Air quality monitoring from global to local scales

Applications of satellites and microsensors – examples of two rapidly evolving technologies

Philipp Schneider

With contributions from Nuria Castell, Matthias Vogt, William Lahoz, Alena Bartonova, Kerstin Stebel, and the entire CITI-SENSE team

NILU

Outline

1. **Satellite-based air quality monitoring**

    Can satellite observations of atmospheric composition help with air quality monitoring?

2. **Low-cost microsensors for air quality mapping**

    Given the current state of sensor technology, how can we best exploit low-cost microsensors for urban-scale air quality mapping?

NILU

PART 1: SATELLITE MONITORING

NILU

Why the view from space?

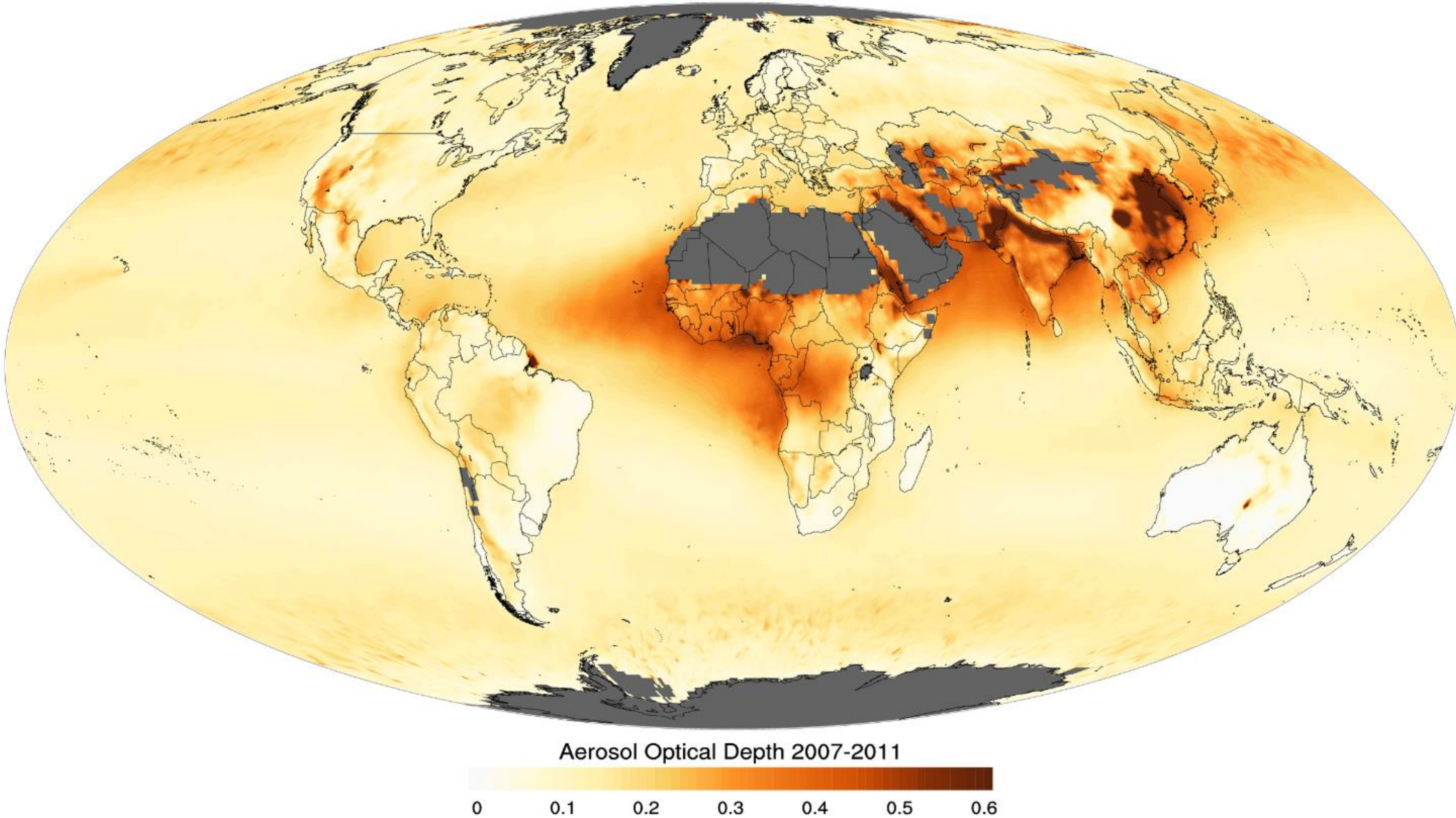
- Spatially exhaustive information
- Global data availability
- Consistent and homogeneous time series of data
- Archive of several decades of worldwide data

Satellite-based air quality monitoring

- Technically not that “new”… has been around since mid-1990s
- However: So far mostly used for global and regional applications due to coarse spatial resolution
- Only now are instruments slowly becoming suitable for (slightly) more detailed observations of urban air quality

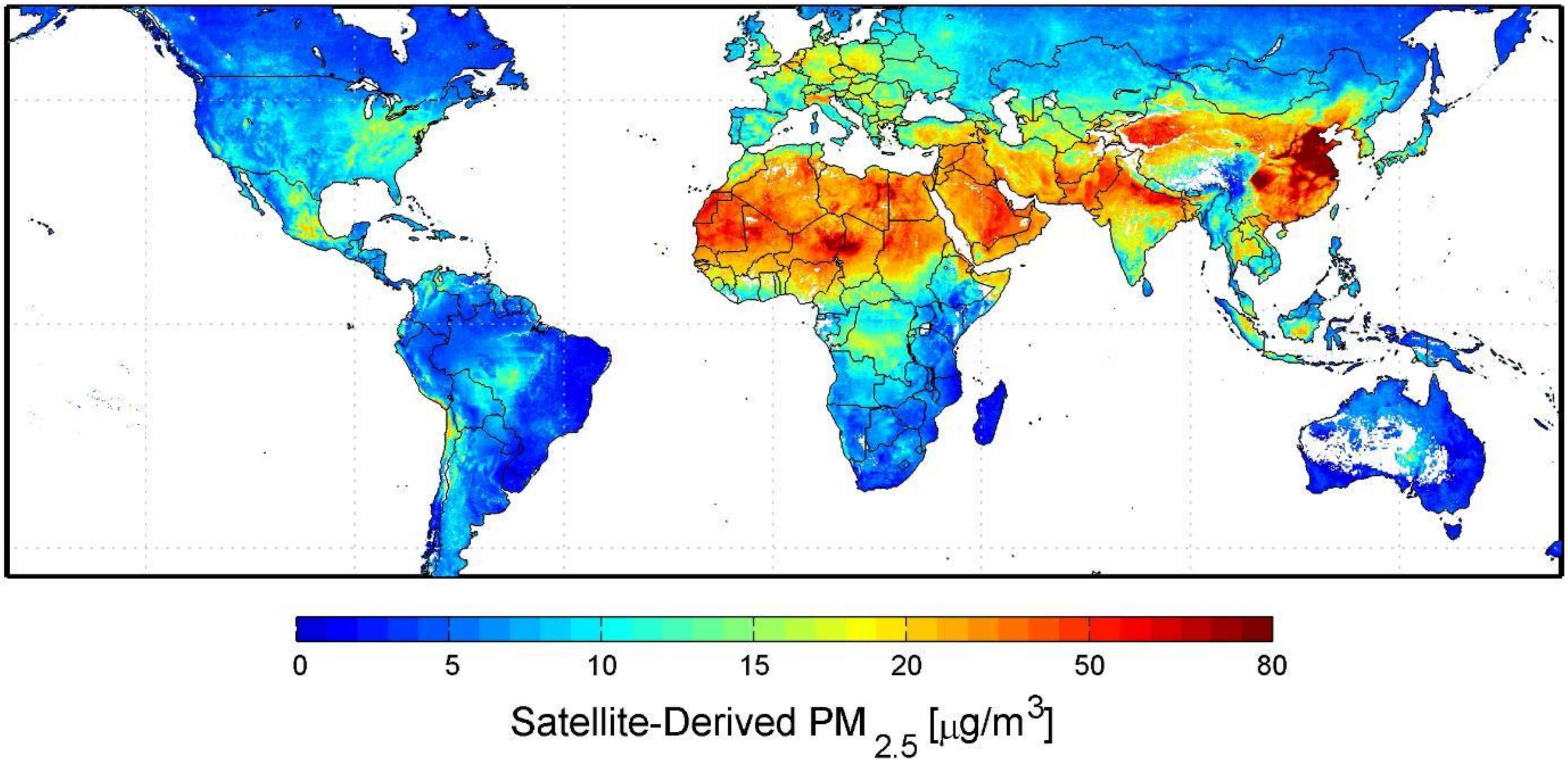
NILU

Aerosol Optical Depth

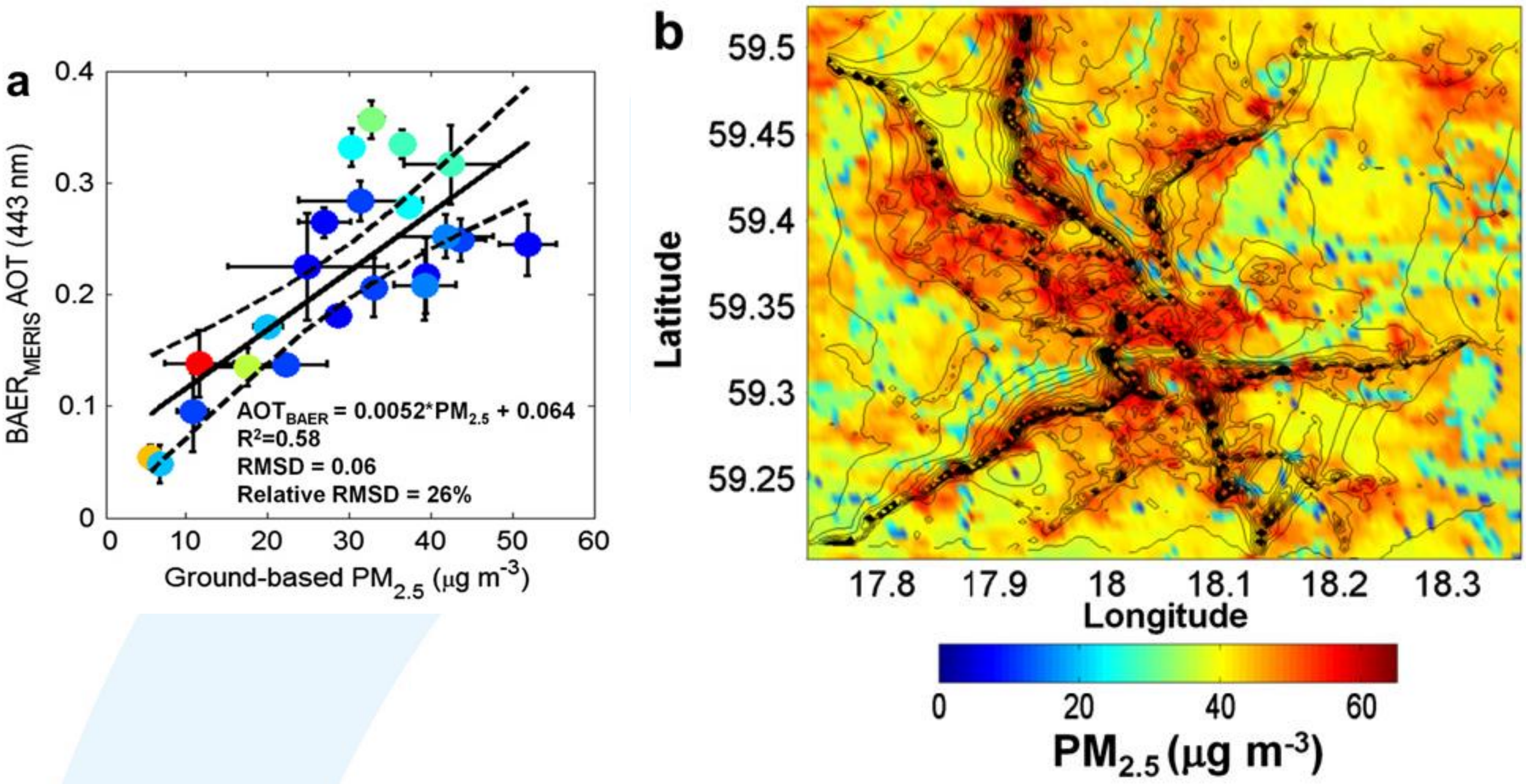


Modis Terra Aerosol Optical Depth at 550nm 2007-01 to 2011-12 average.

