INFLUENCE OF POINT SOURCES OF POLLUTION ON AIR QUALITY IN MAŁOPOLSKA – FIRST TESTS OF A NEW VERSION OF FORECASTING OF AIR POLLUTION PROPAGATION SYSTEM

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Abstract

Polluted air is dangerous to human life and health. Particulate matter, among others PM10, is one of the most harmful substances. In Małopolska and its capital Kraków, the concentrations of harmful substances often exceed the standards set by the World Health Organization. Kraków, thanks to the ban on residential heating with solid fuels, has significantly reduced emissions of pollution, but they remain high in the remaining part of the region, affecting air quality in the capital as well. With the frequent occurrence of high concentrations of pollutants, in addition to the necessary measures aimed at reducing emissions, forecasting of air pollutant concentrations is needed to inform the population if normative concentrations are likely to be exceeded. The FAPPS (Forecasting of Air Pollution Propagation System), based on the AROME/MM5/CALMET/CALPUFF model ensemble, has been operating in Małopolska since 2014 and has been used to create pollution concentration forecasts for Kraków and Małopolska. In this study, the influence of emissions from point sources on air quality in Małopolska was investigated based on the results of modelling with this system. Modelling results indicate that this influence is negligible. The quality of PM10 forecasts for four versions of the FAPPS system, differing in the meteorological model used – MM5 (Fifth-Generation Penn State/NCAR Mesoscale Model) or WRF (Weather Research and Forecasting) and the emission input (2015 emissions from the Małopolska Marshal's Office, updated with data from the City of Kraków for 2018, or the 2020 emission inventory from the Central Emission Database) was tested. The quality of forecasts was assessed based on the results of measurements at the 22 air pollution monitoring stations for three smog episodes that occurred on 11–17.11.2021, 11–15.12.2021 and 13–18.03.2022. The best results for Kraków were obtained using an approach based on the WRF model and the emission inventory from the Central Emission Database, for which an RMSE (Root Mean Square Error) value of 30.02 μg/m^3 was obtained for selected episodes. In the case of Małopolska, the lowest RMSE value (33.58 μg/m^3) was obtained

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for the system using the emission inventory obtained from the Marshal's Office and the WRF model. First tests indicate that changing the meteorological model from MM5 to WRF can lead to improved modelling results, but further research is needed to confirm it.

Keywords: emission of air pollution, air quality modelling, FAPPS, CALPUFF, MM5, WRF

1. Introduction

Air pollution remains a significant problem in many countries. According to World Health Organization (WHO) every year millions of people are dying prematurely because of it (WHO, 2021). Attempts are being made to reduce the number of harmful substances in the atmosphere, but there is still a long way to go. To do it efficiently, it is necessary to monitor their levels, but also to be able to warn people whenever it would become dangerous for them to be outside because of their high concentrations. This is the purpose of systems that develop forecasts of the dispersion of pollution. Such systems are designed using different techniques, but one of the most important and efficient ones is numerical modelling. In Europe, air quality modelling is currently conducted using various modelling systems (Adani et al., 2022; Frohn et al., 2022). An example of large-scale modelling is the near-real-time surface ensemble forecast system CAMS – Copernicus Atmosphere Monitoring Service (https://atmosphere.copernicus.eu) based on the results of nine chemical transport models: CHIMERE, EMEP, EURAD – IM, LOTOS-EUROS, MATCH, MOCAGE, SILAM, DEHM and GEM-AQ. The advantage of continent-wide models is that they can predict air quality not only from local emissions but also from emissions originating from distant sources. A disadvantage, especially for non-standard local and regional applications related to land use planning and determining the environmental impact of single sources or sectors of emission sources, is the difficulty in modifying emission input data. An additional complication is a modelling resolution - in this case 0.1^{o}, the consequence of which is the inaccurate consideration of orography that may significantly impact the quality of forecasts in the case of areas with varied topography. The same effect, especially for urbanized areas, is exerted by an insufficient resolution of data on land use and low resolution of emission sources.

Forecasting of Air Pollution Propagation System (FAPPS) is a system developed in the Institute of Meteorology and Water Management National Research Institute (IMWM-NRI), which is being used for forecasting concentrations of four major pollutants –particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2), and which creates daily a forecast for the region of Małopolska and the city of Kraków (http://smog.imgw.pl/home). FAPPS forecasts have a resolution of 5 km for Małopolska and 1 km for Kraków. The resolution of emission sources is adjusted to these resolutions, except that the dispersion of pollutants emitted from large point sources takes into account detailed information about the emitter. FAPPS has also been used in other cases, like modelling the effects of emissions from industrial plants or estimating the ecological effect that the decommissioning of solid furnaces had on air quality air in Kraków. The main part of FAPPS is Lagrangian–Gaussian CALMET/CALPUFF atmospheric dispersion modelling system (Scire, 2000; Scire, Strimaitis, Yamartino, 2000). High-quality forecasts obtained using FAPPS for Kraków and Małopolska show that the FAPPS system is a valuable tool for modelling air pollution in urbanized and industrialized areas with complex terrain (Godłowska, Kaszowski, K., Kaszowski, W., 2022). CALMET/CALPUFF system was used in many recent studies to model the dispersion of air pollution in various places located at different latitudes and longitudes (Ruggeri et al., 2020; Bezyk et al., 2021, Ravina et al., 2021).

Modelling of dispersion of pollution is a field that is constantly being improved. This development occurs in several areas – high-resolution meteorological data are becoming easier to obtain, models are being improved, and more accurate emission inventories are being developed. In recent years, the Fifth-Generation Penn State/NCAR Mesoscale Model MM5 (Grell, Dudhia, Stauffer, 1994) has been successively replaced in air quality applications by the Weather Research and Forecasting (WRF) (Skamarock et al., 2021). It allows parallel runs which makes the calculations quicker, it is also still being updated, which allows the introduction of corrections in accordance with the current state of the science. Significant progress has also been made in standardizing and improving methods for developing emission inventories. In Poland, such an emission inventory method has recently been developed by the National Centre for Balancing and Emission Management KOBIZE (Gawuc et al., 2021). In this respect, creating a new version of FAPPS that will continue to provide accurate forecasts was deemed necessary.

This paper examines the impact of modifications to the modelling system architecture, the type of meteorological model used and the emissions inventory used as input to the FAPPS on modelling results. The impact of the adopted modifications was tested for three several-day periods of elevated pollutant concentrations and analysed for consistency of the modelling results with measurements made at the air quality monitoring station of the Chief Inspectorate of Environmental Protection in Małopolska.

