Anthropogenic and natural aerosols in the atmosphere – examples of practical applications of modelling and measurements

Małgorzata Werner & co-authors

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Introduction – what is the motivation? Why are we worried about air pollution?

- **Air pollution & health**

Chemical pollutants (e.g. PM2.5, UFP): respitarory, cardiovascular system, other.

- **Increasing thrend in allergies – allergenic pollen (natural pullutants)**

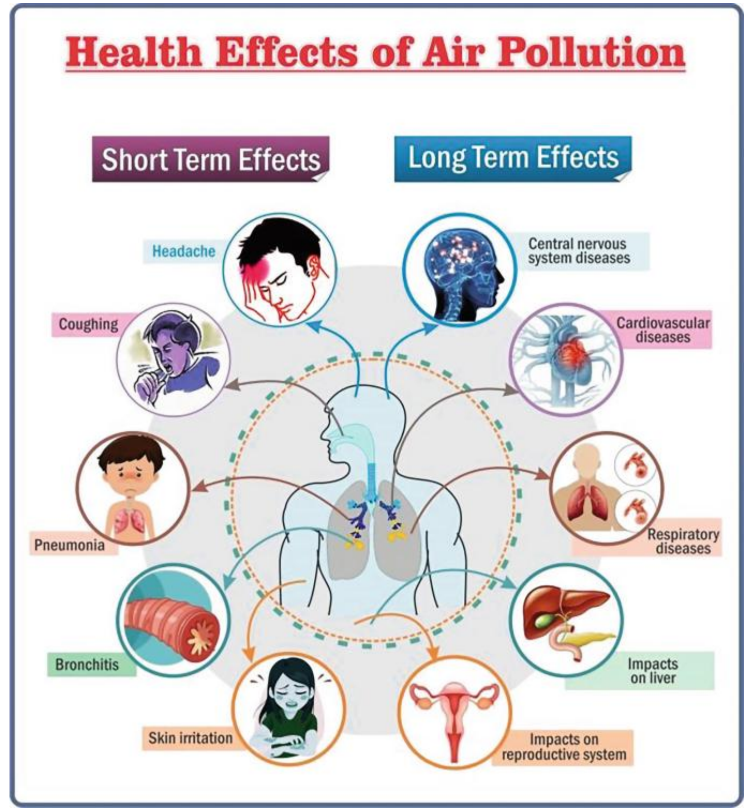
Pollen grains: allergic rhinitis/hay fever, asthma attacks.

- **Aerosol implications on environment/climate**

Direct radiative effects; scattering aerosols, absorbing aerosols.

Cloud-aerosol interactions.

Semi-direct effects.



https://link.springer.com/chapter/10.1007/978-3-030-96486-3_10

Introduction – sources of air quality information

- **Numerical modeling and observations** are used to provide spatial and temporal information on air pollution/bioaerosols concentrations.
- **Air quality directive encourages** combining measurement data with modelling methods to assess ambient air pollution levels [AAQD 2024/2881].

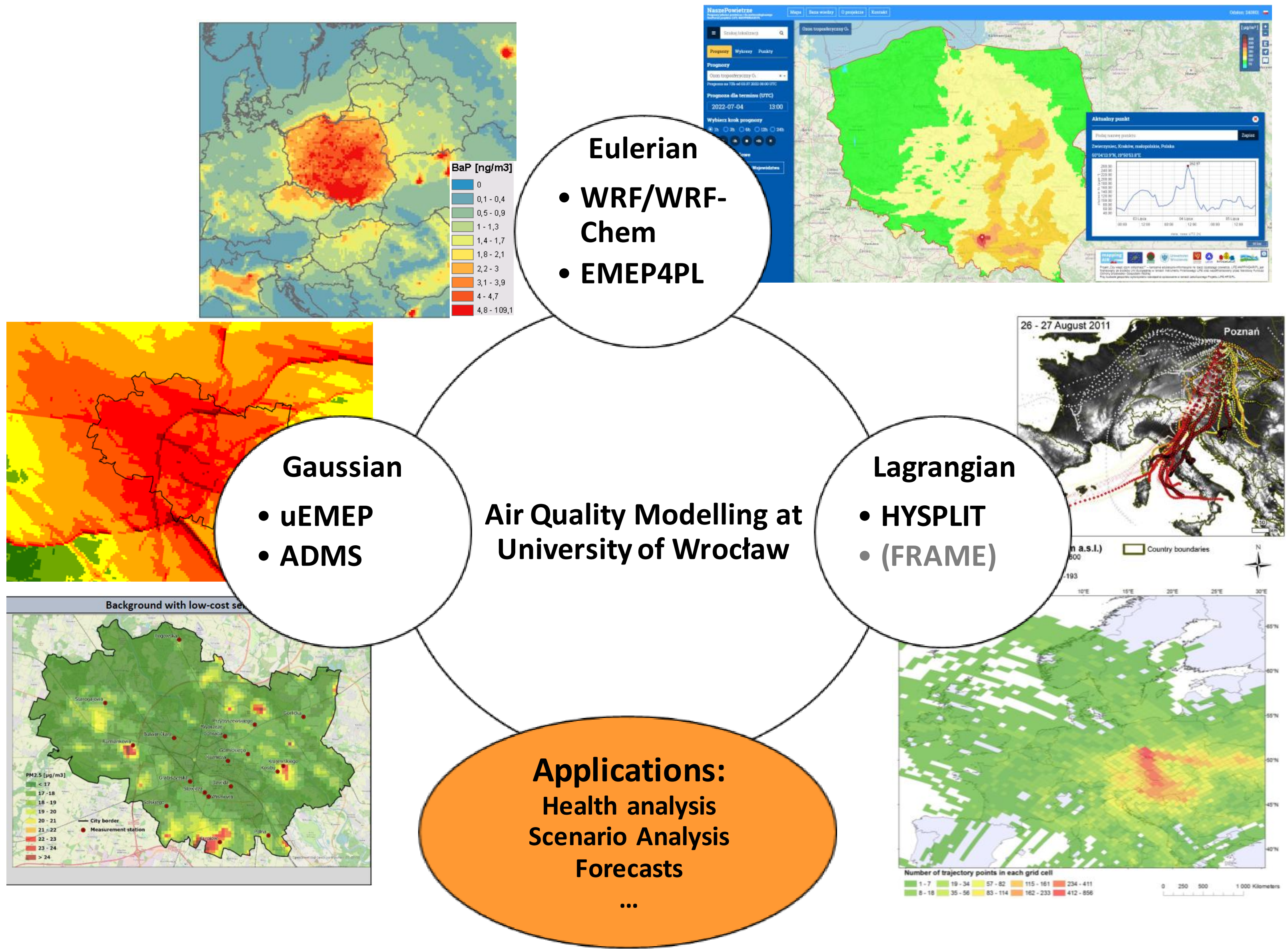
Examples of modeling applications:

- Assessment of the current situation; exceedances of limit values.
- Source apportionment and emission control strategies – to identify which sources contribute the most to pollution levels.
- Air quality scenarios for the future – e.g. emission changes/climate changes.
- Epidemiological studies.
- Air quality forecasts.
- Episodes analysis – e.g. long range transport of Saharan dust, forest fires pollution, volcanic dust.

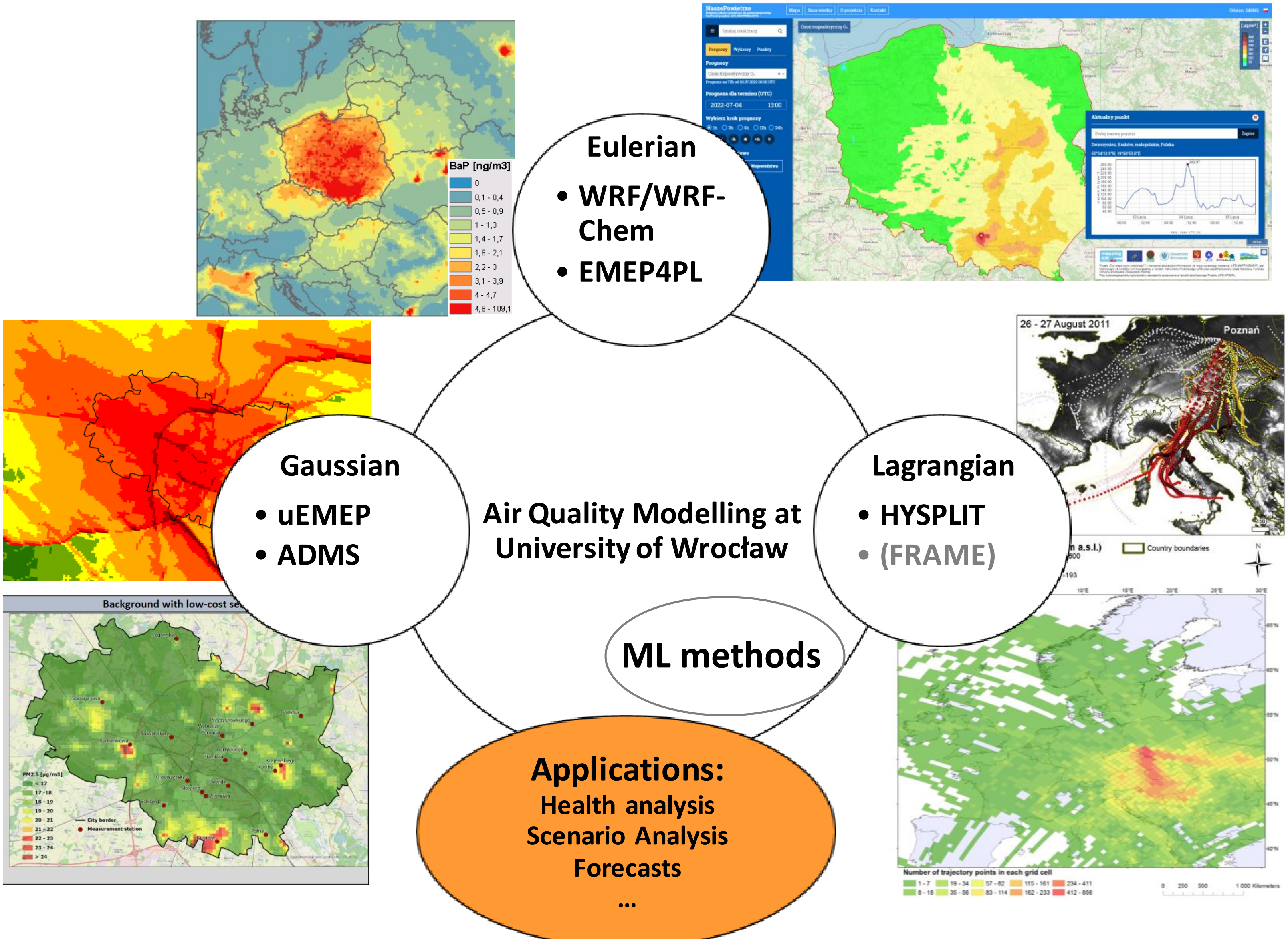
Aim of the presentation

- Present examples of applications of air quality models and measurements for Central-Eastern Europe/Poland.
- Present application of CTMs that are on an open licence (most of them)
  - They can be developed, tested, used for other applications.
  - New parameterisation can be included.
- Focus on results that might be of general interest; hopefully..