Particulate Matter



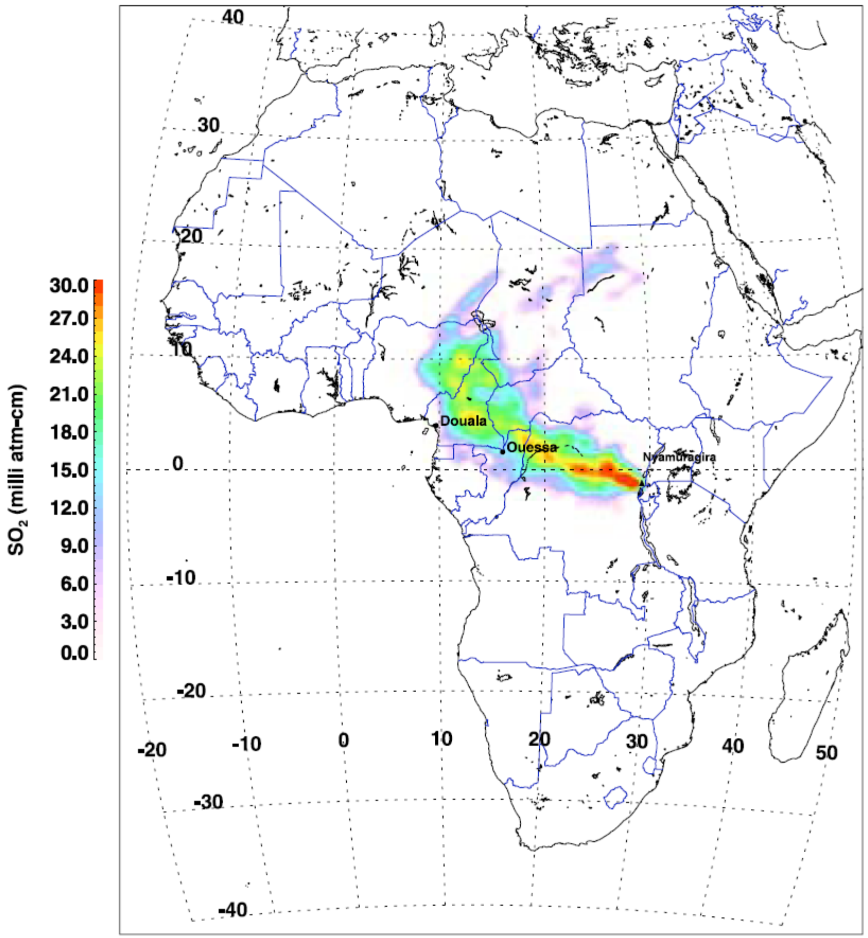
Global satellite-derived map of $PM_{2.5}$ averaged over 2001-2006. MODIS and MISR AOD was used. From: Van Donkelaar et al. 2010.



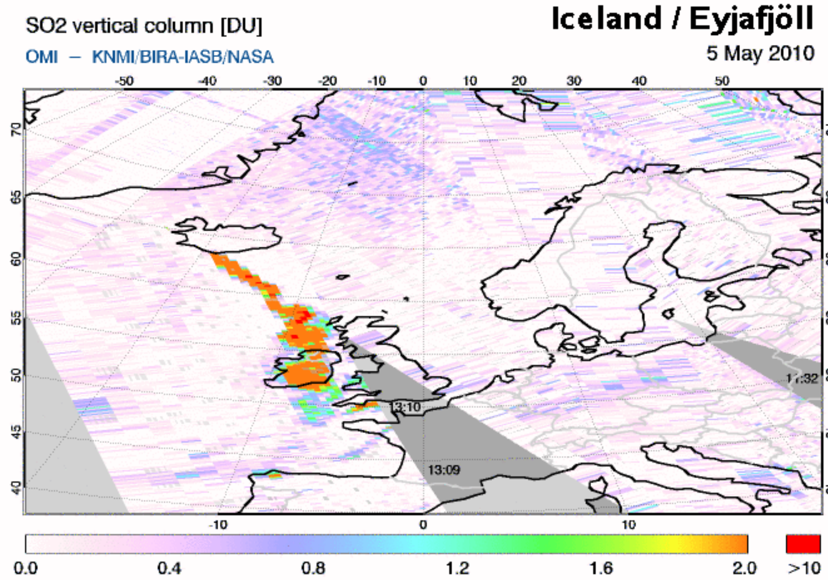
Relationship between AOD and station $PM_{2.5}$ (left panel) and satellite-mapped PM2.5 in the Stockholm area (right panel). From Glantz et al. (2009)

NILU

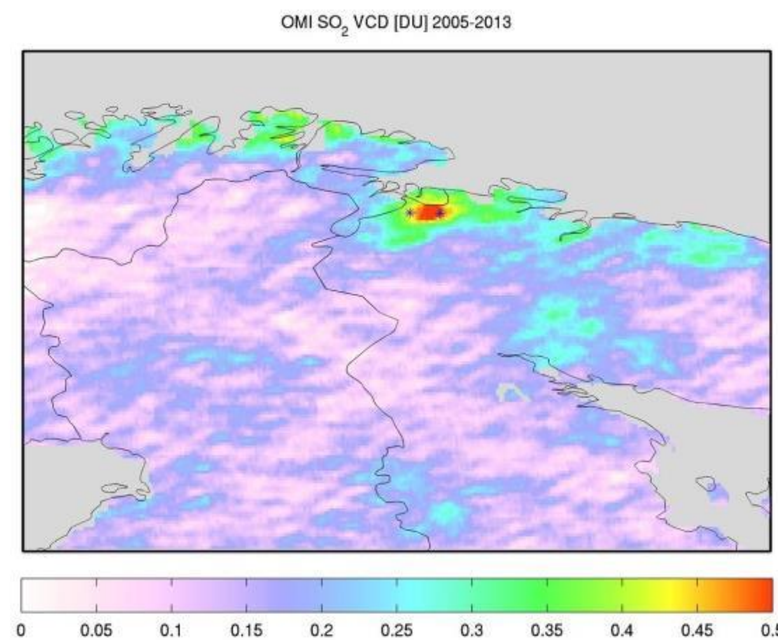
Sulphur dioxide (SO_2)



AIRS-derived regional scale SO_2 plume from Nyamuragira volcano, 28 Nov to 3 Dec 2006. From Prata and Bernardo (2007)



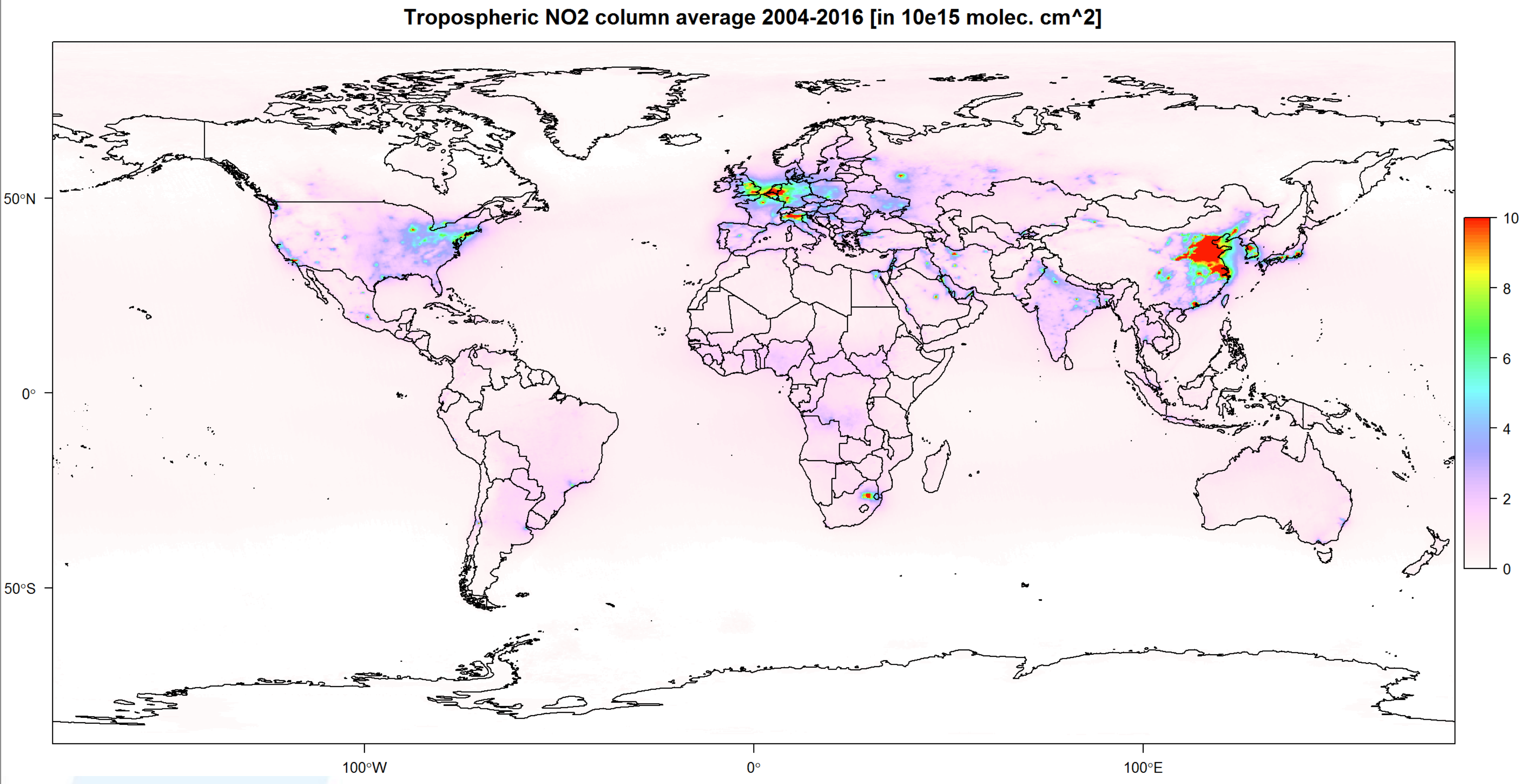
SO_2 plume of the eruption of the Eyjafjallajökull volcano, Iceland, May 2010.



SO_2 hotspot over the Svanvik/Nikel area on the Norway/Russia border, based on OMI data (K. Stebel/N. Theys).

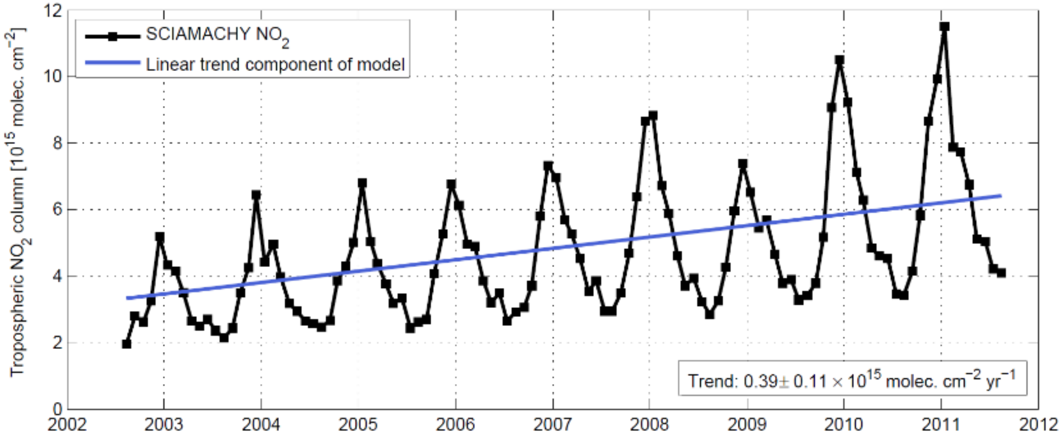
NILU

Nitrogen Dioxide (NO_2)



Long-term average tropospheric NO2 column as measured by the OMI instrument onboard of the Aura platform. Units in 10^{15} molecules per cm^2.

