22nd International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
10-14 June 2024, Pärnu, Estonia

OPERATIONAL AIR QUALITY FORECAST FOR CENTRAL EUROPE

Dušan Štefánik[1], Juraj Beňo[1], Tereza Šedivá[1,2], Jana Krajčovičová[1], and Jana Matejovičová[2]

[1]Slovak Hydrometeorological Institute, Jeséniova 17, 833 15 Bratislava, Slovakia
[2]Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Slovakia

Abstract: In September 2023, the operational air quality forecast was launched for the first time in the history of Slovak Hydrometeorological Institute (SHMÚ). The core of the air quality forecast is the chemical-transport model CMAQv5.3.3, which uses meteorological forecasts from the ALADIN model (ALARO 2-e). The boundary conditions are taken from the CAMS GLOBAL and CAMS EUROPE air quality forecasts. Operational air quality forecast is running in two terms: 00 and 12 UTC for +48 hours. The horizontal resolution of the model is 2 km. The forecast is focused mainly on the most studied air pollutants: PM_{10}, $PM_{2.5}$, NO_2, and O_3. The deployment of the operational air quality forecasting system on the SHMÚ HPC cluster is briefly described. Some selected forecasts are analysed and compared with measured concentrations from the National Air Quality Monitoring Network operated by SHMÚ and with CAMS EUROPE air quality forecast.

Key words: *air quality forecast, chemical transport model, air quality modelling, PM, NO_2, O_3.*

INTRODUCTION

The air quality forecast is running on the HPC3 cluster operated at Slovak Hydrometeorological Institute (SHMÚ). The core of the system is the chemical transport model CMAQv5.3.3 (Byun and Schere 2006; US EPA, 2021), which uses meteorological field forecasts from ALADIN prognostic model (ALARO 2-e) (Derková, 2017). The meteorological data are preprocessed by the meteorological preprocessor PYcip developed at SHMÚ and are stored in the netCDF format suitable for the CMAQ model. The 2m temperature is used to operationally calculate the emission flows for local heating systems using the emPY preprocessor (Štefánik, 2019). Chemical boundary conditions are extracted from the CAMS GLOBAL and CAMS EUROPE models. The forecasts are in form of maps of pollutant concentrations for PM_{10}, $PM_{2.5}$, O_3, and NO_2. Map products can be viewed at the address available on the SHMÚ intranet, but it is planned to place the forecasts the public web site in this year. Schematic picture of the operational air quality forecast system is in Figure 1.

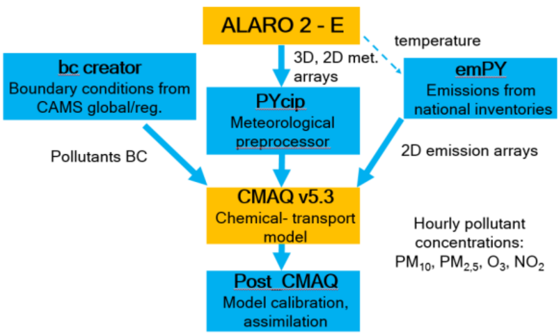

Figure 1. Schematic picture of the operational air-quality forecast

Individual programs of the operational suite are managed using run_app system, which was developed at NWP department of SHMÚ. This system allows to run applications in a modular, unified and automatic manner, it also enables monitoring of applications using a visual environment.