The article analyses the first test results of a potential new version of the FAPPS system. To assess the impact of the size of the area comprised by the modelling on the quality of predictions, tests were carried out of the effect of emissions from point sources located in Poland inside and outside of Małopolska on pollutant concentrations inside the region during smog episodes. System modifications involved both the meteorological and dispersion parts of the modelling system. The effect of replacing the MM5 meteorological model with the Weather Research and Forecasting model (WRF) was also tested, as well as the effect of using the modelling system with emission data from the Central Emission Database developed by KOBIZE, valid for 2020. Three smog episodes that occurred on

11–17.11.2021, 11–15.12.2021 and 13–18.03.2022 were investigated. The modelling results for these episodes were compared with measurements at the stations of the Chief Inspectorate of Environmental Protection for four different approaches.

2. Methodology

2.1. Study Area

The Małopolska region is located in the south of Poland. The region's landscape is mountainous, but also quite diversified – the difference in height between the highest and lowest points exceeds 2000 meters. The region has significant problems with air pollution — concentrations of harmful substances, especially particulate matter and benzo[a]pyrene (GIOŚ, 2021) are often higher than guideline values set by WHO. One of the main reasons for this is that in the region many households still continue to use solid fuels for heating. The other factor that causes a high level of pollution in the area is the inflow of pollution from neighbouring areas, for example, from the Silesia region with its industry (several power plants are located there).

Kraków is the largest city in Małopolska. For a long time, the city had trouble with high concentrations of pollution – in the 2014/2015 heating season daily averages on the measuring station PL0501A exceeded WHO norms 95 times. Thanks to the decision of the city council to liquidate solid fuel heating in the households, air quality improved. In the season 2019/2020, norms were exceeded 47 times (Rataj, Holewa-Rataj, 2020). However, further improvement is needed.

2.2. Elements of the modelling system

FAPPS is a modelling system based on numerical weather forecasts provided by a set of three meteorological models: numerical weather prediction AROME (Yessad, 2019), Fifth-Generation Penn State/NCAR Mesoscale Model MM5 (Grell, Dudhia, Stauffer, 1994) and CALMET (Scire et al., 2020) meteorological preprocessor. The tested version of the system uses the WRF (Skamarock et al., 2021) model. The CALPUFF model (Scire, Strimaitis, Yamartino, 2000) in the FAPPS system is responsible for air quality modelling.

AROME

AROME is a non-hydrostatic spatial model used for the operational development of forecasts of meteorological conditions for Poland at the Institute of Meteorology and Water Management - National Research Institute (IMW-NRI). It is powered by the global model ARPEGE (Yessad, 2019). AROME provides initial and boundary conditions that are later used by MM5 or WRF.

MM5/WRF

MM5 (Grell, Dudhia, Stauffer, 1994) is a mesoscale, regional, three-dimensional prognostic model. It has been developed at the PENN State University and was widely used to simulate processes that are taking place in the atmosphere. It was chosen for FAPPS because, at the time when it was being developed, it was a reliable choice for system purposes. Its active development was discontinued in 2005.
The Weather Research and Forecasting (WRF) (Skamarock et al., 2021) is a mesoscale weather-prediction system. It was developed in a collaborative effort of the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the Earth System Research Laboratory), the U.S. Air Force, the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF was built with a software architecture in mind that allows parallel computation intended to make calculations quicker. It is still being further developed and improved.

CALMM5/CALWRF

CALMM5/CALWRF are processors that extract data from output files created by MM5/WRF and generate a file that could be used directly as input in CALMET.

CALMET

The meteorological model CALMET (Scire et al., 2000) [4] includes parametrized treatment of slope flows, kinematic and terrain blocking effects. It adjusts wind speed and direction to orography by modelling the influence of these effects. Thanks to these capabilities, CALMET can be used for high-resolution modelling.

CALPUFF

CALPUFF dispersion model (Scire, Strimaitis, Yamartino, 2000) is a Lagrangian Gaussian puff model that allows taking into account complex terrain effects, wet and dry removal and simple chemical transformation. Modelling of chemical processes is based on the MESOPUFF II mechanism.

2.3 Emission inventories

In the work two different emission inventories were used – one which is being used to run the current operational version of FAPPS (EM) and an emission inventory based on data from the Central Emission Database (CED) (Gawuc et al., 2021). The current operational version of the FAPPS system is using the inventory provided by Marshal's Office of Małopolska for 2015, updated by data from the Kraków City Hall for 2018 (EM). For the area outside Małopolska use was made of data from the European Monitoring and Evaluation Programme (EMEP) from 2018.

As this inventory is getting outdated, the need to update the emission inventory keeps growing more urgent. Thanks to the effort of the National Balancing and Emission Management Centre (KOBiZE), the Central Emission Database (CED) was developed using the bottom-up methodology. This effort to create a more centralized and more accurate emission inventory for Poland should lead to improvement in the results of air pollution modelling. Emission inventory based on Central Emission Database is up to date for the year 2020.

Emission variability specific to each source category was applied for both emission inputs. For sources from means of transport – daily variability, while for heating sources – temperature variability.

2.4. Smog episodes

This paper analyses the modelling results for three smog episodes that occurred on 11–17.11.2021, 11–15.12.2021 and 13–18.03.2022. The reason behind this choice was that the current model performed unsatisfactorily in their cases. The variability of PM_{10} concentrations during these three smog episodes in Kraków and Małopolska outside Kraków is shown in Figures 1 to 3. This variability was determined from the hourly average concentrations measured at the stations of the Chief Inspectorate of Environmental Protection in Małopolska. For each hour, the maximum and minimal values, as well as the 25th and 75th percentiles of PM_{10} concentrations are presented. The presentation of pollution measurements, shown in Figures 1–3, allows a better representation of the variability of pollution concentrations in the study area. In the first of the smog episodes in question, relatively undifferentiated levels of concentrations were recorded in the Kraków area and considerable variation outside it, in the Małopolska region. Maximum concentrations of PM10 particulate matter in Małopolska on November 14, 2021 reached 300 mg/m^3, while for Kraków they oscillated around 50 mg/m^3. During the other two episodes, pollution in Kraków was characterized by a similar variability of concentration levels as in Małopolska (taking into account the greater territorial extent of Małopolska), with the third quartile of concentrations shifted towards the maximum. At the high point of the second episode on 14.12.2021, the concentrations measured in Kraków were found to be higher for most stations than in the Małopolska region. The third of the episodes was characterized by similar variability of concentrations within and outside Kraków. However, the highest concentrations were recorded outside Kraków.

