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TAKING THE PULSE OF OUR PLANET FROM SPACE

CitySatAir: Exploiting Sentinel-5P NO_2 data for the urban scale

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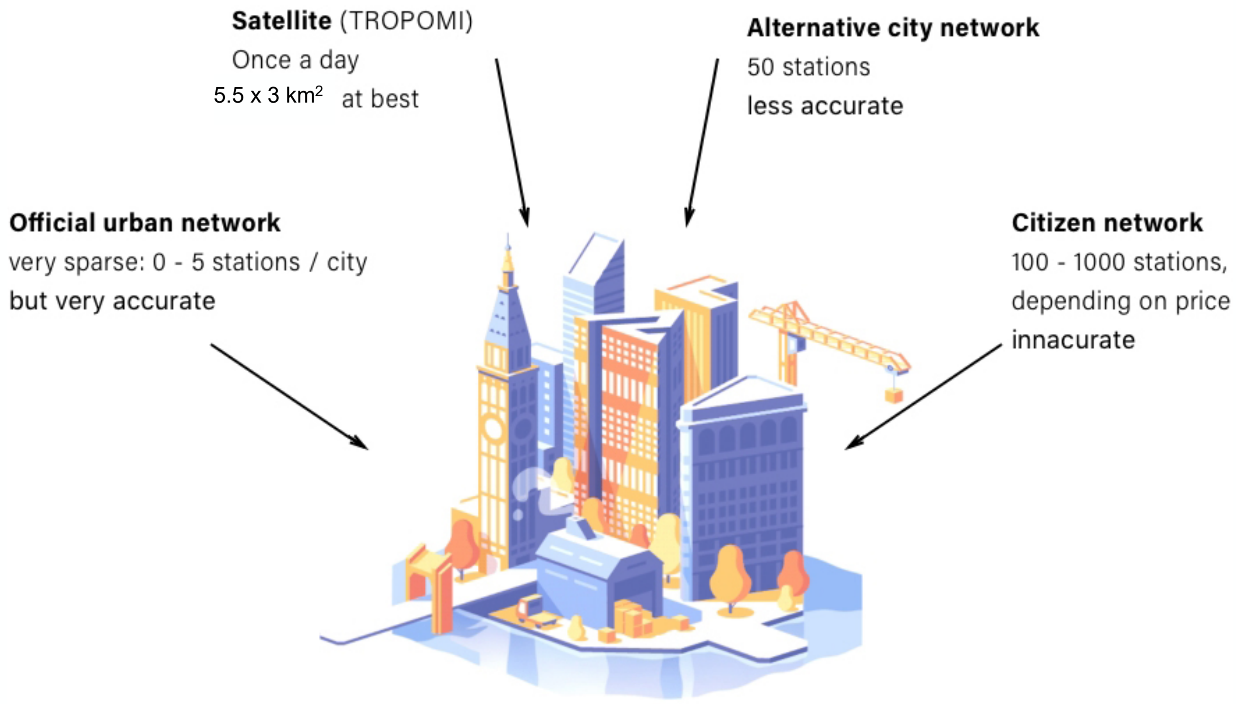
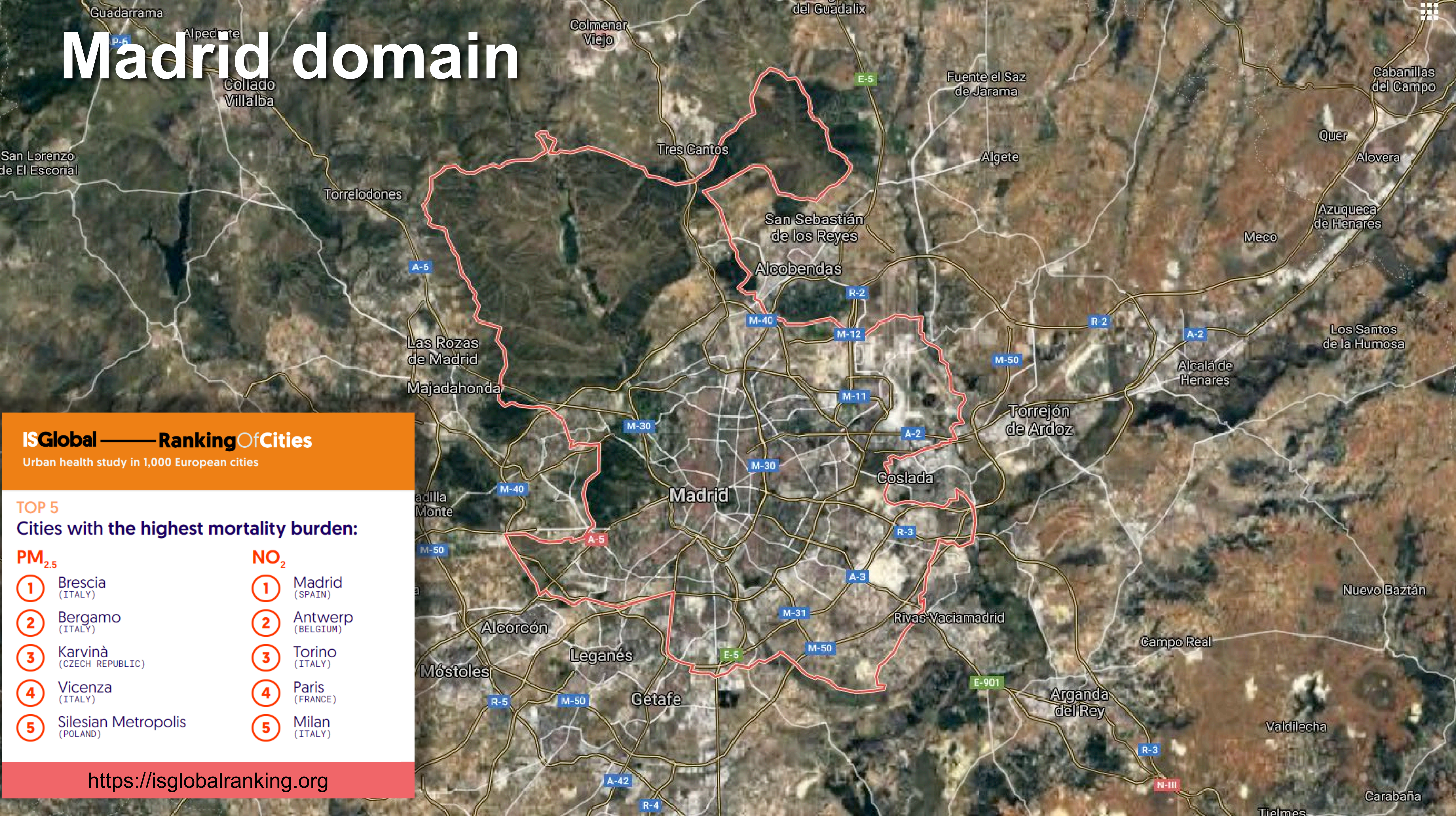
A1.03.1 - 24 May 2022

CitySatAir in a nutshell

- **Motivation:** How can Sentinel-5P/TROPOMI data (tropospheric NO_2 columns) be better exploited for monitoring and mapping urban air quality at scales relevant for human exposure?
- **Goal**: hourly air quality maps of NO_2 at 100 m resolution for selected cities.
- **Approach**: Integrate TROPOMI NO_2 data in urban-scale air quality model, together with station data and low-cost sensor networks (not covered here)
- Direct assimilation of NO2 TVCD of limited use (short NO_2 lifetime and typically rapid signal decay in the DA system)
- Primary focus on improving emissions estimates
- Two contrasting study sites: **Madrid and Oslo**