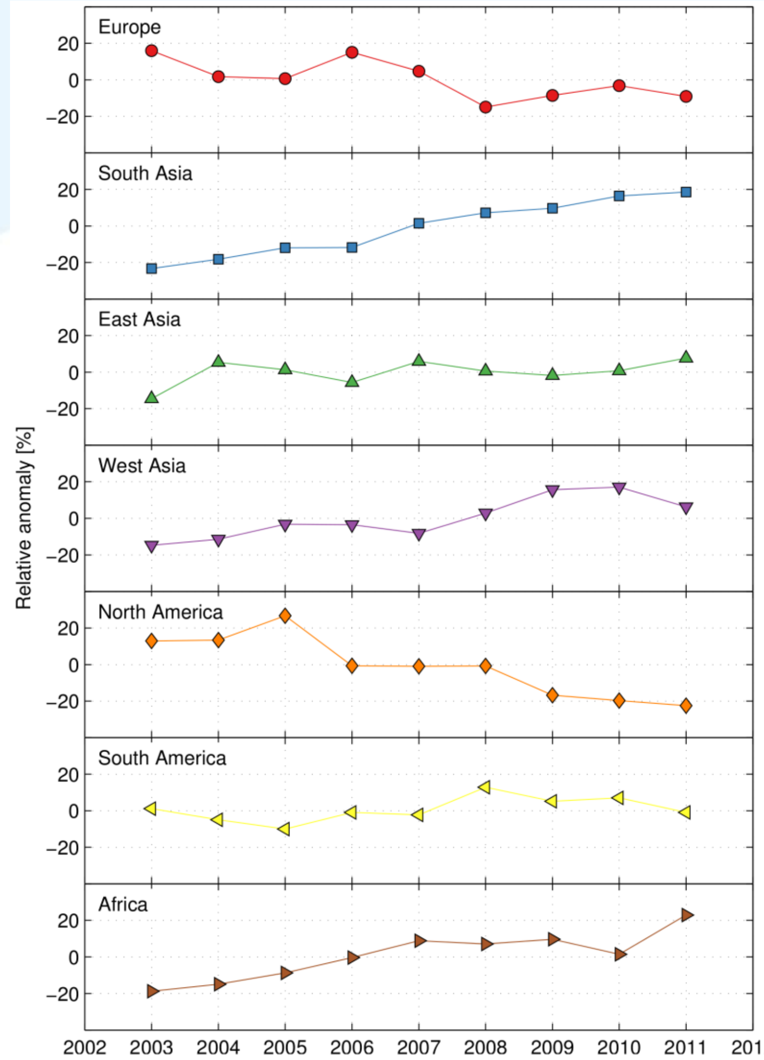
Temporal evolution



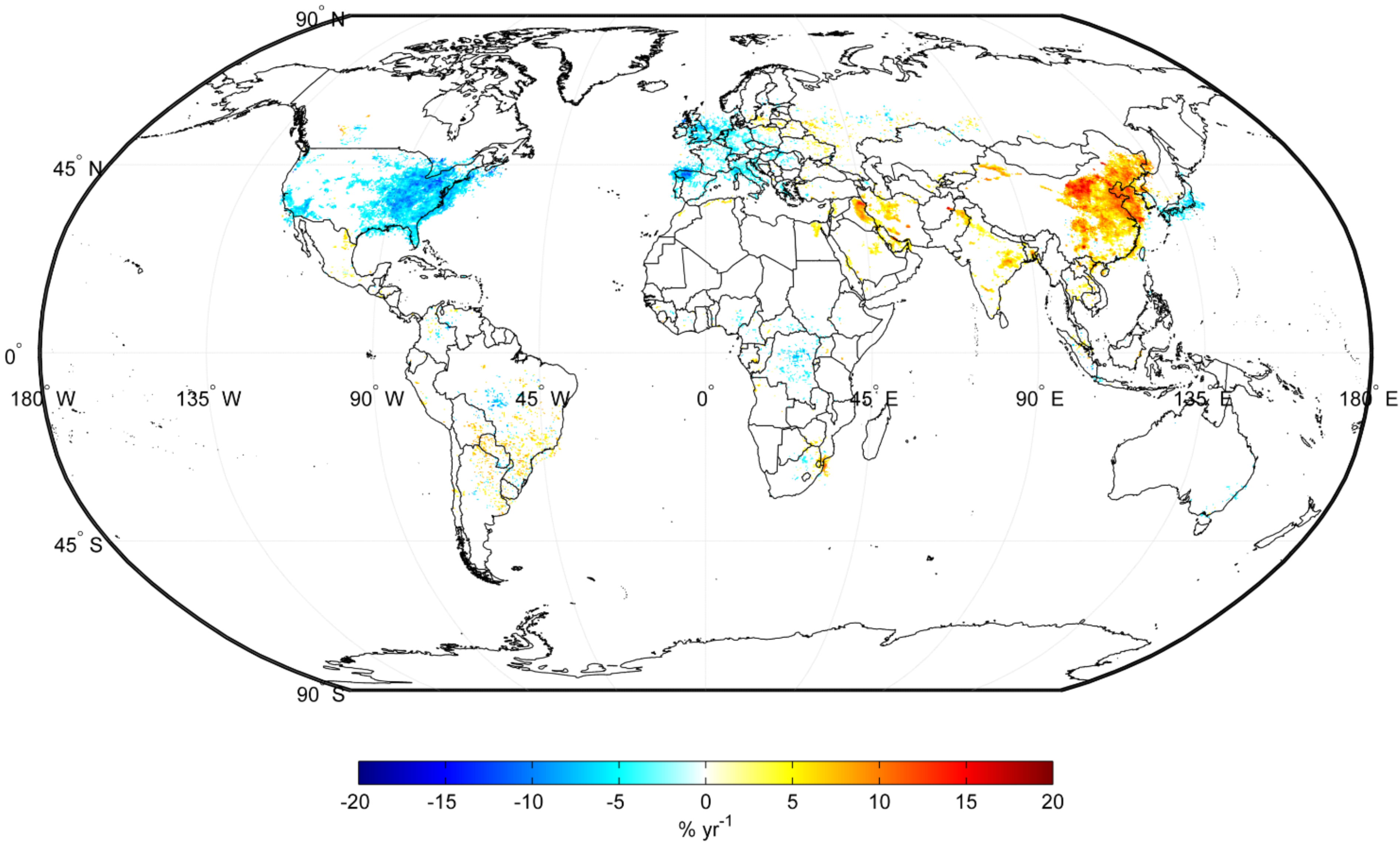
Time series of tropospheric NO_2 over China

Note on measurement uncertainty

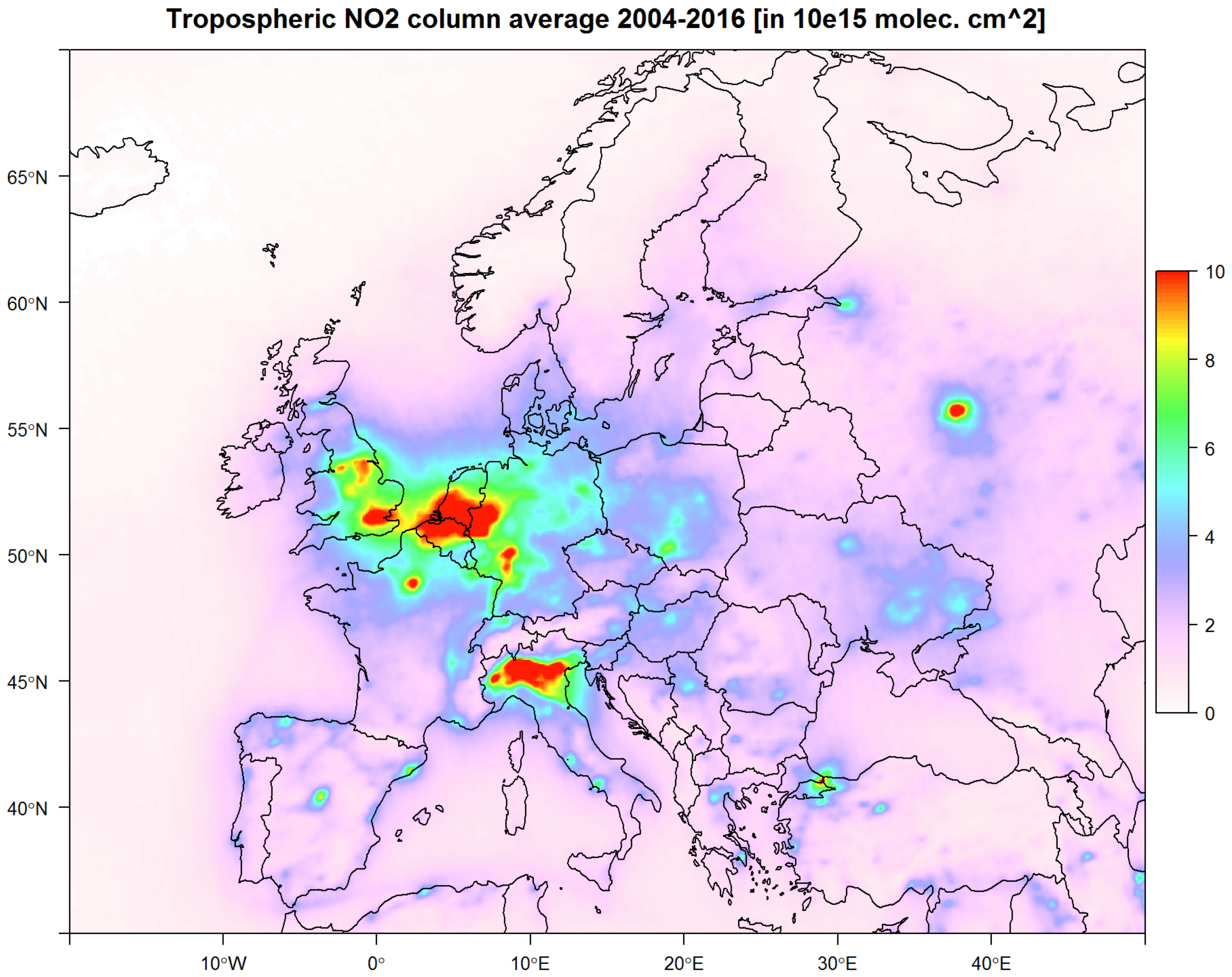
The average relative uncertainty of individual (daily) satellite observations of NO_2 is approximately 30%. This random error is reduced significantly when multiple measurements are averaged over time (e.g. monthly averages)