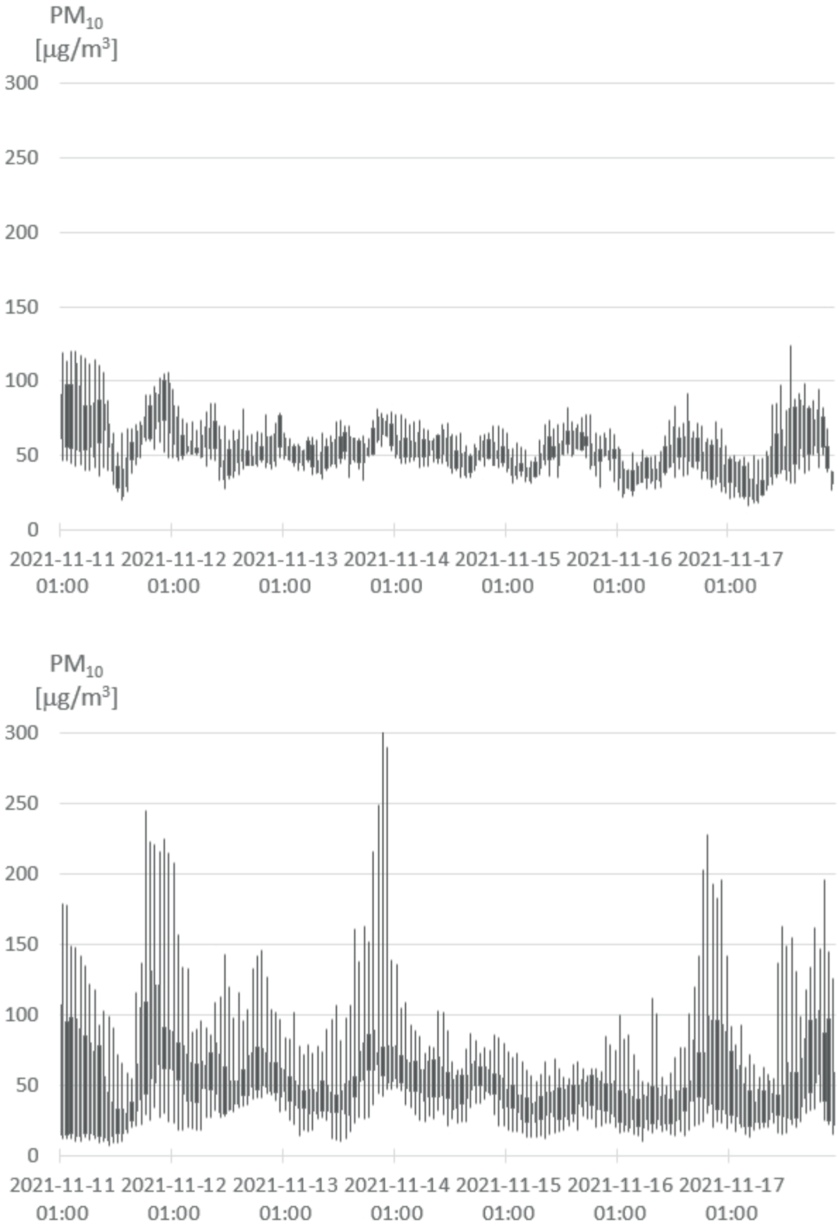
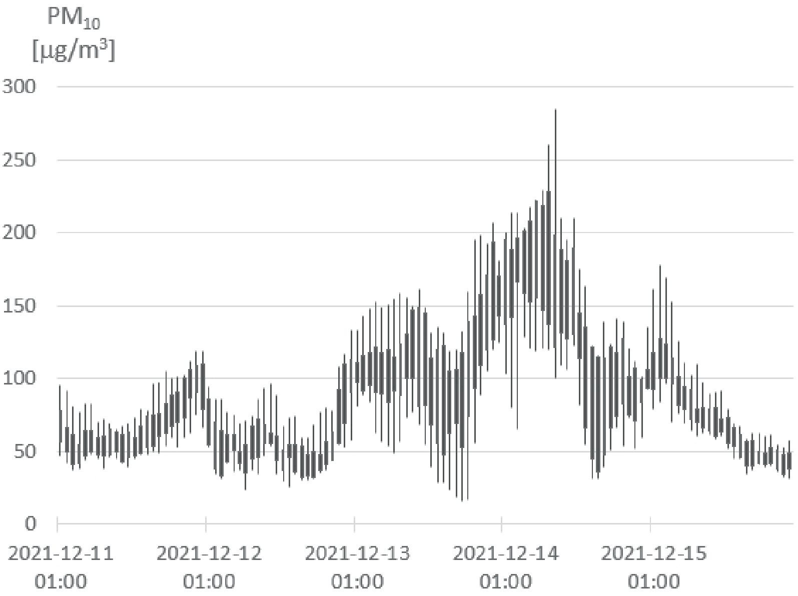


Figure 1. Maximum and minimum values (thin lines) and values between the 25th and 75th percentile of concentration of PM10 for 11–17.11.2021 measurement at the stations of Chief Inspectorate of Environmental Protection in Kraków (at the top) and in Małopolska excluding Kraków (at the bottom)

Source: own study, based on data from (GIOŚ, 2022)



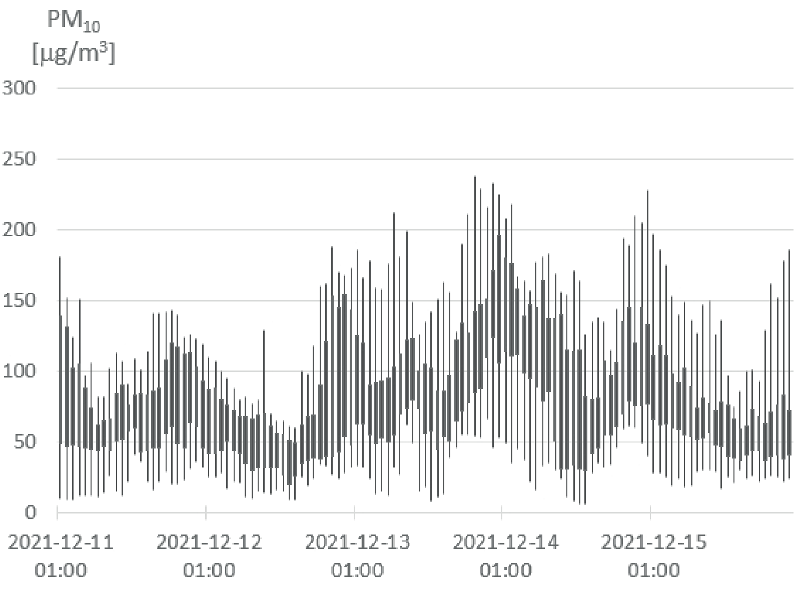
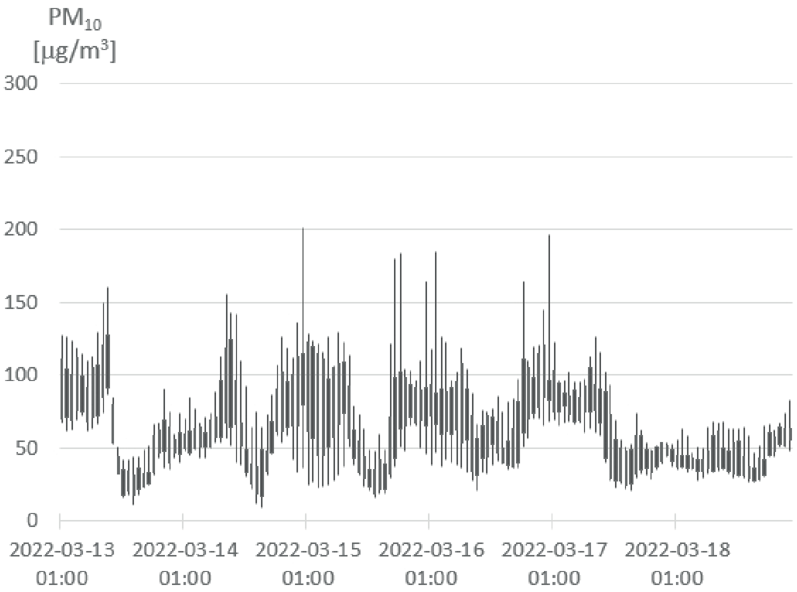