Madrid domain



ISGlobal —— RankingOfCities
Urban health study in 1,000 European cities

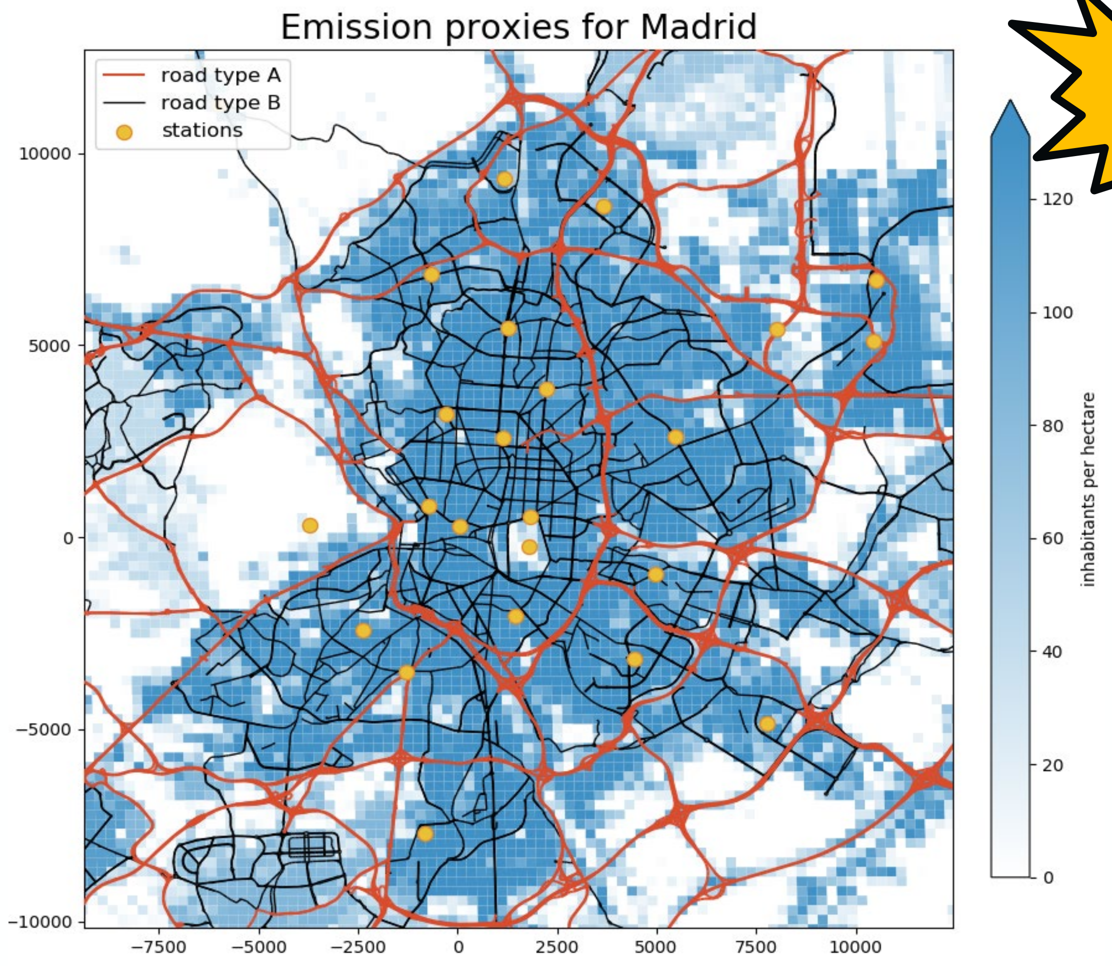
TOP 5
Cities with the highest mortality burden:

$PM_{2.5}$	NO_2
1 Brescia (ITALY)	1 Madrid (SPAIN)
2 Bergamo (ITALY)	2 Antwerp (BELGIUM)
3 Karvinà (CZECH REPUBLIC)	3 Torino (ITALY)
4 Vicenza (ITALY)	4 Paris (FRANCE)
5 Silesian Metropolis (POLAND)	5 Milan (ITALY)

https://isglobalranking.org

Urban emissions

- Not accurately known
- Estimate with proxies of activity data
- Three sectors considered: traffic (highway and primary) and residential
- Emission factors unclear (e.g. “diesel gate”)
- **Estimate emission factors from observations**



Open data!

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The RETINA algorithm

Emissions

Transport
- Road location/type (OSM)
- Traffic flow (Madrid open data)

Residential
- Population density (GHS)