Different approaches and complexity of chemical transport models (CTMs)



Different approaches and complexity of chemical transport models (CTMs)



CTMs – basic input data

Meteorological data

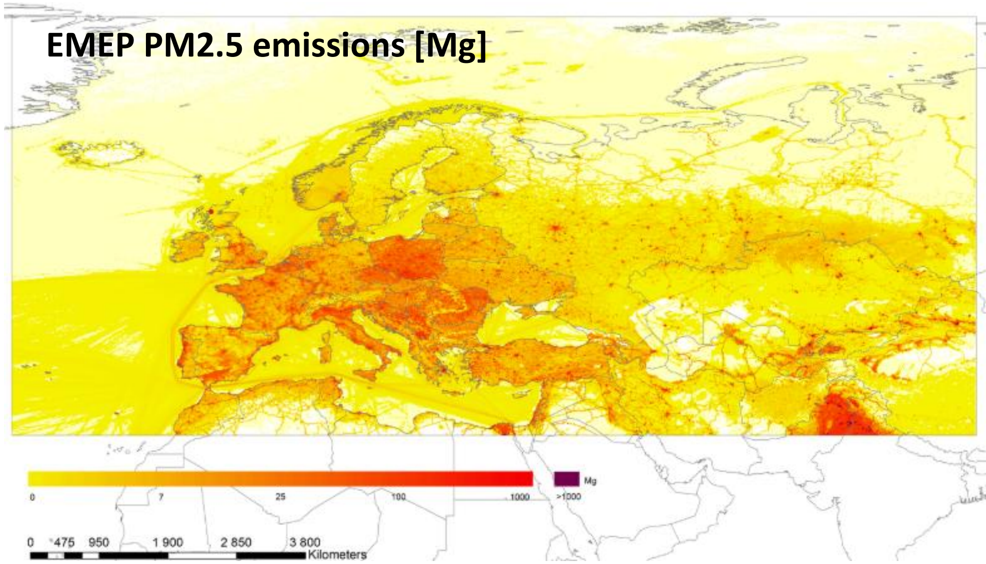
- Usually gridded from a model, e.g. Weather Research and Forecasting (WRF).
- For local models can be from the point observations.
- Basic parameters: T2, WSPD10, WDIR, R, solar radiation.

Emissions

- Gridded or other formats.
- European databases: EMEP, CAMS, EDGAR (global).
- Polish database: National Centre for Emissions Managemant.
- Emission models for local scale, e.g. COPERT for road transport.

Other

- Landuse.
- Digital Elevation Model.
- Observational data: model evaluation & „integration” with CTMS.



Regional scale modelling

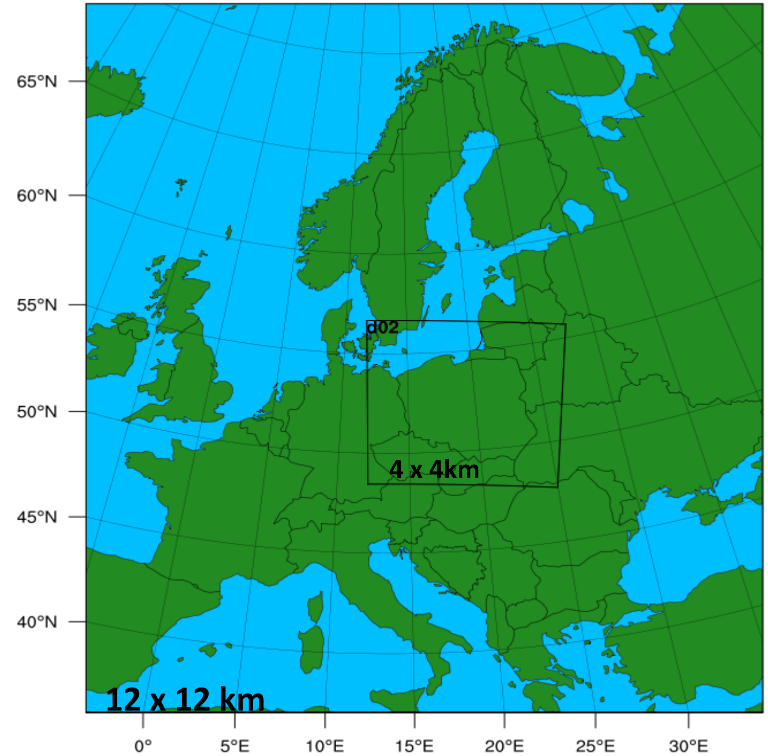
BaP concetrations for Poland

- *Harmfull and cancerogenic compound of PM*
- *Belongs to PAHs (Policyclic Aromatic Hydrocarbons)*
- *Combustion processes*
- *Poland is a hot-spot in Europe*

Main objectives

- Spatial distribution of BaP concentrations over Central Europe [not available at that time for Poland].
  - Adding BaP to CTMs [EMEP4PL] and model evaluation.
  - The impact of winter severity on BaP concentrations and exceedances of the target value.
  - Population exposure to BaP concentrations in Poland.

Methods – modelling framework

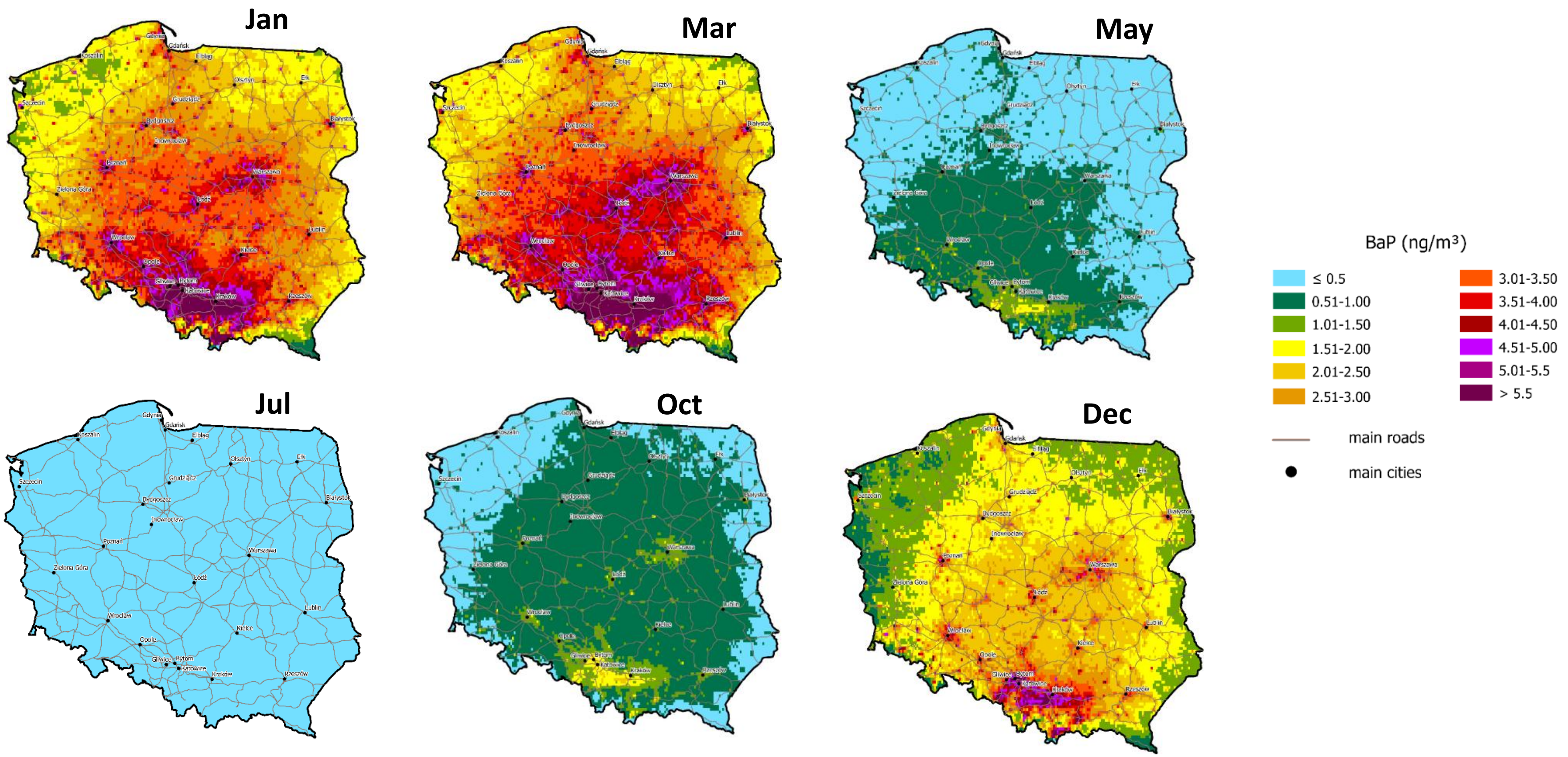


- Chemical transport model: **EMEP4PL**
- Met data: **WRF** model
- Emissions:
  - EMEP 0.1° x 0.1° for Europe
  - Polish database, 1km x 1km

