National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Measurement strategy for air quality policy support and public information

Optimal combination of reference measurements and cheap sensors

Ronald Hoogerbrugge
Joost Wesseling

Content

- Calibration of air quality models
- Uncertainty of calibration
- Optimum use of measurements
- Conclusions
- Questions

National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

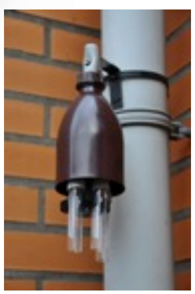
Calibration of models

- Every year concentration maps are calculated for all of the Netherlands.
- Best available emissions and dispersion conditions.
- Maps for the previous year are calibrated using reference measurements of the National Air Quality Monitoring Network of the RIVM.
- Up to 45 measurement sites for the main substances: NO2, PM10, PM2.5
- Also maps for ammonia and soot (EC).

- Always pressure to minimize the cost of the measurements.
- How many reference measurements do you need to calibrate the models?

National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Simple model calibration

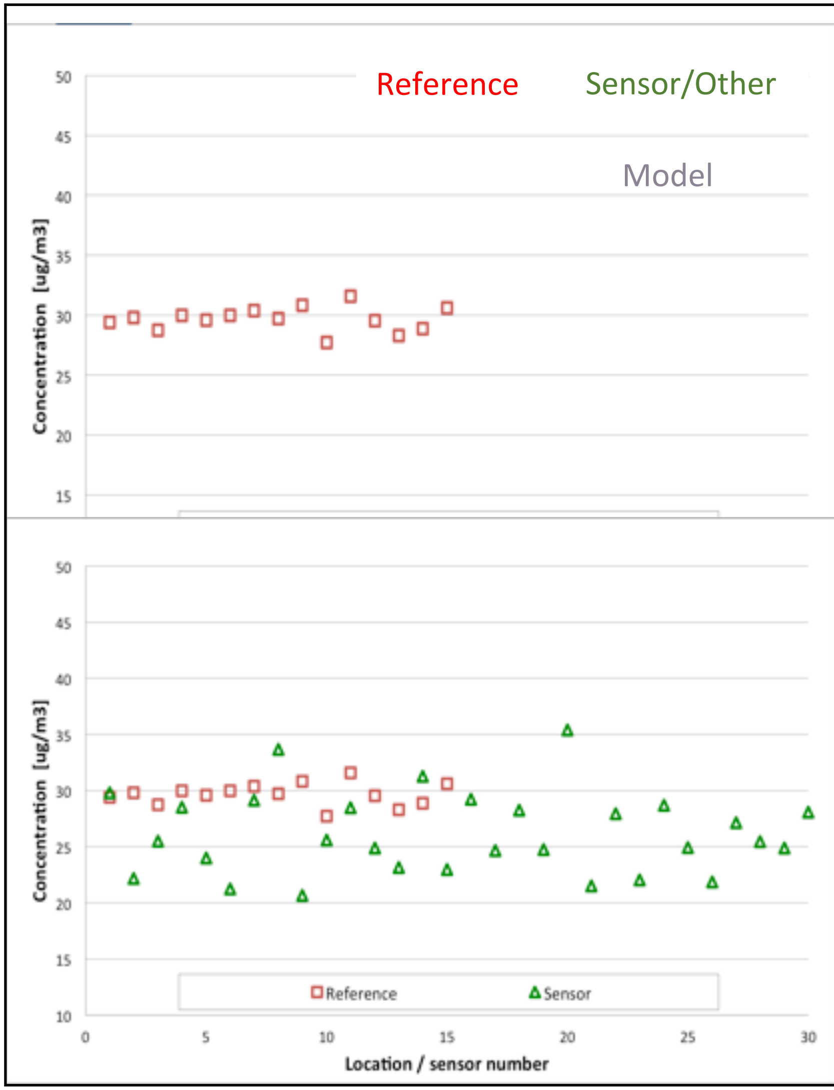


Assumptions:

- There are K locations with
  - Reference measurements,
  - Sensor/other measurements and
  - Model results.