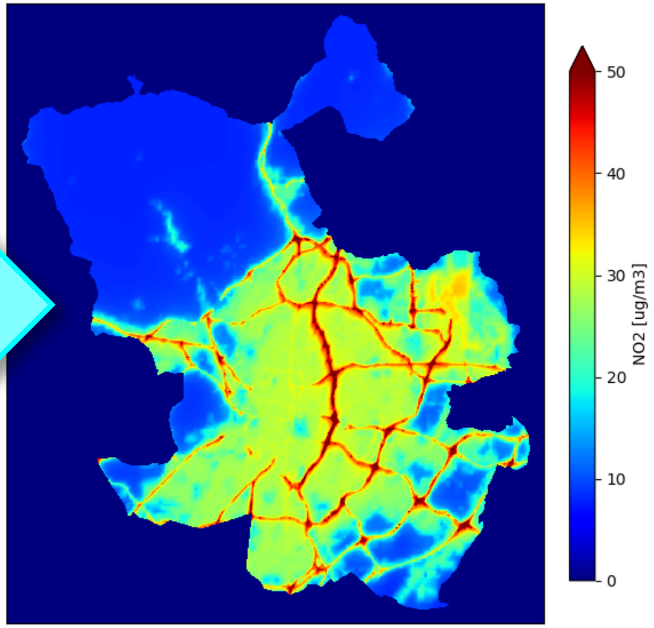
Meteorology

ECMWF

Background concentrations

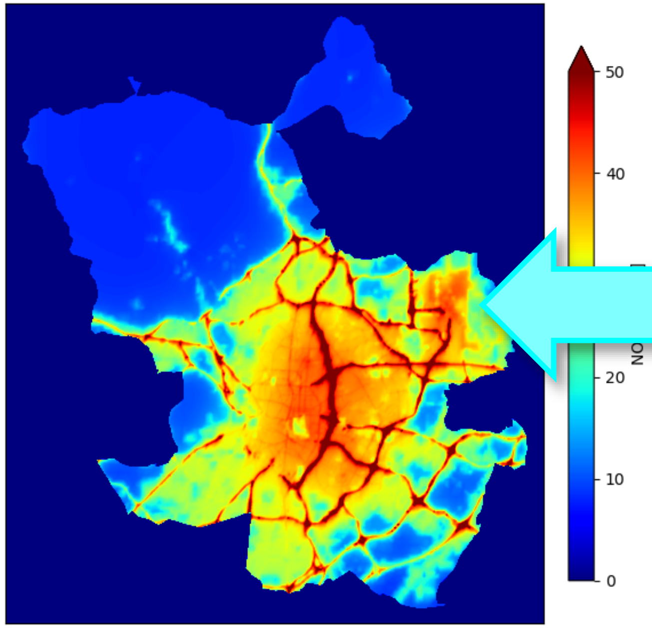
CAMS

Simulation (AERMOD) and Calibration



19 Aug 2020, 6-12 UTC

Assimilation



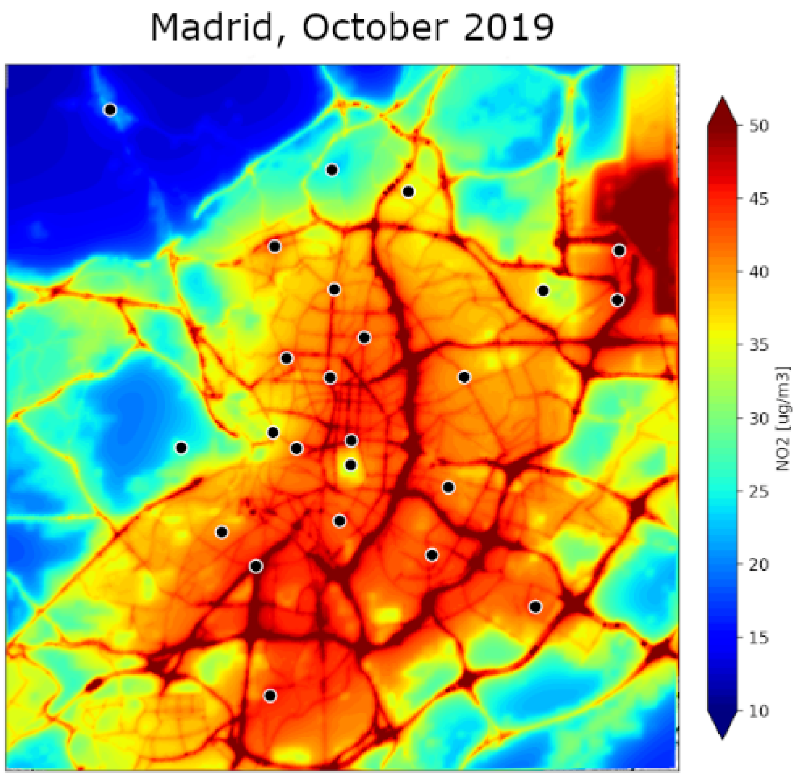
19 Aug 2020, 6-12 UTC

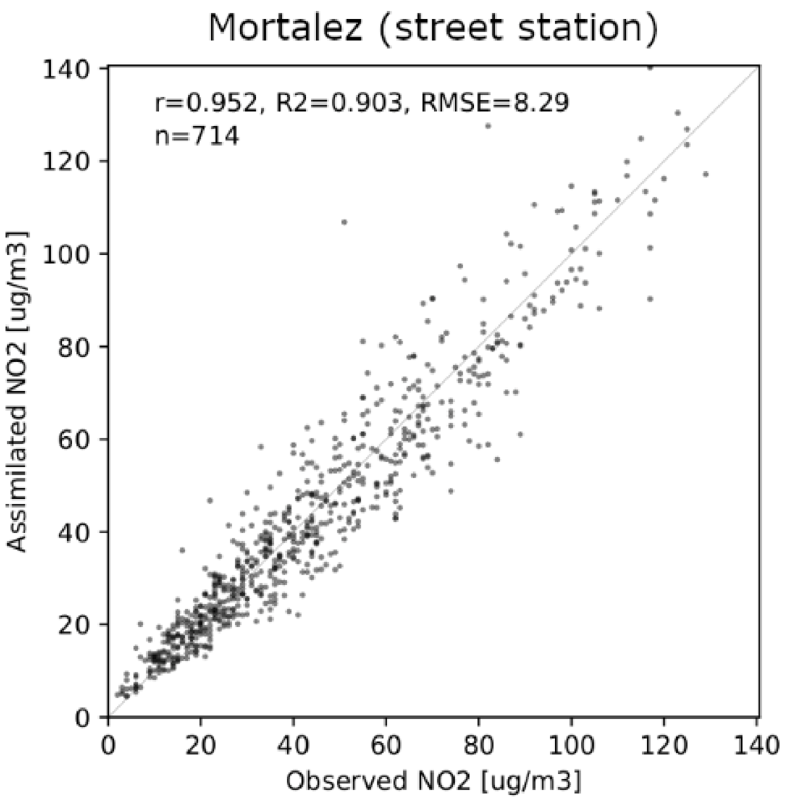
Observations

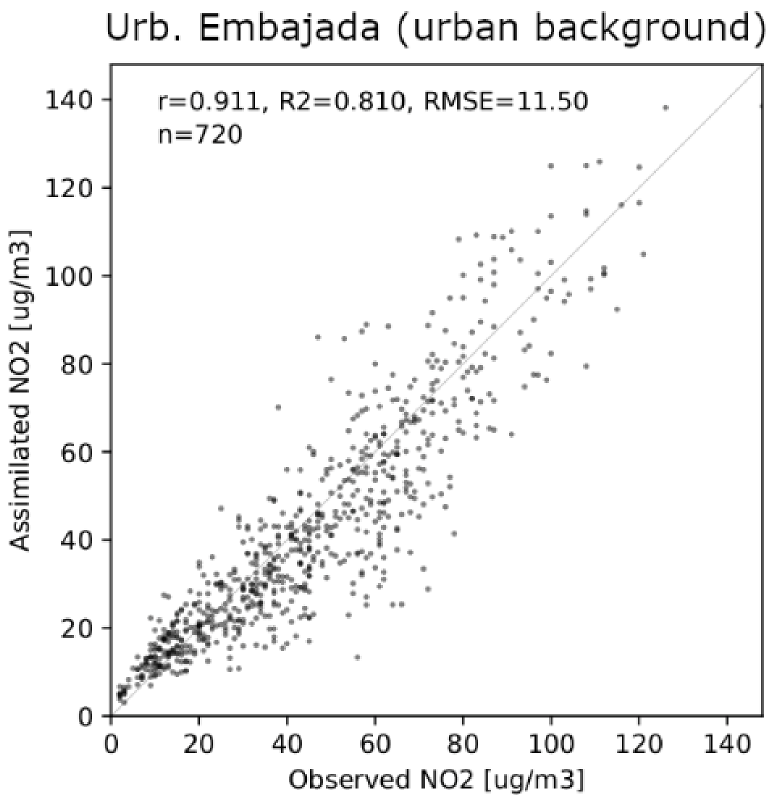
Local ground network:
24 stations

Mijling, B.: *High-resolution mapping of urban air quality with heterogeneous observations: a new methodology and its application to Amsterdam*, Atmos. Meas. Tech., 13, 4601–4617, https://doi.org/10.5194/amt-13-4601-2020, 2020.

