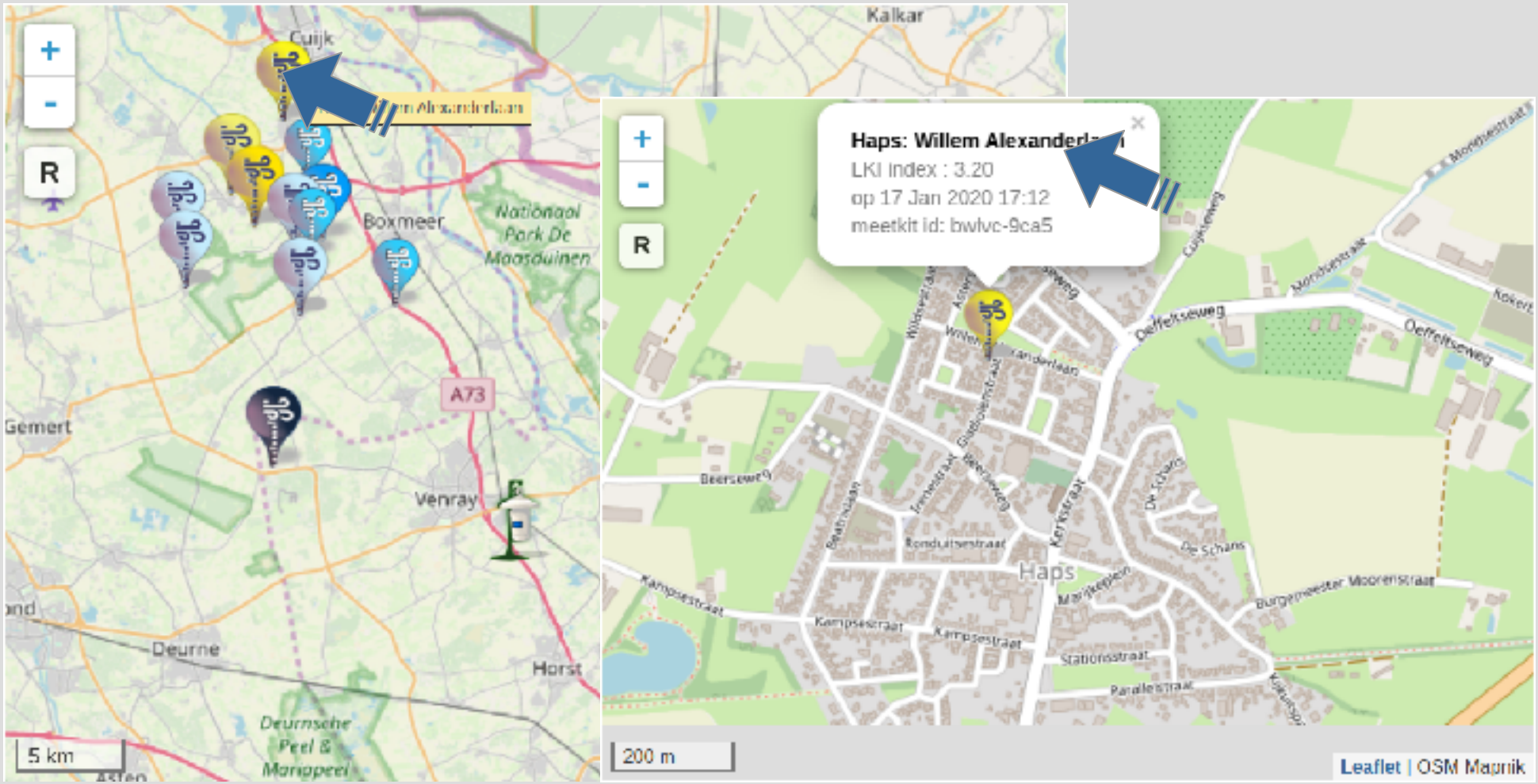
  **yellow** clock SCL, **white** data SDA
- **UART/TTL pins** (Tx,Rx,optional Pwr):

  (P1,P0,[P18]),(P4,P3,[P19])(P11,P10,[P20]) (check this); None: no pwr management
- **I2C pins:** (SDA P23,SCL P22,[P21]) parallel connected

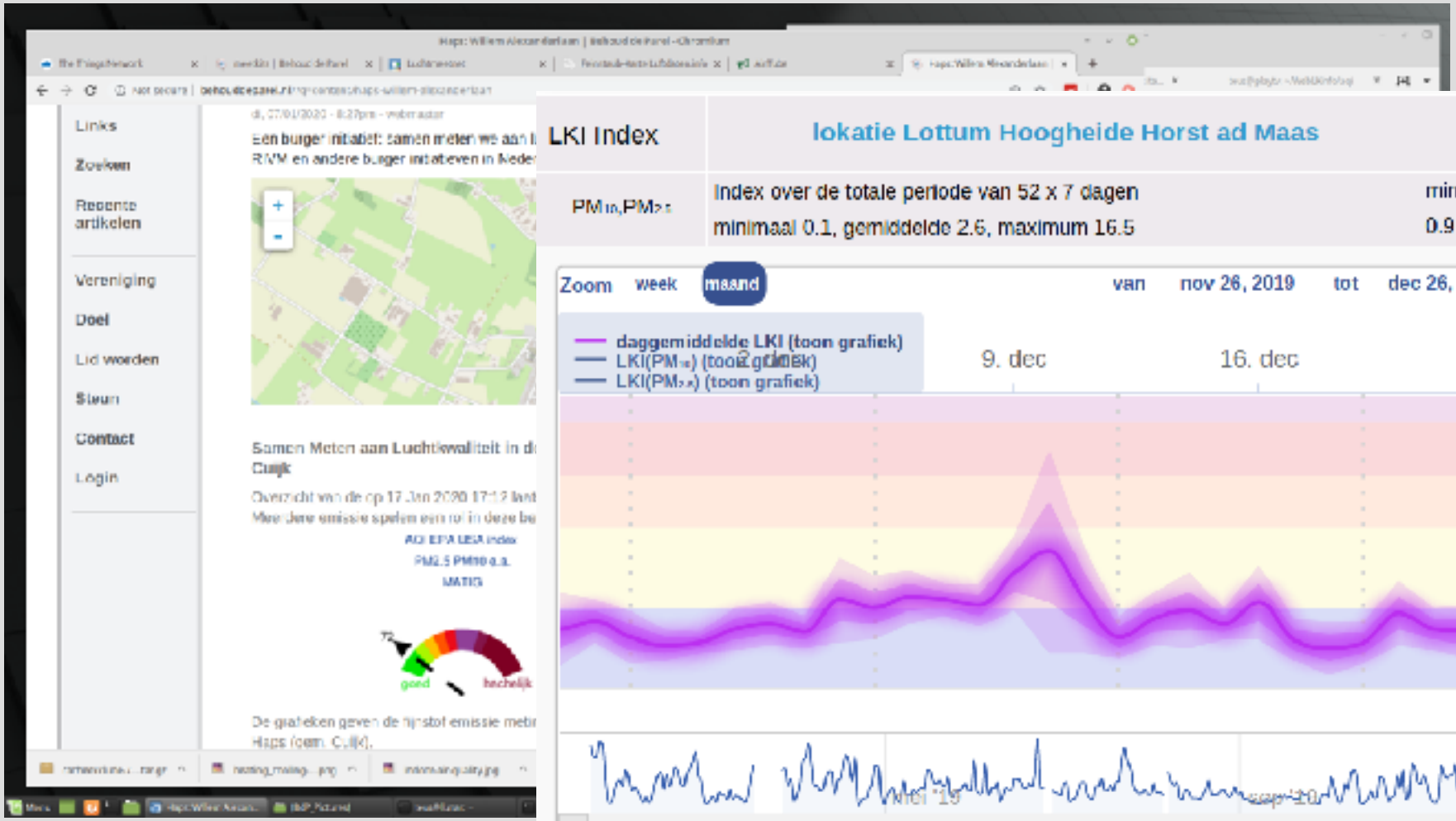
- older Fontys PCB V1 is not supporting power management
- Fontys V2.1 and BWLvC PCB can (de)**power** sensors, (solar) accu voltage check
- deepsleep function (solar/accu management support)