Figure 2. The same as in Figure 1, for 11–15.12.2021

Source: own study, based on data from (GIOŚ, 2022)



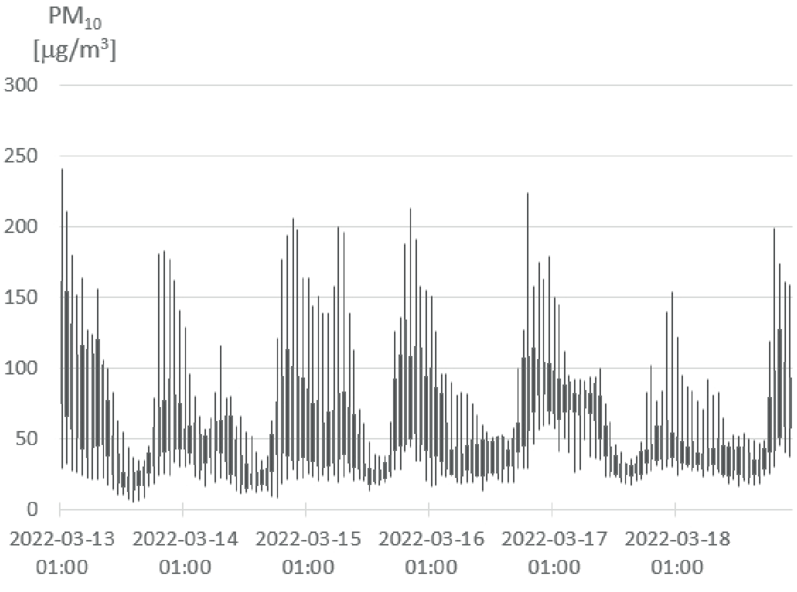


Figure 3. The same as in Fig.1, for 13–18.12.2021

Source: own study, based on data from (GIOŚ, 2022)

2.5. Approach to modelling

2.5.1. Configuration of the modelling system

The current operational version of the FAPPS system and three other modelling approaches were tested.

Modelling with MM5/WRF was conducted in two domains. The mother domain covers Poland's entire territory, has a grid resolution of 13.5 km and contains 60x65 grid cells. The second, nested domain has a grid size of 4.5 km and comprises 82x82 cells covering the central and southern parts of Poland. MM5 was run with the Grell cumulus scheme, MRF PBL, Dudhia shortwave and longwave radiation scheme. WRF was run with Lin et al. microphysics scheme, Grell cumulus scheme, RRTM longwave radiation scheme and Dudhia shortwave radiation scheme. The output files produced by prognostic models were run through CALMM5 or CALWRF, which produced the files that can serve as input to CALMET. In FAPPS modelling of the transport of pollution is being performed in three domains (the same for CALMET and CALPUFF). The external E domain with a resolution of 50 km is responsible for modelling the inflow of pollutants from regions outside Małopolska. The second MP domain has a resolution of 5 km and is responsible for modelling the immission of pollutants emitted in Małopolska. The third domain KR with a resolution of one kilometre is used to perform modelling on the territory of the city of Kraków.

In the FAPPS system, point sources of emission with a height less than 40 meters are considered as VOLUME sources, while those with a height exceeding 40 meters as POINT sources. For POINT sources, the modelling considers the source's parameters (stack height and diameter) and emissions (temperature and velocity of the exhaust gases).

In this paper, four different approaches to modelling were used and tested. The versions of the FAPPS system differ in their approach to meteorological modelling (interchangeable use of WRF and MM5 models) and the emission input used (EM or CED), with different meteorological models or emission inventories. They are presented in Table 1.

Table 1. Approaches to modelling used in this study

Approach	Meteorological model	Emission inventory
A1 (currently used operationally)	MM5	EM
A2	WRF	EM
A3	MM5	CED
A4	WRF	CED

2.5.2. Assessment of the results of modelling for Kraków and Małopolska

The quality of forecasts was assessed with the use of statistical measures such as Normalized Mean Bias (NMB), Fractional Bias (FB), Normalized Mean Square Error (NMSE), Root Mean Square Error (RMSE) and the data fraction index (ETC/ACM, 2013; Holnicki et al., 2017; Juda-Rezler, 2010). These statistical measures were applied to the four versions of the system separately for Kraków and the rest of Małopolska, using measurements of PM_{10} concentrations conducted at the Chief Inspectorate of Environmental Protection stations in Małopolska as reference values. Calculations were made in accordance with the formulas:

$$NMB = \sum_{k=1}^{n}\left(C_{ok} - C_{mk}\right) / \sum_{k=1}^{n} C_{ok} \tag{1}$$

$$FB = 2\left(\bar{C}_o - \bar{C}_m\right) / \left(\bar{C}_o + \bar{C}_m\right) \tag{2}$$

$$NMSE = \sum_{K=1}^{n}\left(C_{ok} - C_{mk}\right)^2 / n\bar{C}_o\bar{C}_m \tag{3}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(C_{ok} - C_{mk}\right)^2} \tag{4}$$

$$\text{FAC2 = fraction of data for which: } 0.5 \le C_{mk} / C_{ok} \le 2 \tag{5}$$

where C_{ok} are daily concentrations of PM_{10} measured at the stations of Chief Inspectorate of Environmental Protection, and C_{mk} are modelled daily concentrations at grid points corresponding to the location of the stations, $\bar{C}_o$ and $\bar{C}_m$ are their mean values and n is the number of observations.