- Simulations design with EMEP4PL
  - **average**: 2018, meteorology **2018**, emissions **2018**
  - **cold**: 2010, meteorology **2010**, emissions **2018**
  - **warm**: 2020, meteorology **2020**, emission **2018**

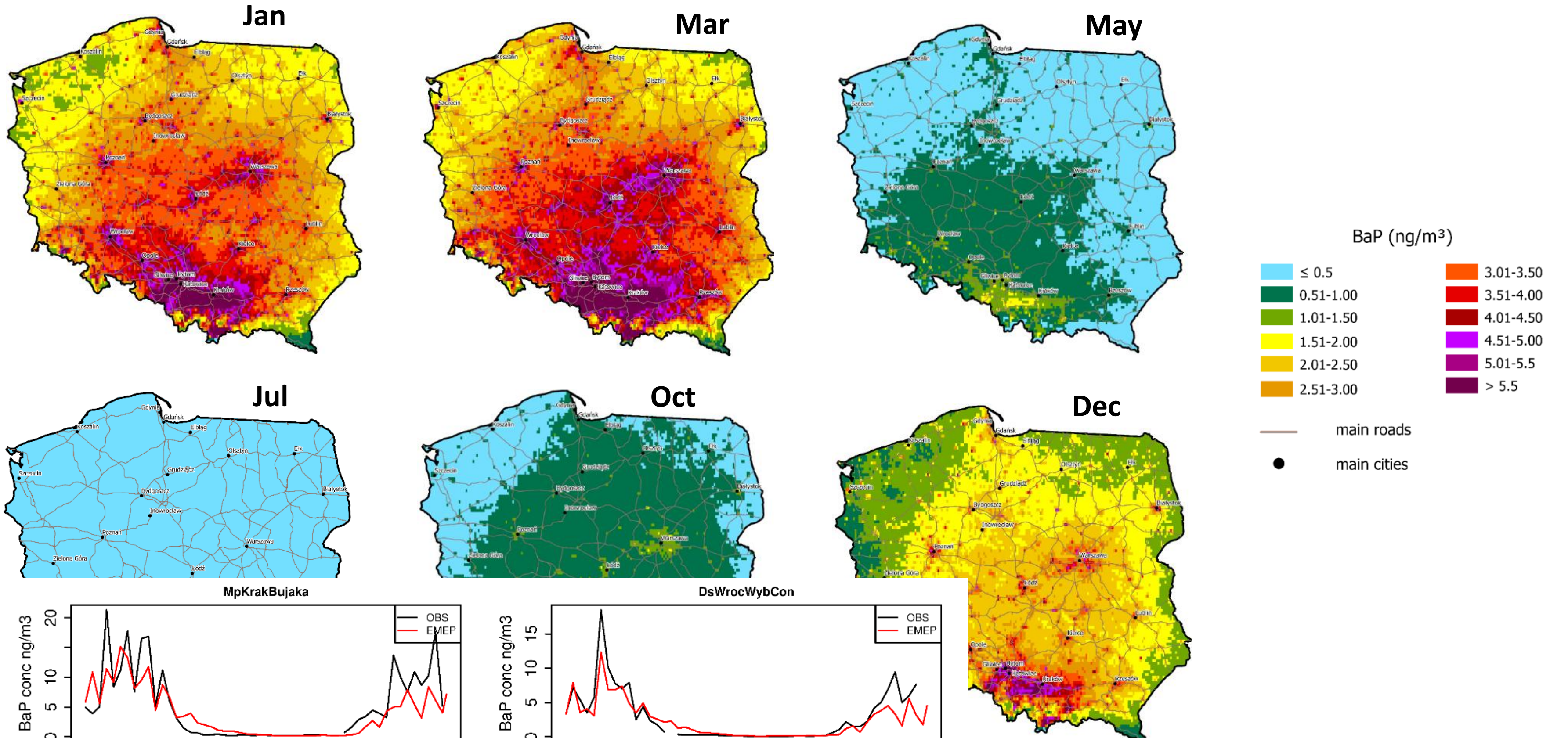
- Validation
  - Weekly data from CIEP for the year 2018, 120 stations

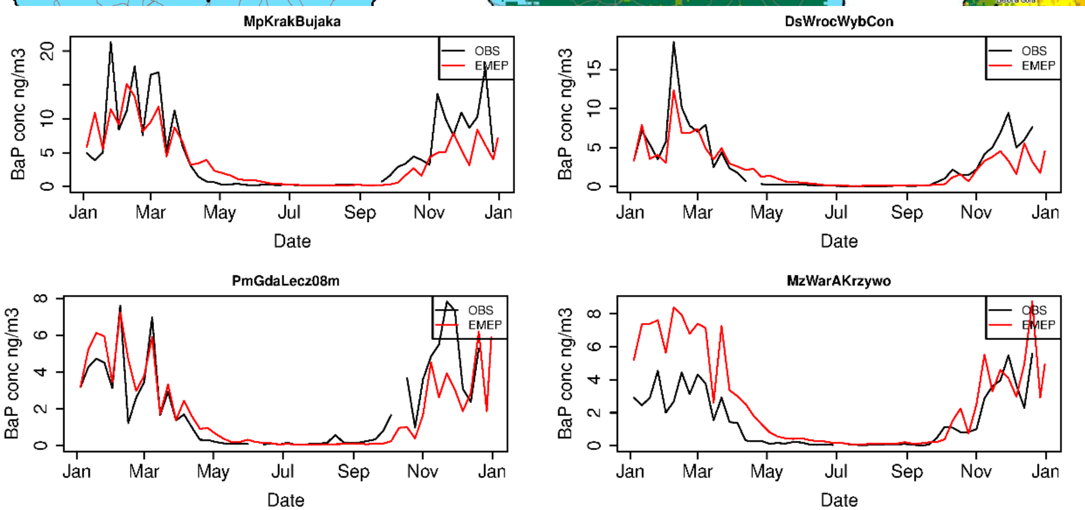
BaP concentrations, monthly, 2018



winter: 20 x higher than summer

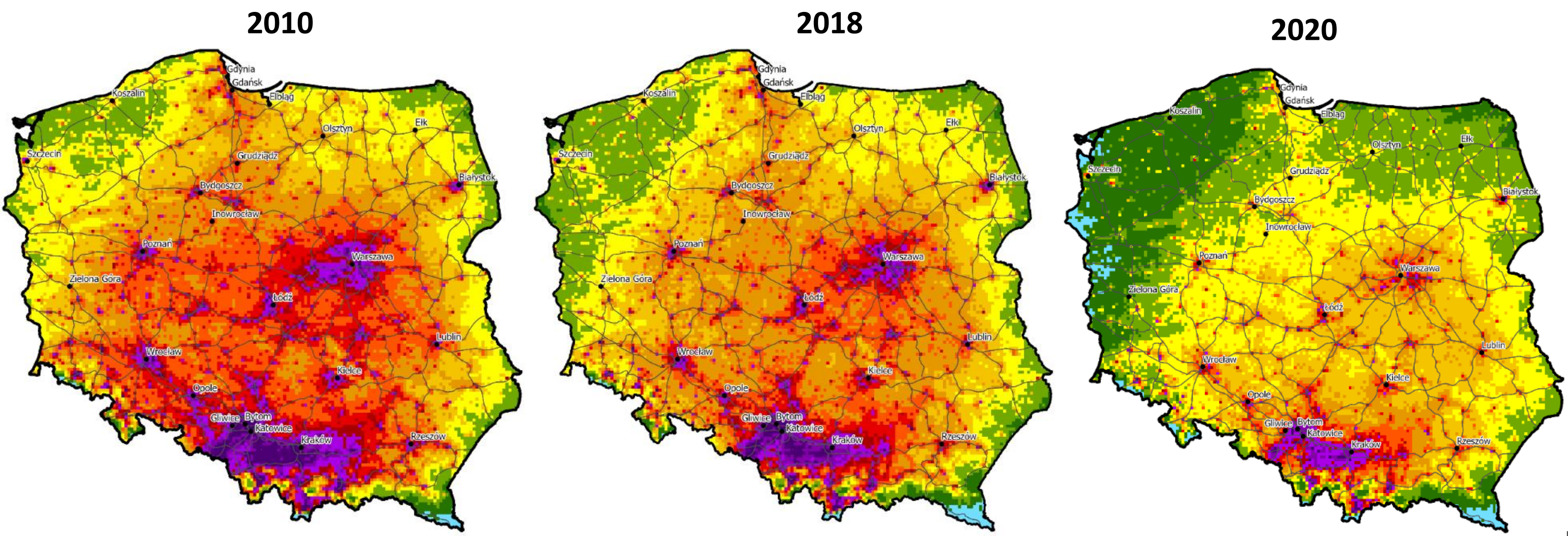
BaP concentrations, monthly, 2018

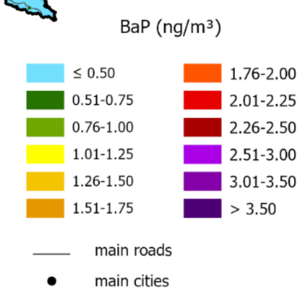




Time series of modelled and observed BaP concentrations in 2018 in Krakow, Wroclaw, Gdańsk, Warszawa.