# data from sensor kit via LoRaWan (TTN) to data archive and to the data portals

# visualisation of measurements
# e.g. try http://BehoudDeParel.nl/meetkits



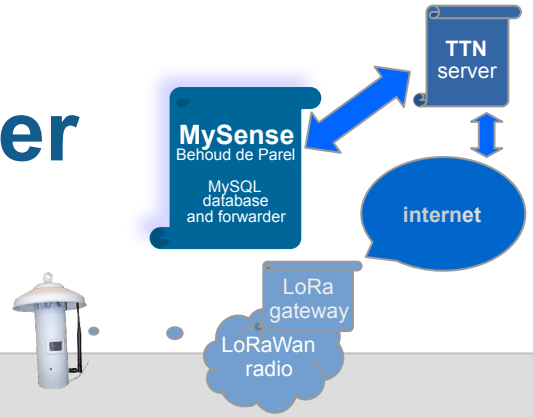
# dust ($PM_1$, $PM_{2.5}$, $PM_{10}$), meteo sensor local measurement details of the sensor kit



# the data visualisation How-We-Do-It

- **Drupal CMS** running on **Linux PC** (Mint)
  - Leaflet Open Street map (marker style: LKI air quality index)
  - HighCharts graphs (for now raw data) and air quality index LKI and AQI
  - administrative sensor kit meta data Drupal forms
- **scripts** (Bash shell, Perl, Python, PHP, and JavaScript)
  - every 24 hours check of data integrity
  - every hour collect and check measurements from governmental stations (RIVM, PLIM)
  - generate graphs for Drupal CMS using HighCharts and RRDtool data logging & graphs every hour from MySQL archive (mirrored on 2nd PC for backup)
  - removal of outliers in measurements (Chi square, sliding window 4 hours)
  - coming up: local calibration of measurements with rel. humidity and temperature (RIVM, initiatives Berghaven en MySense)
  - Open Source licensed: GPL V3, copyright: ver. Behoud de Parel and Teus Hagen

# the measurements data collect layer




**MySense framework** (Python): the (json) data handler

- **input channels** (collector):
  - ***TTN MQTT server*** (LoRaWan) data package handler
  - Mosquitto, InfluxDB, raw backup measurement data, etc.
  - various sensors (RaspBerry Pi, mainly via USB/TTL)
- **output channels** (forwarder):
  - *archiving*: MySQL database, console, monitoring, CMS visualisation
  - *data forwarding*:

    Mosquitto, InfluxDB, CSV, (S)HTTP, MySense data handler, etc.

    data portals: Luftdaten (RIVM, AirTube, OpenSense)
  - *sensor kit events*: per group of sensors, per sensor, per type of event

    via email or Slack notices

# MySense data handling functions

- **data**: internal dataformat **JSON**
  - *meta data (optional & dynamic fields) e.g.*

    GPS home location, sensor types and measurement unit,

    devices, version, ...
  - *(measurement) data (optional & dynamic fields) e.g.*

    time stamp, sensor id, sensor measurement(s),

    gps location change, rssi signal strength, accu voltage, ...
- **events**: low accu, (re)start reason
- **remote control**: configuration changes (via LoRaWan)

  e.g. sample & interval timing, devices/WiFi/controller on/off, ...

# MySense: what and how-to (lantern type)

## measure: the kit and the sensors

see: **shttp://github.com/teusH/MySense**/*tree/master/PyCom*


- **meta data** e.g.:
  GPS location and time (Neo-6), type sensors
  ***device calibration*** (Taylor factors)***:*** solve difference per sensor
- **meteo (I2C-bus)**: **Sensirion** (SHT31), **Bosch** (BME280/680)
  temperature, rel. humidity, air pressure, (VOC gas)
- **dust (TTL)**: **Nova** (SDS011), **Plantower** (PMS7003/PMSx003), **Sensirion** (SPS30)
  particle *weights/volume* **$PM_1$** (not Nova)**, $PM_{2.5}$** and **$PM_{10}$**
  counts of *particles/volume* in 6 **$PM_{0.3\text{-}10}$ bins**, average size (not Nova)
- **indicative VOC gasses (in studie)**: **Bosch** (BME680)
- gas: $NO_2$, $NH_3$, $O_3$, $CO_2$, etc. for now not feasible
- **visualisation**: tiny oled display (I2C-bus) and RGB led
- **energy**: 5V DC adapter or solar/accu under control of the ESP8266

# MySense: about the controller


- PyCom LoRa *ESP8266* based **LoPy-4**
  - **micro Python** advantages:

    functionality, reliability, reuse, open source, multi-threading, support devices, availability, state of the art, development ease, dynamic library support, debugging on workstation, share code with RaspPi
  - **network devices**: WiFi, LoRaWan support (OTAA and/or ABP), mesh networking, and future IoT networking e.g. LTE-M

- **Processor Connector Board** (PCB):
  - advantage: less soldiering, ease to change from device/sensor, powering on/off sensors

# MySense Python ‘firmware’

**shttp://github.com/teusH/MySense/tree/masterPyCom**


- **(micro) Python** fully used, OTA upload via WiFi
  Atom/Pymakr (WiFi or USB) or just ftp/telnet (WiFi)
- **multi threading**, e.g. oled display
- **remote control** via WiFi and LoRaWan
- software **watch dog**
- **energy savings**, use of deep sleep in case of solar/accu
- **auto configuration** on I2C-bus and TTL (device library, baud rate and connector socket detection)
- ease of **configuration**