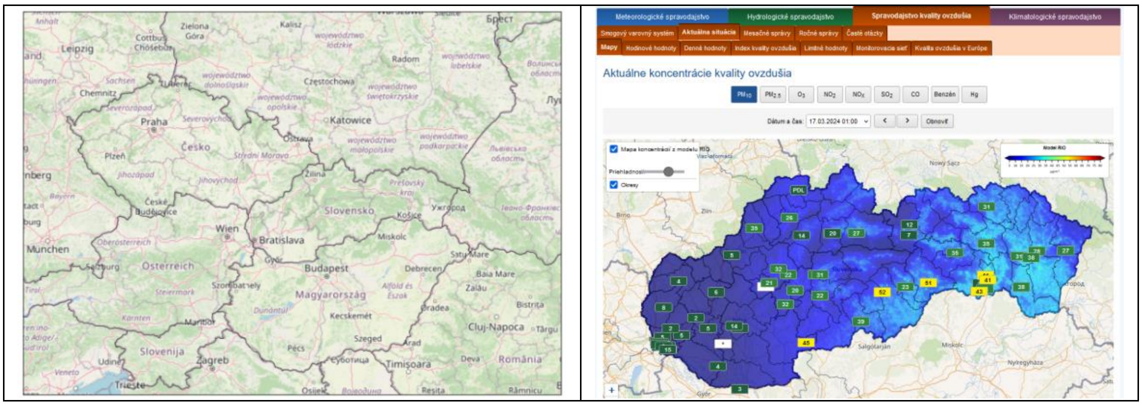

Figure 2. Computing domain (left); near-real time measured and interpolated concentration by model RIO aviable at www.shmu.sk.

The model domain with 2 km horizontal resolution is plotted in Figure 2 (left). It covers the territory of Slovakia, Czechia, Hungary, Slovenia, substantial part of Austria and parts of their neighboring states. The model results have been validated against the data from the National Air Quality Monitoring Network automatically on daily basis, calculating RMSE, BIAS, and r statistics and plotting scatter plots of model results against measurements. In addition, the episodes can also be compared graphically with the near-real time maps created by the interpolation-regression model RIO (Janssen, 2008) using measured data (Figure 2 right). This visual comparison between the forecast and measurements can give us valuable spatial information about the model performance during specific episodes, which we cannot be obtained from pure statistic validation. It is worth to note that the European near-real time concentration maps suitable for a visual comparison with the model results are not available. The only available EEA air quality index map may be appropriate for the information of public, but not for scientific purposes such as checking the model results in a way how meteorologists check the forecasts in the weather rooms.

SELECTED SITUATIONS

Winter adverse dispersion situation from 29/01/2024 to 02/02/2024 afected by the local heating

Between 29/01/2024 to 02/02/2024, stagnant conditions with temperature inversion occurred over Slovakia, leading to poor air quality due to high PM_{10} and $PM_{2,5}$ concentrations. In Figure 3, the evolution of PM_{10} concentrations during 01/02/2024 measured at the monitoring stations and spatially interpolated by RIO model are presented. PM_{10} concentrations predicted by the CMAQ model with the same time steps as in Figure 3 are in Figure 4. Concentrations measured at 4 monitoring stations and modelled by CMAQ and CAMS models during the whole episode are in Figure 5. We can see that the model predicted increased concentrations at both 03:00 and 10:00 CET during 01/02/2024, which qualitatively agrees with the observations. However, at 12:00 CET, the model already predicts a gradual improvement in the air quality thanks to the advancing front, although, in reality, the measured values still remain very high, even increased in some places. Measured concentrations decreased gradually towards the evening, except for eastern Slovakia. Models agree quite well with measurements at Bratislava, Jeséniova station (Figure 5 top left). This station is situated in the hillside of Carpathian Mountains in the south-west part of Slovakia. This region is considered to be quite windy and sensible to the impacts of the Atlantic weather. It was also observed that after the end of the stagnant conditions the air in this areas starts to mix rapidly and the air pollution is diluted quickly when the front passes. According the measurements in Trnava station (Figure 5, top right) the high PM_{10} concentrations remain few hours longer than in the Bratislava station. Trnava is situated 50 km north-east from the Bratislava, but it lies in the lowland. The Little Carpathian mountain range situated 20 km to the west effectively block the Atlantic weather impact, resulting in Trnava having a little bit more continental climate compared to Bratislava. This can be the reason why, during winter front passages, the ground level air is mixed a little bit more slowly compared to Bratislava region. From Figure 5 (top right), we can also see that on 01/02/2024 the models diluted high PM_{10} little bit sooner than it is reflected in the measurements. At Košice, Amurská monitoring station (Figure 5, bottom right) located in eastern Slovakia, the high PM_{10} concentrations persist in the lower levels of PBL many hours after the models predicted the air quality improvements. We assume it being due to the large Carpathian mountain ranges preventing mixing with the lower level air for much longer than in the west of Slovakia. This situation indicates that during the fronts in winter, the model tend to mix the ground layer significantly and quickly, although in reality, the older air mass likely remains in the ground layer for several hours longer than predicted. Another drawback of the models is that they do not capture the poor air quality in settlements located in deep valleys which are polluted by local heating systems. Such example is Jelšava station (Figure 5, bottom left) where none of the models is able to predict high PM_{10} concentrations.