BaP annual mean, 2010, 2018, 2020





Annual Target Value: 1 ng/m^3

Population exposure to BaP annual mean concentrations for the year 2010, 2018 and 2020

BaP, year, annual average, exposed population (%)				
< TV		> TV		
< 0.12 ng m^{-3}	0.12 – 1 ng m^{-3}	1 – 2 ng m^{-3}	2 – 4 ng m^{-3}	> 4 ng m^{-3}
2018				
0	3	41	52	4
2010				
0	2	37	58	4
2020				
0	10	57	32	1

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		2018		
0	3	41	52	4
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		2020		
0	10	57	32	1

> 90% of population is exposed to BaP above 1 ng

Population exposure to BaP annual mean concentrations for the year 2010, 2018 and 2020

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		2018		
0	3	41	52	4
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		2020		
0	10	57	32	1

In average and cold year, > 50% of population is exposed to BaP at least 2 x higher that the target value.

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Full length article

Modelling benzo(a)pyrene concentrations for different meteorological conditions – Analysis of lung cancer cases and associated economic costs

Paweł Porwisiak [a,*], Małgorzata Werner [a], Maciej Kryza [a], Massimo Vieno [b], Mike Holland [c], Helen ApSimon [d], Anetta Drzeniecka-Osiadacz [a], Krzysztof Skotak [e], Lech Gawuc [e], Karol Szymankiewicz [e]

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[b] UK Centre for Ecology & Hydrology, Edinburgh Research Station, Bush Estate, Penicuik, Midlothian EH26 0QB, UK
[c] Ecometrics Research and Consulting, Reading RG8 7PW, UK
[d] Centre for Environmental Policy, Imperial College London, London SW7 1NE, UK
[e] Institute of Environmental Protection–National Research Institute, Krucza 5/11D, 00-548 Warsaw, Poland

Local scale modeling

Modelling of PM2.5 concentrations for Wrocław

Main objectives

Application of ADMS – Urban to:

- Recognise the spatial structure of PM2.5 concentrations in the city.
- Estimate the contribution of major emission sources.
- Assess the role of local sources and inflow from outside the city.

Data and methods

- Chemical transport model: **ADMS-Urban**
- Met data: **observations** from UWr station
  - Temperature, wind speed and direction, precipitation, relative humidity, cloud cover
  - Year 2022
- Emissions
  - Road transport: **COPERT** model+traffic model – line emissions
  - Polish database, points or grids depending on the sector
- Observations data from CIEP for the model evaluation (2 sites in Wrocław).

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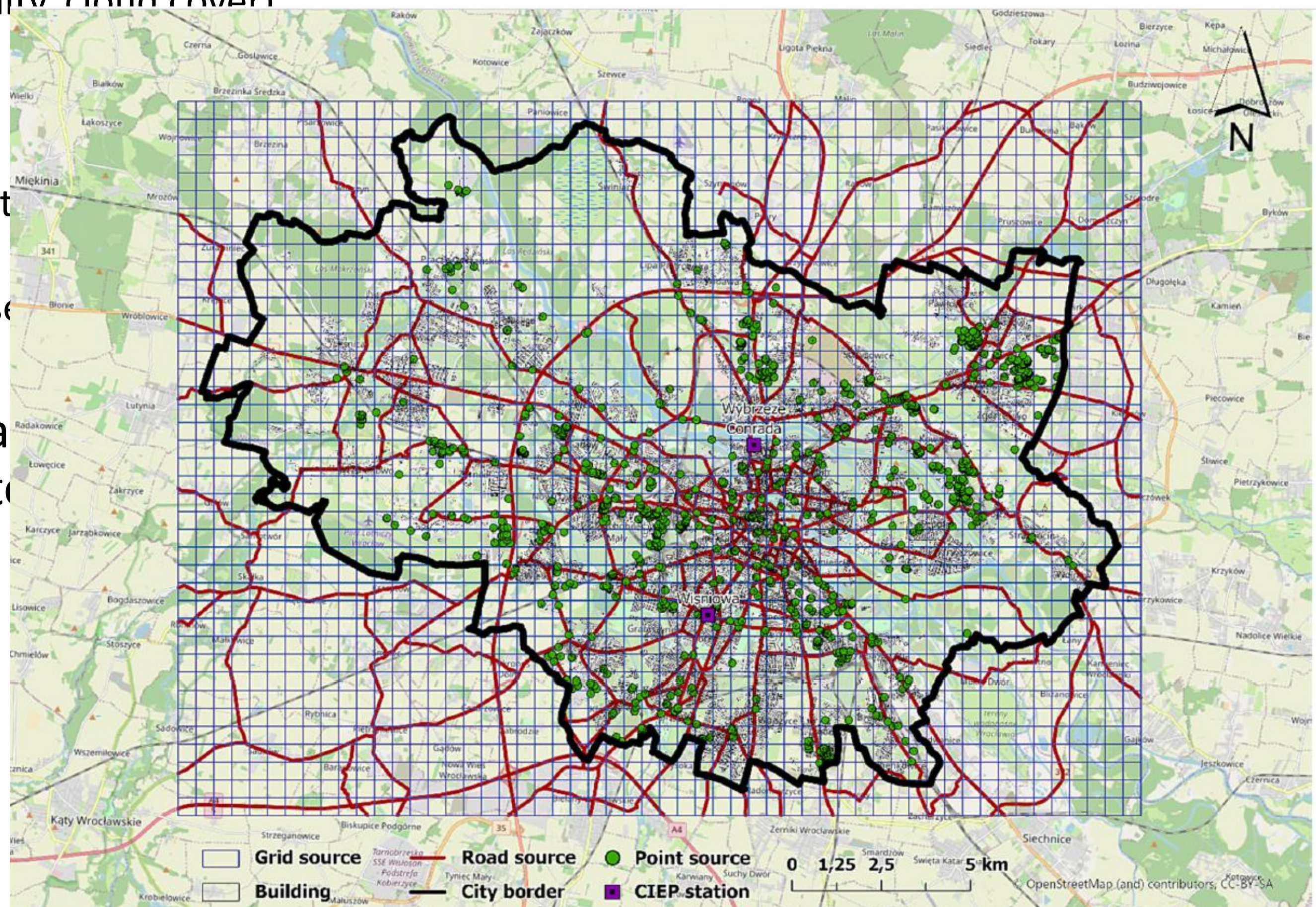
- Emissions
    - Road transport emissions
    - Polish database sector
- Observations da evaluation (2 sit



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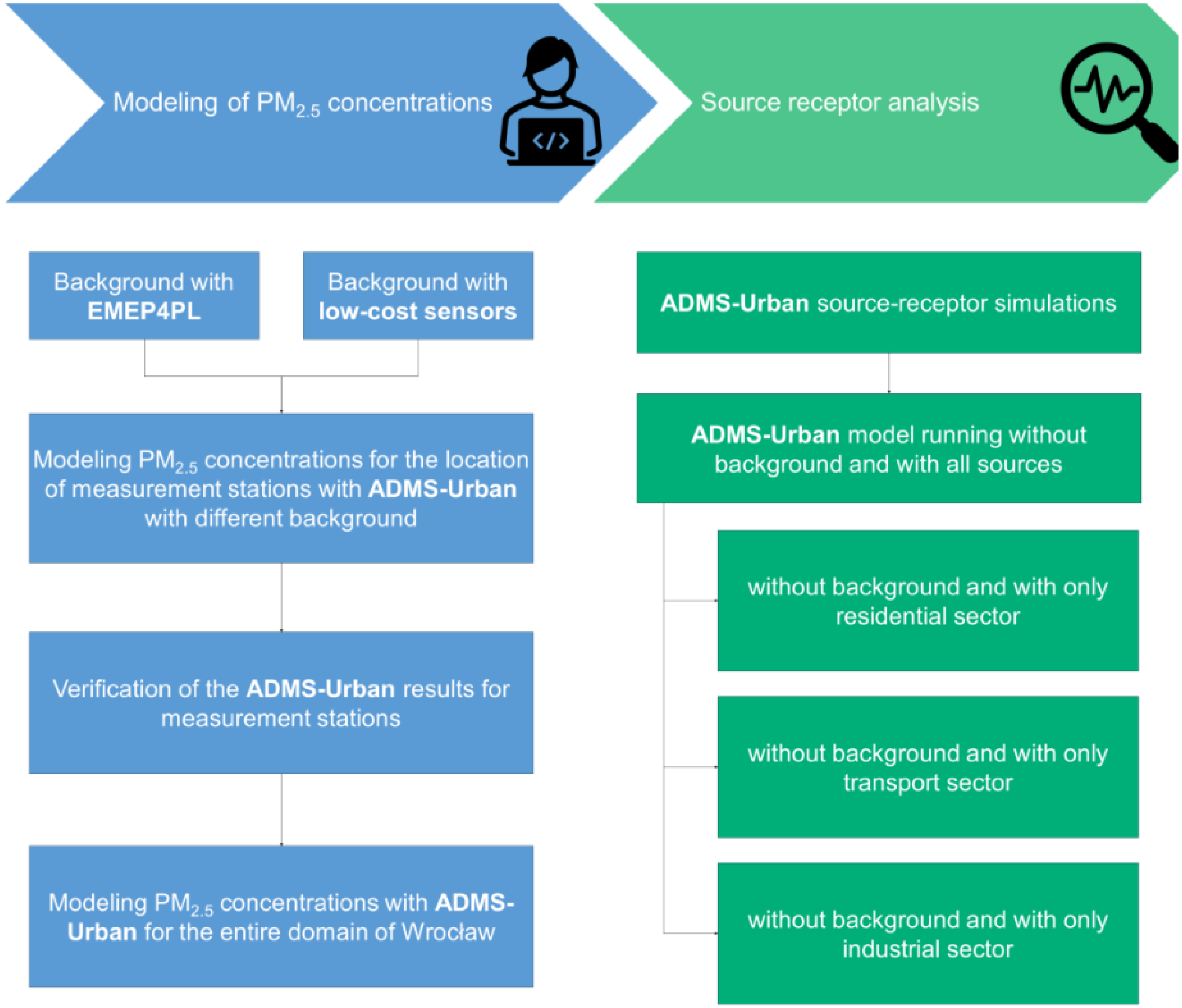
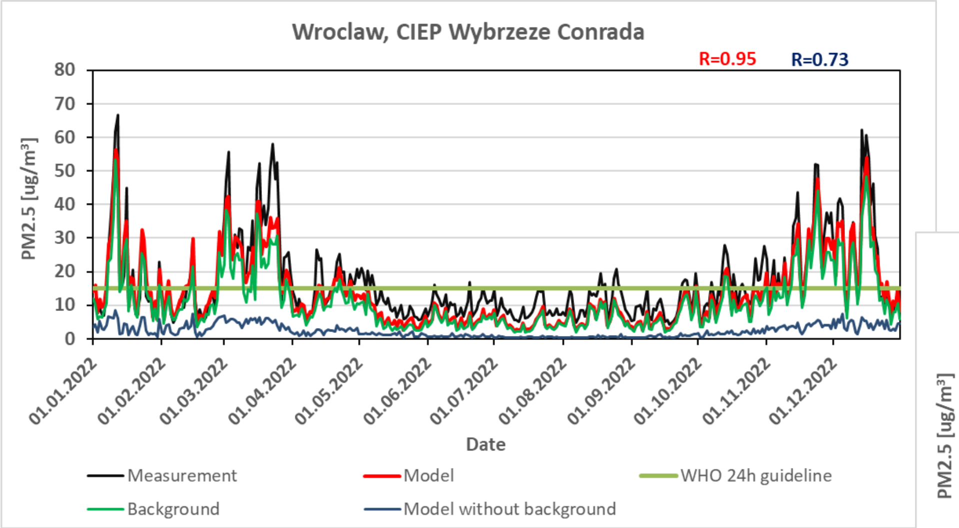
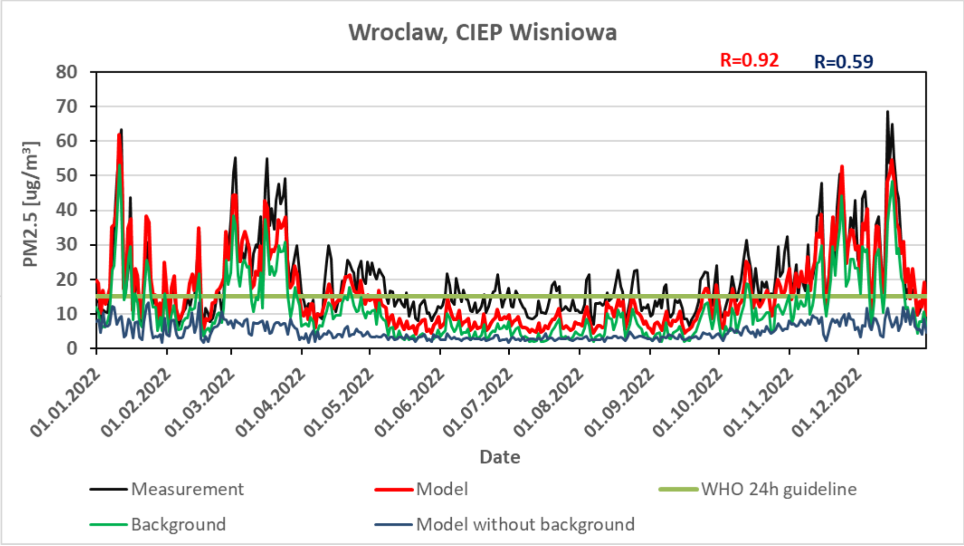
Calculations