# lessons learned (1)

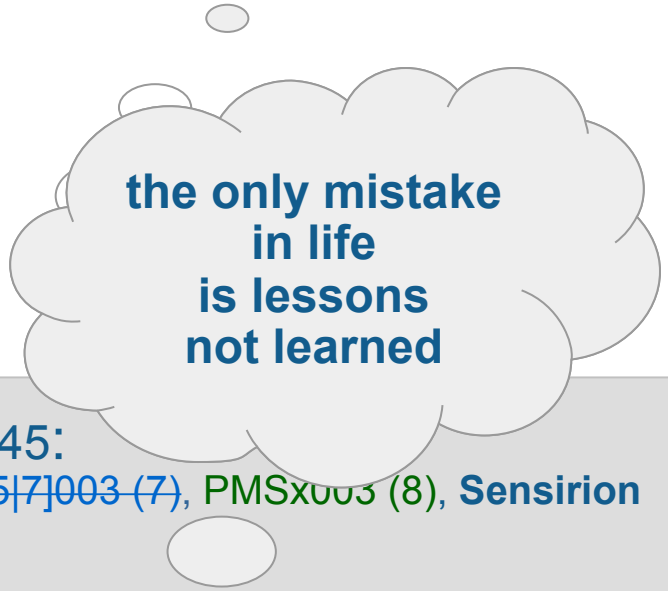
**the only mistake in life is lessons not learned**
*Albert Einstein*

- **WiFi beacon can cause drops below 3V3**
  e.g. disrupting dust sensor measurements
- no 5V chargers or long adapter wiring, power -/+ swap will happen
  user may need the V230 socket for vacuum cleaner
- PyCom is young and will change firmware (Python libs)
- **ESP: deep sleep might cause infinite sleep**
- always be sure LoRa antenna is connected
- antenna pigtail: careful (re)connect with LoPy (connector misforms)
- Bosch (and Sensirion?) sensor needs to dry
- **Plantower and Sensirion**
  show different $PM_{2.5}$ values
  bin counts bounds differ (Plantower uses 'from', Sensirion up to)
  Plantower: do not use first 3 PM values

# lessons learned (2)


- **TTN server will not always be on-line**
- as well your TTN data collector service will die
- mirror data and be able to replay data storage
- use version control
- WiFi may disrupt data e.g. on upload firmware
- be warned for direct sunshine
- **LoRa: 10% of your datagrams are lost**
- LoRaWan (TTN) coverage may be disrupted
  sometimes your lucky once in an hour a data gram (<30 km)
- **make sure the dust sensor cleans itself and has full 5V5 power**
- sun power (solar panels)  in winter time is much different from specifications
- **you need an event support system**

# lessons learned (3)
## our and your mileage may vary
## hardware (ca € 100 - € 150)




**dust sensors** we tried and use (points*), € 15 - € 45:

~~**Shiney** PPD45 (2)~~, **NoVa** SDS011 (6), **Plantower** ~~PMS[A|5|7]003 (7)~~, PMSx003 (8), **Sensirion** SPS30 (8?)

**meteo sensors** we tried and use (points*), € 5 - € 20:

~~DHT11/22 (2)~~, **Sensirion** SHT31 (8), **Bosch** BME280 (7), BME680 (8-)

**controllers** we tried and use (points*):

~~arduino (C/C++) (4)~~, RaspBerry Pi (Python,Linux!, WiFi, USB, € 35) (8), **LoPy-4** (micro Python,LoRa, € 40) (9), for visual feedback: **oled display** (€ 5) and **color led** (€ 1)

**housing** we tried and use (points*): +3D printed parts

~~V230 boxes (5)~~, ~~PVC pipes (5)~~, **double sided PVC exhaustion pipes** (€ 7.50) (8)

**processor connector boards** (PCB, ca € 15.-):

device connection, device power switch (mosfet), minimal 3 TTL (dust, gps), minimal 3 I2C (meteo, display), Grove sockets, pins (accu voltage, program modus, sleep modus, reset)

# lessons learned (4)
## our and your mileage may vary
## **configuration** via OTA, software & hardware


(*OTA LoRaWan*) **configuration**:

- ✓ **timings**: samples, interval measurement,
- ✓ **intervals**: measurements, meta info, GPS distance/updates
- ✓ **power off/on** devices: display, RGB led, sensors, WiFi
- ✓ hardware **sleep** on/off
- ✓ **calibration**: Tailor factors, off/on, VOC base
- ✓ sensors on/off, dust bin style
- ✓ **watch dogs**: accu voltage & progress (location via LoRa OTA)

**Processor Connector Board** (PCB) pin configuration:

- ✓ accu (solar) voltage level
- ✓ run / (REPL) programming modus (Hall sensor)
- ✓ deep sleep on/off (strap)
- ✓ V5 or 3.3V power to devices (strap)

# lessons learned (5)
## our and your mileage may vary


**version upgrades:**

- ✓ use Makefile for installation/upgrading
- ✓ one need an SDcard for e.g. libraries, archiving/backup data
- ✓ need to use micro python shell for flashing scripts/configs

✓ non-techi's prefer ready to use e.g. **Grafana client** for visualization

✓ nodes can go wild on data interval (< 15 secs): use throttle function

# statistics: calibration

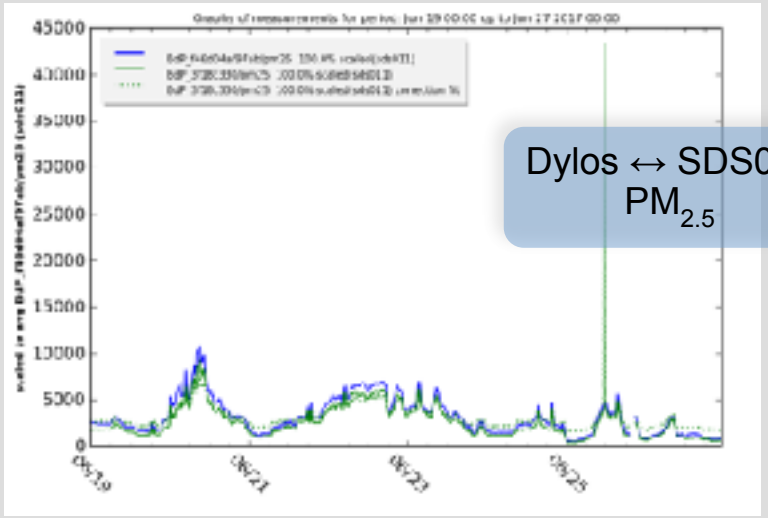
**much to thank RIVM (NSL stations) and Scapeler/Visibilis in Berghaven**

**ref: article aug 2019 in international journal Atmosphere 'Samen Meten'**
**ref: Visibilis report dec 2019 calibration/validation of PM sensors**