2.5.3. Assessing the impact of emission from point sources

To establish the influence of distant point sources on the concentration of PM_{10} in Małopolska modelling was conducted in two domains— E (Figure 4) and M (Figure 5). In E influence of point sources located outside of Małopolska was tested, while in domain M emissions from sources located in Małopolska were modelled. Sources with heights over 40 meters were treated as POINT sources, while those under 40 meters were treated as VOLUME emission sources. Emissions from sources lower than 40 m were summed in the grid point to form one VOLUME source.

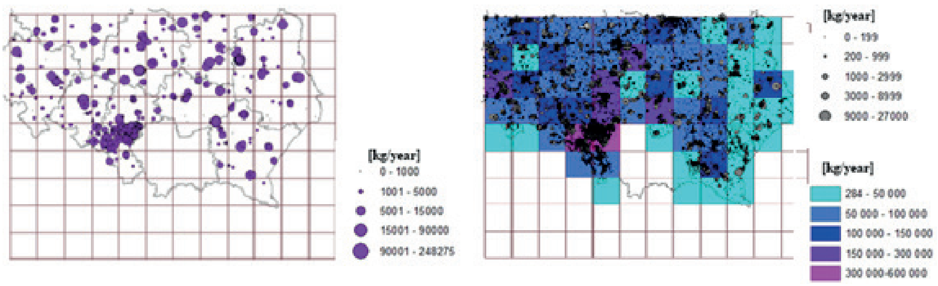


Figure 4. Point sources located outside of Małopolska – higher than 40 m (on the left) and lower than 40 m (on the right)

Source: own study, based on Central Emission Database

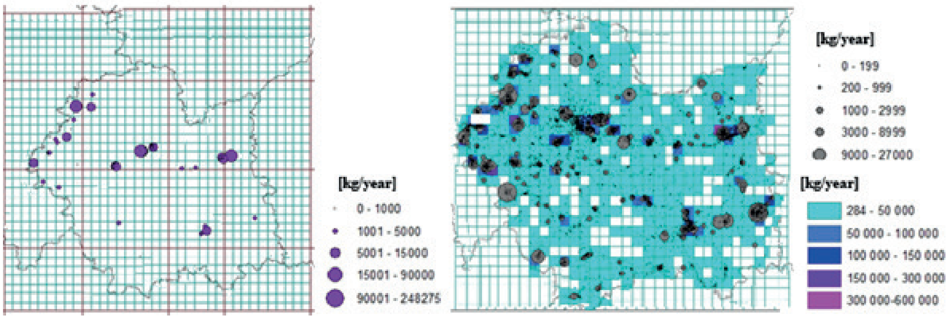


Figure 5. Point sources located inside Małopolska – higher than 40 m (on the left) and lower than 40 m (right)

Source: own study, based on Central Emission Database

3. Results

3.1. Influence of point sources on the concentration of PM10 in Małopolska according to CED

To verify whether the inaccuracy of forecasts for the operational version of the FAPPS system could be caused by the failure to account for emissions from distant point sources, it was decided to test the effect of emissions from point sources located inside and outside of Małopolska on PM_{10} concentrations in Małopolska. For this purpose, the CED emission inventory was used. Using Central Emission Database as the base for developing an emission inventory seemed to be the right choice, because it should have the most current information about emission sources. The results are presented in the form of average and maximum values of average daily PM_{10} concentration for the Małopolska area.

In the period 11–17.11.2021 (Figure 6), the average PM10 immission in Lesser Poland from emission sources located outside the region remained low, only occasionally exceeding 1 μg/m^3. This is such a small amount that its impact is negligible. For sources located inside Małopolska, the results are even lower, although it is worth noting that the maximum immission from sources lower than 40 m located in the region in one case exceeded 10 μg/m3.

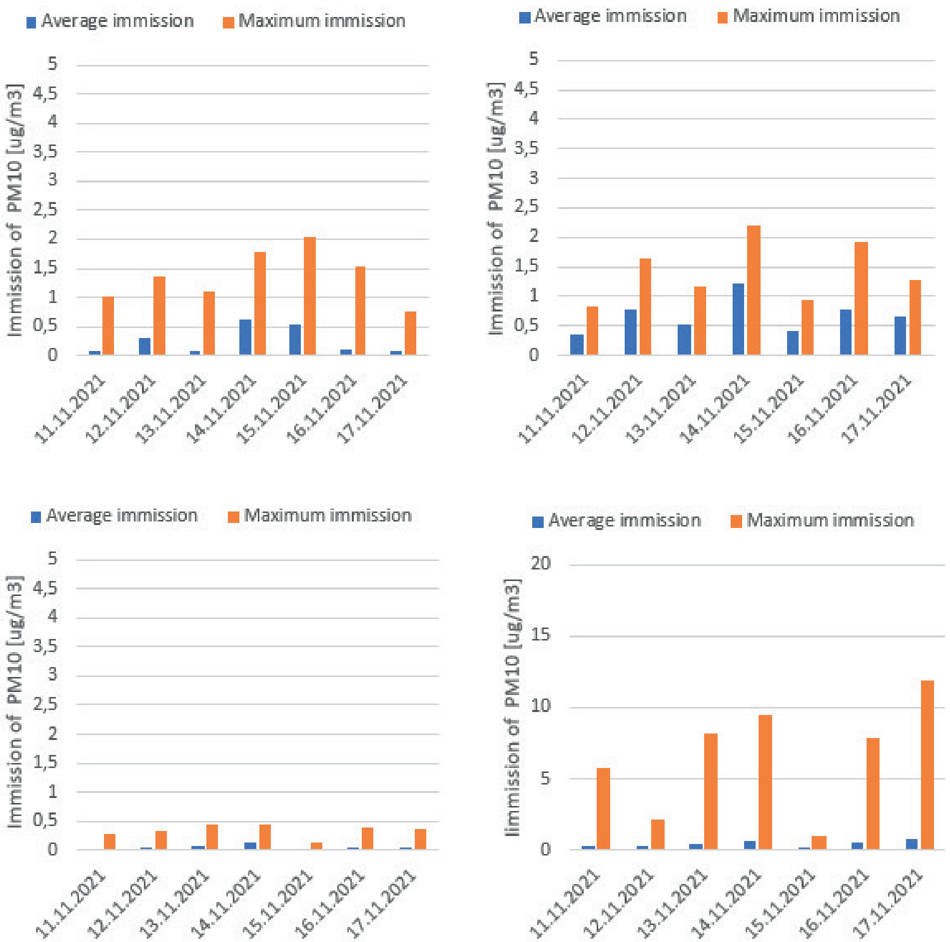


Figure 6. Maximum and average immission in the area of Małopolska from point sources located outside (upper left sources higher than 40 metres, on the right lower than 40 metres) and inside this region (upper left sources higher than 40 metres, on the right lower than 40 metres) for 11–17.11.2021

For the period 11–15.12.2022 (Figure 7), the modelled concentrations were slightly higher than in the previous period, but the average immission did not exceed 2 μg/m^3. Similarly to November, they were higher for sources located outside of Małopolska, but maximum immission again was the highest for sources lower than 40 m and located inside the region.