Calibration with surface measurements



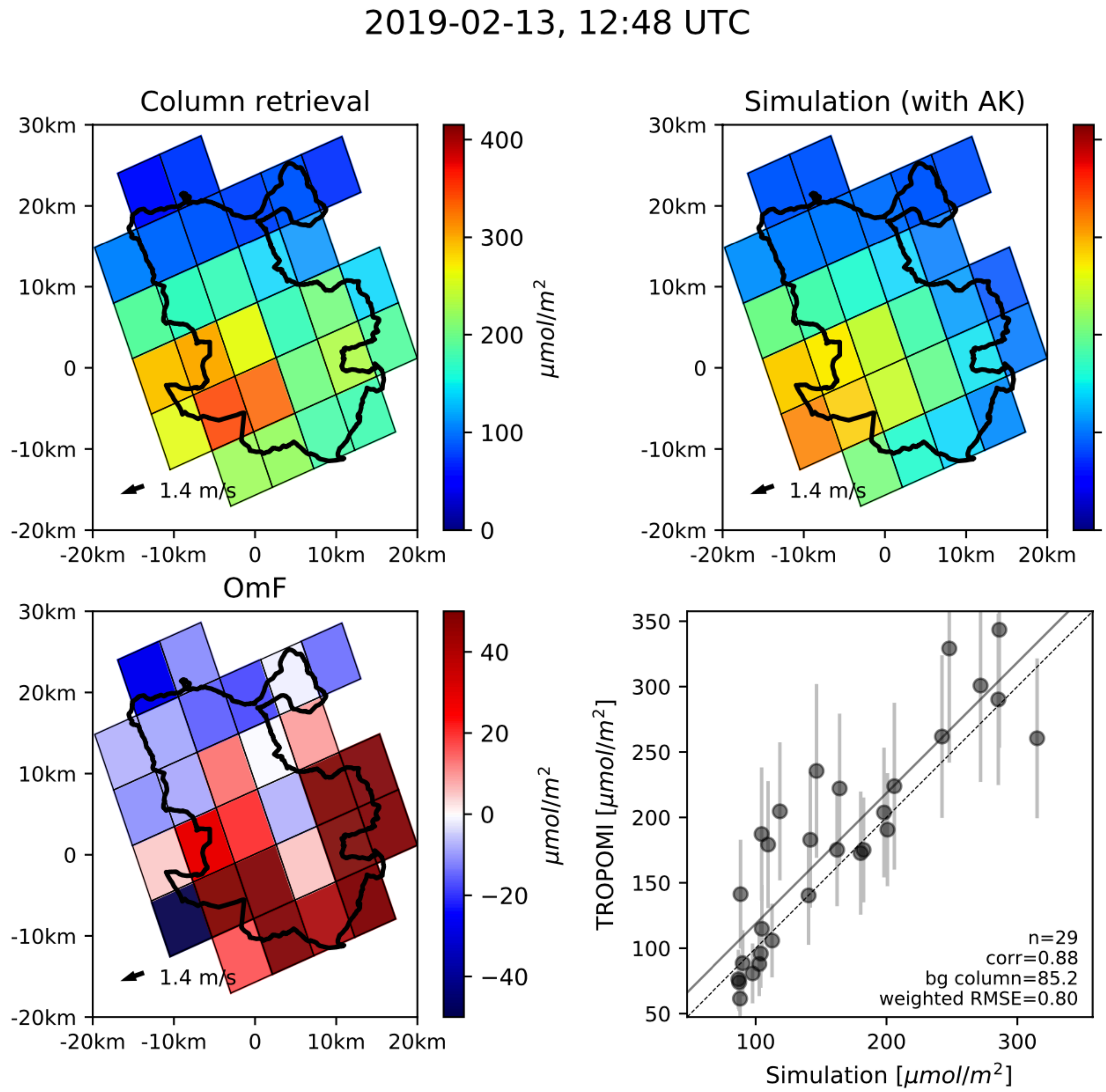




Leave-one-out cross validation

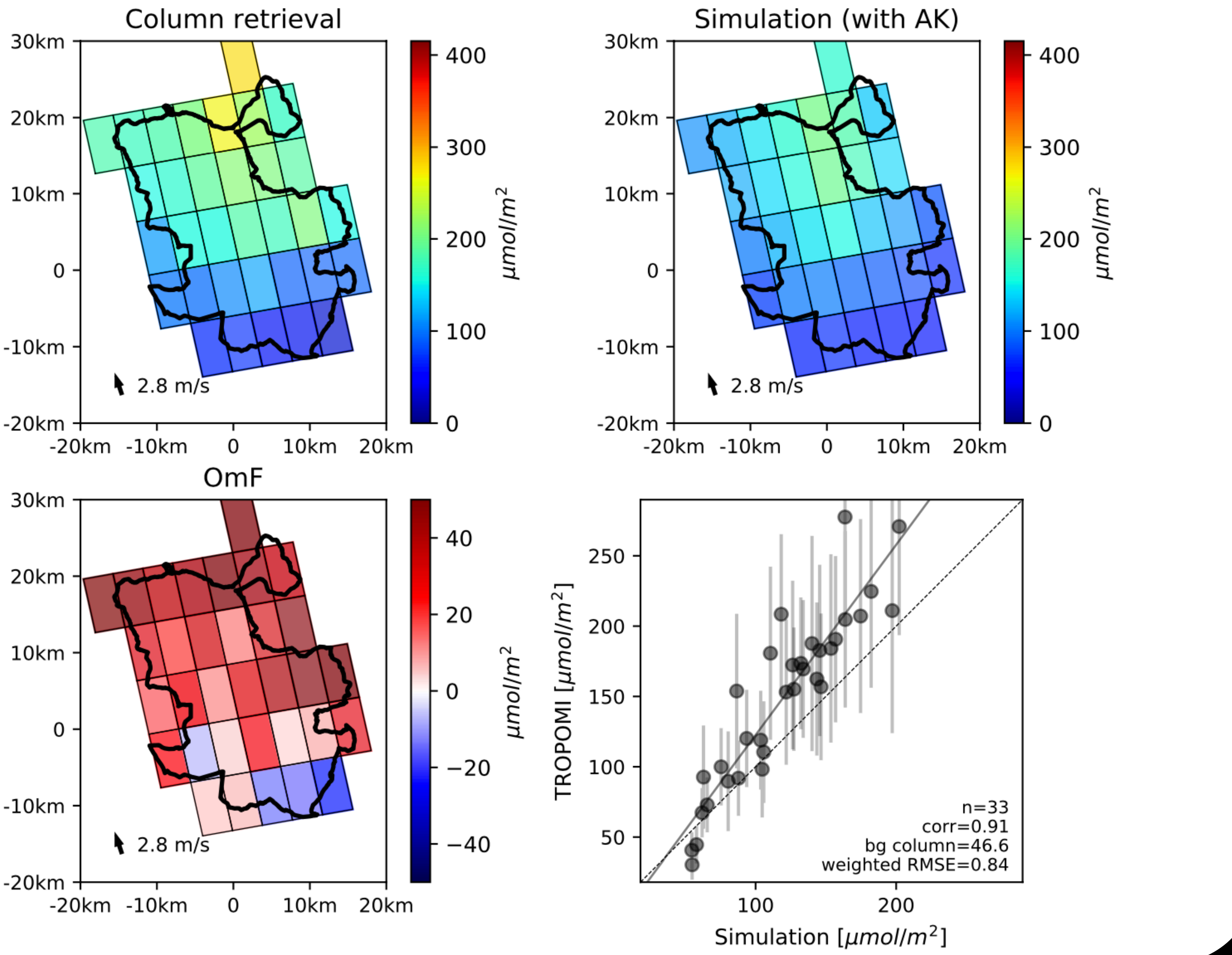
Twin model for atmospheric dispersion

Blink-surface	Blink-3D
Madrid domain (40 x 43 km^2)	
Fast dispersion calculation based on emission kernels calculated by AERMOD	
Simulations for separate emission sectors: traffic, residential, hotspots	
Surface level only	9 horizontal levels, up to 5 km
10 meter resolution ("street level")	250 meter resolution
NO2 ratio from Ozone Limiting Method, based on CAMS ozone background	NO2 ratio from CAMS regional ensemble
Background NO2 taken from CAMS	Background column unknown

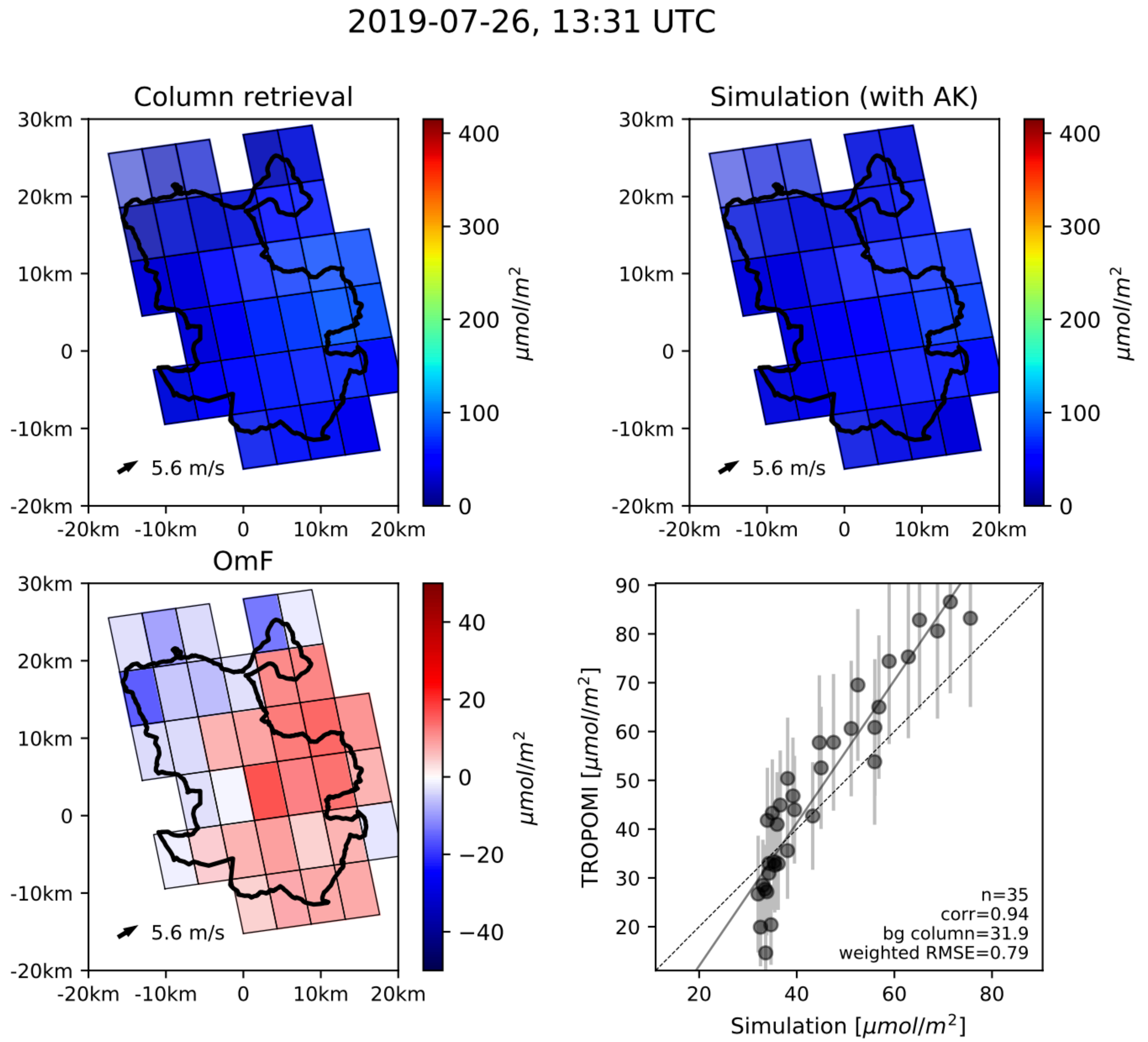


ground
to
column

2019-04-16, 13:25 UTC



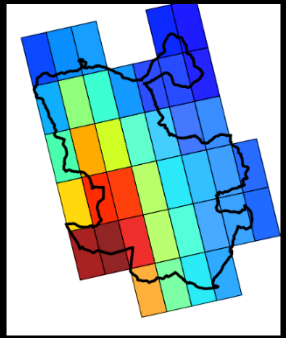
ground to column



ground
to
column

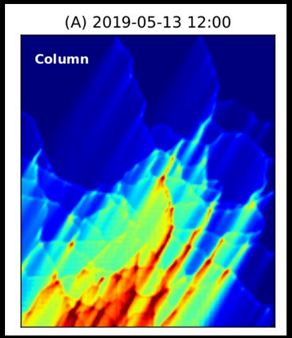
Column to Ground

(sector fit by linear regression)