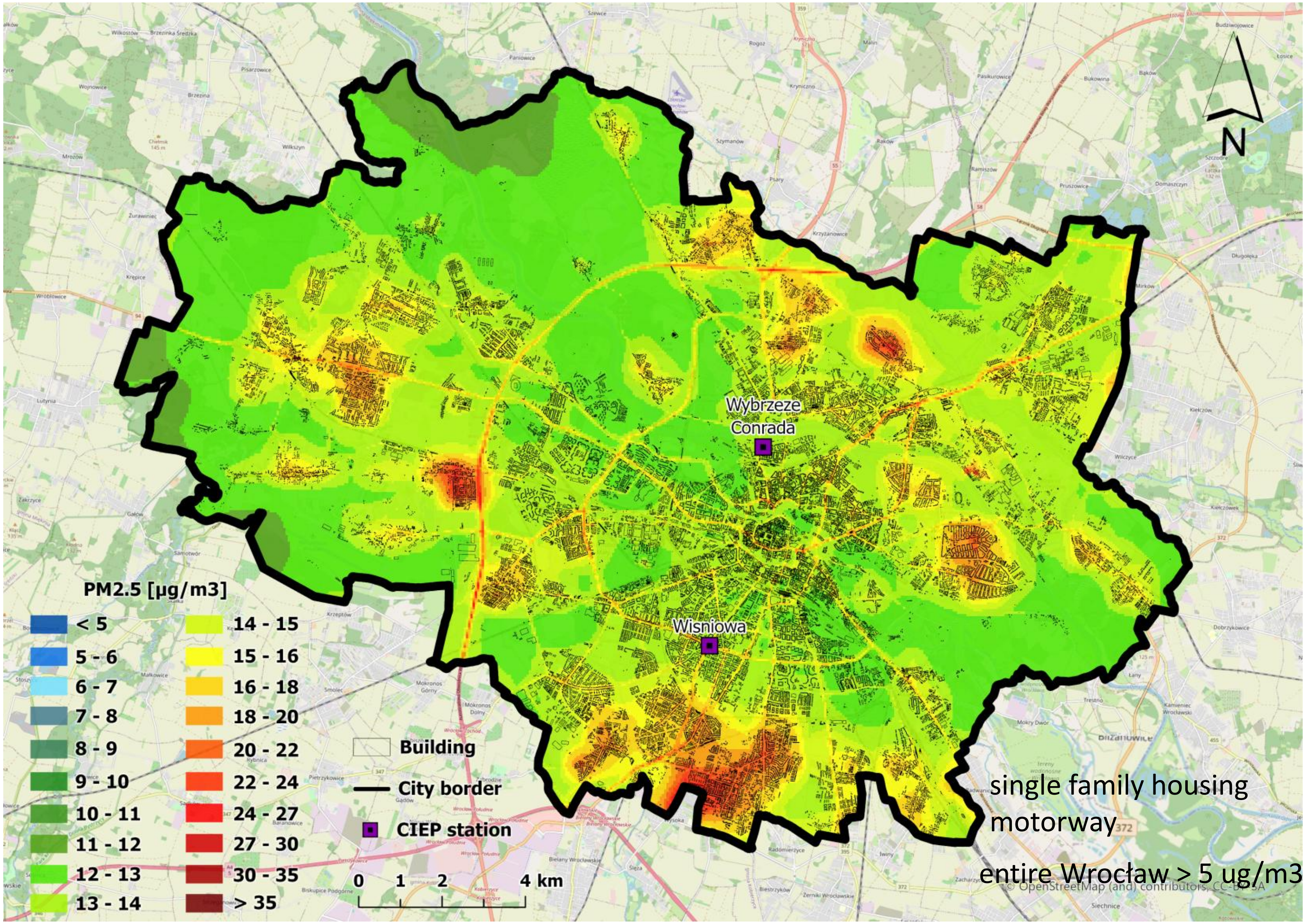
Model verification

Statistic [unit]	Spring	Summer	Autumn	Winter
		Background with low-cost sensors		
R	0.95	0.85	0.95	0.93
MB [µg/m³]	-4.85	-5.09	-3.66	-3.38
NMB	-0.23	-0.42	-0.19	-0.19
MAE [µg/m³]	5.22	5.09	4.02	4.43





Annual mean PM2.5 concentrations, 2022



Annual PM2.5 concentrations - scenarios

Scenario	Annual concentrations (µg/m³)			
	Mean	Minimum	Maximum	Contribution (%)
All emission sources and low-cost sensors background	**13.8**	11.7	29.0	-
All emission sources without background	**2.6**	0.4	17.5	-
Residential sector without background	**2.0**	0.4	16.7	**77**
Transport sector without background	**0.5**	0.0	12.9	**20**
Industry sector without background	**0.1**	0.0	13.8	**3**

1) Contribution of local (city) sources: ~20% of total PM2.5 concentrations.

Annual PM2.5 concentrations - scenarios

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1) Contribution of local (city) sources: ~20% of total PM2.5 concentrations.
2) For local sources; domination of residential heating.