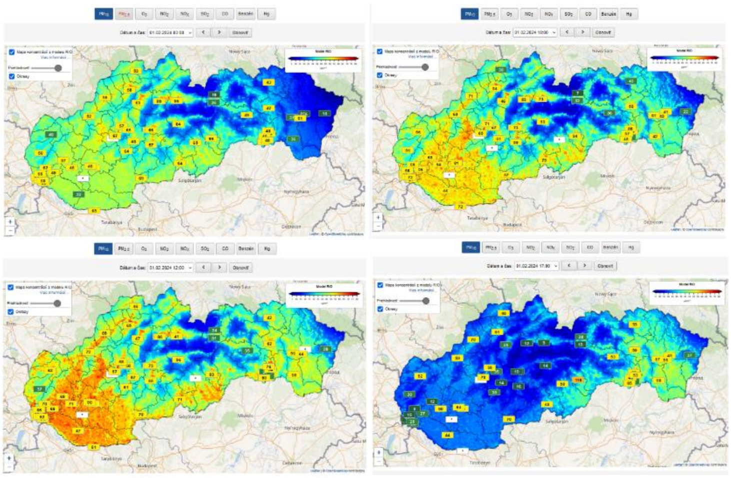

Figure 3. Measured PM_{10} concentrations interpolated by RIO model on 01.02.2024 at 03:00, 10:00, 12:00 and 17:00 UTC .

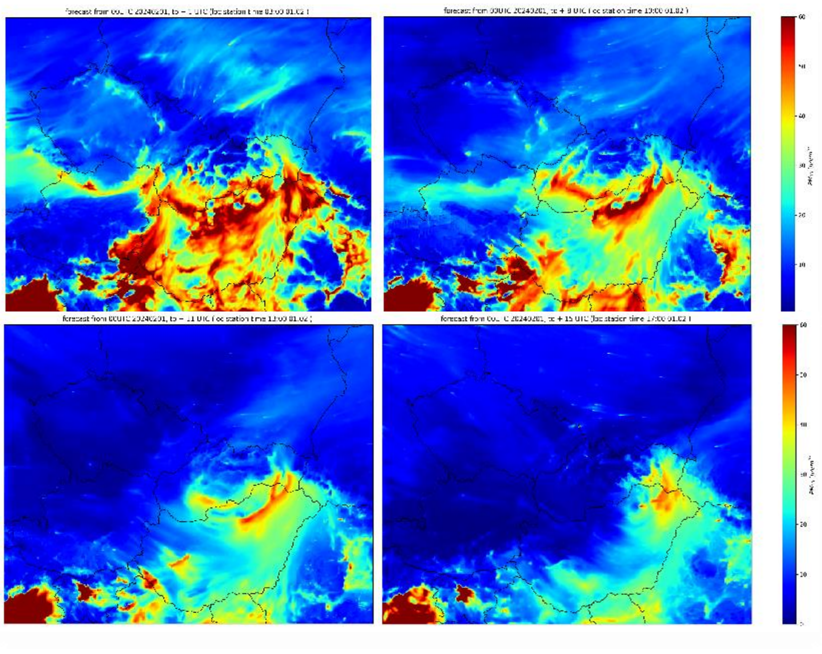

Figure 4. PM_{10} concentrations modelled by CMAQ model on 01.02.2024 at 03:00, 10:00, 12:00 and 17:00 hours UTC.