- There are L additional locations with
  - Sensor/other measurements and
  - Model results.

- Uncertainties measurements/model
  - Reference measurements unbiased, random uncertainty s_R
  - Sensor measurements contain bias, random uncertainty s_E
  - Model results contain bias, random uncertainty s_M

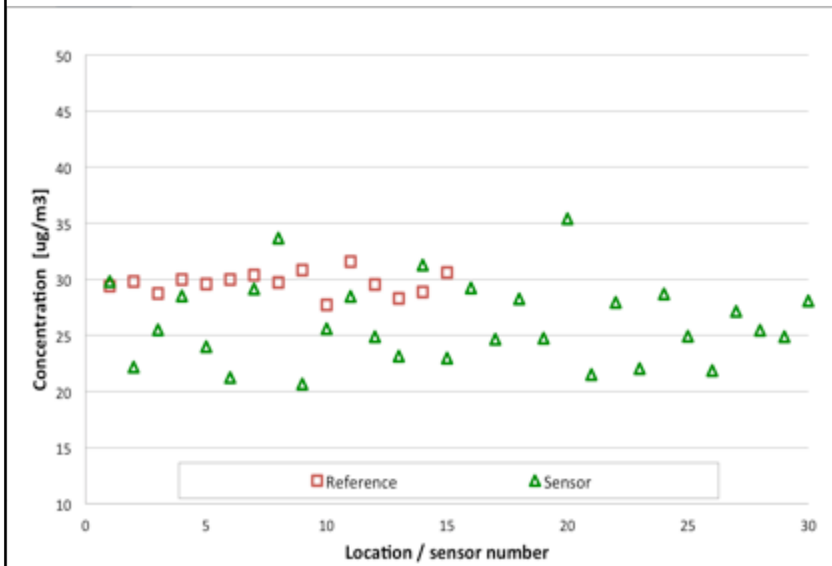


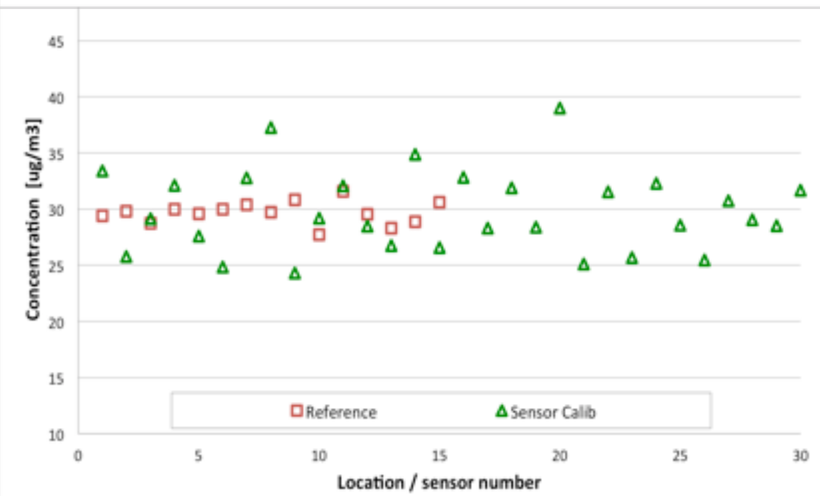
Uncertainty of calibration

Procedure:

- Estimate the bias of the K co-located sensors from a comparison with the reference measurements.
- Calibrate the sensors, assume the calibration obtained for the K sensors to be valid for *all* sensors.
- Estimate the bias of the model from a comparison with the K reference measurements <u>and</u> the L calibrated sensors
- Determine the calibration uncertainty:

$$s_{MER}^2 = \frac{\left(\frac{(s_M^2 + s_R^2)(s_E^2 + s_M^2)}{K\,L} + \frac{(s_E^2 + s_R^2)(s_M^2 + s_R^2)}{K^2}\right)}{\left(\frac{s_E^2 + s_M^2}{L} + \frac{s_E^2 + s_M^2 + 2\,s_R^2}{K}\right)}$$