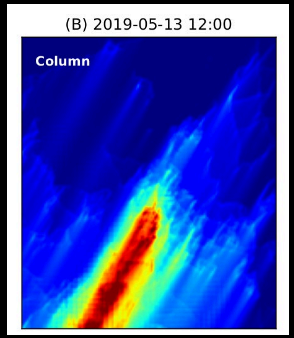
TROPOMI column

$= c_A$



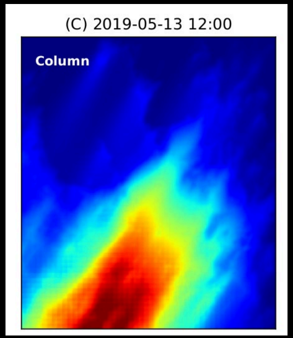
Highway contribution

$+ c_B$



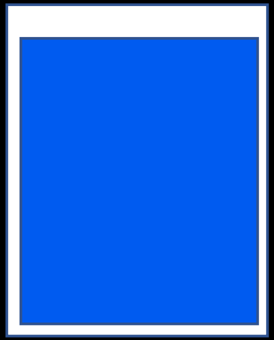
Primary road contribution

$+ c_C$



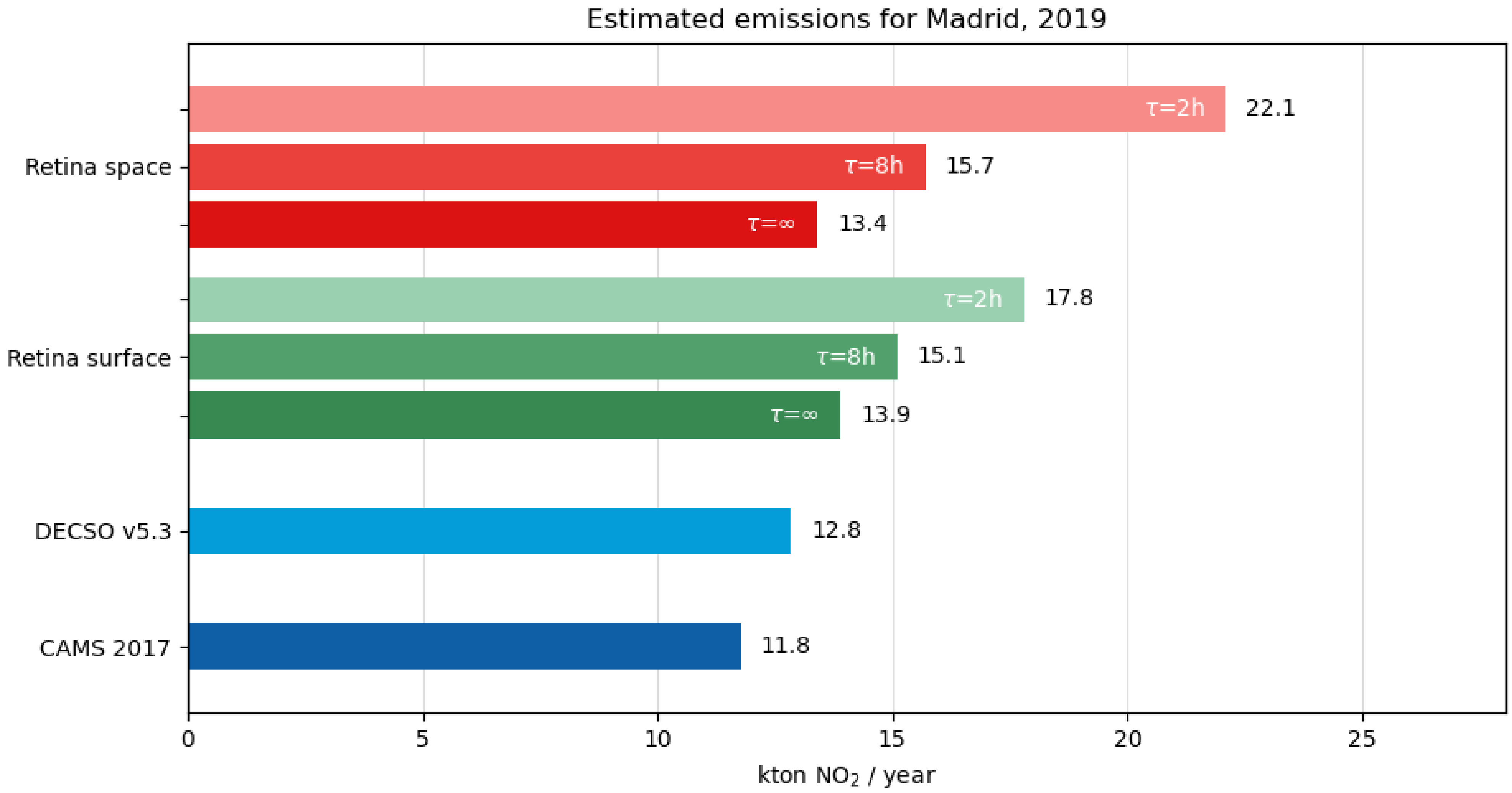
Residential contribution

$+$



Background

Estimated 2019 emissions for Madrid



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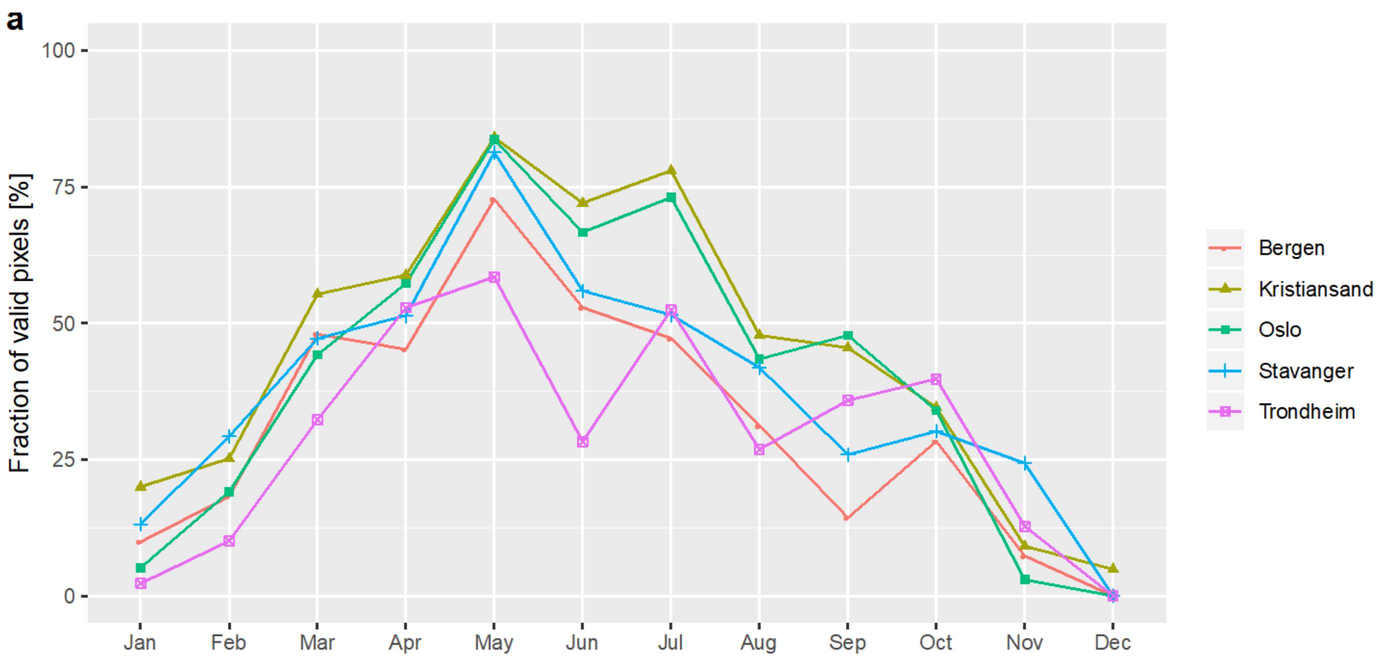
CitySatAir Oslo Case Study

esa

- Oslo: a challenging case due to
  - Relatively low/localised pollution levels
  - Abundant cloud cover
  - Low light level in the winter months
- Goal: Exploit S5P/TROPOMI NO_2 TVCD for urban-scale applications in Norway.
- Two approaches:
  - **Indirect approach**: Spatiotemporal correction of bottom-up emissions
  - **Direct approach**: Geostatistical downscaling to higher spatial resolutions



S5P NO_2 data availability throughout the year over major cities in Norway

Schneider, P., Hamer, P. D., Kylling, A., Shetty, S., & Stebel, K. (2021). Spatiotemporal Patterns in Data Availability of the Sentinel-5P NO2 Product over Urban Areas in Norway. Remote Sensing, 13(11), 2095.

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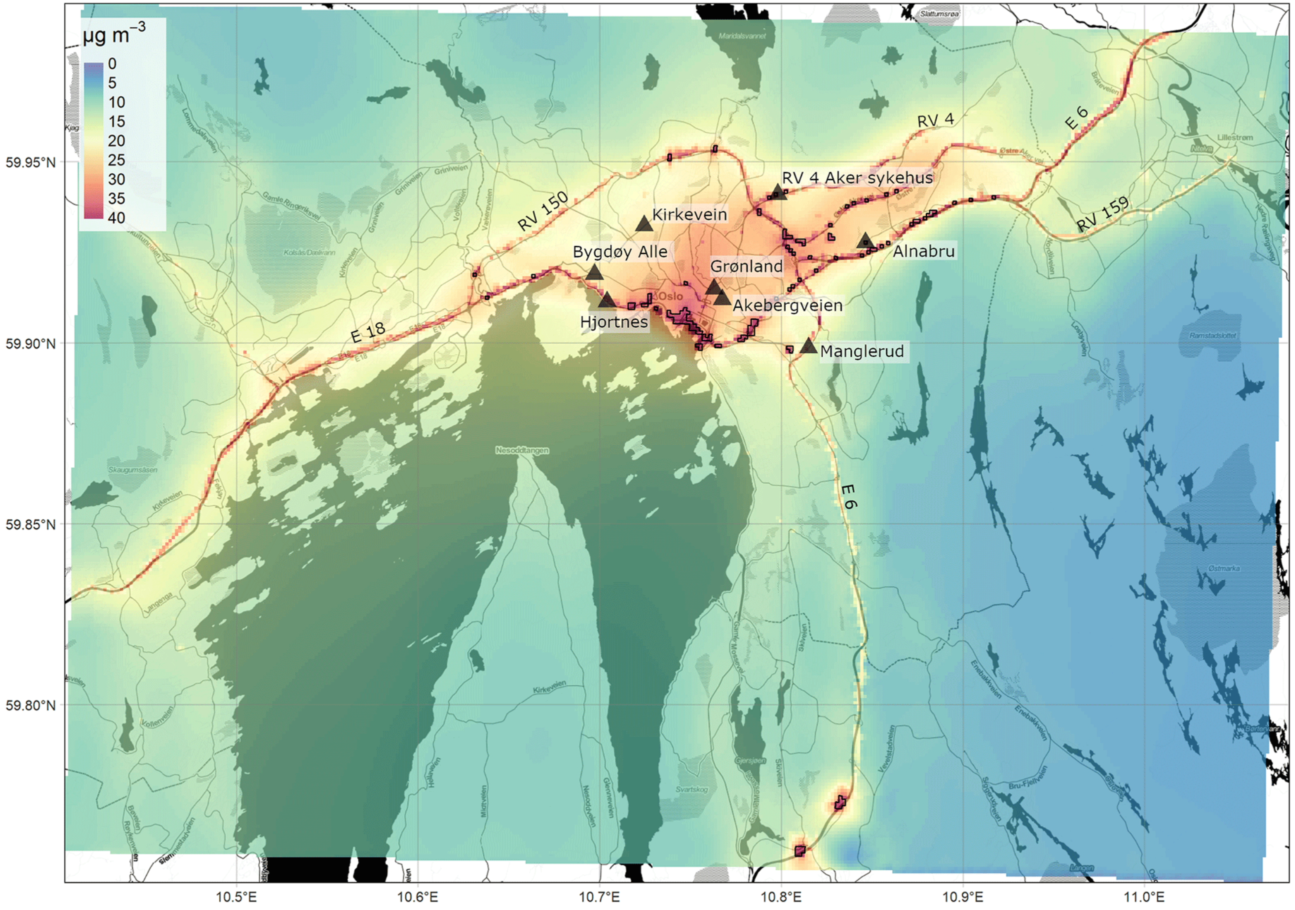
The EPISODE urban dispersion model

- Eulerian grid-scale model that allows coupling with regional scale models, e.g., CAMS.
- Sub grid models consist of a combination of *Gaussian line and point source dispersion models*.
- Simultaneous and seamless representation of urban background and fine scales.
- Computationally cheap to solve the equations of motion.
- Adaptable approach allows incoporation of more sophisticated sub-grid models, e.g., Operational Street Pollution Model (OSPM).