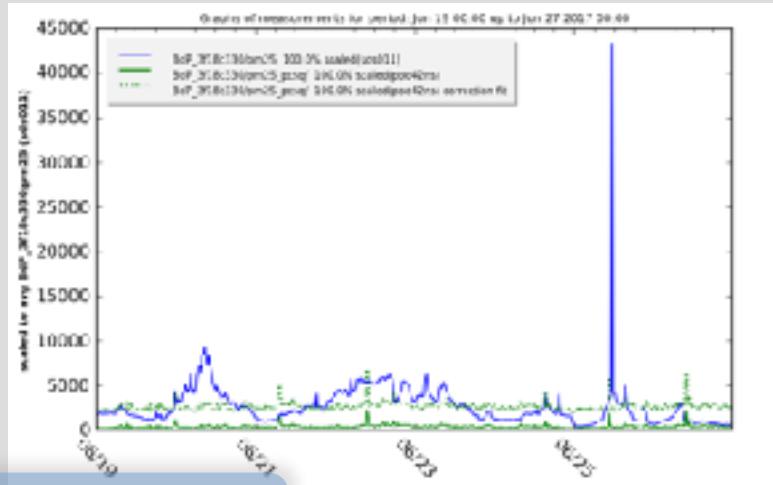
- **using statistical/correlation/regression software**
  - public domain python software
  - input: database measurement data
  - correlation order N, statistics e.g. $R^2$ check, and much more ...
- ***at this moment we use 1 minute averaged samples every 15 min***:
  - Sensirion/Nova/Plantower is correlating 'fine' with ref BAM1020, but …
    corrections from rel. humidity, temp, wind, ... for local situation
  - meteo sensors differ among each other ~2 ºC, RH ~10% !!!
  - dust sensor PPD42NS is a dump (e.g. too many $PM_{10}$ "null readings")
  - one need particle count values from dust sensors!, e.g. Plantower and Sensirion

# some correlation results

## 7 days of PM measurements
## raw data, 1 minute samples June 2017
## Dylos DC1100 Pro, Nova SDS011, Shiney PPD42NS



Dylos ↔ SDS011
$PM_{2.5}$



SDS011 ↔ PPD42NS
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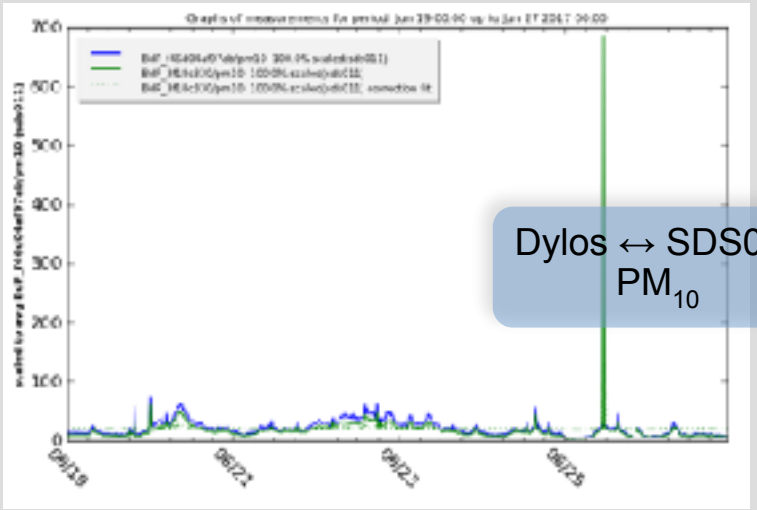

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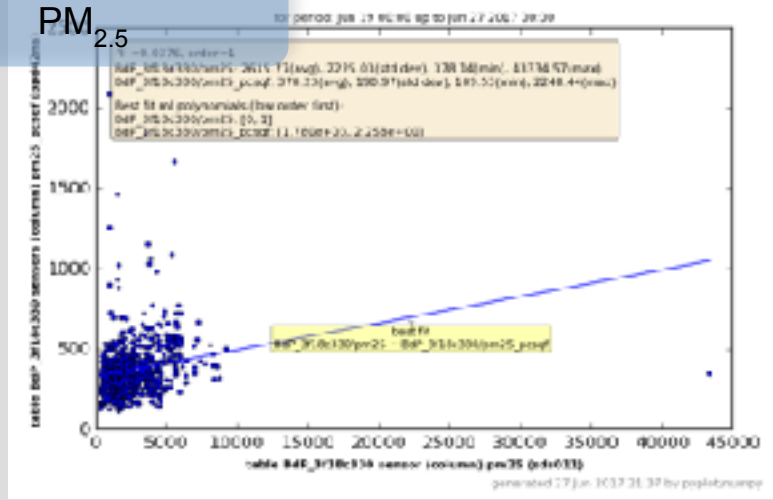

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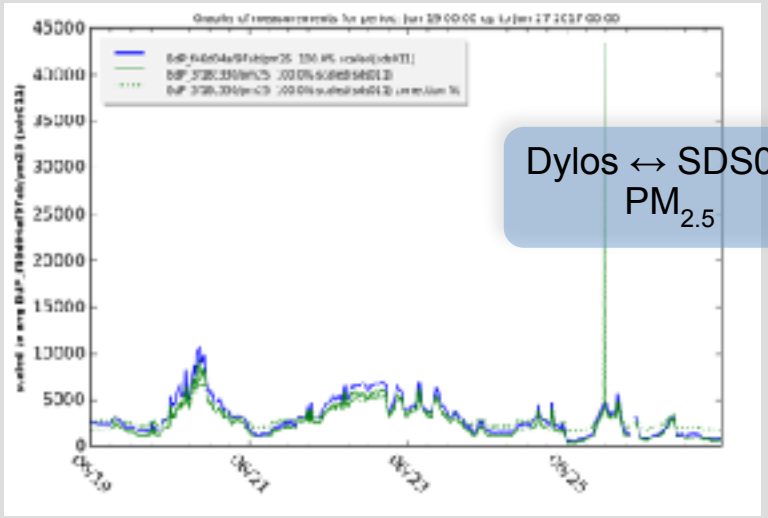