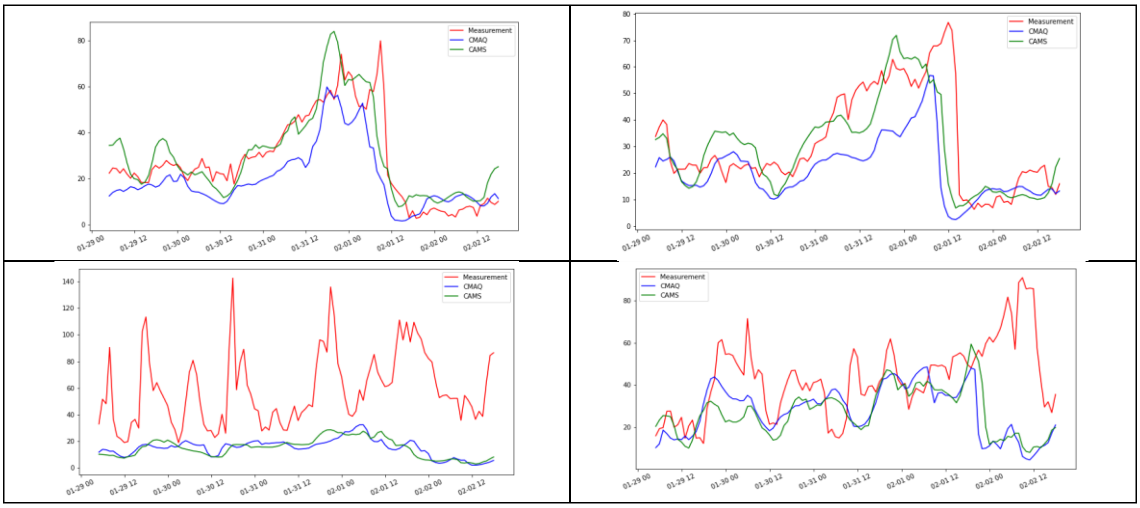

Figure 5. Measured and modelled PM_{10} concentrations in µg m^{-3} at Bratislava, Jeséniova (top left), Trnava (top right), Jelšava (bottom left), Košice Amurská (bottom right)

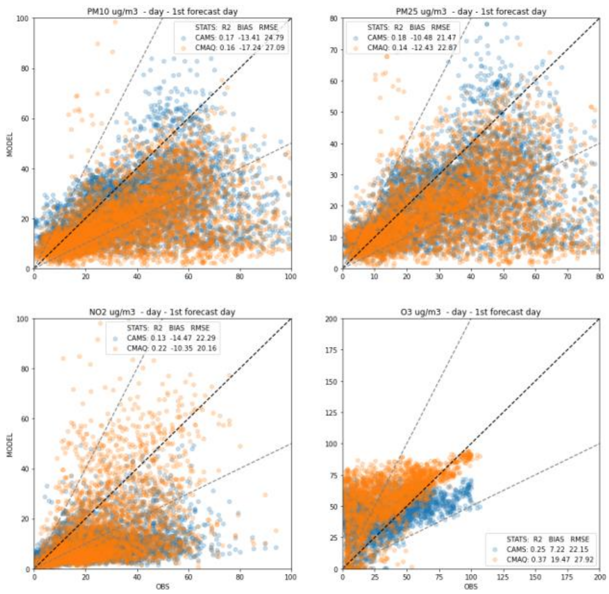

Figure 6. The performance of the models during the episode from 29.01. to 02.02.2024.

Figure 6 contains the scatterplots and statistics of both CAMS and CMAQ models against measurements from 29.01. to 02.02.2024. In case of PM, CMAQ model performs slightly worse than CAMS. This could be caused by the following factors: 1) CAMS model is assimilated using observations while CMAQ is not, 2) coupling CMAQ with CAMS as boundary conditions is insufficient, 3) operational CMAQ uses boundary conditions from +1d CAMS model forecast in order to enable the model running operationally at 2:30 UTC. 4) CAMS is an ensemble model, in which possible systematic errors of individual models can be cancelled out in the averaging process. On the other hand, CMAQ model has better horizontal resolution, allowing it to predict smaller and local hotspots. This is the reason why CMAQ model outperforms CAMS model in NO_2 predictions (NO_2 concentrations decrease rapidly with the distance from the source, so the space resolution is crucial). In case of O_3, CMAQ model correlates with the observations quite well but it has rather large systematic BIAS. The origin of this BIAS will be subject to further study.