Annually averaged NO_2 concentrations (µg m^{-3}) from the EPISODE model over Oslo (100 m × 100 m horizontal resolution). The black triangles indicate the locations of air quality observation stations.

Hamer, P. D., Walker, S.-E., Sousa-Santos, G., Vogt, M., Vo-Thanh, D., Lopez-Aparicio, S., Schneider, P., Ramacher, M. O. P., & Karl, M. (2020). The urban dispersion model EPISODE v10.0 – Part 1: An Eulerian and sub-grid-scale air quality model and its application in Nordic winter conditions. *Geoscientific Model Development*, *13*(9), 4323–4353.

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Indirect exploitation: EPISODE processing

The **urban dispersion model EPISODE** (Hamer et al, 2020) was used. Processing steps included:

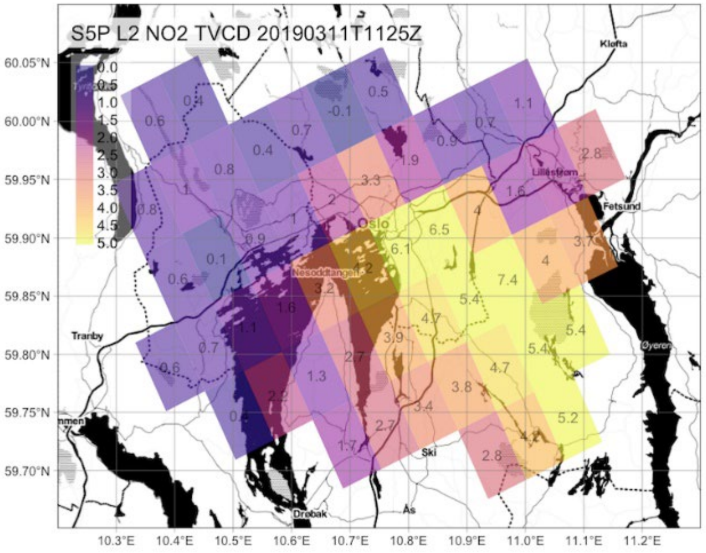
1. Temporal interpolation of the hourly EPISODE data to the exact TROPOMI overpass time.

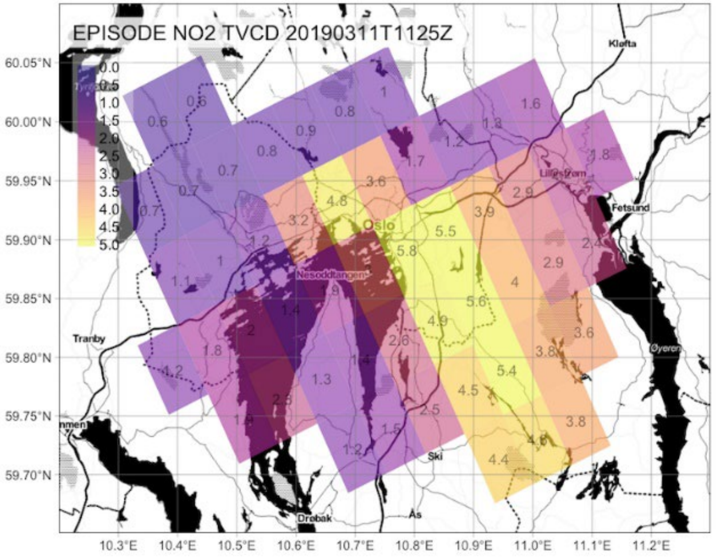
2. The temporally interpolated data is **projected to the CRS of the target geometry** and **spatially interpolated** to the irregular TROPOMI L2 pixel footprints using **areal-weighted** polygon-to-polygon interpolation

3. Vertically interpolate the NO_2 concentration to the vertical layers of the TM5 model from the retrieval.

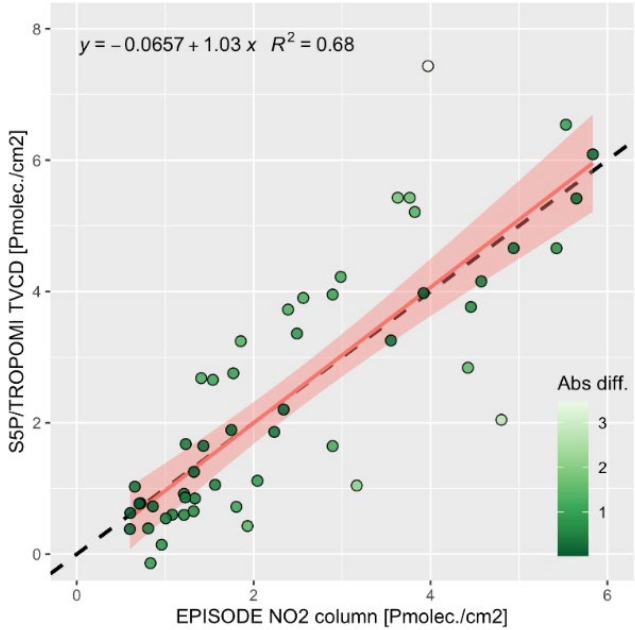
4. Application of the **TROPOMI L2 averaging kernel** to the output from Step 3 on a pixel-by-pixel and layer-by-layer basis.

5. Calculation of **partial NO_2 columns** for each TM5 layer, and **vertical integration** and **conversion** to units of 10^{15} molec. cm^{-2}.





NO_2 plumes originating from Oslo seen as S5P TVCD (left) and EPISODE TVCD (right) for 11 March 2019 at 11:25 UTC (units in Pmolec/cm2).



EPISODE-derived NO_2 columns against S5P/TROPOMI NO2 columns for the overpass on 11 March 2019 at 11:25 UTC. Each marker represents one TROPOMI pixel geometry. Red line: linear regression fit to the data. Black dashed line: 1:1 reference line.

Hamer, P. D., Walker, S.-E., Sousa-Santos, G., Vogt, M., Vo-Thanh, D., Lopez-Aparicio, S., Schneider, P., Ramacher, M. O. P., & Karl, M. (2020). The urban dispersion model EPISODE v10.0 – Part 1: An Eulerian and sub-grid-scale air quality model and its application in Nordic winter conditions. Geoscientific Model Development, 13(9), 4323–4353.