Dylos ↔ SDS011
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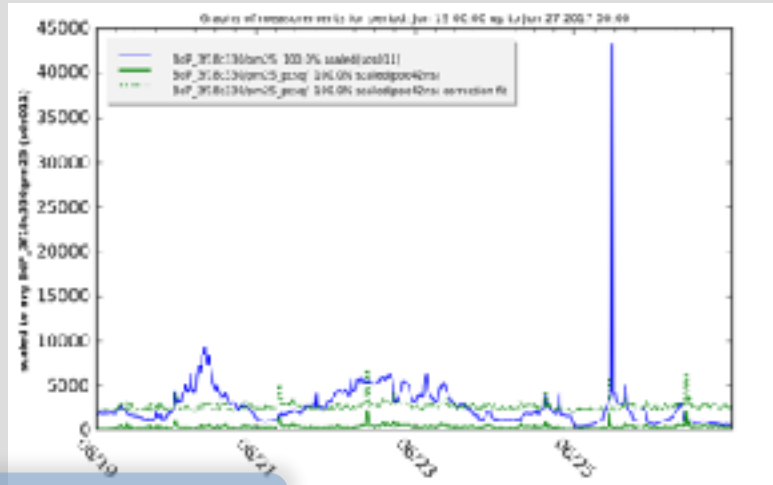
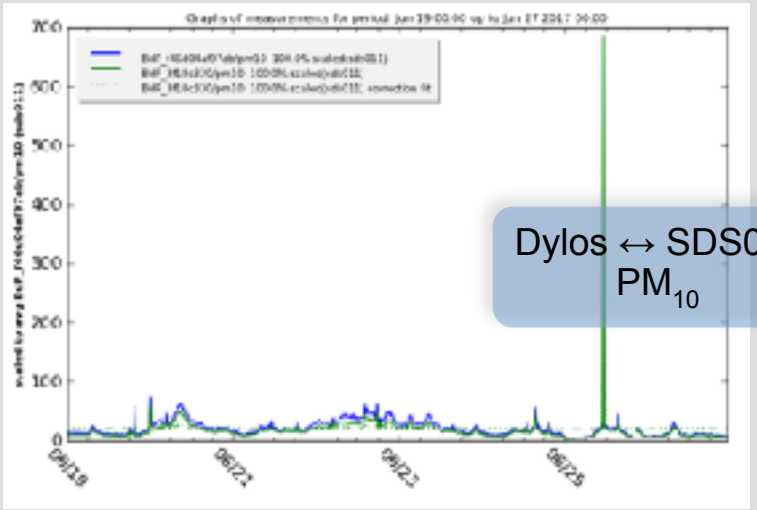
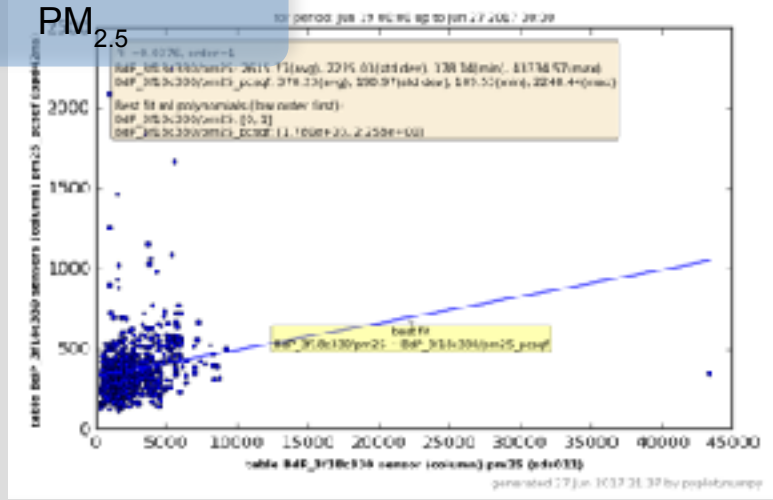