Saharan dust situations

Episodes with very high PM_{10} concentrations caused by the Saharan dust occurred rather frequently over the Central Europe in the past years. Recently, two big Saharan dust episodes occurred in Slovakia (Figure 7) – one between 20. and 21. October 2023 and the second, which caused historically the highest PM_{10} ground-level concentrations caused by the Saharan dust measured in Slovakia, from 30. March to 2. April 2024. While the mean concentrations in the first episode were predicted quite well except for the beginning which was underestimated, in the second episode, the predicted mean concentrations were significantly lower and the first measured peak was missing in the predicted concentrations.

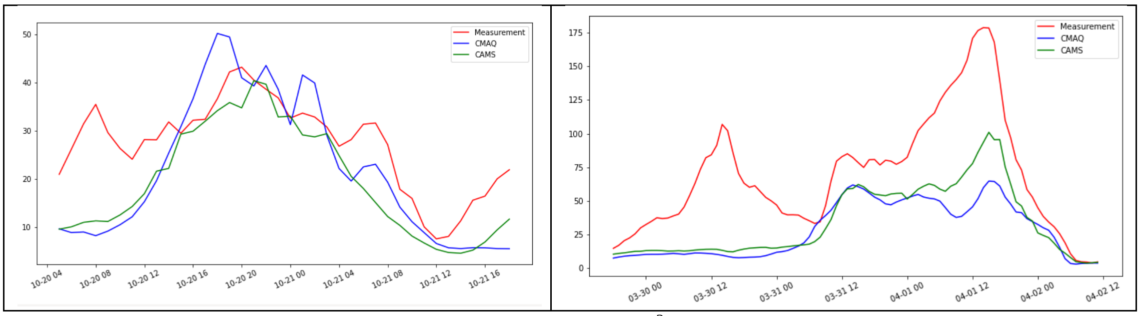

Figure 7. Measured and modelled PM_{10} concentrations in µg m^{-3} – the lines represent concentrations averaged through all national monitoring network stations and a model concentrations from the respective grid cells. Left: Episode from 20. to 21. October 2023, Right: Episode from 03. March to 02. April 2024.

CONCLUSIONS

Air quality forecasts can be an important source for informing the public and the local administrations about possible coming smog episodes or adverse air quality conditions. It was demonstrated that CMAQ model provides the air quality forecast comparable to CAMS ensemble model. Both models have some common drawbacks – often they are not able properly describe stable conditions in the lower part of boundary layer. Especially difficult is the pollution prediction in narrow deep and poor ventilated valleys. In winter, during the front passages, the models tend to mix the ground levels of atmosphere too quickly, even when observations such as surface temperature, calm wind, and high pollution indicate the stagnant conditions near the ground. Air quality forecasting system at SHMU is still under the development and further improvements, i.e., updated emission inputs, better coupling to the CAMS model, observation assimilation, are expected to be implemented in the near future.

REFERENCES

Byun, D., Schere, K., 2006: Review of the governing equations, computational algorithms, and other components of the Model-3 Community Multiscale Air Quality (CMAQ) Modeling System. Appl. Mech. Rev. 59 (2), 51–77. https://doi.org/10.1115/1.2128636.

CAMS global atmospheric composition forecasts [Data] https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-atmospheric-composition-forecasts?tab=form

CAMS European air quality forecasts [Data] https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-forecasts?tab=form

Derková et. al., 2017: Recent improvements in the ALADIN/SHMU operational system. Meteorologický časopis SHMÚ, Vol.20, No. 2, pp 45-52.

Janssen, S., Dumont, G., Fierens, F., Mensink, C., 2008: Spatial interpolation of air pollution measurements using CORINE land cover data., Atmospheric Environment, 42, 4884 – 4903

Štefánik, D., 2019, emPY [Software]. Available from https://github.com/dusssaaan/emPY/blob/master/emPY_User_Guide.pdf

United States Environmental Protection Agency, 2021: CMAQ (Version 5.3.3) [Software]. Available from 10.5281/zenodo.5213949