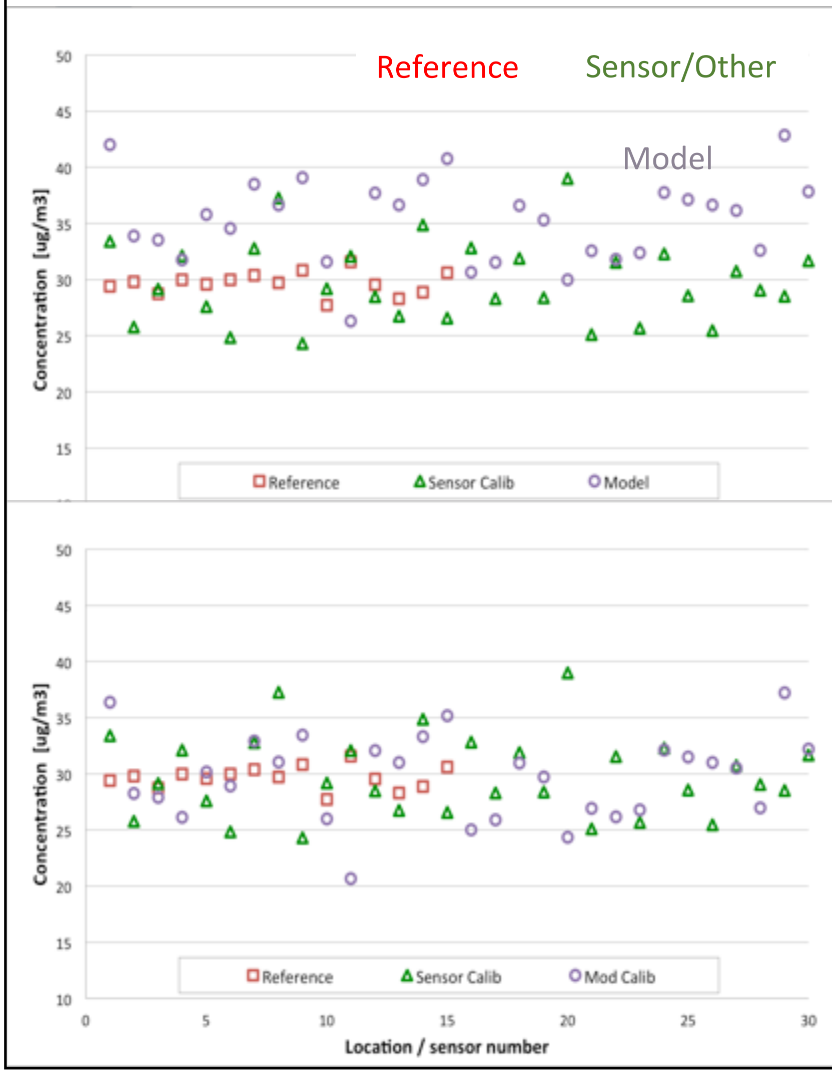


Uncertainty of calibration

Procedure:

- Estimate the bias of the K co-located sensors from a comparison with the reference measurements.
- Calibrate the sensors, assume the calibration obtained for the K sensors to be valid for *all* sensors.
- Estimate the bias of the model from a comparison with the K reference measurements <u>and</u> the L calibrated sensors
- Determine the calibration uncertainty:

$$s_{MER}^2 = \frac{\left(\frac{(s_M^2 + s_R^2)(s_E^2 + s_M^2)}{K\,L} + \frac{(s_E^2 + s_R^2)(s_M^2 + s_R^2)}{K^2}\right)}{\left(\frac{s_E^2 + s_M^2}{L} + \frac{s_E^2 + s_M^2 + 2\,s_R^2}{K}\right)}$$



Uncertainty of calibration

Procedure:

- Estimate the bias of the K co-located sensors from a comparison with the reference measurements.
- Calibrate the sensors, assume the calibration obtained for the K sensors to be valid for *all* sensors.
- Estimate the bias of the model from a comparison with the K reference measurements <u>and</u> the L calibrated sensors
- Determine the calibration uncertainty:

$$s_{MER}^2 = \frac{\left(\frac{(s_M^2 + s_R^2)(s_E^2 + s_M^2)}{K\,L} + \frac{(s_E^2 + s_R^2)(s_M^2 + s_R^2)}{K^2}\right)}{\left(\frac{s_E^2 + s_M^2}{L} + \frac{s_E^2 + s_M^2 + 2\,s_R^2}{K}\right)}$$