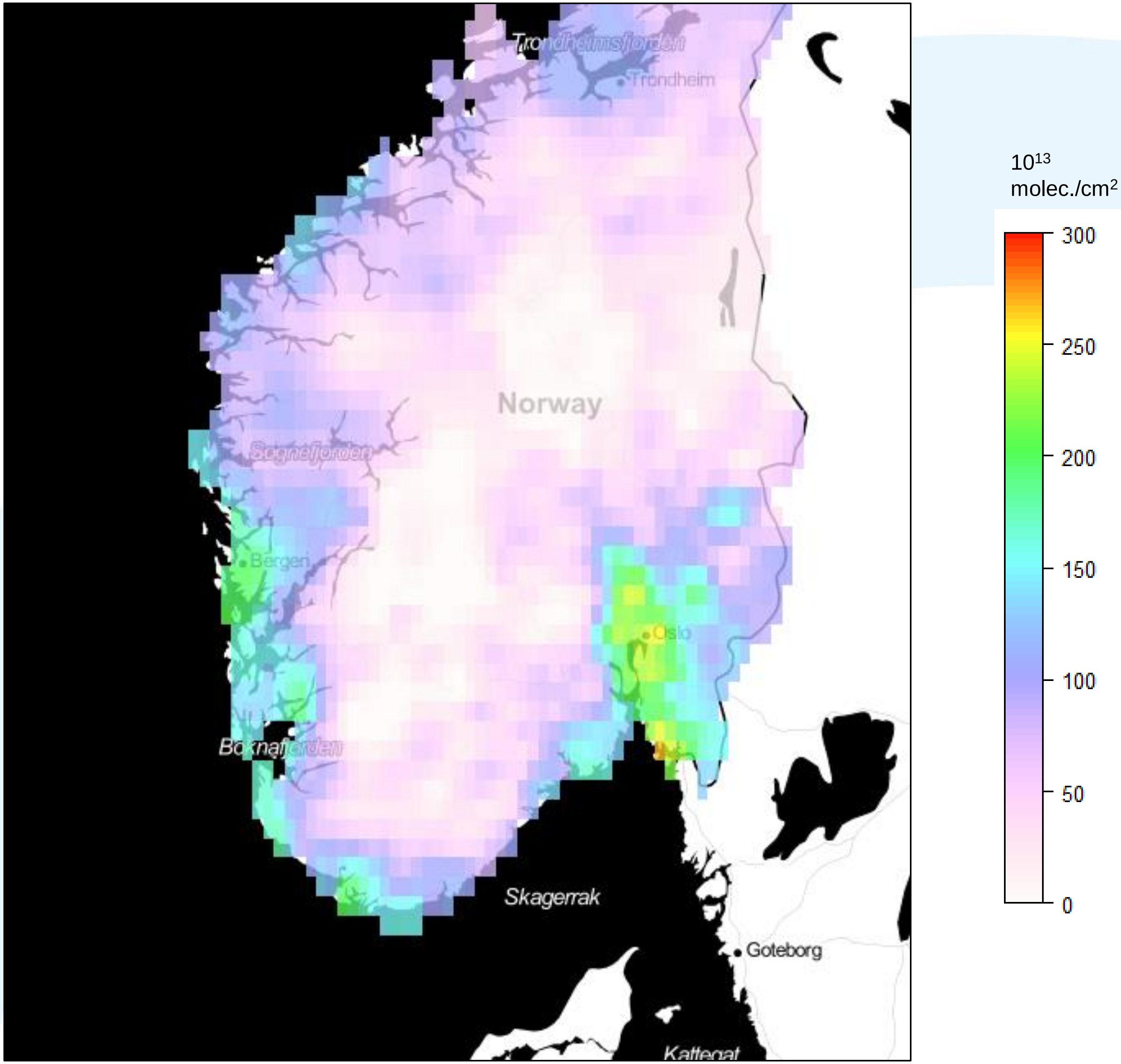


Satellite based annual average NO_2 by region

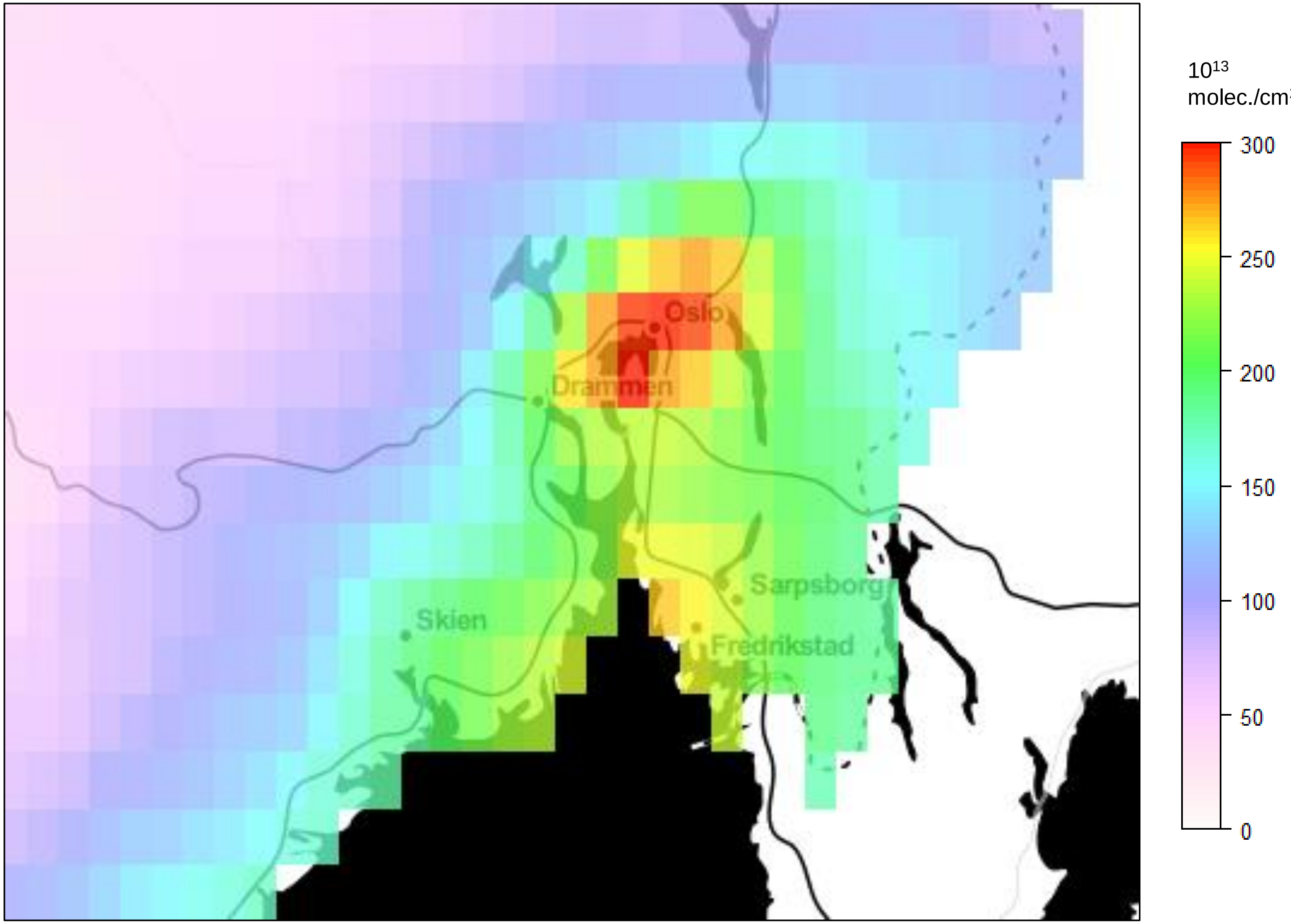


OMI-based estimate of relative change (in percent of long-term average) of nitrogen dioxide (NO_2) between 2004 and 2016. (Schneider et al., 2015, ACP)


Tropospheric NO2 column average 2004-2016 [in 10e15 molec. cm^2]
65°N
60°N
55°N
50°N
45°N
40°N
10°W
0°
10°E
20°E
30°E
40°E
10
8
6
4
2
0


Trondheimsfjorden
Trondheim
Norway
Sognefjorden
Bergen
Oslo
Boknafjorden
Skagerrak
Goteborg
Kattegat
10^{13} molec./cm^2
300
250
200
150
100
50
0

NILU

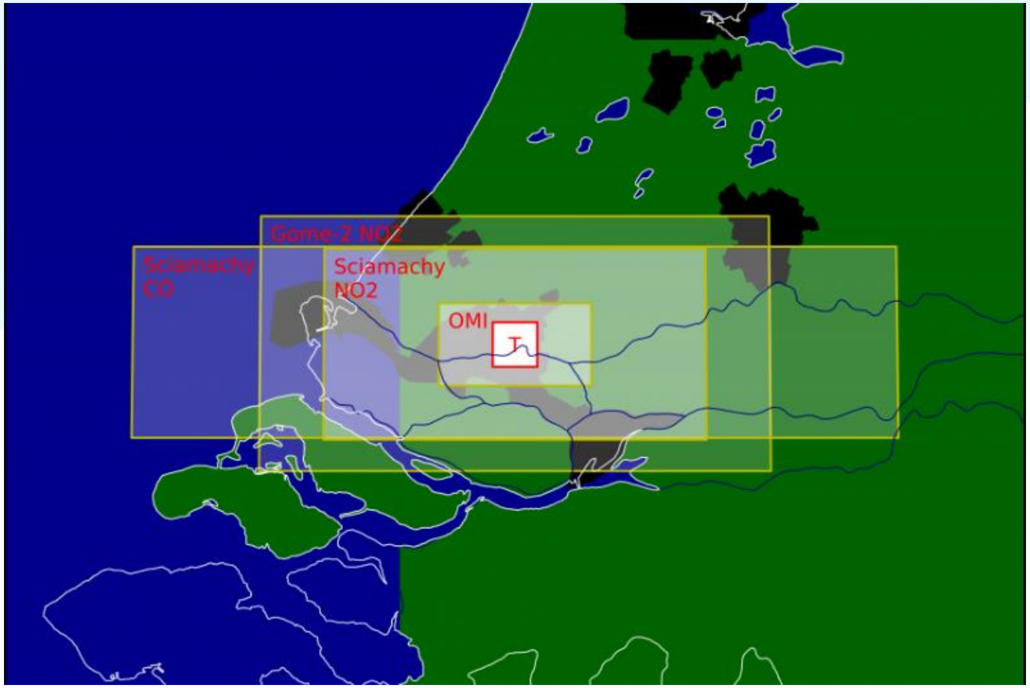


Oslo
Drammen
Sarpsborg
Skien
Fredrikstad
10^{13} molec./cm^2
300
250
200
150
100
50
0

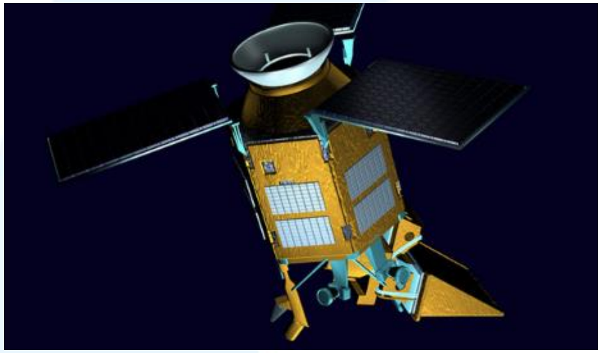
NILU

New opportunities: TROPOMI

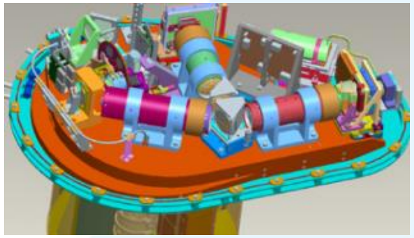
- TROPOMI is an instrument on the upcoming Sentinel-5P mission
- Launch in June 2017
- Spatial resolution of 7x7 km^2
- Products for NO_2, O_3, SO_2, CO, HCHO, CH_4, and Aerosols

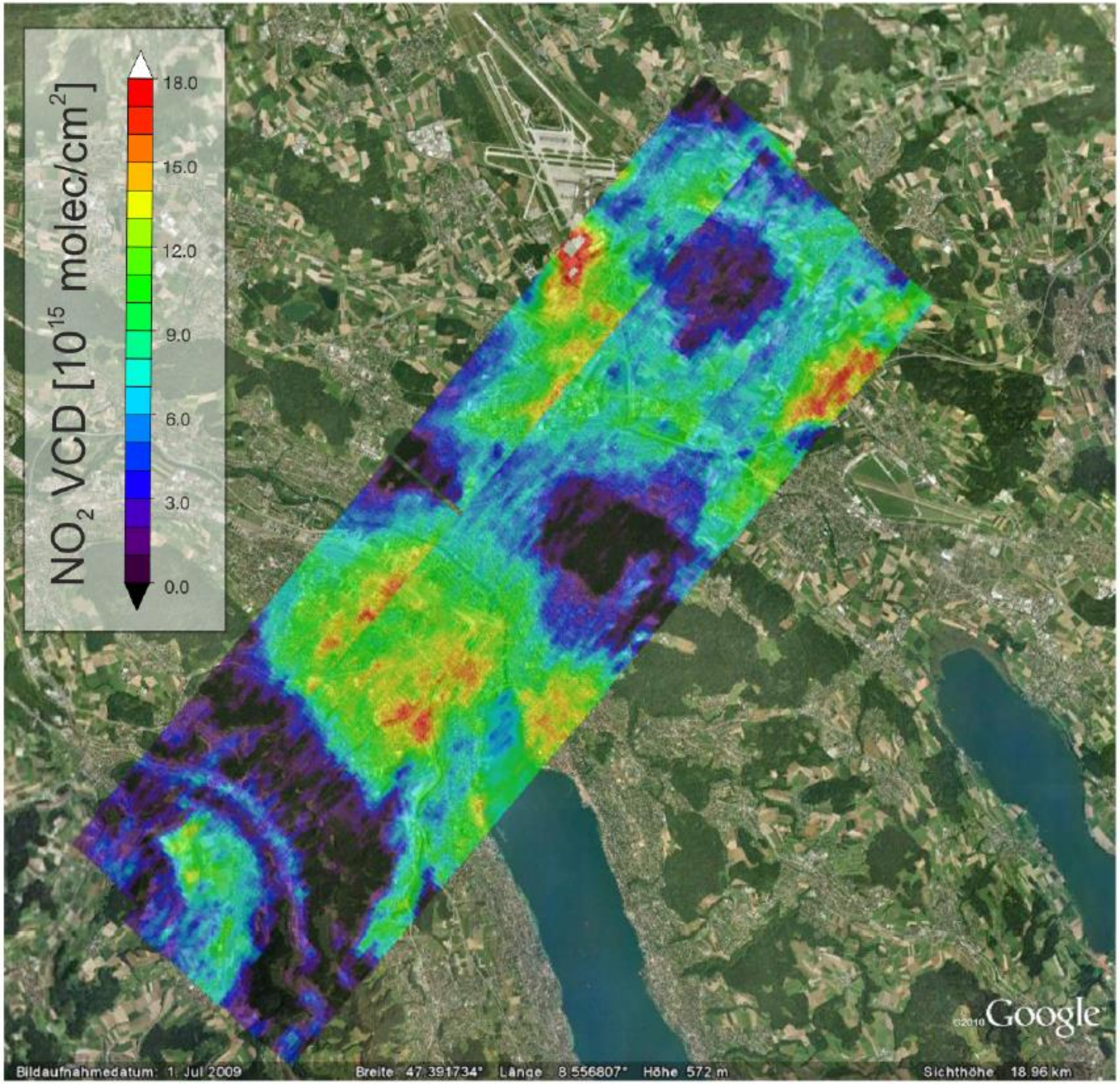


A comparison of the footprint of TROPOMI (nadir pixel) to past and current air quality satellite instruments



Airborne NO_2 mapping with the APEX instrument





From Popp et al. (2012)

NILU

PART 2: LOW-COST MICROSENSORS

Traditional Air Quality Monitoring

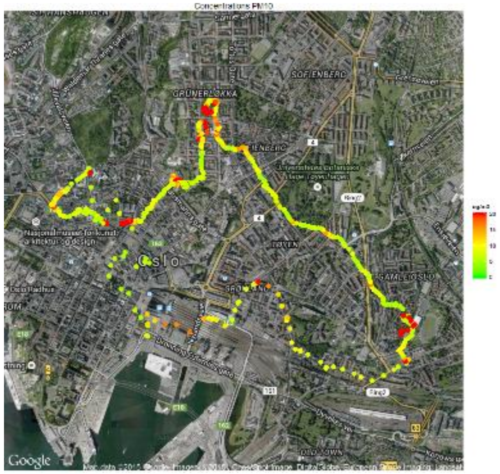
Is there another way?

