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EVALUATION OF THE PERFORMANCE OF CHIMERE CHEMICAL TRANSPORT MODEL IN FOG SITUATIONS OVER HUNGARY

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Abstract: Air pollution is a serious environmental problem in Hungary. Primarily during winter and fall seasons, episodes of poor air quality related to high concentrations of particulate matter are frequent, especially in the eastern part of the country. These situations are often connected to special meteorological conditions which hinder the mixing and dilution of air pollutants. Such a situation occurred at the end of January 2017 when a cold air cushion evolved over Hungary, leading to foggy weather, very low temperature conditions and high surface PM_{10} concentrations. Chemical transport model (CHIMERE) calculations have been carried out to evaluate this smog episode. At first a sensitivity analysis was made to determine the most important meteorological parameters affecting the concentration fields that we obtain as results of the chemical transport model simulations. The following aim was to examine the meteorological background which could contribute to the developing of the smog situation. Imprecisions in meteorological data can cause significant inaccuracies in the calculated gas and aerosol concentrations. The mass concentrations have been compared with measured PM_{10} concentrations for the validation of the simulation results.

Key words: *particulate matter, cold air cushion, fog, chemical transport model simulation*

INTRODUCTION

Air quality and the impact of air pollution on the environment and health are actual issues in Hungary. The main concern is related to particulate matter (PM), which is the most frequent constituent of smog episodes throughout the country. PM has many negative effects on the ecosystem, built environment and especially on human health. In order to alleviate these effects, PM reduction strategies are elaborated in Hungary, in which local and regional meteorology, long-range transport and pollution dispersion are all factors that have to be taken into account.

A key issue regarding air quality research in the Carpathian Basin is to identify the sources of aerosol particles and the influencing meteorological factors, which may lead to increased concentrations of particulate matter. Data in emission inventories have improved significantly in Europe in the latest years, however, the quantitative contributions of different sources (e.g. domestic heating and automobile exhaust) to the total emission are still highly uncertain. In addition to the uncertainties in anthropogenic emission data, another difficulty lies in our limitation in the accurate understanding of the connection between local meteorological conditions and the environmental concentrations of pollutants. Analysis of local and regional meteorology – including wind speed, wind direction, atmospheric stability and precipitation – is crucial to completely understand the processes responsible for the spatial and temporal distribution of PM in all geographic regions (Chen et al., 2017; Pearce et al., 2011). The situation is further complicated by the fact that apart from being emitted directly, PM can also form in the atmosphere when gaseous pollutants (SO_2 and NO_x) undergo transformation to yield secondary inorganic particles (Ferenczi et al., 2018), and this complexity adds to the importance of meteorology in air pollution analyses.

In this study we present a few examples to show how meteorological variables affect the distribution of PM concentrations in the Carpathian Basin and then we summarize an analysis of a smog situation that happened under special meteorological conditions in Hungary at the end of January 2017.

THE EFFECT OF METEOROLOGY

The transport and dilution of pollutants emitted into the atmosphere is mainly driven by the actual meteorological conditions. Based on a unified emission inventory, a sensitivity analysis that is carried out with real meteorological data describing different weather patterns reflects the effects of meteorological variables well. In this work we demonstrate the effects of wind speed and precipitation.