SDS011 ↔ PPD42NS
$PM_{2.5}$



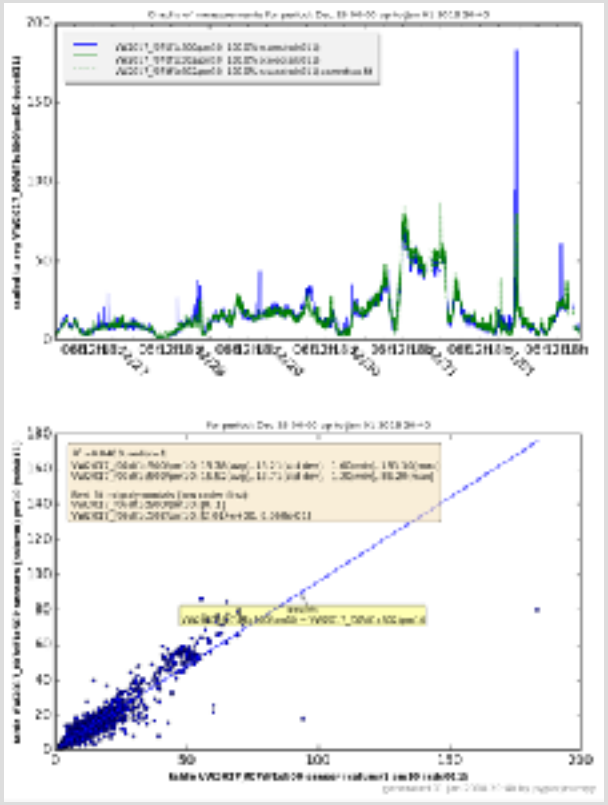
Dylos ↔ SDS011
$PM_{10}$

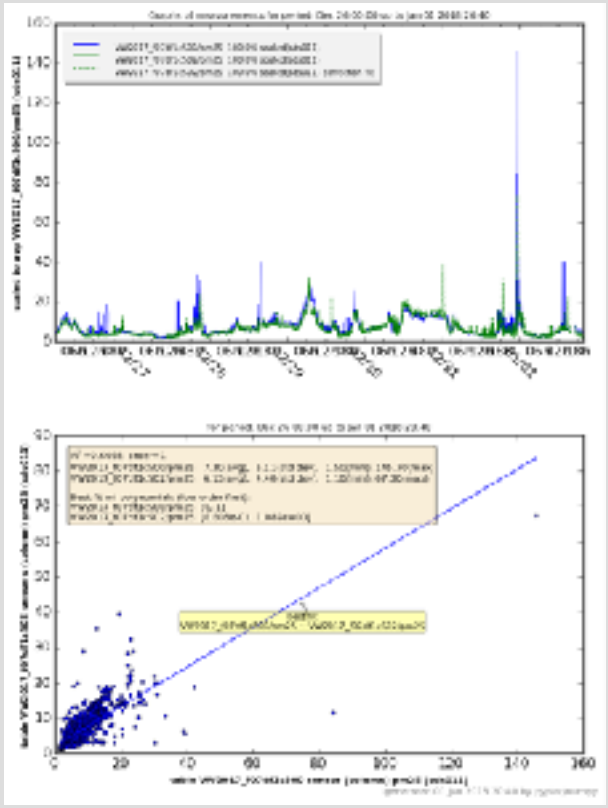


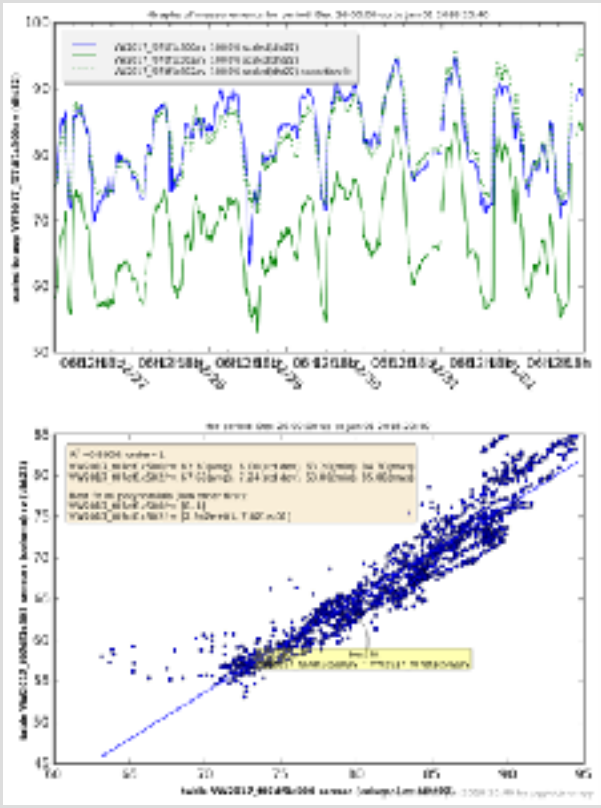
# RIVM firework project 2017

## correlation of 2 kits (side by side):

**PM10 (SDS011)** **PM2.5 (SDS011)** **rel. humidity (DHT22)**

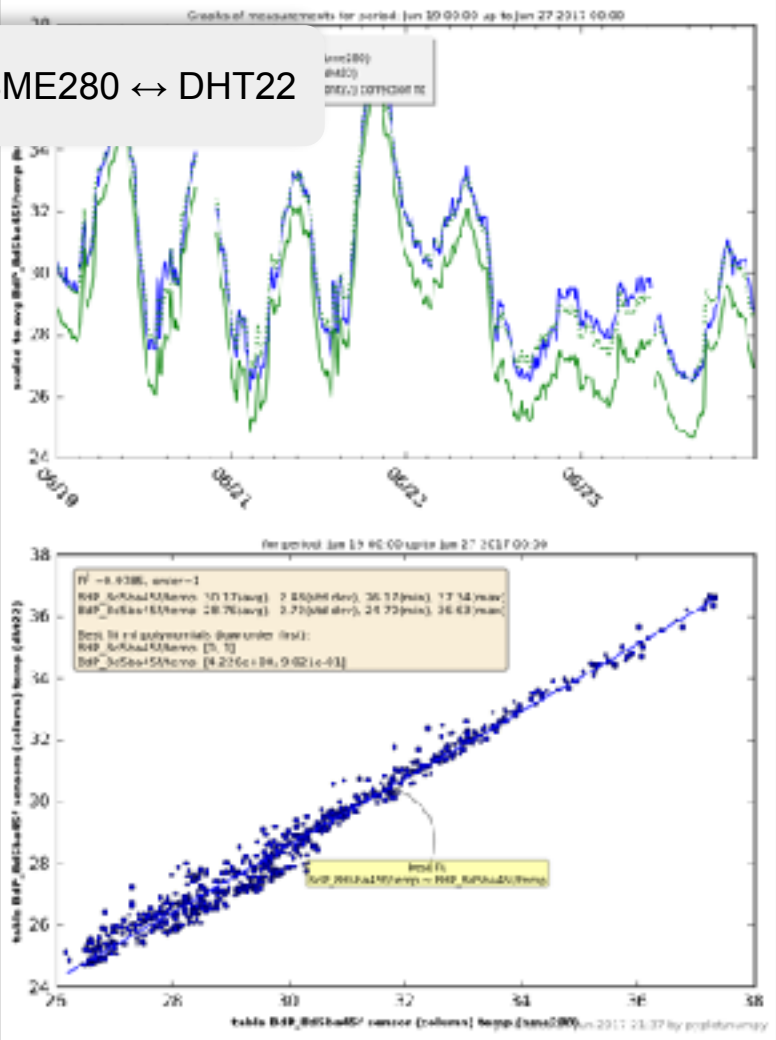




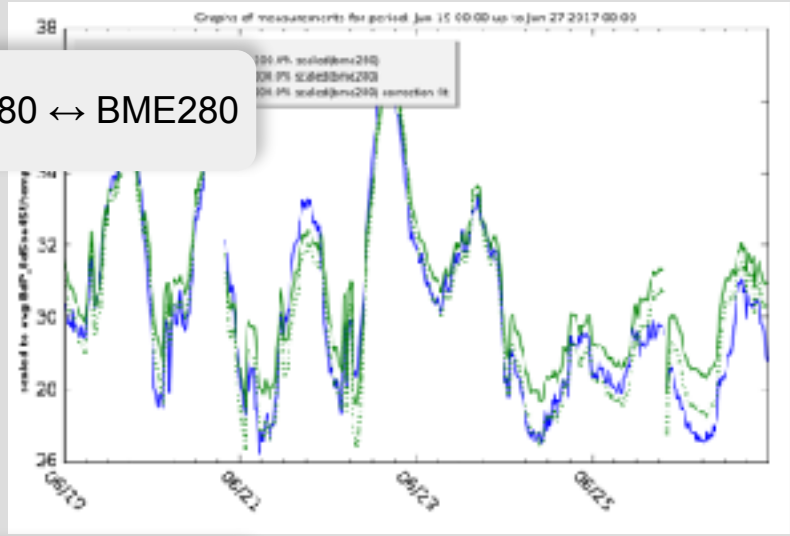


# correlation results: 7 dagen measuring temperature raw data, 1 minute samples, June 2017 BME280 and DHT22

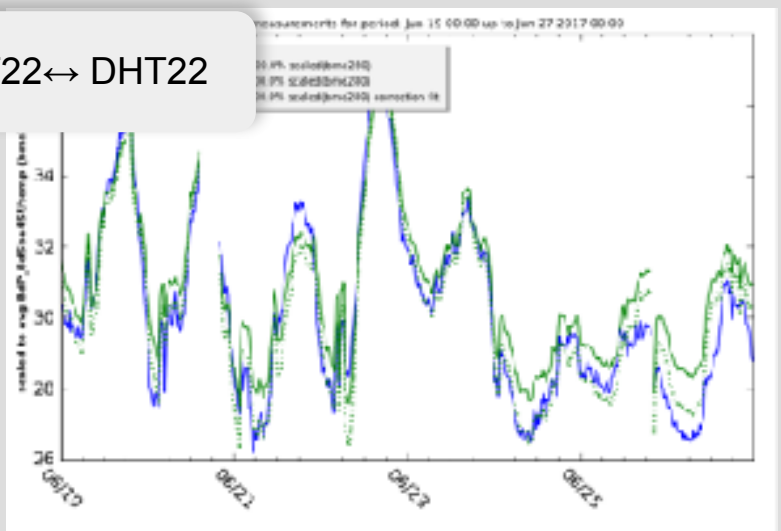