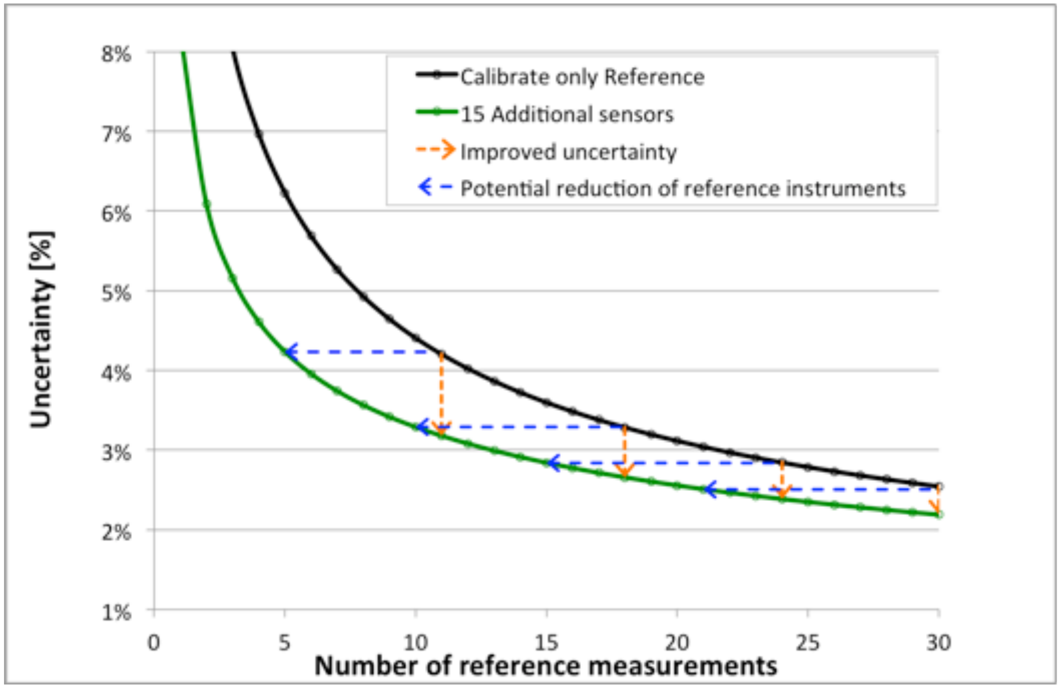
National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Optimum use of measurements

Compare the calibration uncertainty in the NO_2 model for several options:

- calibration using only reference NO_2 measurements;
- calibration using reference measurements and 15 additional calibrated sensors or indicative measurements (Palmes tubes).