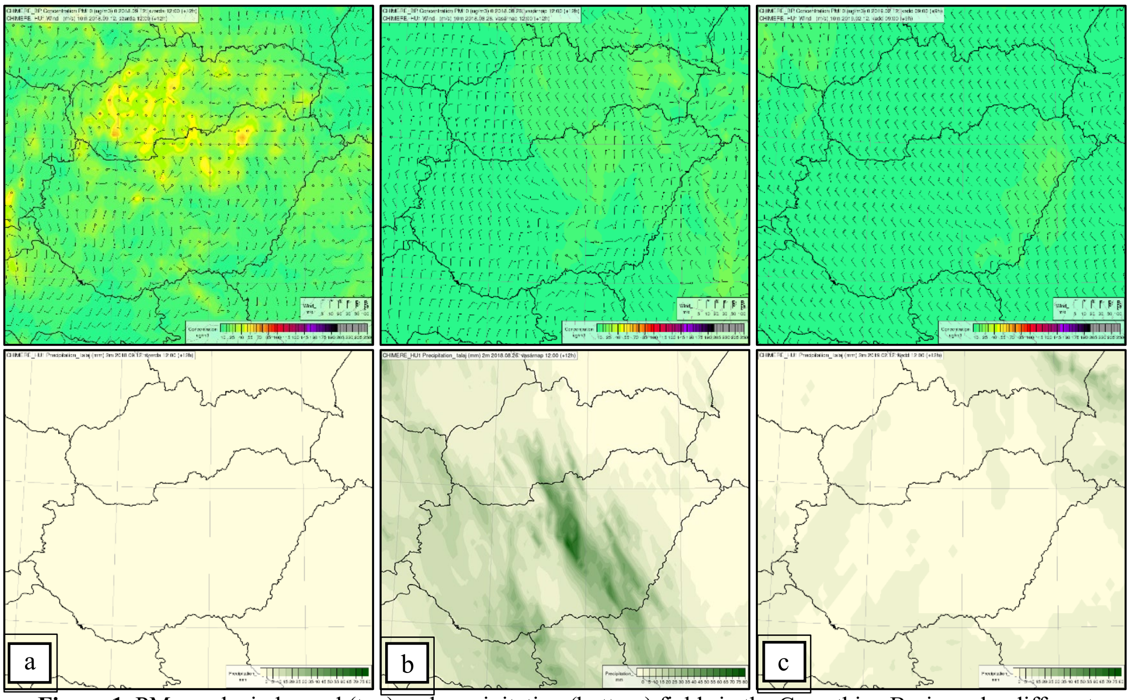

Figure 1. PM_{10} and wind speed (top) and precipitation (bottom) fields in the Carpathian Basin under different weather patterns: a) a dry day with low wind speed, b) a day with a large amount of precipitation and c) a day with strong winds. The maps show the 12 UTC situation.

In our analysis we needed real meteorological data representing weather conditions in which certain meteorological variables were dominant compared to others, therefore their effects could be differentiated. We worked with daily data in a 1-hour temporal resolution. In order to capture the impact of precipitation and wind speed on concentration levels we chose 3 different days to examine: one with mostly light winds and without precipitation, one with a large amount of precipitation and another day when strong winds were dominant. Table 1 contains the characteristics of the chosen data.

Table 1. Meteorological data in the sensitivity analysis

Time period	Dominant weather type
12 September 2018, 00 UTC – 13 September 2018, 00 UTC	Light wind and no precipitation
12 February 2019, 00 UTC – 13 February 2019, 00 UTC	Strong wind
26 August 2018, 00 UTC – 27 August 2019, 00 UTC	Rain

Figure 1 shows the simulation results for each day at 12 UTC. The distribution of PM_{10} concentration is shown in the top row together with the related wind fields and in the bottom row precipitation conditions are illustrated. Results demonstrate the effects of precipitation and wind speed well. On the day when wind speed remained low and there was no precipitation, conditions were favourable for PM_{10} to accumulate, while in the presence of rain and strong winds concentrations dissipated quickly in the areas affected.

A SPECIAL SMOG SITUATION IN HUNGARY

A cold air cushion is a special meteorological situation that is related to inversion in the upper atmosphere and it is coupled with very low surface air temperatures. It most frequently evolves in areas that are surrounded by chains of mountains. Anticyclonic events trigger the development of cold air cushions as they foster downward motions in the air. By serving as a barrier for mixing motions, inversion causes the air to stabilize and it hinders the movement of the air mass out of the basin. This effect is enhanced by the presence of the surrounding mountains. Low temperatures boost residential heating and in the absence of sufficient mixing and dilution, pollutants of anthropogenic origin accumulate rapidly and concentrations can easily reach and exceed levels that are considered harmful for the health.