BME280 ↔ DHT22



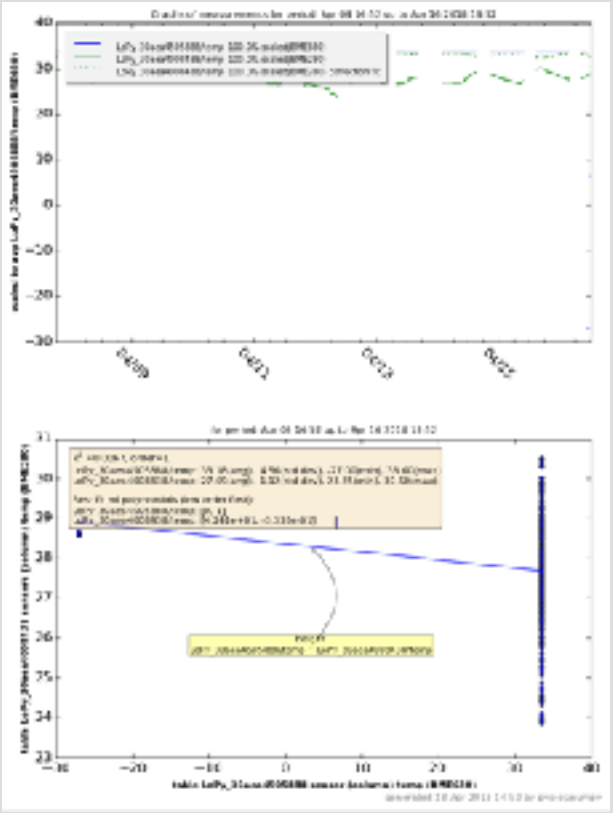
BME280 ↔ BME280

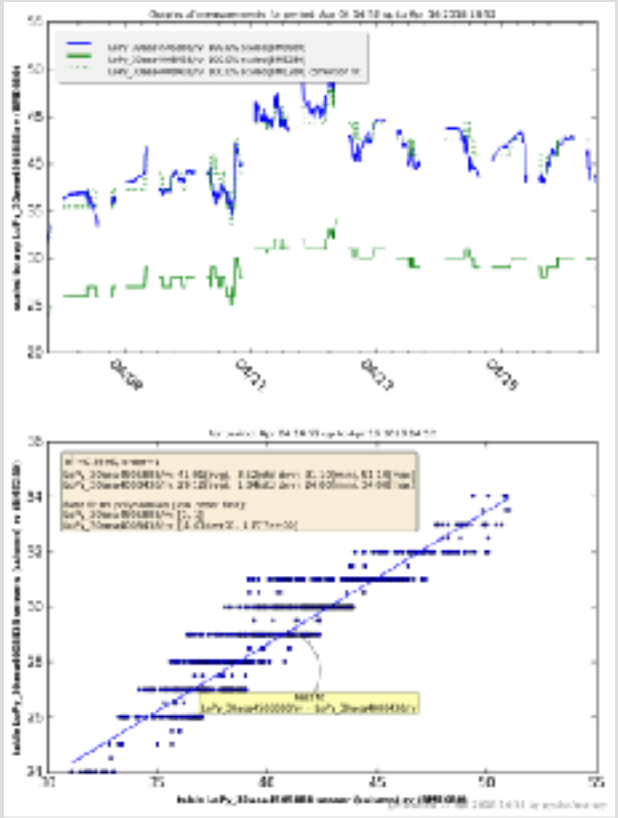


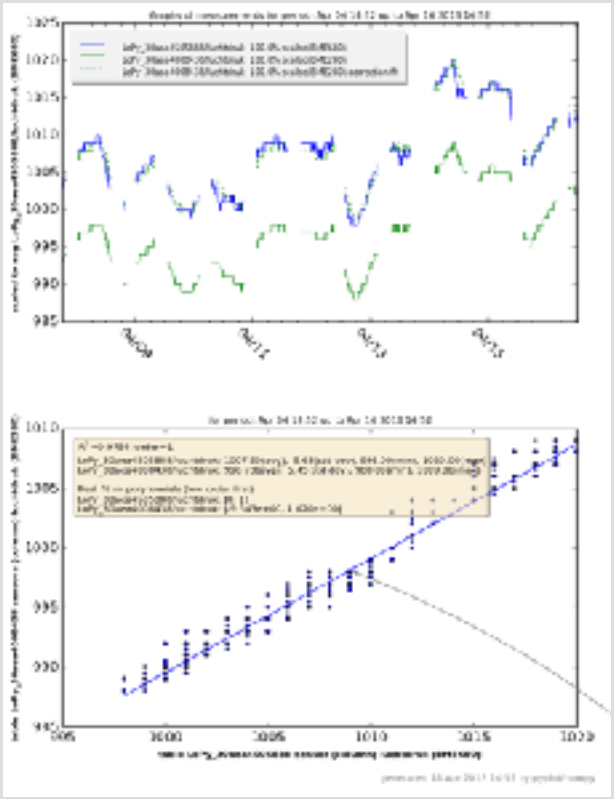
DHT22↔ DHT22



# April 2018 BME680 en BME280
## temperature rel. humidity air pressure

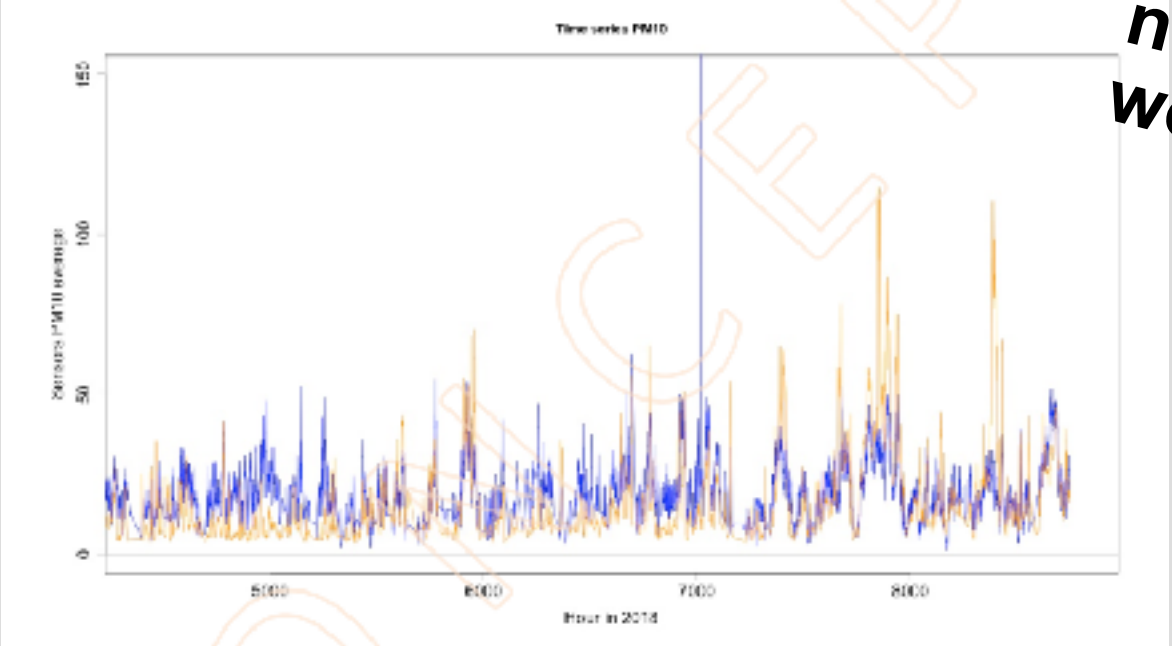




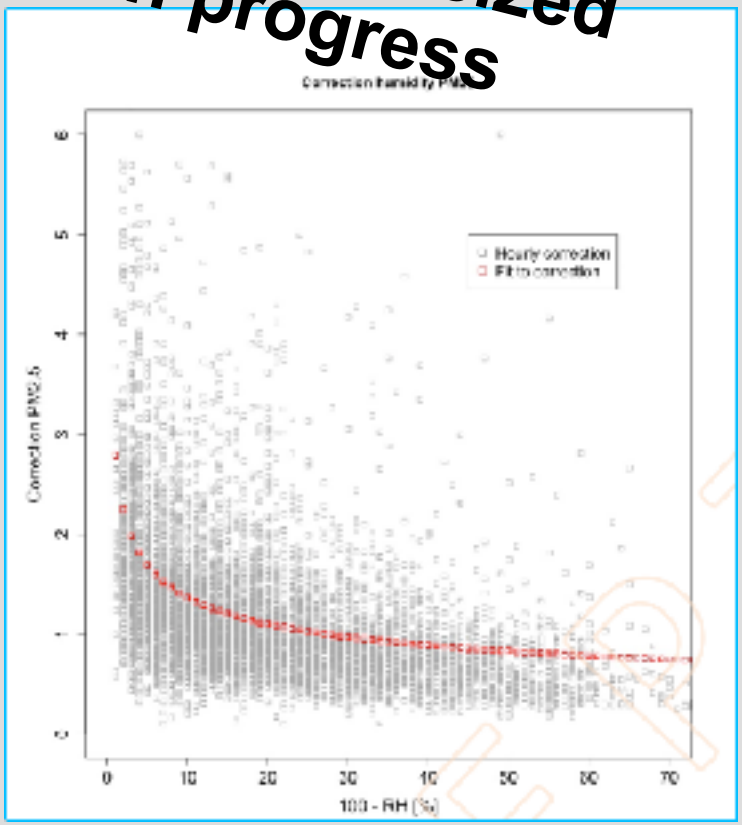


# calibration ref BAM1020 (Met One)?

## 2019-2020 data is studied (RIVM, two citizen science initiatives)
## (RIVM student Uni Leiden starts in Februar 2020 with calibration study)

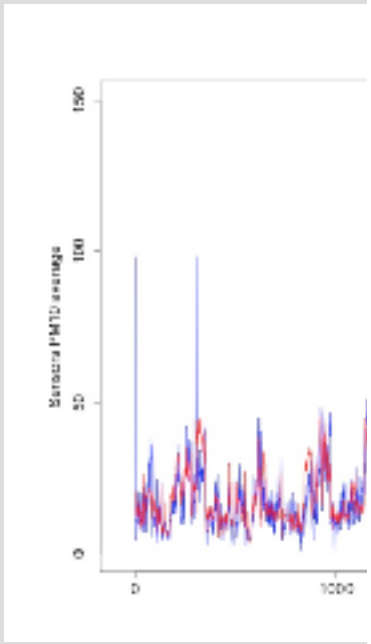