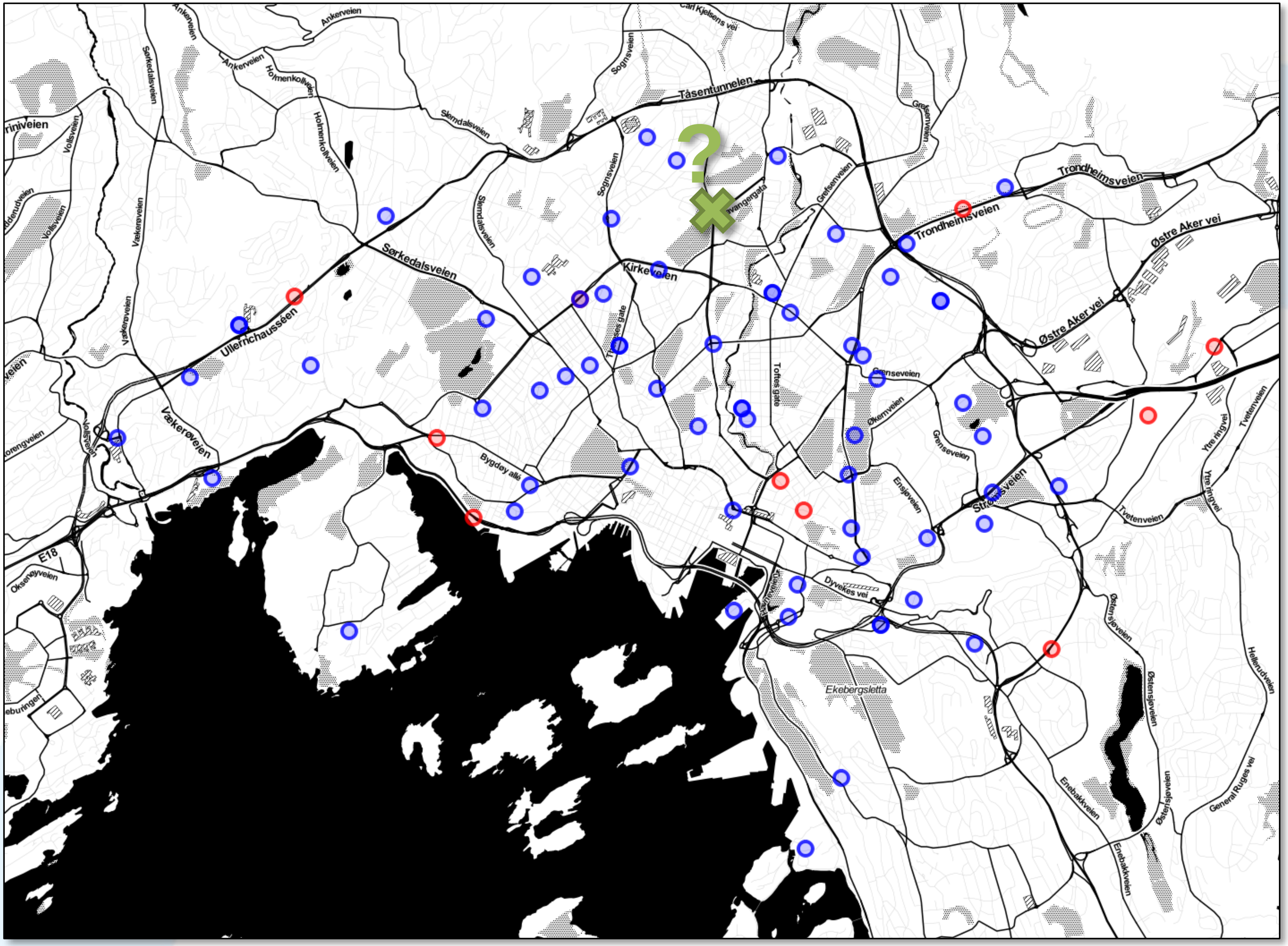
- Large
- Complex
- High-maintenance
- Expensive

→ Very sparse

Bidgee

There might be…



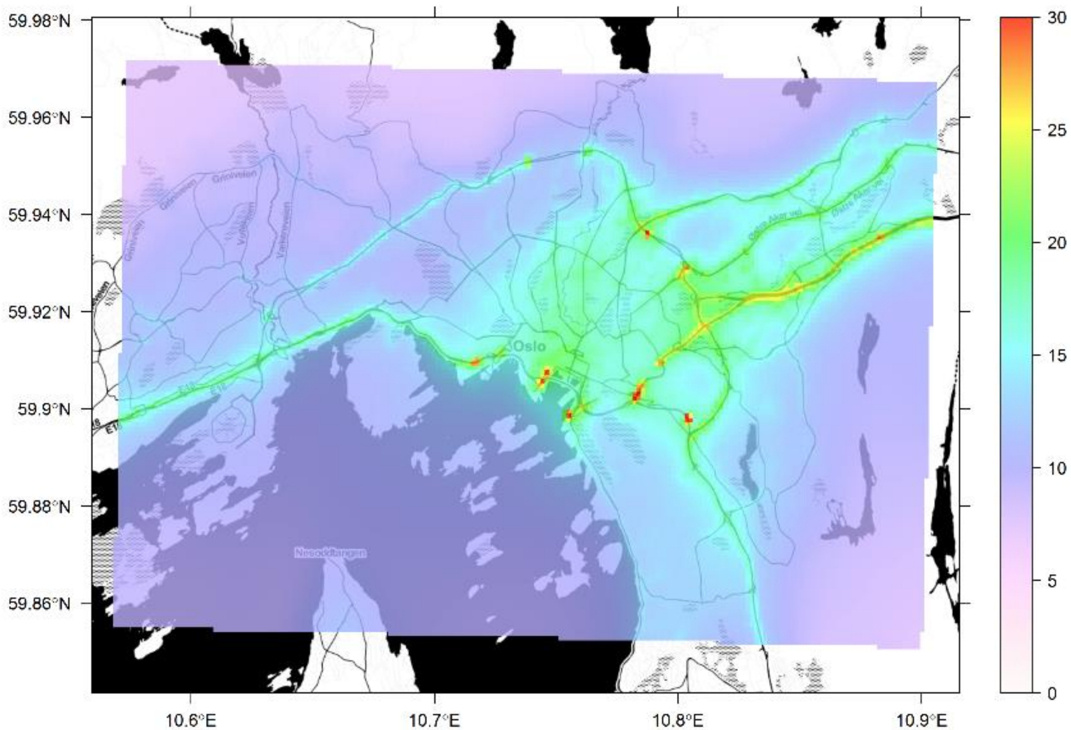


Red markers: Locations of Air Quality Monitoring stations for NO_2
Blue markers: Deployment sites of low-cost microsensors

NILU

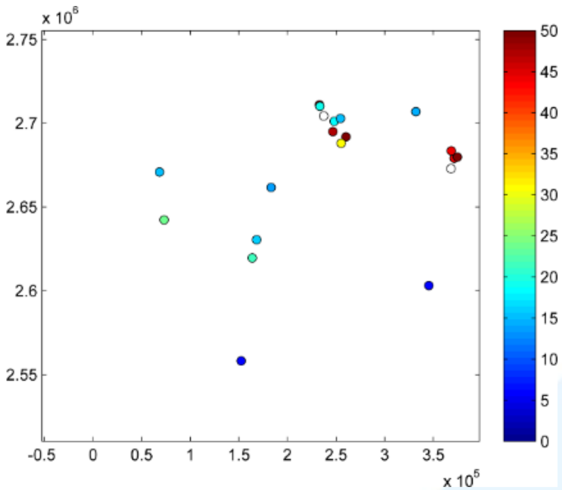
Combination with model output

- To map the observations from the low-cost sensors onto a high-resolution grid in a scientifically meaningful way we need to use a spatial auxiliary dataset that guides the interpolation
- We use here the output from the EPISODE air quality model (high-resolution long-term average concentration maps)



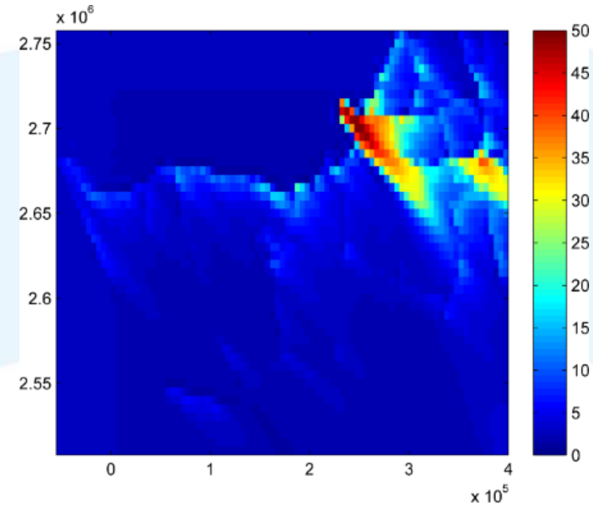
Annual average concentration of NO2 for 2014 as compute by the EPISODE air quality model.

NILU

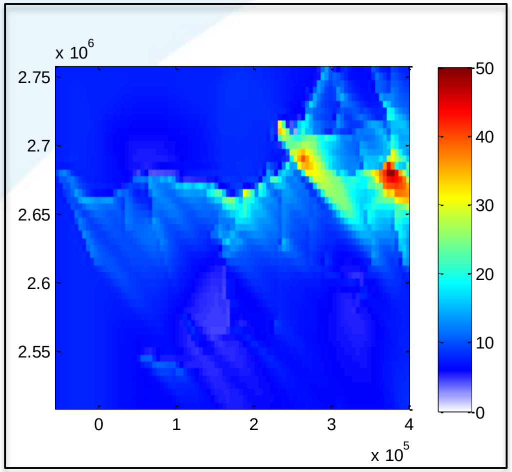


Observations

DATA FUSION



Modelling results or other auxiliary data

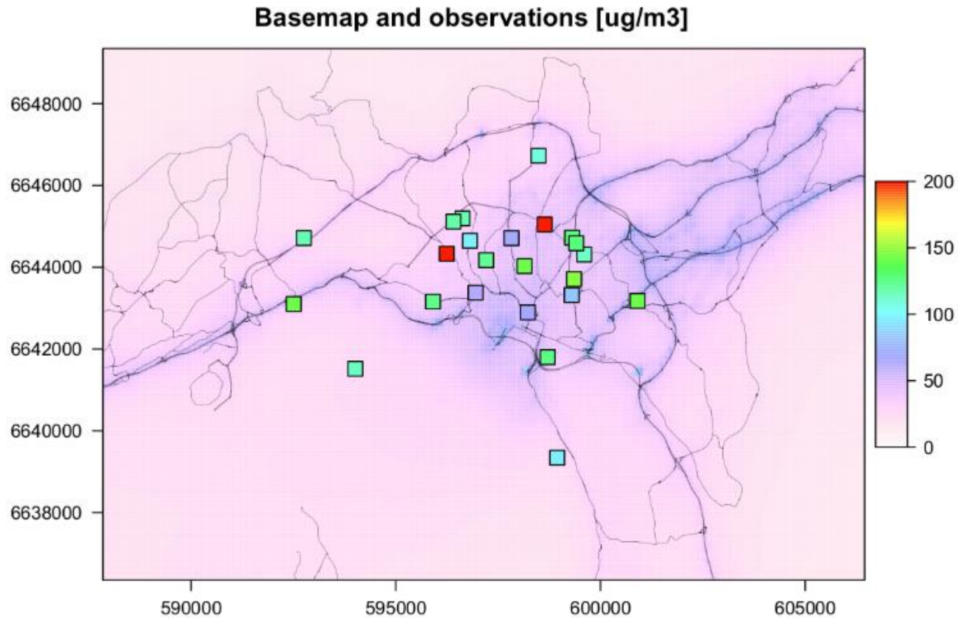


Combined map

Data fusion (as a subset of data assimilation) creates a value-added product by

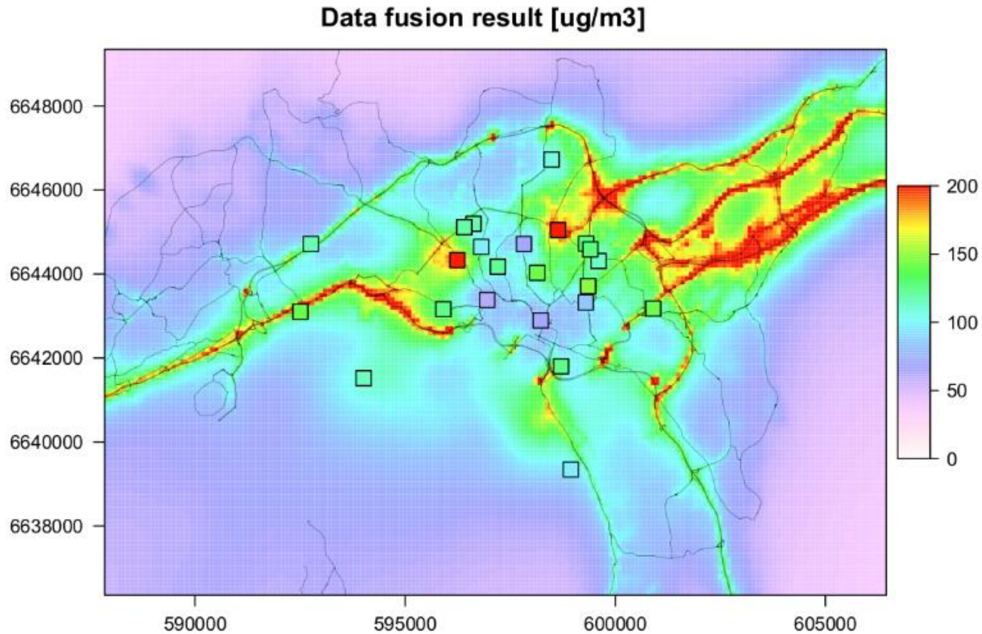
a) Interpolating the observations in an objective way
b) “correcting” the model estimates with true observations

Data fusion method used here provides a combined concentration field by separately interpolating the observational residuals from a regression model and then combining both.