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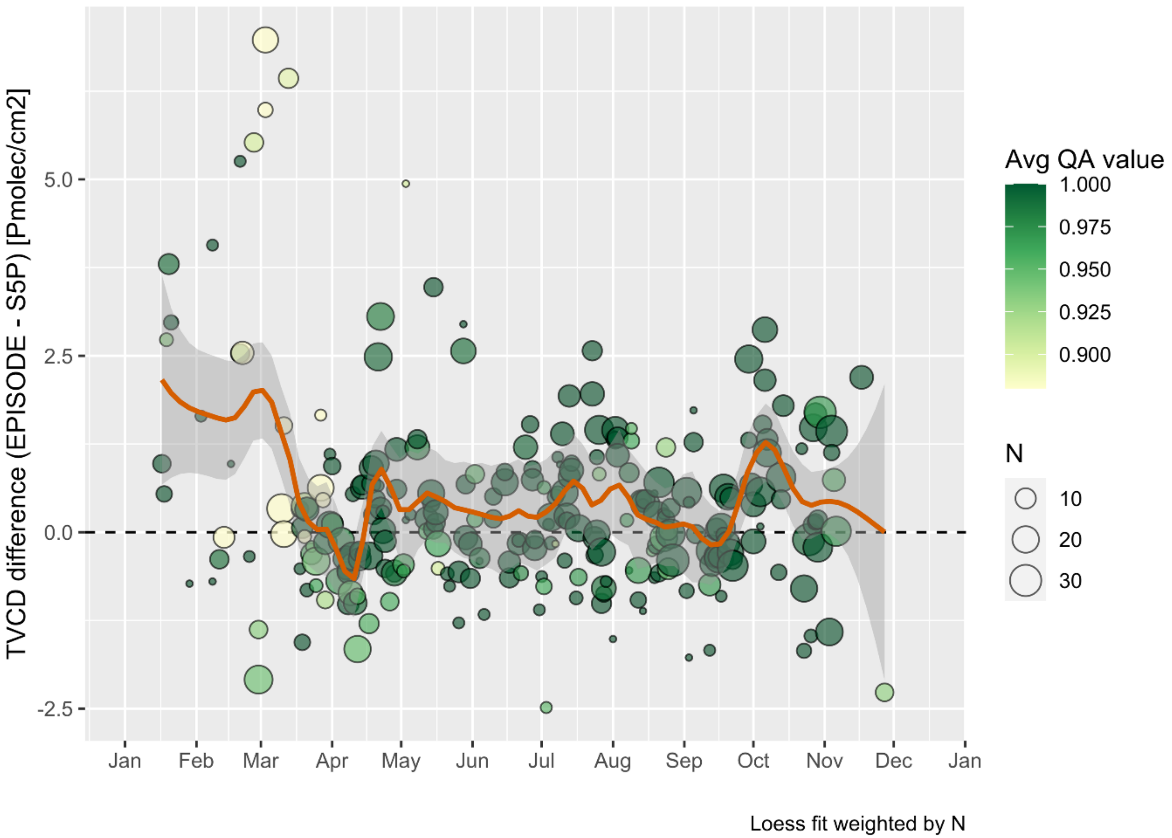
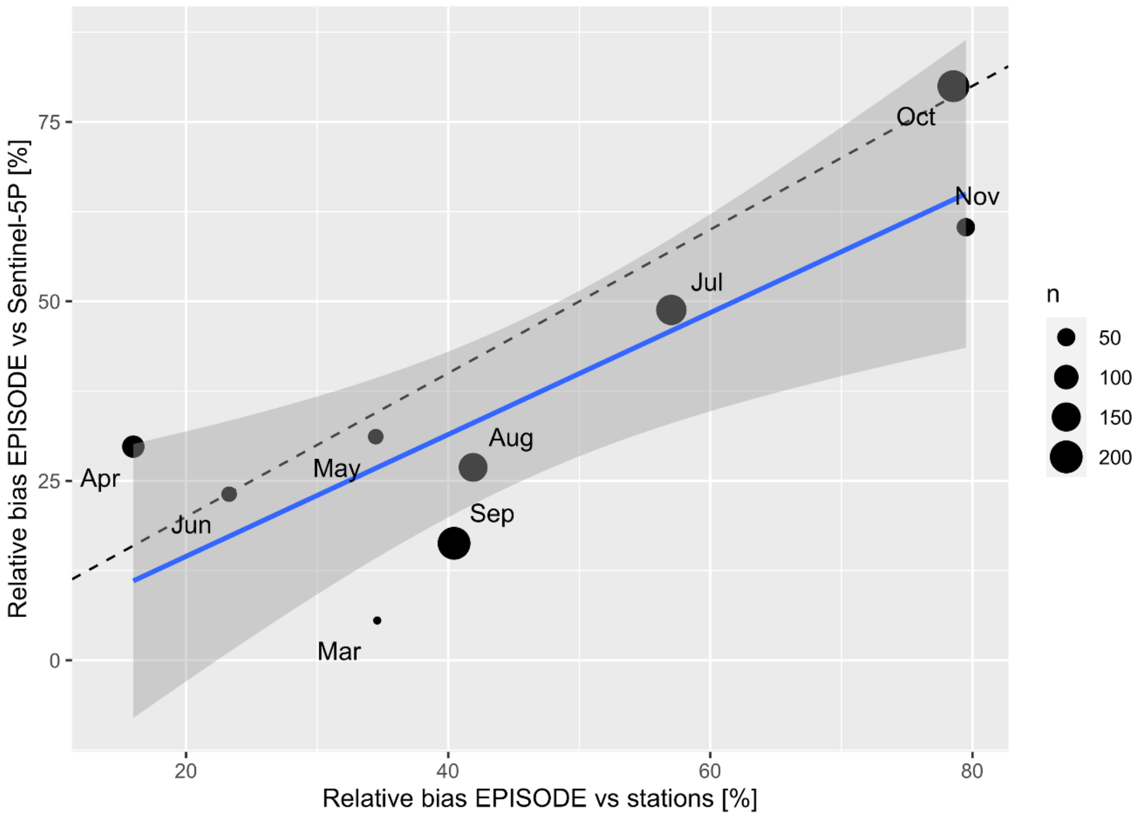
Indirect exploitation: Satellite-model biases



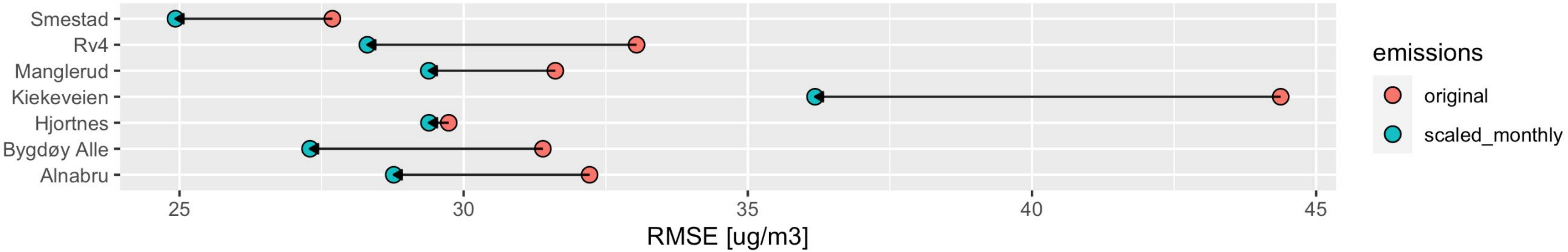
The S5P-EPISODE difference shows biases in model output throughout the year.



S5P-derived model bias agrees well with model bias against stations throughout the year.

Indirect exploitation: Satellite-based emission correction

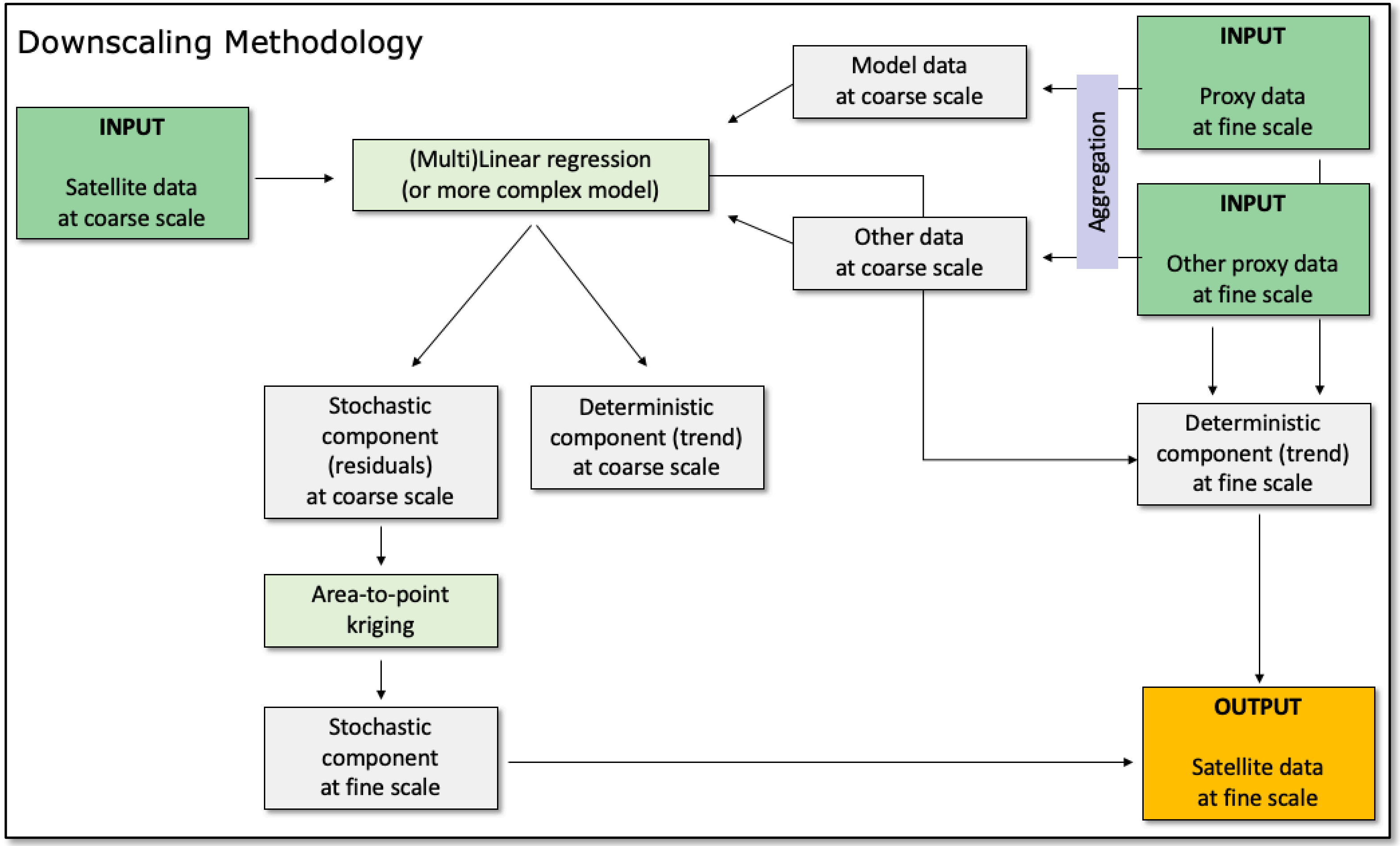
1. The S5P-derived monthly correction factors were applied to the bottom-up emissions.
2. EPISODE was re-run with the bias-corrected emissions for the entire year
3. New model output was compared against observations from reference stations



S5P/TROPOMI-corrected emissions result in up to **20% higher accuracy of the model** throughout the year.