Annual PM2.5 concentrations - scenarios

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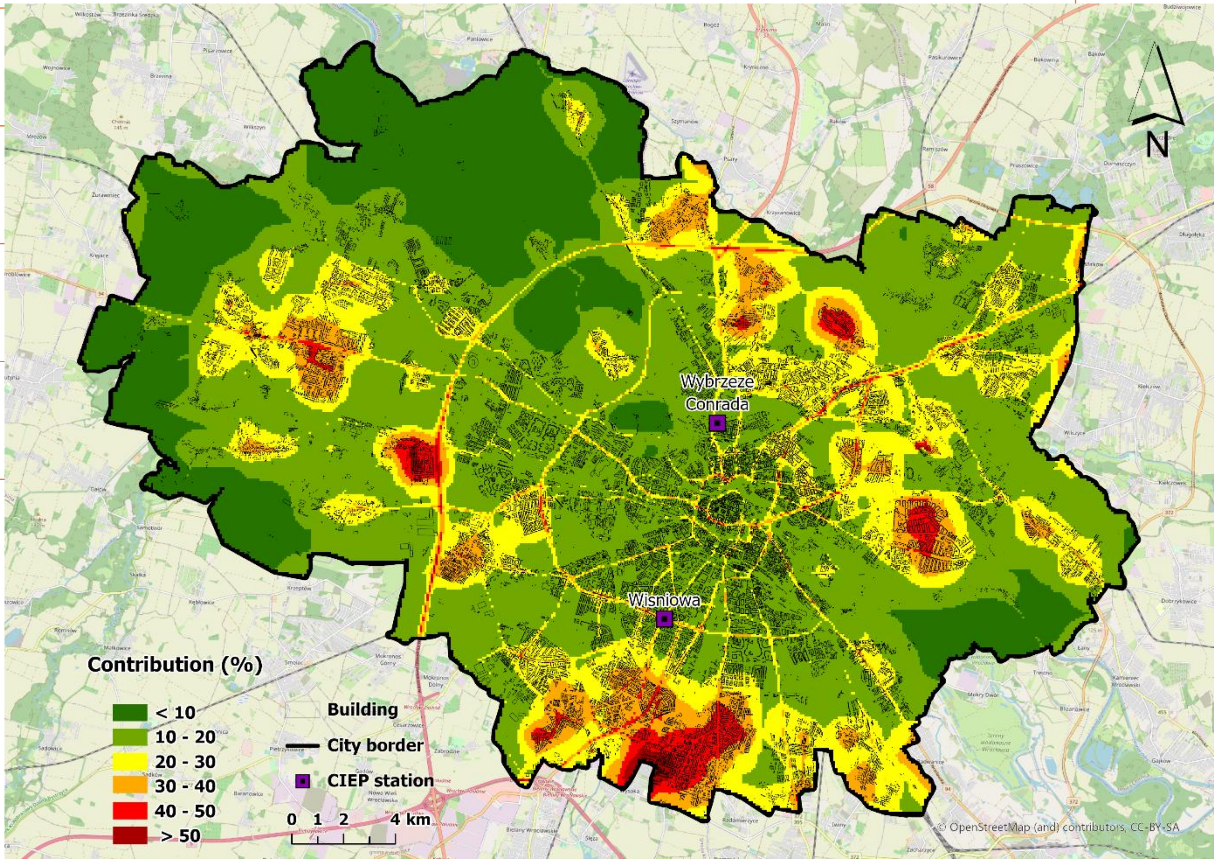

Contribution of city sources in total PM2.5

Science of the Total Environment 907 (2024) 168011

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Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Application of ADMS-Urban for an area with a high contribution of residential heating emissions - model verification and sensitivity study for $PM_{2.5}$

Paweł Porwisiak [a,*], Małgorzata Werner [a], Maciej Kryza [a], Helen ApSimon [b], Huw Woodward [b], Daniel Mehlig [b], Lech Gawuc [c], Karol Szymankiewicz [c], Tymoteusz Sawiński [a]

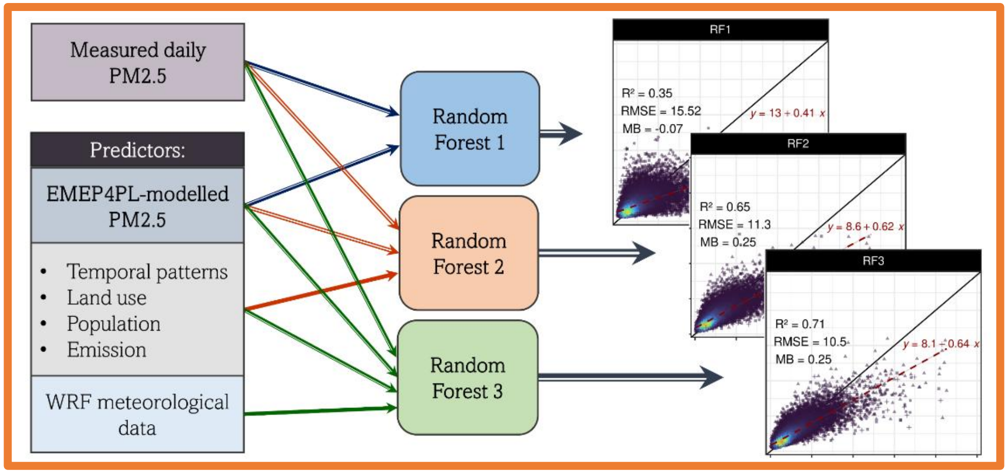
[a] *Faculty of Earth Sciences and Environmental Management, University of Wrocław, Kosiby 8, 51-621 Wroclaw, Poland*
[b] *Centre for Environmental Policy, Imperial College London, London SW7 1NE, UK*
[c] *Institute of Environmental Protection–National Research Institute, Krucza 5/11D, 00-548 Warsaw, Poland*

HIGHLIGHTS

GRAPHICAL ABSTRACT

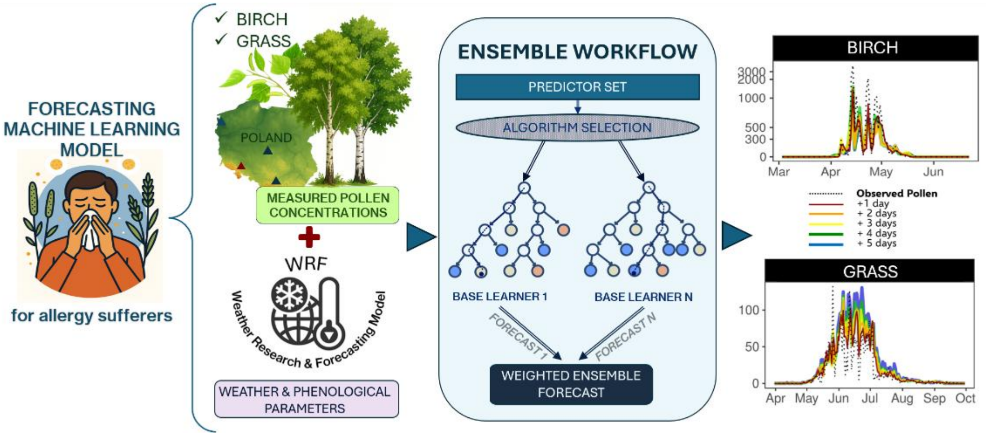
Application of ML

1) To improve the predictions of the EMEP4PL for PM2.5 through the integration of its results with the measurements using Random Forest.



Vovk et al. 2024, Atmos Environ, Using random forest to improve EMEP4PL model estimates of daily PM2.5 in Poland

2) Multi-day pollen forecasting with ML algotithms.



Vovk et al. 2025, under review

Main objectives

- **Main idea**: Use historical measured pollen data to train and verify machine learning (ML) models, which will be applied to forecast pollen concentrations.

- **Determine the optimal ML algorithms** for forecasting pollen concentrations of the two most allergenic taxa in Europe **– birch and grasses.**

Methods

Data:
Measured daily birch *(Betula)* and grass *(Poaceae)* pollen concentrations
Period: 2006-2022, Wrocław
Period: 2023-2024, Wrocław, Kraków, Łódź, Szczecin

Weather Research & Forecasting modelled parameters derived for the station location

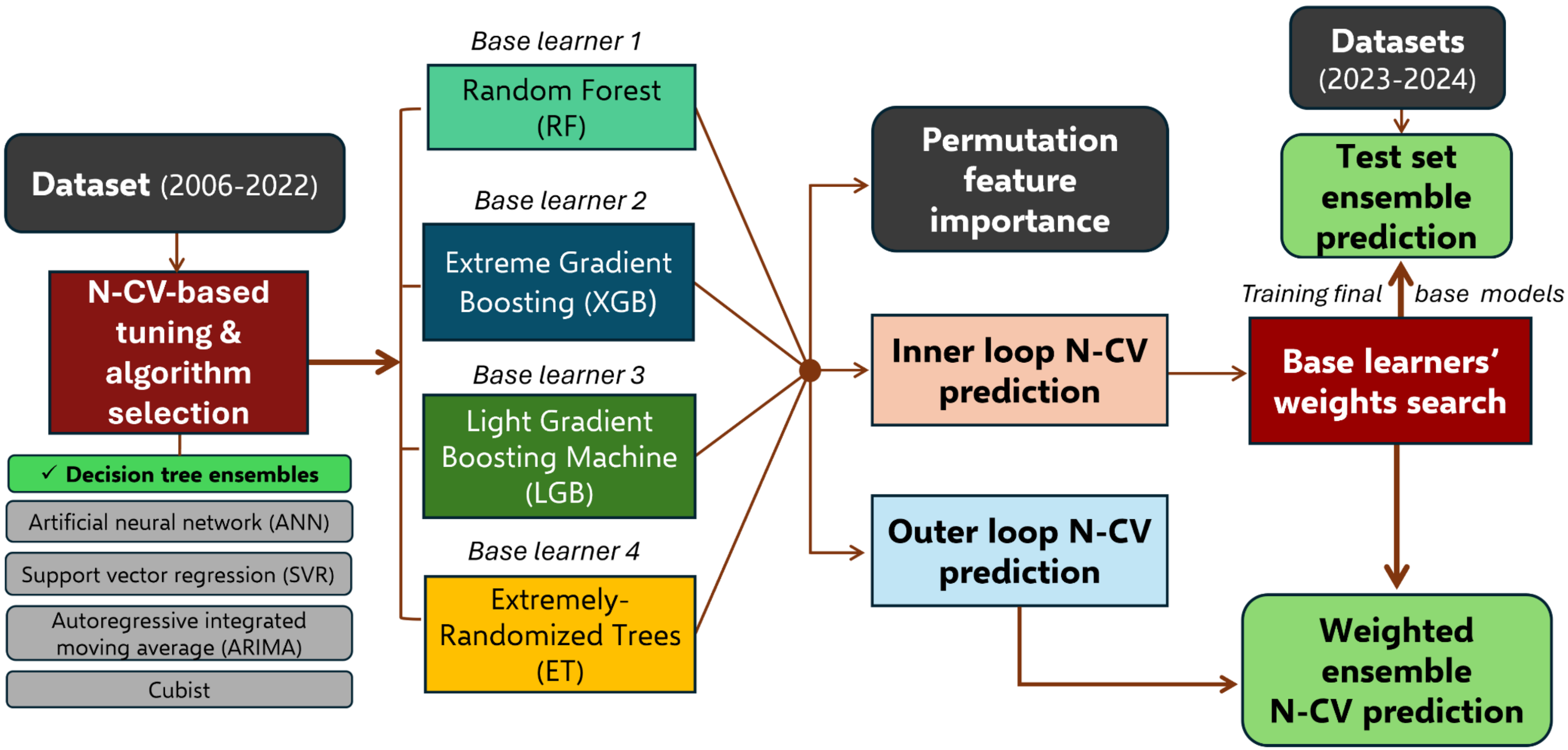
Modells trained and validated on Wrocław data (2006-2022).
Independant validation: Wrocław and other stations: 2023-2024.