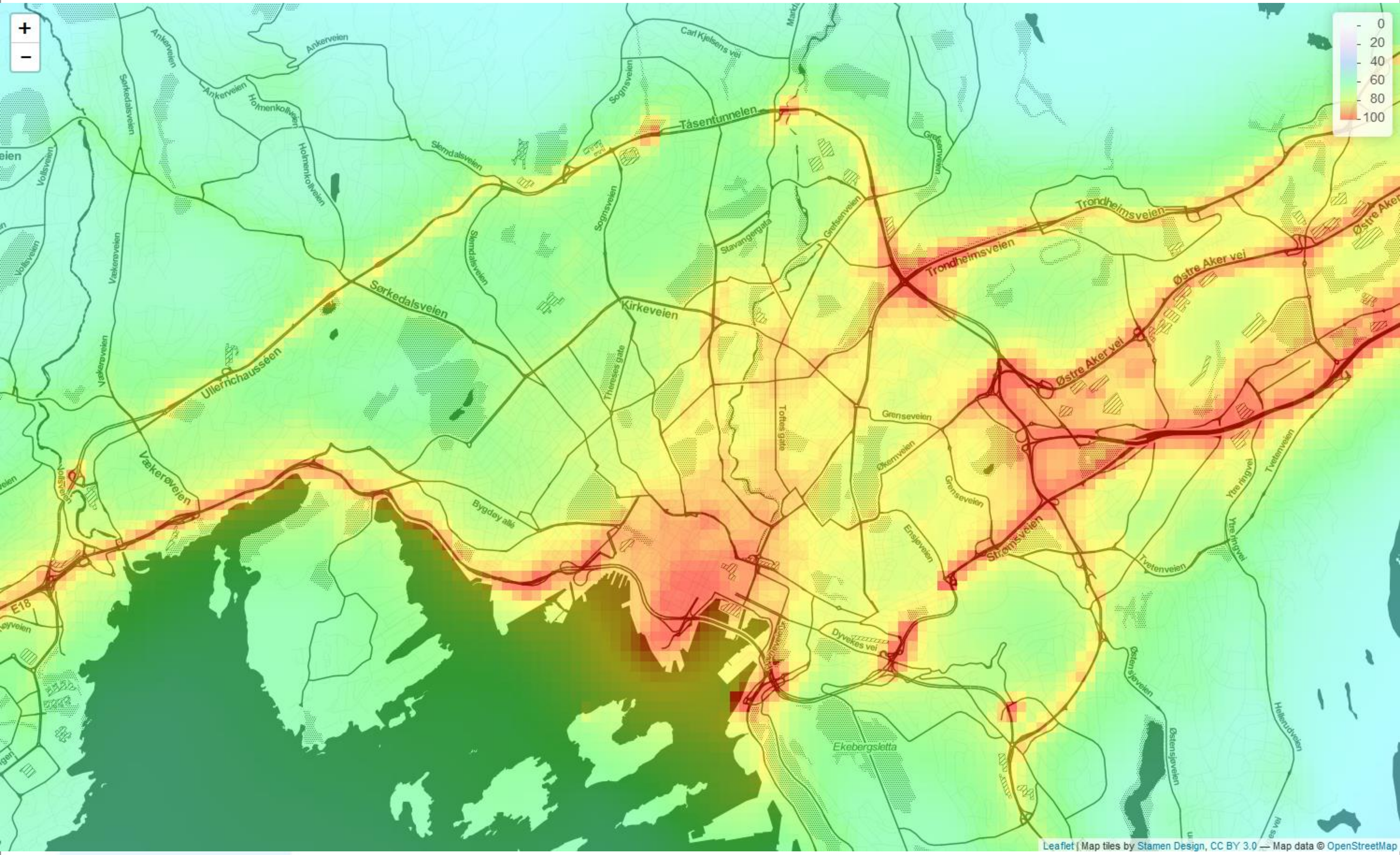
Oslo NO_2 model-derived annual average basemap (background) and observations from AQMesh nodes (markers) on 6 January 2016 at 9:00 UTC. Units in µg/m³.

Note: The sensors used here were all **co-located for several weeks** at the Kirkeveien AQ monitoring station **before deployment** and are thus **field-calibrated**!



Result of data fusion process (background) and observations from AQMesh nodes (markers). Units in µg/m³.

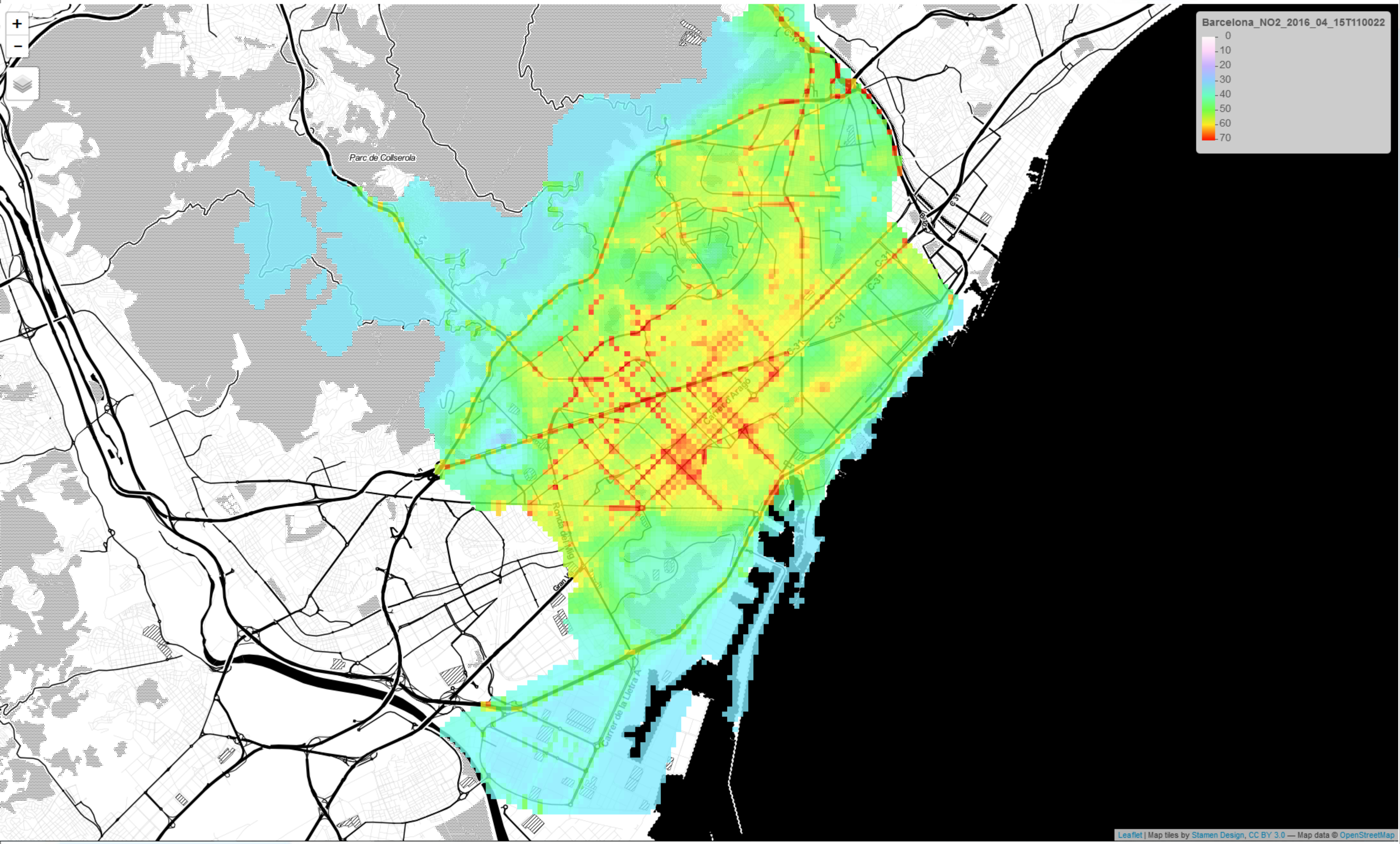
NILU



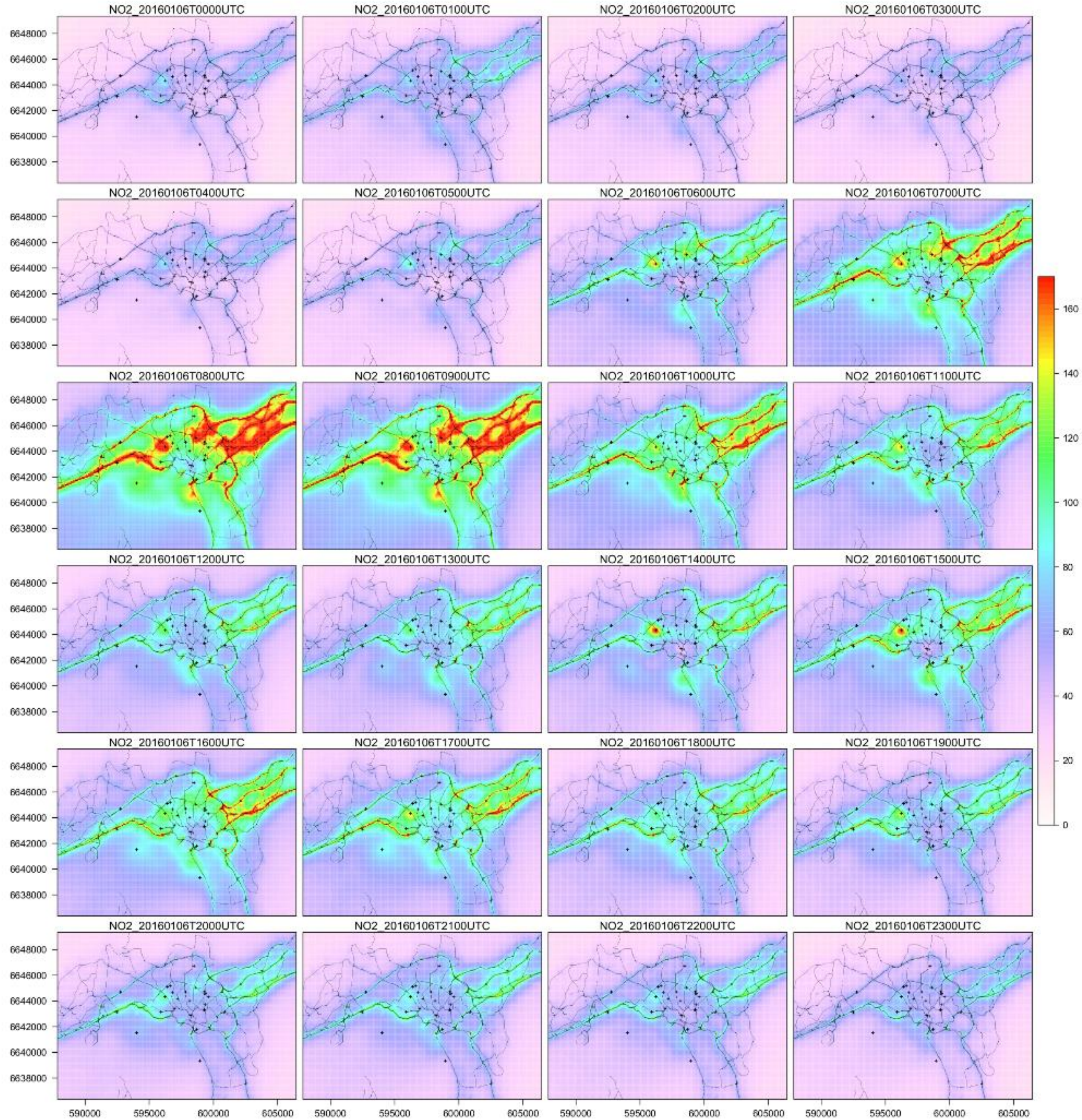
Example of a data fusion-based surface concentration field of NO_2 for Oslo, Norway, at 100 m spatial resolution (link).


no2
20
30
40
50
60
70
SOGN
SLEMDAL
GAUSTAD
HOLMEN
NYDALEN
GREFSEN
TÅSEN
STIG
TONSENHAGEN
LOFTHUS
DISEN
BROBEKK
LINDERUD
HUSEBY
VINDEREN
ULLEVÅL HAGEBY
SANDAKER
REFSTAD
MONTEBELLO
BORGEN
SAGENE
TORSHOV
RISLØKKA
VOLVAT
MARIENLYST
LOVISENBERG
ØKERN
HEGGELI
SØRKEDALSVEIEN
ØSTRE AKER VEI
HOFF
MAJORSTUEN
ABBEDIENGEN
HEGDEHAUGEN
GRÜNERLØKKA
KEYSERLØKKA
ALNABRU
SKØYEN
FROGNER
LILLE TØYEN
ULVEN
BESTUM
URANIENBORG
VALLE
HAMMERSBORG
TØYEN
VÆKERØ
TVEITA
TEISEN
HELSFYR
VIKA
SKILLEBEKK
BYGDØY
TJUVHOLMEN
JORDAL
ETTERSTAD
SØRENGA
KVÆRNERBYEN
SKØYENÅSEN
EKEBERGSKRENTEN
ROGNERUD
EKEBERG
Ekebergsletta
SIMENSBRÅTEN
OPPSAL
OSLO
AKERSHUS
Leaflet | © OpenStreetMap © CartoDB