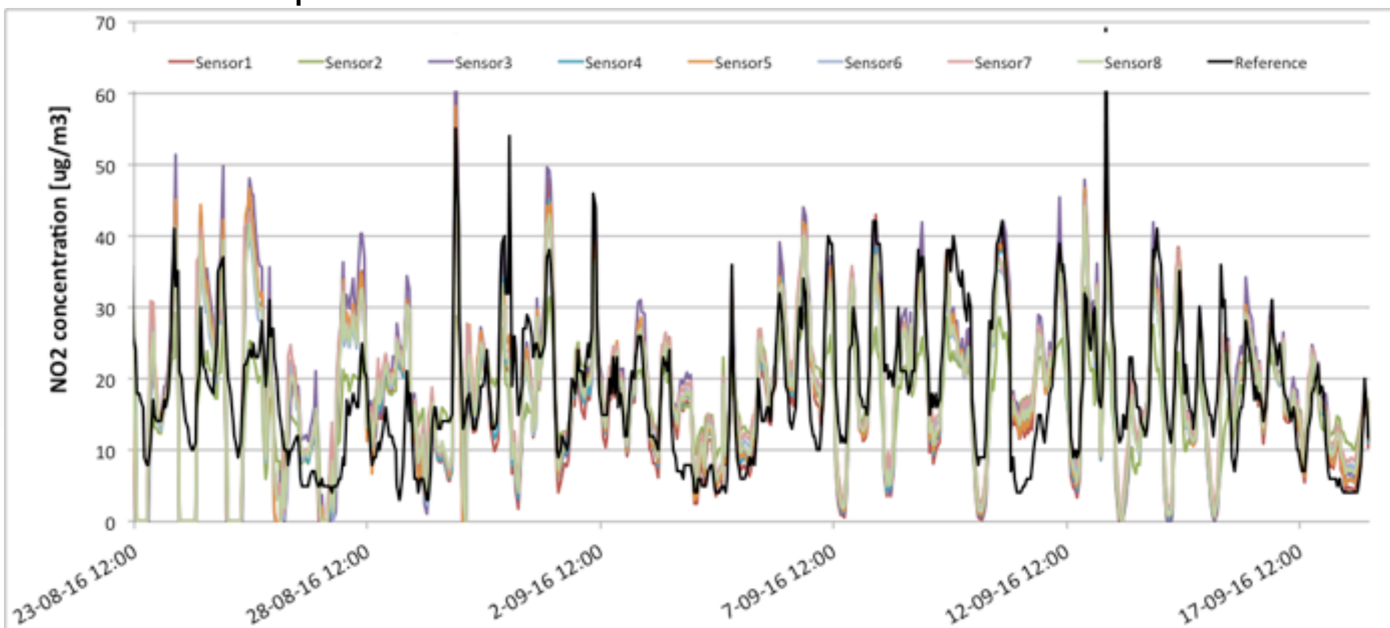
Uncertainty parameters are taken from actual Palmes tubes NO_2 measurements.



National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Example Alphasense B43F NO2

- Work started on using the Alphasense B43F NO2 sensor.
- A fit of the output of the sensor to reference measurements, temperature and ozone yields a reasonable description of the actual NO2 concentrations.

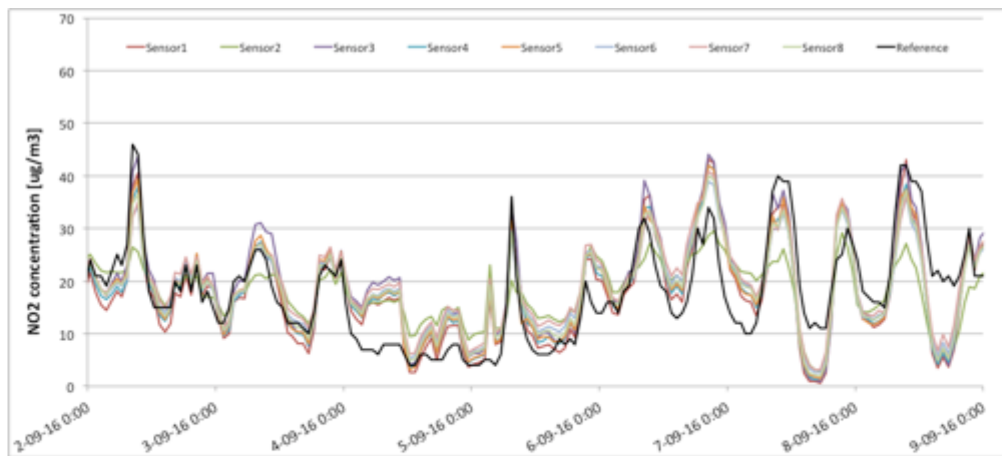


National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Example Alphasense B43F NO2

- Work started on using the Alphasense B43F NO2 sensor.
- A fit of the output of the sensor to reference measurements, temperature and ozone yields a reasonable description of the actual NO2 concentrations.

- Several options for calibrating the sensors, among these:
  - Periodic check against reference measurements;
  - Combination of sensor and Palmes tube(s);
  - ‘On the fly’ calibration using detailed hourly air quality maps.