Location of monitoring sites for training/validation (red) and final test (blue).

Methods: predictors

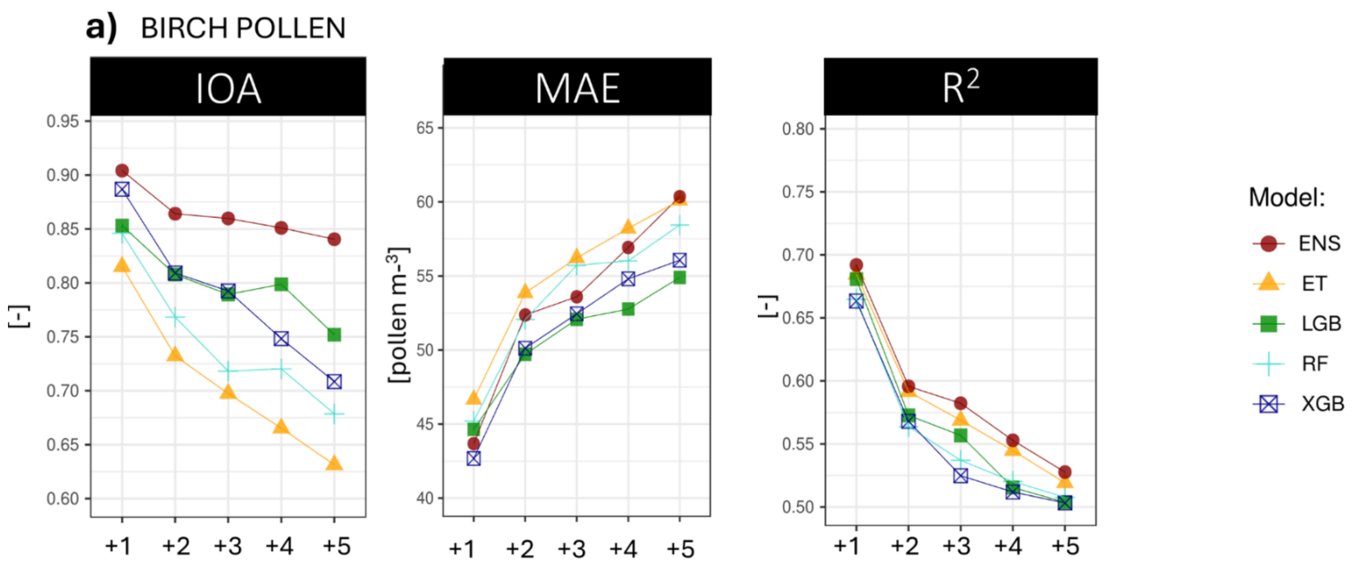
Group of variables	Variables
Lagged pollen concentrations	-1 day, -2 days, -3 days, -3, 5, 10 days lagged sum
Current day weather parameters (WRF)	• Temperature • Wind speed & wind direction • Precipitation • Atmospheric pressure • Planetary boundary layer height • Solar radiation
Temperature-based phenology parameters	• Growing degree days (current/lagged) • Chilling hours (current/lagged)
Pollen sums from previos season	• Past 1-2 years
Calendar features	Week number, month number, year number

Methods



N-CV: nested cross-validation

Evaluation, birch, Wrocław



Evaluation, birch, Wrocław

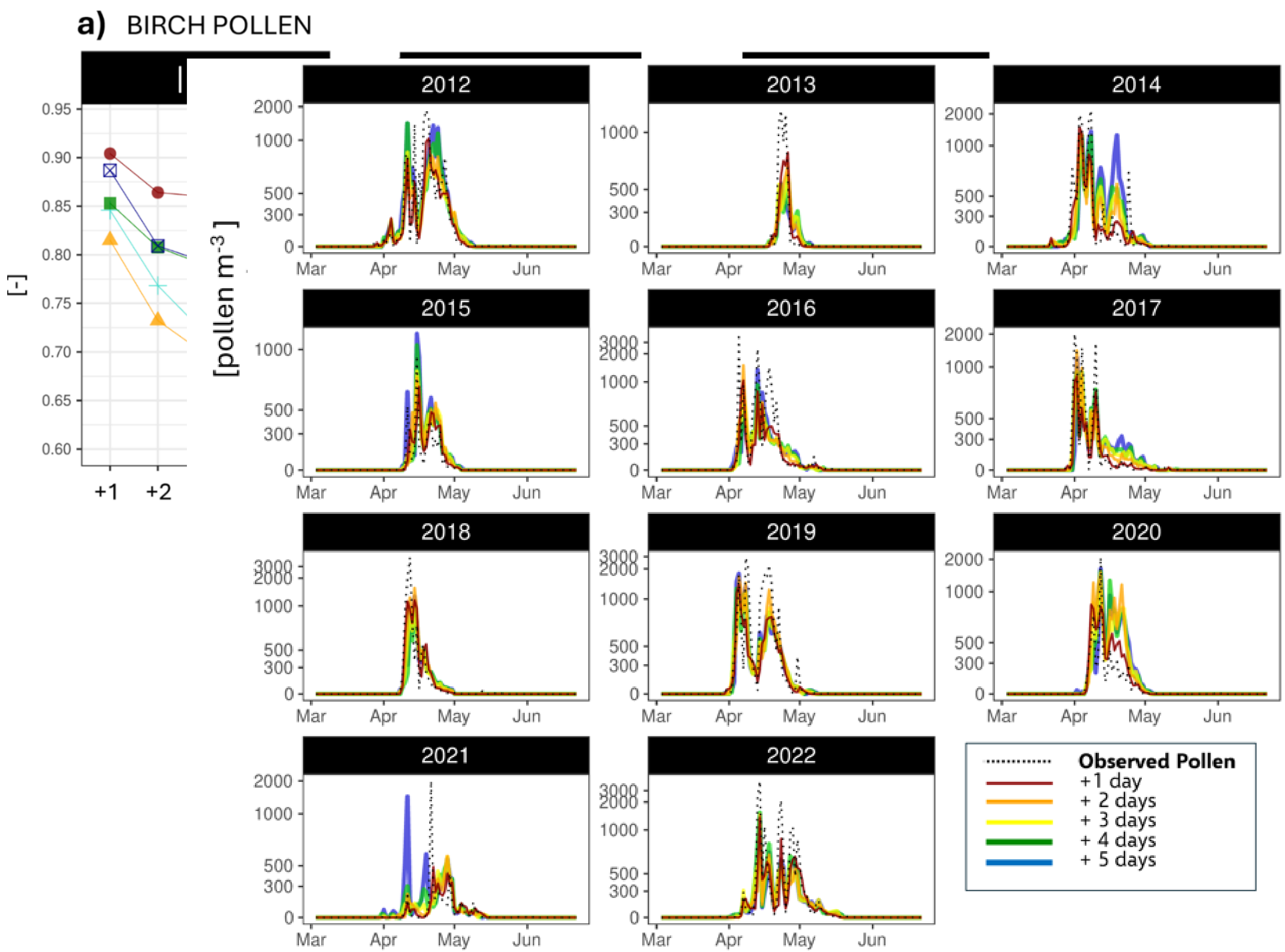
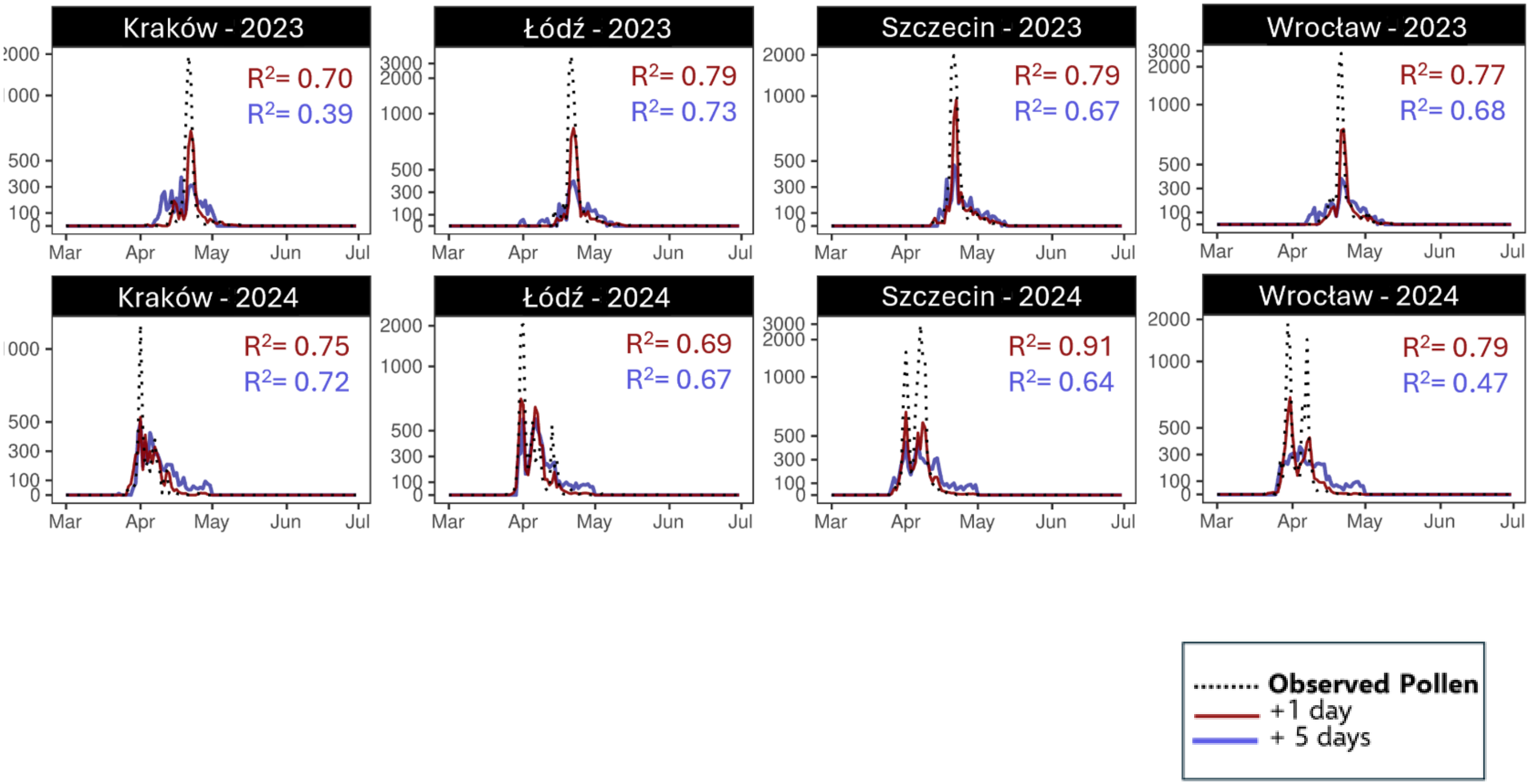