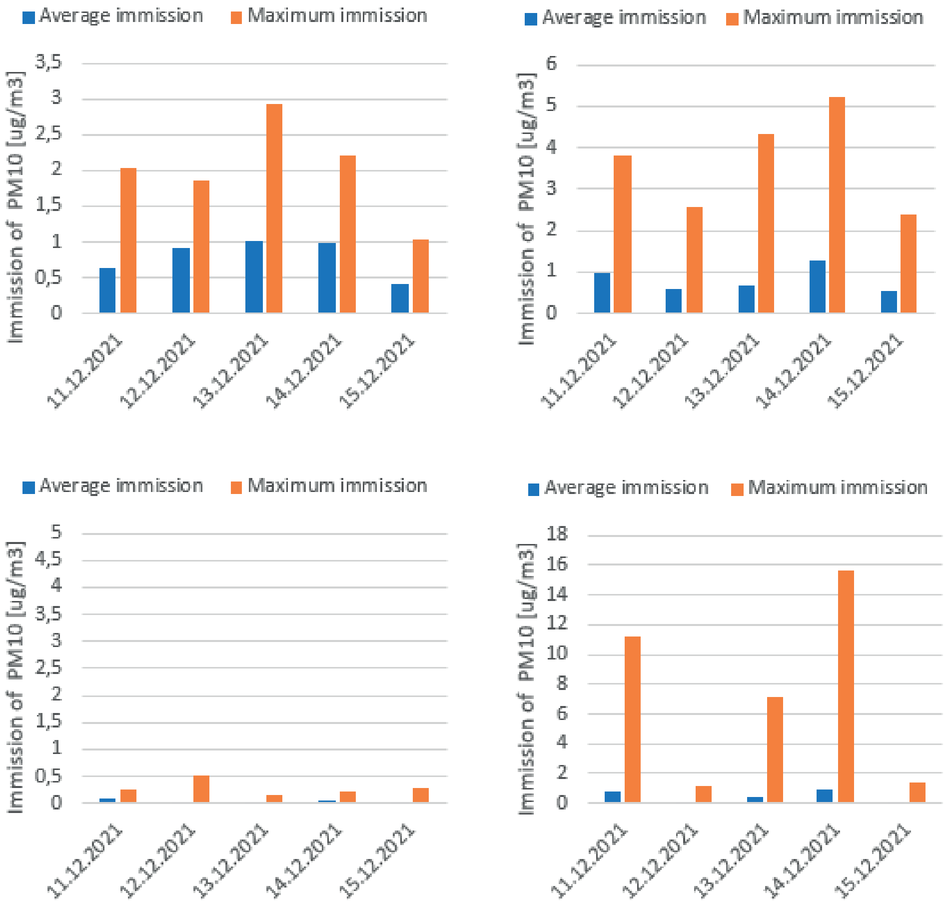


Figure 7. Maximum and average immission in the area of Małopolska from sources located outside (upper left sources higher than 40 metres, on the right lower than 40 metres) and inside this region (upper left sources higher than 40 metres, on the right lower than 40 metres) for 11–15.12.2021

For the last period (11.03–15.03.2022), the results presented in Figure 8 are similar. The modelled influence of point sources on concentrations of PM10 in the region is very small and sources located outside of the area had a bigger impact on air quality.

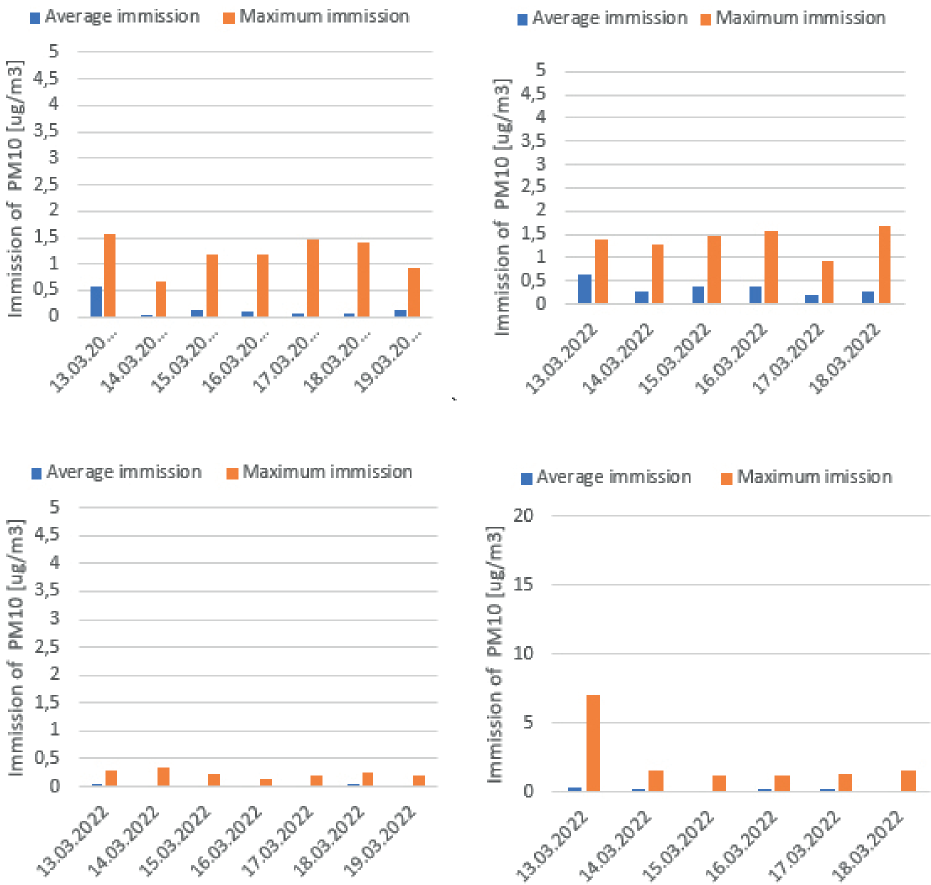


Figure 8. Maximum and average immission in the area of Małopolska from sources located outside (upper left sources higher than 40 metres, on the right lower than 40 metres) and inside this region (upper left sources higher than 40 metres, on the right lower than 40 metres) for 13–18.03.2022

3.2.1. Results of modelling with the use of all emission sources for Kraków and Małopolska

The modelling results for Kraków are presented in Table 2 and for Małopolska in Table 3. Measurements from all Chief Inspectorate of Environmental Protection air pollution monitoring stations located in Małopolska were used to validate different modelling approaches.