**not to be publicized**
**work in progress**



# calibration with ref BAM1020 (Met One)?

## 2019 figures just in study
## (RIVM and 2 citizen science initiatives)



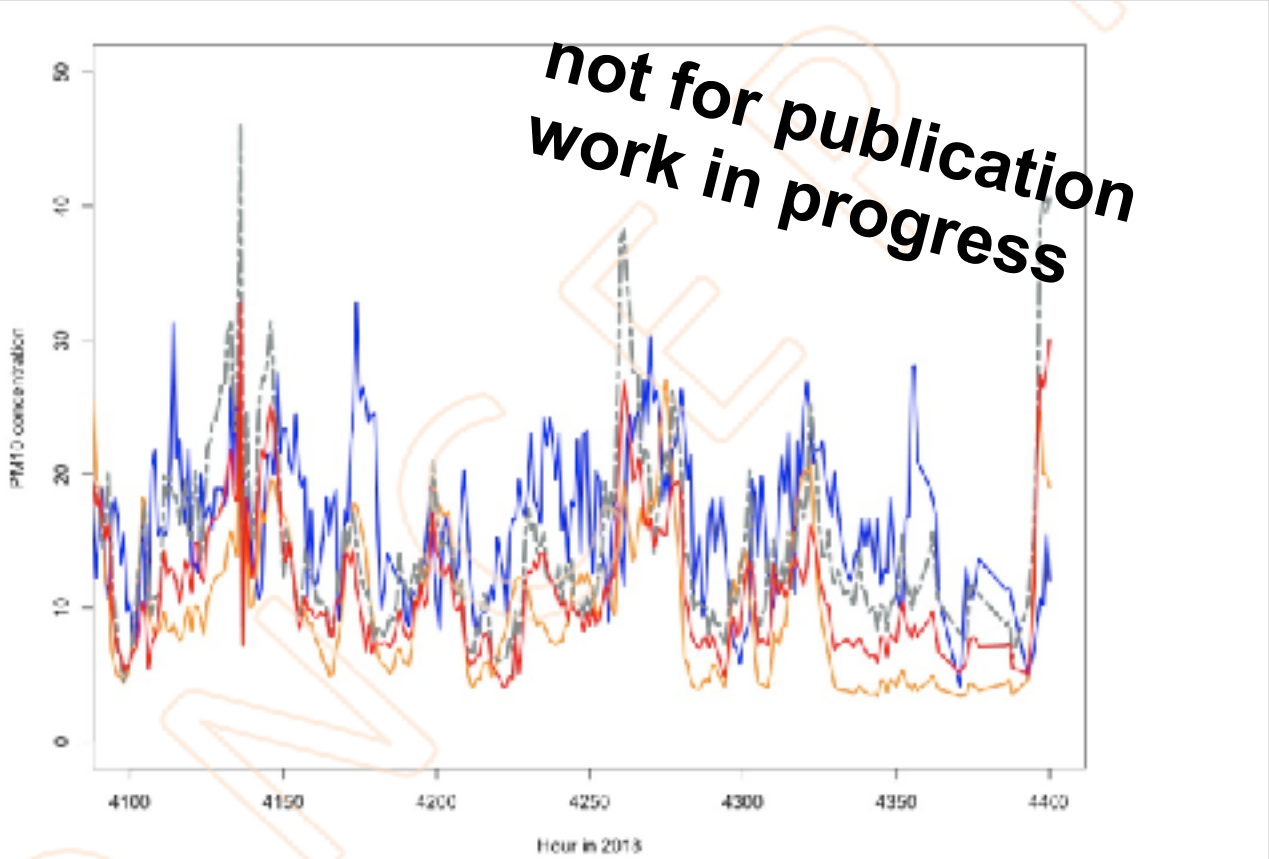



***Figure 10*** *Average PM10 results of the sensors in Amsterdam in 2018 (orange), the results of reference measurements in Vondelpark (blue), corrected values using humidity only (red) and corrected values using randomForest (grey, dashed).*

## status MySense kits: in 2019 20, Jan 25, Feb 40, Dec 50

# questions / comments