Figure 3. Ensemble N-CV forecasts for birch pollen concentrations (Wrocław, Poland; years 2006-2022). Each colored solid line shows separate forecast lead time (from +1 to +5 days). The dotted black line represents observed pollen concentrations across seasons.

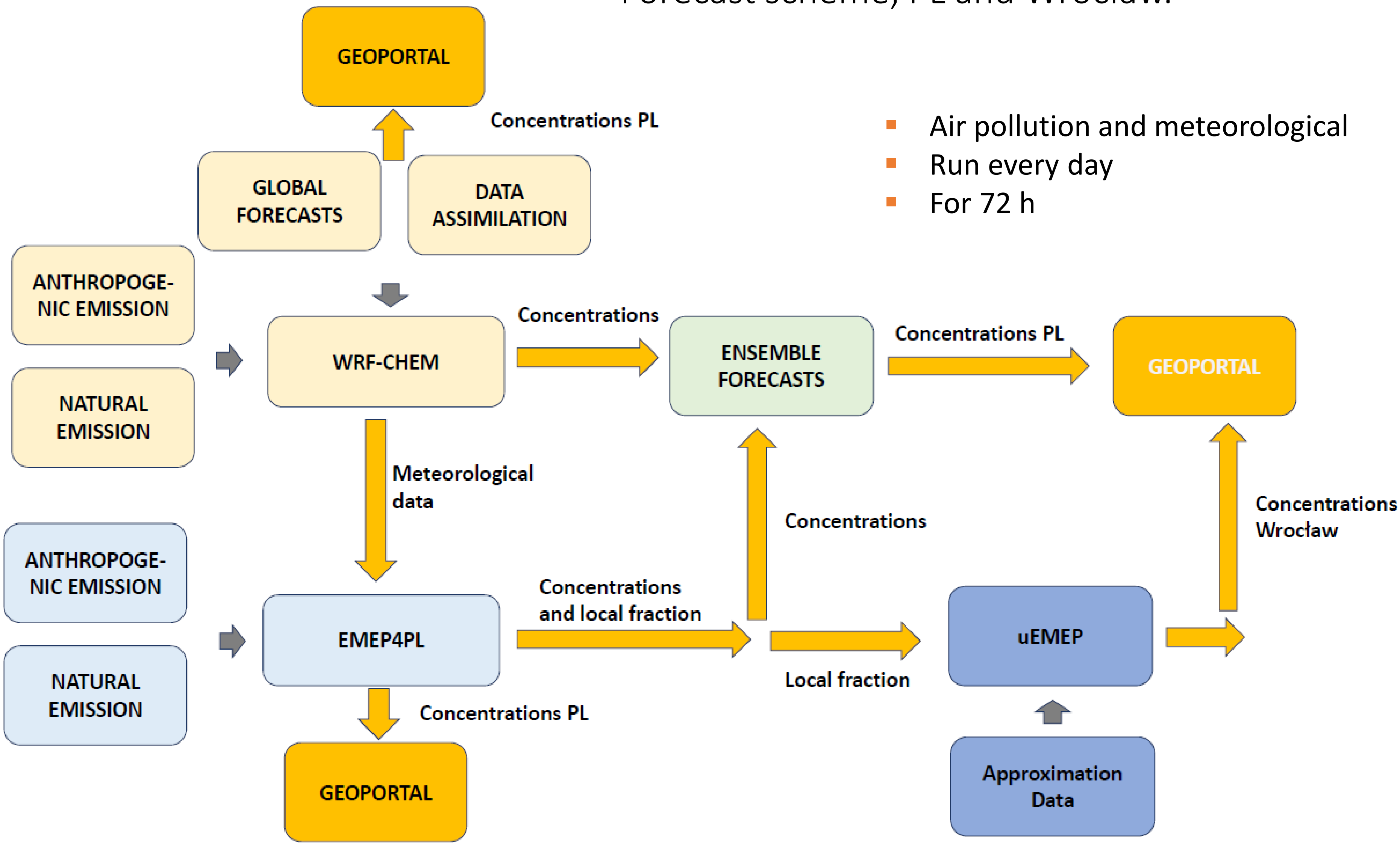
Evaluation, birch, Wrocław and other cities, independent dataset



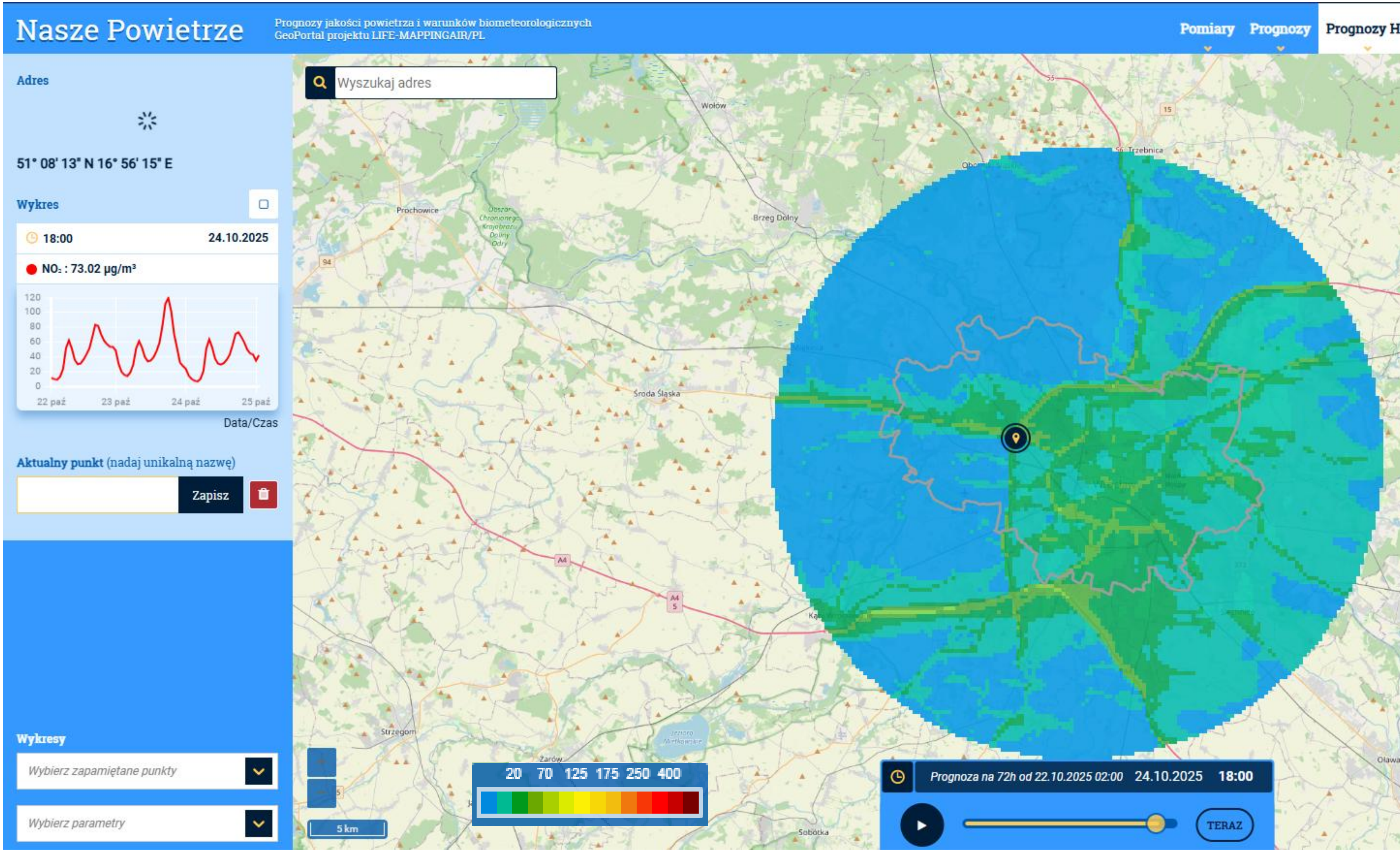
Regional and local scale air pollution forecast for Poland

Forecast scheme, PL and Wrocław.

- Air pollution and meteorological
- Run every day
- For 72 h



https://airquality.uni.wroc.pl/forecasts



Challenges and next steps

- Development of automatic pollen (and spores?) measuremetns.
  - Two new devices installed in Wrocław this autumn.
- Development of spatial local scale (and regional) pollen forecasts.
- Application of pollen measuremets to improve CTMs forecasts [limited numer of observations].

Thank you