Table 2. Results of comparison results of measurements and modelling for Kraków

Indicator/approach	A1	A2	A3	A4
NMB	0.028	0.292	-0.179	0.034
FB	0.029	0.342	-0.164	0.035
NMSE	0.273	0.307	0.336	0.211
RMSE [μg/m³]	34.244	30.992	41.832	30.022
FAC2	0.757	0.792	0.681	0.806

Source: own study with the use of data from [16]

Table 3. Results of comparison results of measurements and modelling for Małopolska

Indicator/approach	A1	A2	A3	A4
NMB	0.086	0.378	-0.185	-0.175
FB	0.090	0.465	-0.169	-0.161
NMSE	0.473	0.470	0.495	0.350
RMSE [μg/m³]	40.817	33.579	47.541	39.801
FAC2	0.658	0.641	0.611	0.701

Source: own study with the use of data from (GIOŚ, 2022)

The results in tables 2 and 3 illustrate the verifiability of predictions for specific locations. This gives only a partial assessment of the quality of the solutions used. To show how imperfect this approach is, an example of PM_{10} immission maps determined for four tested versions of the FAPPS system is presented. A comparison of the spatial distributions of modelling results of daily average concentrations of PM_{10} with measurements at the Chief Inspectorate of Environmental Protection stations is shown for the day with the highest concentrations for the first smog episode considered (Fig. 9).

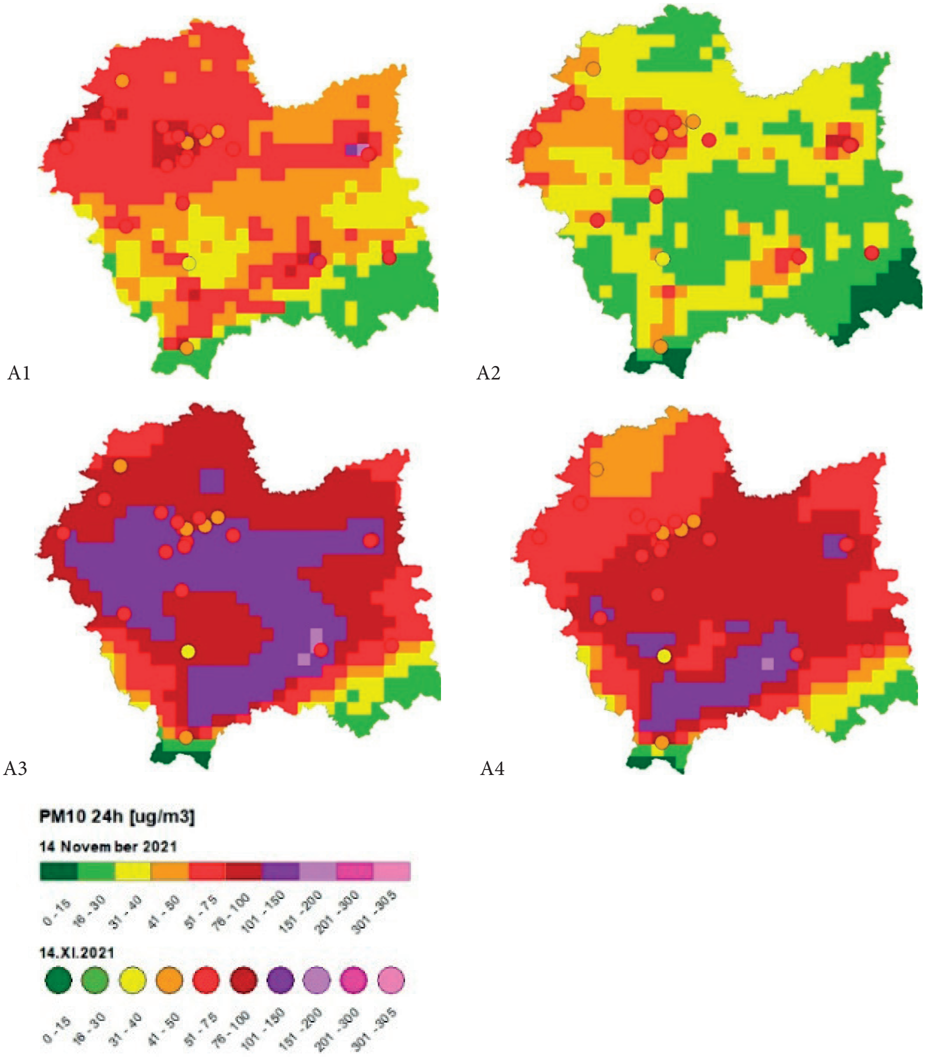


Figure 9. Results of modelling for different modelling approaches for 14.11.2021. Coloured dots are results of the measurement taken at the stations of the Chief Inspectorate of Environmental Protection at the locations of the stations. Versions for EM inventory (approaches A1 and A2) at the top and for CED emissions inventory (approaches A3 and A4) at the bottom. From the left: A1, A2, A3 and A4 approaches. Versions with the use of MM5 model (A1 and A3) on the left and with the use WRF (A2 and A4) on the right

4. Discussion

The results of modelling of immission from point sources for smog episodes that occurred on 11–17.11.2021, 11–15.12.2021 and 11–15.03.2022 indicate that they did not have a big influence on the concentration of PM_{10}. Therefore, it can be assumed that emissions from sources different than point sources caused high concentrations of this pollutant during chosen episodes. Considering that these concentrations were observed during the heating season when temperatures in the south of Poland are low, it could be assumed that most of them were caused by heating homes with solid fuels. It is worth pointing out that according to modelling results the effect of emissions of PM_{10} from point sources located outside of Małopolska was higher than from sources located inside the region. This could arise from the fact that most of the point sources that can influence air quality in Małopolska are located outside that region. The study shows that it is not advisable to enlarge the external modelling domain, since the contribution to immissions in Małopolska resulting from the inclusion of point sources outside the current external domain should be negligible. Due to the low emission point height for other types of emission sources, the contribution to immissions from other types of sources for sources outside the external modelling domain is also negligible.

The results of modelling using the FAPPS system with the emission input for all emission sources can be compared with measurements. For Kraków, the comparison between different approaches showed that switching the meteorological model from MM5 to WRF could allow gaining more accurate results. It is especially true for the A4 (this approach has low bias and the lowest values of errors).

The situation is more complex in the case of modelling for Małopolska. It has to be noted that all approaches performed worse when they were used to model concentrations of PM_{10} for the whole region than just for the city of Kraków. It is as expected because modelling in Kraków is being carried out at a higher resolution. Moreover, outside of Kraków, air monitoring stations in Małopolska are located more sparsely, mainly in the biggest cities in the region.

In the case of modelling results for Małopolska, the best ones were obtained by adopting approaches A2 and A4, both based on the WRF meteorological model.