NILU

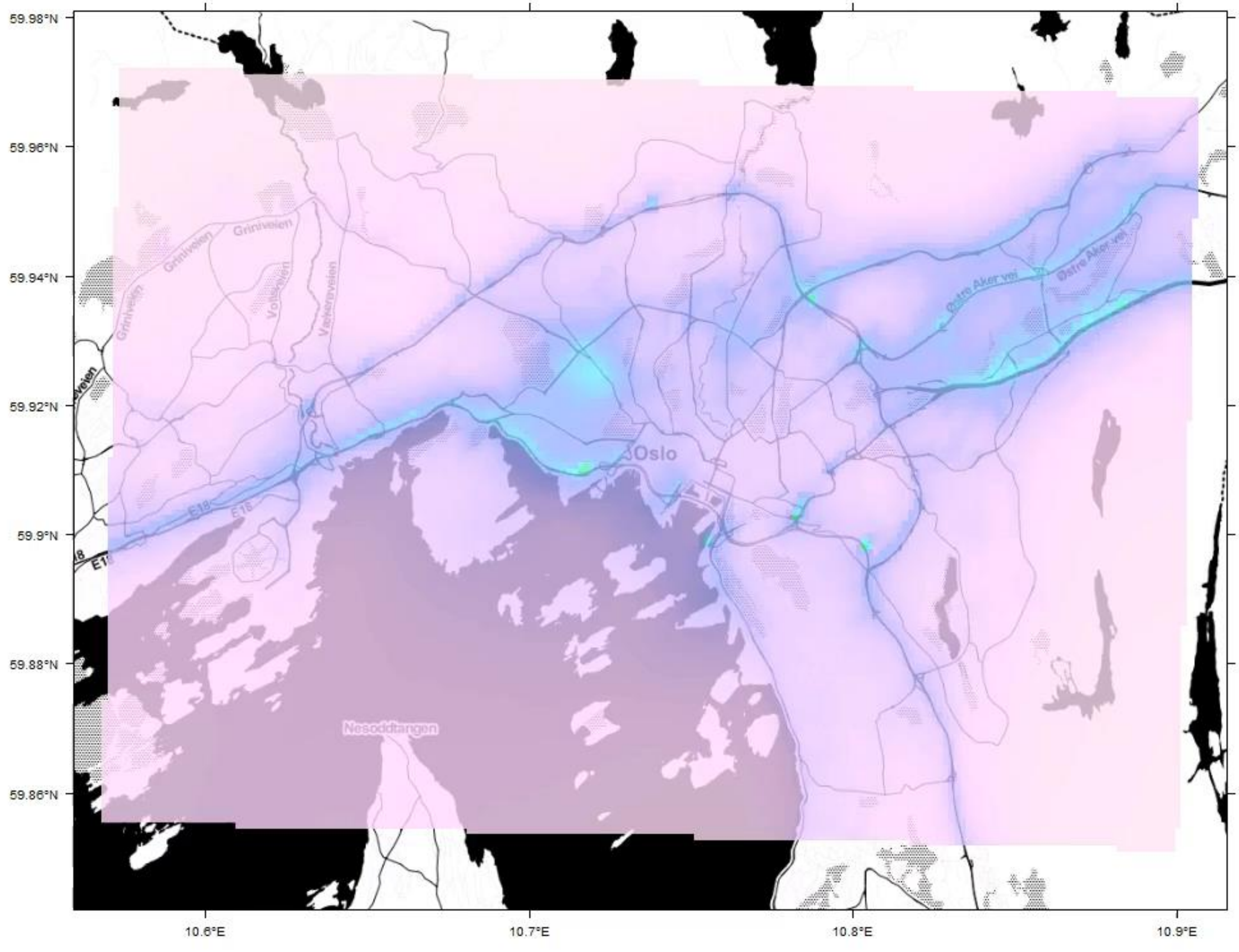


Example of a data fusion-based surface concentration field of NO_2 for Barcelona, Spain, at 100 m spatial resolution (link).

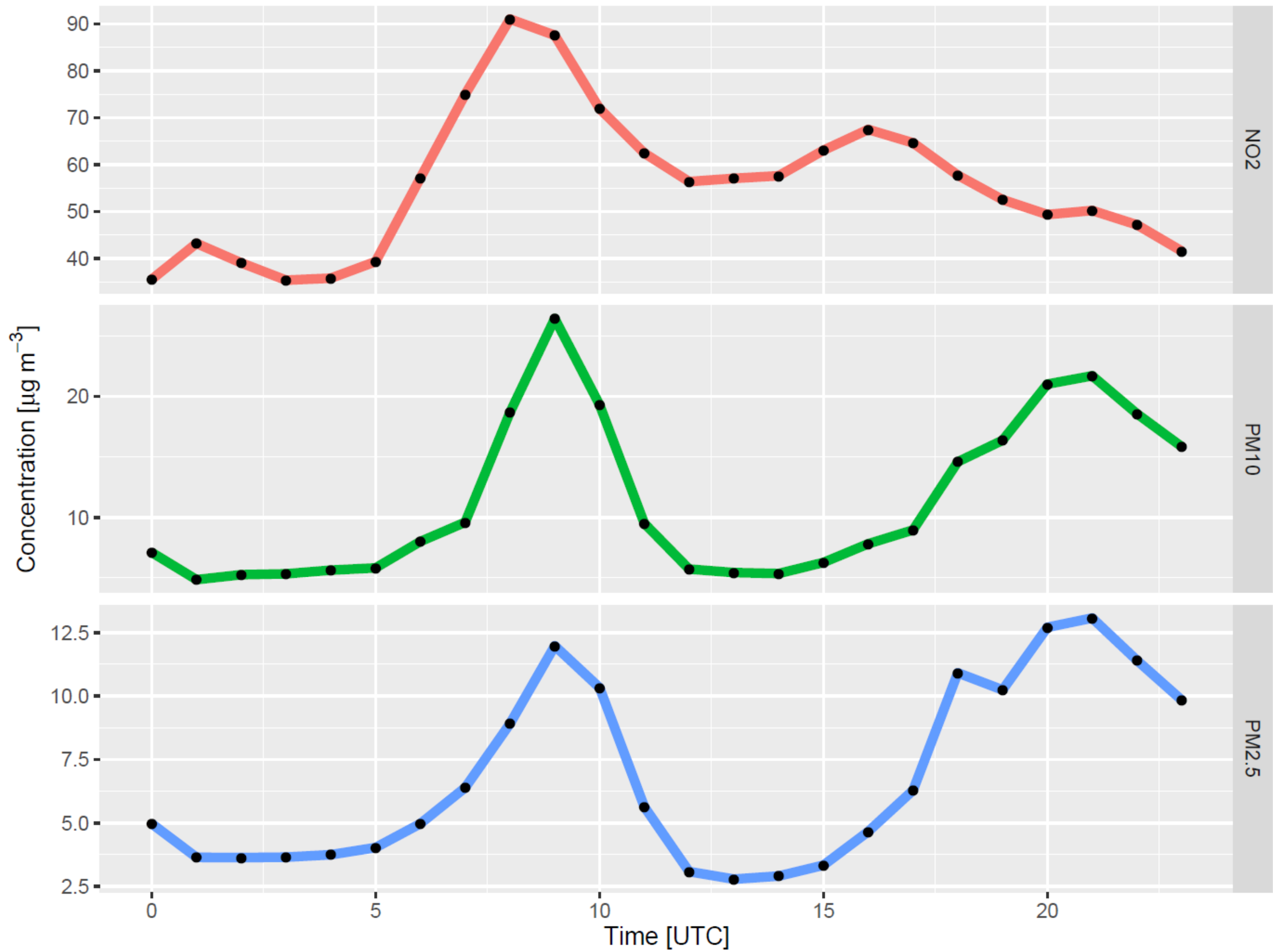


Example of 24 hours of data fusion results in Oslo, combining NO_2 measurements from the AQMesh units with a long-term average basemap derived from the EPISODE model, here shown for 6 January 2016

0000UTC

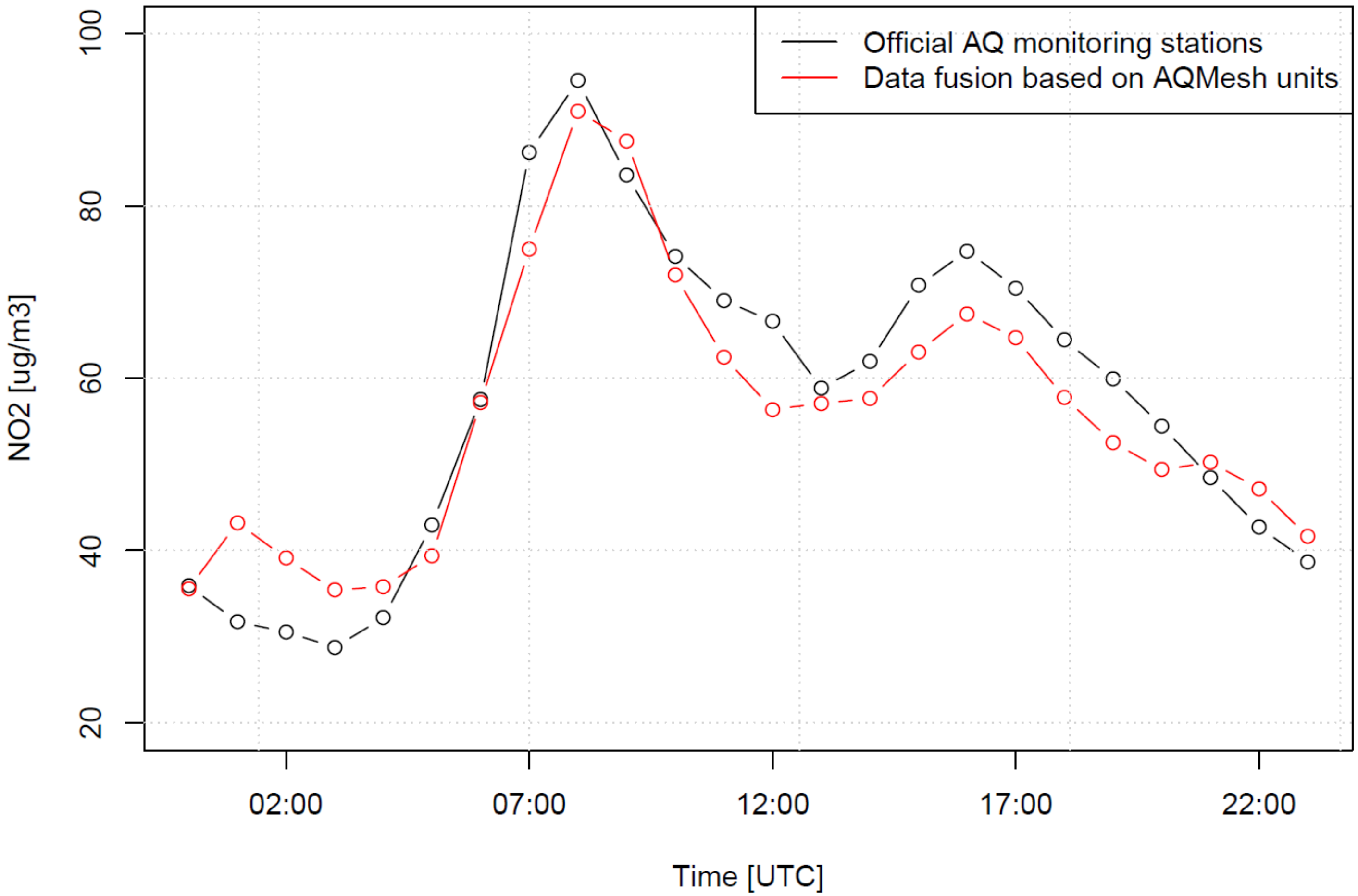


59.98°N
59.96°N
59.94°N
59.92°N
59.9°N
59.88°N
59.86°N
10.6°E
10.7°E
10.8°E
10.9°E
Griniveien
Vækerøveien
E18
Oslo
Østre Aker vei
Nesoddtangen

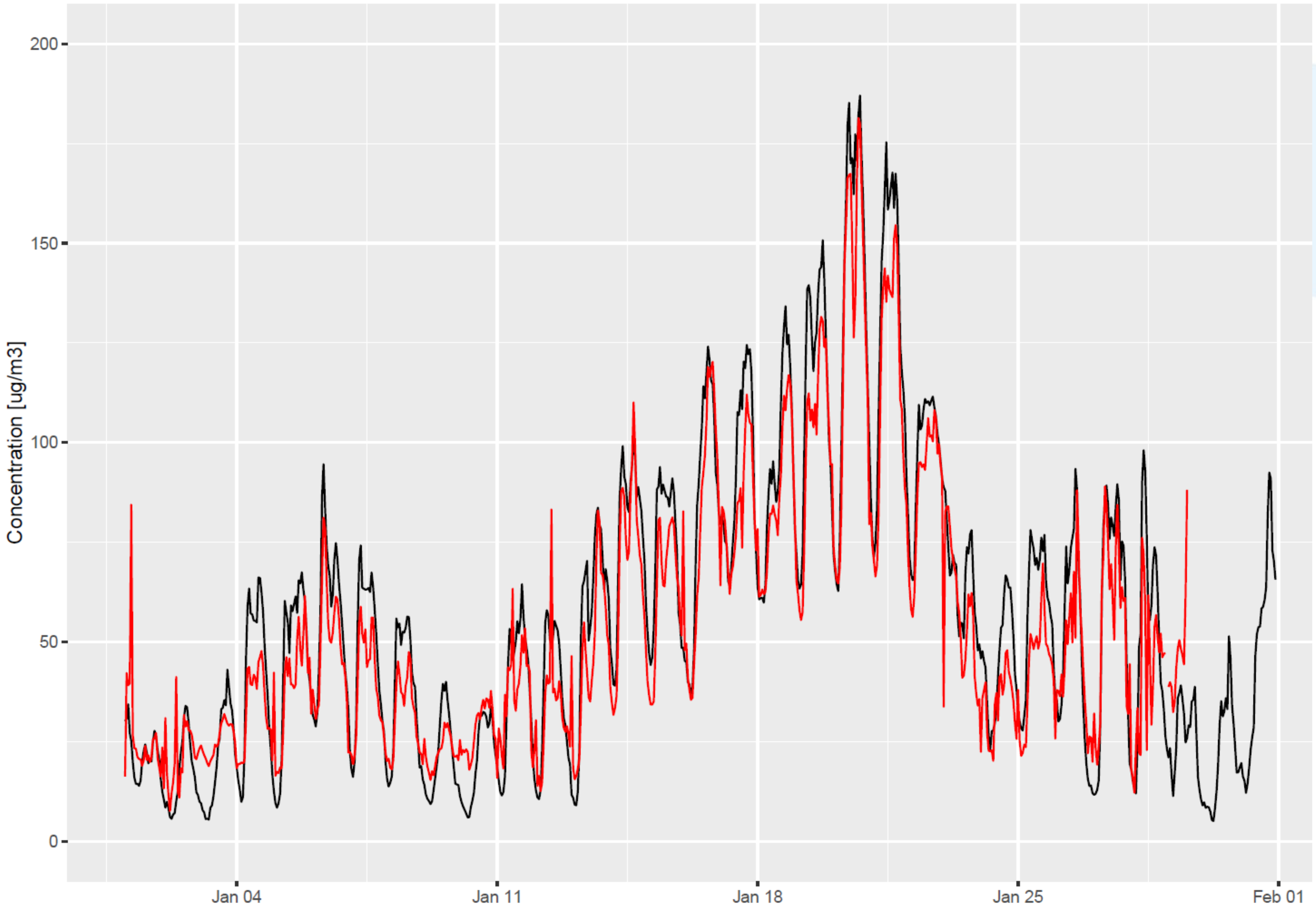


Data fusion maps: Daily cycle of NO_2, PM_{10}, and $PM_{2.5}$ for Oslo on January 6 2016 (NO2) and 22 March 2016 (PM).