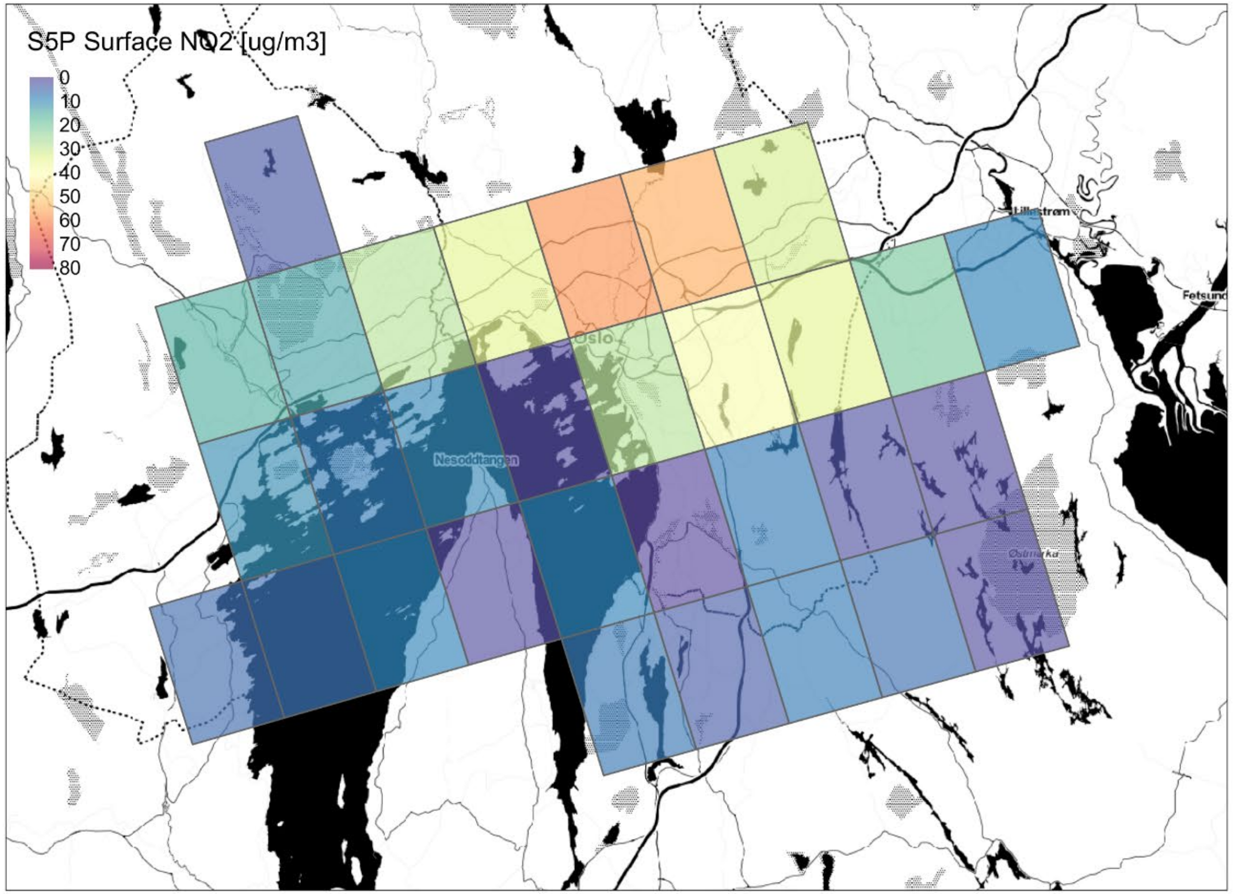
Direct exploitation: Geostatistical Downscaling

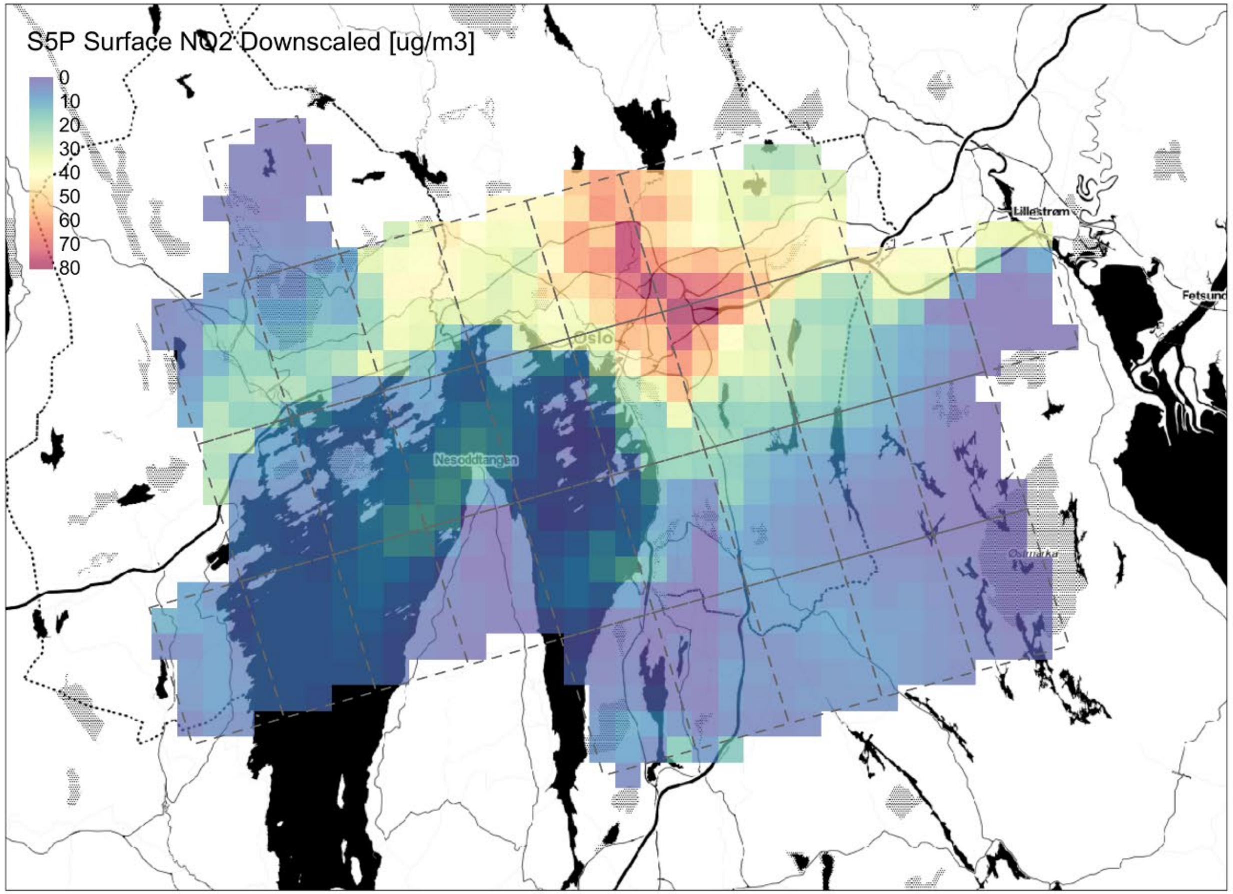
- Geostatistical downscaling allows for increasing the spatial resolution of the S5P NO_2 data by exploiting the spatial patterns from a high-resolution proxy dataset
- We first derive **surface NO_2 concentration** using the EPISODE-based column-to-surface ratio
- Then the **surface NO_2 dataset is downscaled** using residual area-to-point kriging



Stebel, K., Stachlewska, I. S., Nemuc, A., Horálek, J., Schneider, P., Ajtai, N., Diamandi, A., … Zehner, C. (2021). SAMIRA-SAtellite Based Monitoring Initiative for Regional Air Quality. *Remote Sensing*, *13*(11), 2219.

Direct exploitation: Geostatistical Downscaling





Geostatistical **downscaling of S5P-derived surface NO_2** (using the surface-to-column ratio approach) results in **improved spatial resolution** with **realistic spatial patterns**.

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Conclusions

- CitySatAir explores suitable ways for exploiting S5P NO_2 data together with high-resolution models for urban AQ mapping
- Primary focus on correcting the underlying emission datasets
- For the **Madrid case study** we developed a versatile algorithm for observation-based monitoring of air pollution at street-level
  - Based on the AERMOD dispersion model
  - Dynamically calibrated with recent measurements
  - Capable to assimilate low-cost and reference measurements
  - Urban emissions can be estimated from surface and from space observations. Both agree well.
- For the **Oslo case study** we developed and applied two approaches
  1. Indirect exploitation of of S5P NO_2
     - Temporal and spatial emission correction for high-resolution urban-scale dispersion model (EPISODE)
     - Integrating S5P/TROPOMI data significantly improves the model accuracy
     - The "calibrated" model is suited for assimilating observations from stations and low-cost sensor networks
  2. Direct approach: Geostatistical downscaling
     - Geostatistical downscaling with a fine-scale proxy dataset is a a robust method for increasing the spatial resolution of TROPOMI data for urban applications

More information:

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Website: https://citysatair.nilu.no/

References:

Hamer, P. D., Walker, S.-E., Sousa-Santos, G., Vogt, M., Vo-Thanh, D., Lopez-Aparicio, S., Schneider, P., Ramacher, M. O. P., & Karl, M. (2020). The urban dispersion model EPISODE v10.0 – Part 1: An Eulerian and sub-grid-scale air quality model and its application in Nordic winter conditions. Geoscientific Model Development, 13(9), 4323–4353.

Mijling, B. (2020): High-resolution mapping of urban air quality with heterogeneous observations: a new methodology and its application to Amsterdam, Atmos. Meas. Tech., 13, 4601–4617

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