From the results both for Kraków and Małopolska it can be assumed that switching from MM5 to WRF should produce more accurate results. The benefit of changing emission inventory to the one based on CED is less clear, although it is hard to draw firm conclusions on the base of the model's performance just during three smog episodes.

The method of validating the results of modelling by comparing them with measurements at the stations entails certain limitations. The modelling is being performed for the whole domain, while measurement stations are measuring concentrations at a specific location. As an effect, it is only possible to compare modelling results obtained for grid points that correspond to those locations. This is a problem because no information about spatial changes in concentrations is available. However, the stations should be located in places where measurements are representative for an area close to them, yet there is still a high degree of uncertainty connected with comparing modelling results with point measurements. The development of the usage of satellite products in obtaining a pollution concentration could be a promising step that would allow to compare results spatially, not only at specific points (Fioletov et al., 2022; Godłowska et al., 2023).

More research is needed to draw firmer conclusions about the further development of FAPPS. To choose the optimum modelling approach, it is necessary to conduct tests for at least one heating season. Moreover, the changes in the settings of WRF (e.g., selecting a different microphysics scheme) could also influence the results, so further testing is required to see how they will affect the modelling results.

5. Conclusions

This paper presents results of preliminary tests of a new version of the FAPPS system, which has been based on the CALPUFF dispersion model. The work aimed to improve the FAPPS system, launched in 2013, to enhance the quality of forecasts pertaining to pollution concentration, for example, by reducing the number of missed forecasts. To this end, the impact of modifications in terms of the applied meteorological model and emission inventory on modelling results was analysed for three smog episodes for which the operational version of FAPPS gave unsatisfactory forecast results for Kraków.

An attempt was made to assess how point sources influenced the concentration of PM_{10} in the Małopolska region during three chosen smog episodes. The point sources were divided into two domains. One of them included an area outside of Małopolska and the other area inside it. The modelling results show that emissions from point sources had no major impact on the concentration level of PM_{10} during that time. On average, sources located outside of the region contributed more to the pollution level than the sources located in it, but the average modelled PM_{10} immission from them was very low and did not exceed 2 $\mu g/m^3$. Consequently, enlarging the external modelling domain currently in use seems pointless. It would increase the preparation time of the forecast, with virtually no effect on the results obtained.

The paper also presents the results of tests of different modelling approaches for total emission input. The current modelling system used operationally was compared with the approaches that were using different meteorological models and different emission inventories. Based on those results, switching from MM5 to WRF meteorological model seems to improve the modelling results, especially for Kraków where approach A4 based on CED emission inventory and WRF obtained the results closest to measurements (NMSE for this approach is 0.21 and RMSE is 30.02 μg/m^3). For Małopolska, the best approaches were A2 and A4, so it is unclear whether switching emission inventory from EM to CED would improve model performance.

Further testing is needed to decide on the best framework for the new version of the FAPPS system. The research described in this paper suggests that changing MM5 meteorological model to WRF should enhance the modelling results. However, further testing is required. The model needs to predict a high concentration of pollution, but it is also crucial for it to be reliable when the concentrations of pollution in the air are small. That is why the testing should be conducted for at least one whole year and then the results should become more conclusive.

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WPŁYW PUNKTOWYCH ŹRÓDEŁ ZANIECZYSZCZEŃ NA JAKOŚĆ POWIETRZA W MAŁOPOLSCE – PIERWSZE TESTY NOWEJ WERSJI SYSTEMU PROGNOZOWANIA PROPAGACJI ZANIECZYSZCZEŃ POWIETRZA

Abstrakt

Zanieczyszczone powietrze jest niebezpieczne dla ludzkiego życia i zdrowia. Pyły zawieszone, wśród nich PM_{10}, to jedne z najbardziej szkodliwych substancji. W Małopolsce i jej stolicy Krakowie stężenia szkodliwych substancji często przekraczają normy ustalone przez Światową Organizację Zdrowia. Kraków dzięki zakazowi ogrzewania mieszkań za pomocą paliw stałych ograniczył w znacznym stopniu emisję zanieczyszczeń, jednakże emisja w pozostałej części regionu jest wysoka, wpływając na jakość powietrza także w jej stolicy. W sytuacji częstego występowania wysokich stężeń zanieczyszczeń, oprócz koniecznych działań ograniczających emisje, potrzebne jest też prognozowanie wysokości stężeń zanieczyszczeń powietrza, aby informować ludność o możliwości wystąpienia przekroczeń poziomu stężeń normatywnych. W Małopolsce od 2014 r. działa system FAPPS (Forecasting of Air Pollution Propagation System) oparty o zespół modeli AROME/MM5/CALMET/CALPUFF, który jest wykorzystywany do tworzenia prognoz stężeń zanieczyszczeń dla Krakowa i Małopolski. W niniejszej pracy na podstawie wyników modelowania tym systemem zbadano, czy emisja ze źródeł punktowych może mieć znaczący wpływ na poziom stężeń PM_{10} na terenie Małopolski. Wyniki modelowania wskazują, że ten wpływ jest pomijalny. W pracy testowano także jakość prognoz PM_{10} dla czterech wersji systemu FAPPS, różniących się zastosowanym modelem meteorologicznym – MM5 (Fifth-Generation Penn State/NCAR Mesoscale Model) lub WRF (Weather Research and Forecasting) oraz wsadem emisyjnym (emisja z 2015 r. z małopolskiego urzędu marszałkowskiego, uaktualniona o dane z Urzędu Miasta Krakowa dla 2018 r., albo inwentaryzacja emisji z 2020 r. z Centralnej Bazy Emisji). Jakość prognoz oceniano na podstawie wyników pomiarów na stacjach GIOŚ dla trzech epizodów smogowych, które miały miejsce w dniach 11–17.11.2021 r., 11–15.12.2021 r. i 13–18.03.2022 r. Najlepsze wyniki dla miasta Krakowa uzyskano, stosując podejście oparte na modelu WRF i inwentaryzacji emisji z Centralnej Bazy Emisji, dla której dla wybranych epizodów uzyskano wartość RMSE (Root Mean Square Error – średni błąd kwadratowy) równą 30,022 $\mu g/m^3$. W przypadku Małopolski najmniejszą wartość RMSE (33,579 $\mu g/m^3$) uzyskano dla systemu używającego inwentaryzacji emisji uzyskanej z małopolskiego urzędu marszałkowskiego i modelu WRF. Pierwsze testy wskazują, że zmiana modelu meteorologicznego z MM5 na WRF może przynieść poprawę wyników modelowania, jednak konieczne są dalsze badania.

Słowa kluczowe: emisja zanieczyszczeń powietrza, modelowanie jakości powietrza, FAPPS, CALPUFF, MM5, WRF