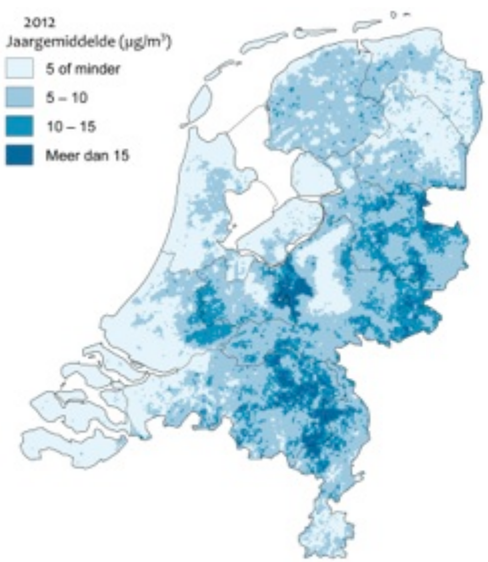


National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Example Ammonia

- The reduction of the deposition of nitrogen (mainly consisting of ammonia) is an important objective in many Natura 2000 area's in the Netherlands.
- Extensive monitoring of ammonia concentrations is required.

- Large model uncertainty.
- Until recent 8 advanced monitors, presently only 6.
- Additional ammonia measurements using diffusion tubes.
- A relatively small number of additional measurements results in a significant reduction of the calibration uncertainty.

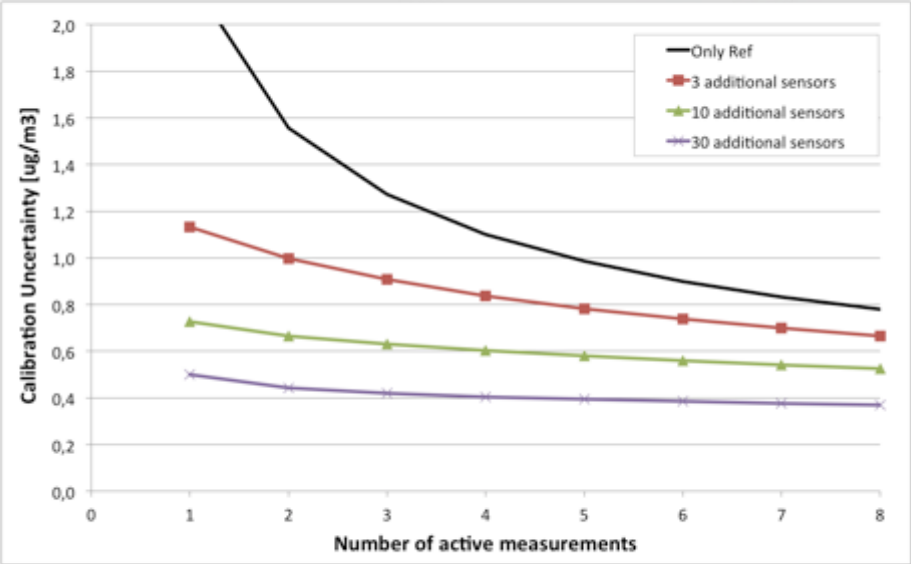


National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Example Ammonia

- The reduction of the deposition of nitrogen (mainly consisting of ammonia) is an important objective in many Natura 2000 area's in the Netherlands.
- Extensive monitoring of ammonia concentrations is required.

- Large model uncertainty.
- Until recent 8 advanced monitors, presently only 6.
- Additional ammonia measurements using diffusion tubes.
- A relatively small number of additional measurements results in a significant reduction of the calibration uncertainty.



Conclusions

- In the near future cheap sensors will be used to augment and to some extent also replace reference measurements.
- Improved model calibration is possible with less reference instruments.
- Presently, all individual sensors must be calibrated.
- It is necessary to determine performance indicators for new sensors (bias, drift, random uncertainty).

- A statistical frame work for monitoring optimization is being developed:
  - Analytic expressions for simple examples.
  - Monte-Carlo simulations for the real world.

Questions?