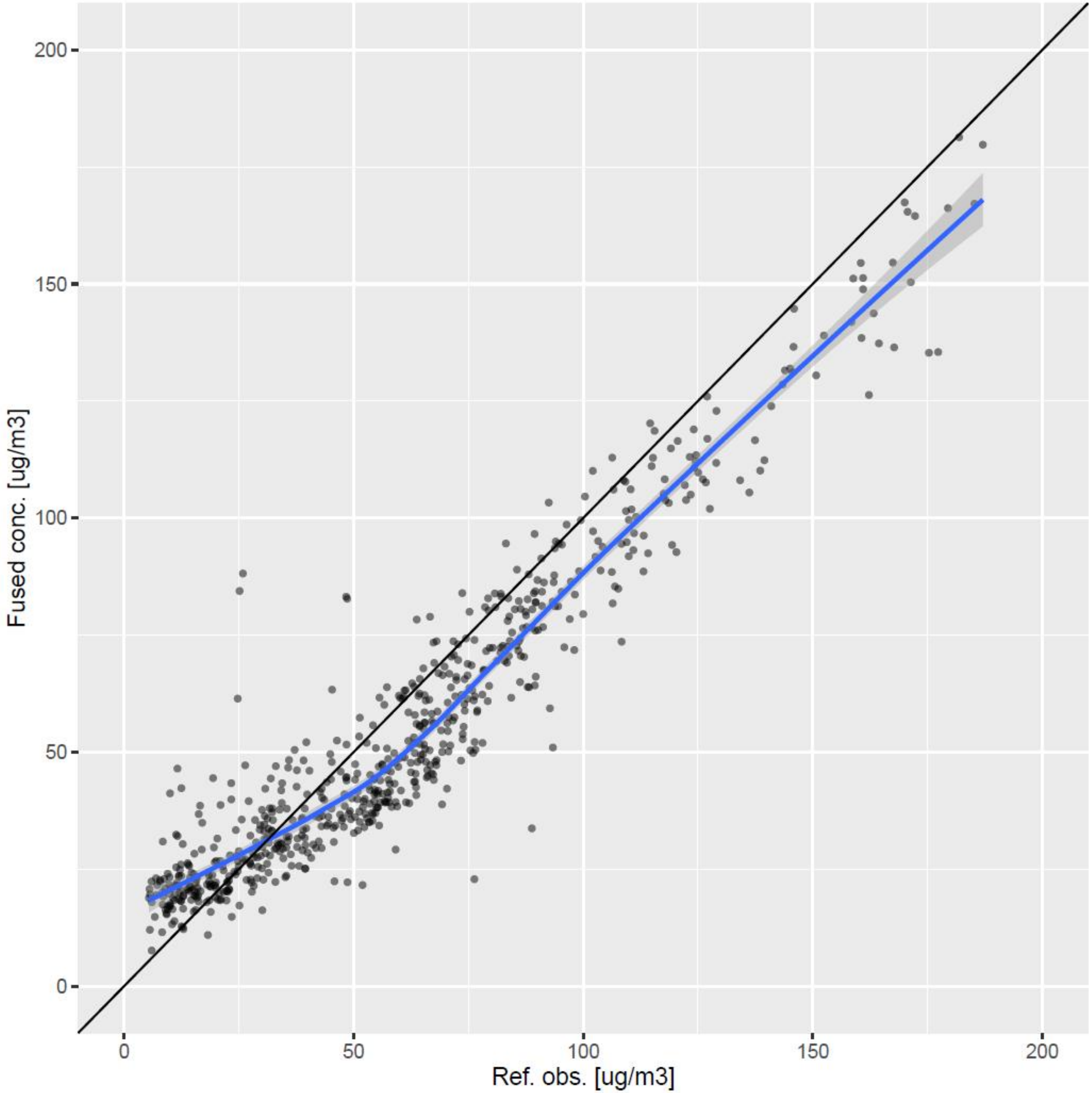
Comparison to AQ monitoring stations



Entire daily cycle of NO_2 as measured by the reference air quality monitoring stations versus the NO_2 concentrations provided by the data fusion map.



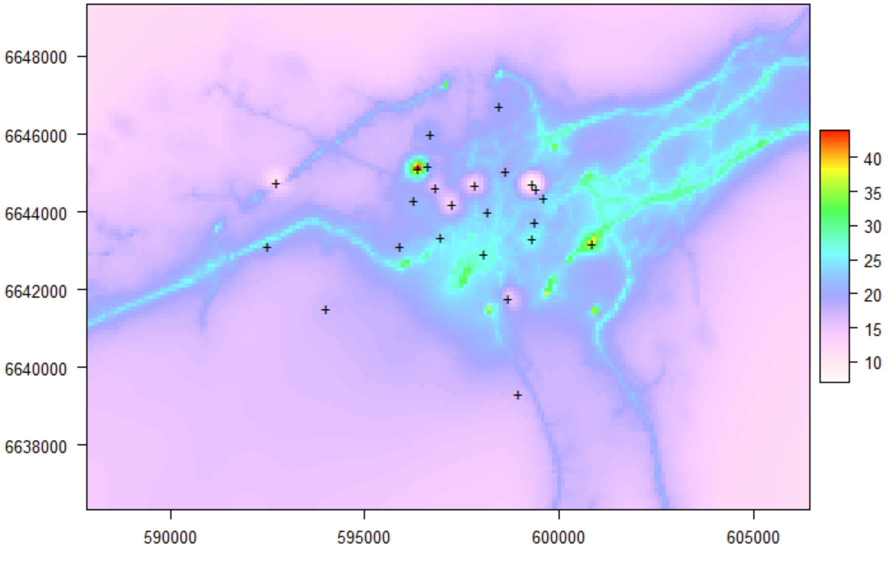
Average NO2 concentration in Oslo in January 2016
Black line: Reference AQM stations
Red line: Data fusion of AQMesh low-cost sensor network and EPISODE



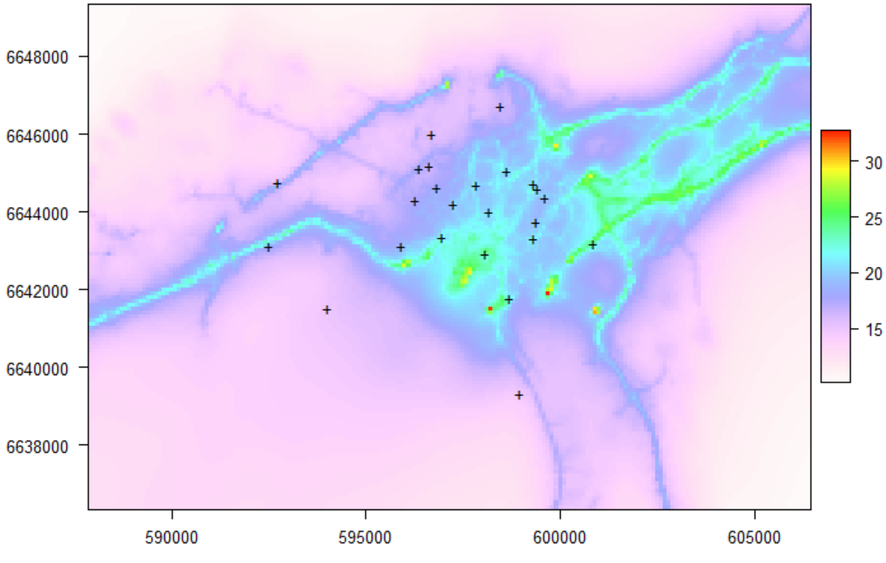
NILU

Field calibration of the sensors is crucial!

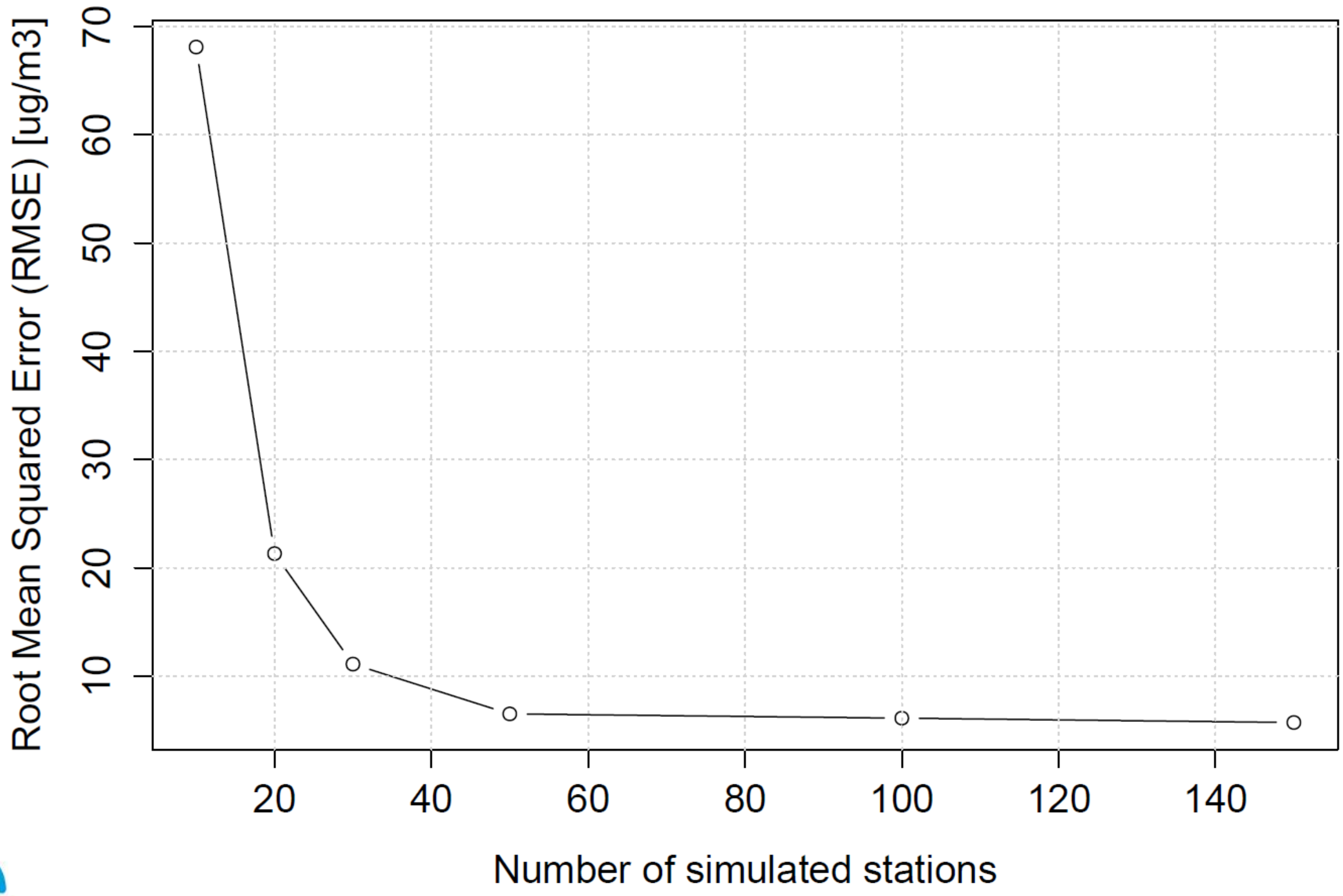
Without field calibration



With field calibration



Dependency of map quality on network size



NILU

Take-home messages

There are currently two exciting developments regarding new monitoring techniques:

1. **Higher-resolution satellite data for AQ monitoring**
   Satellite observations of air quality, which so far are mostly useful for global and regional applications are finally reaching a spatial resolution that make them somewhat usable for (limited) urban-scale applications
2. **Low-cost microsensors for AQ monitoring**
   Despite many challenges at the individual sensor level, low-cost microsensors allow for detailed high-resolution urban-scale mapping of air quality if several conditions are met:
   a) the "swarm knowledge" of the entire network is used
   b) the sensor observations are combined with output from an air quality model
   c) the sensors are calibrated in the field

NILU

Thank you for your attention!

Contact: Philipp Schneider

Email: ps@nilu.no

www.nilu.no

www.citi-sense.eu