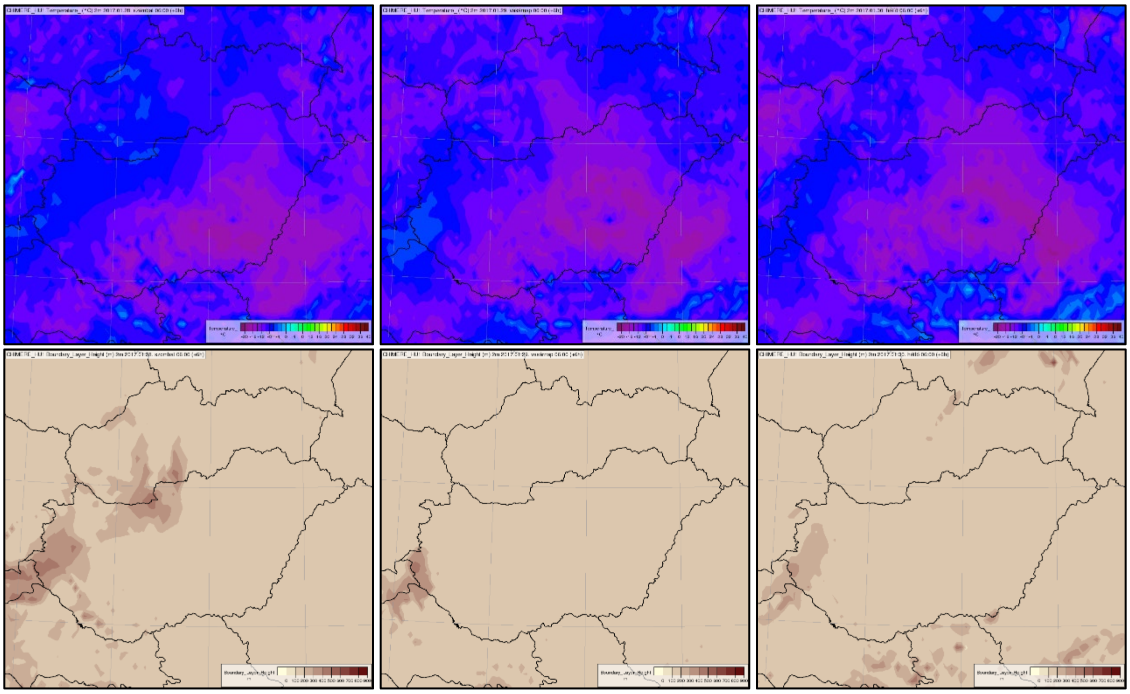

Figure 2. Temperature and boundary layer height in the Carpathian Basin at 06 UTC from 28 to 30 January 2017.

At the end of January 2017, in an anticyclonic weather situation, a cold air cushion evolved over Hungary. Temperatures dropped well below -10°C for the nights throughout the whole country. On account of a lower level inversion, planetary boundary layer height remained below 200 m, winds were light and the air stabilized. Figure 2 shows the temperature and boundary layer height conditions in the Carpathian Basin at 06 UTC from 28 January to 30 January 2017.

This unfavourable meteorological situation led to high concentrations of PM_{10}. The severity of PM_{10} pollution was increased by enhanced emission in the sector of residential combustion, due to very low temperature conditions. Concentrations started to rise on 18 January and reached a peak at the end of the month.

We used the CHIMERE chemical transport model to simulate the transport and chemical transformation of air pollutants during this smog episode. The model domain covered the Carpathian Basin with a resolution of 0.1° (roughly 10 km). For the input anthropogenic emission data the EMEP database was used in a 0.1^{0} spatial resolution. Input meteorology for the model calculations was provided by the AROME numerical weather prediction model. Figure 3 represents the distribution of PM_{10} concentrations in the Carpathian Basin at 12 UTC from 28 January to 30 January 2017.

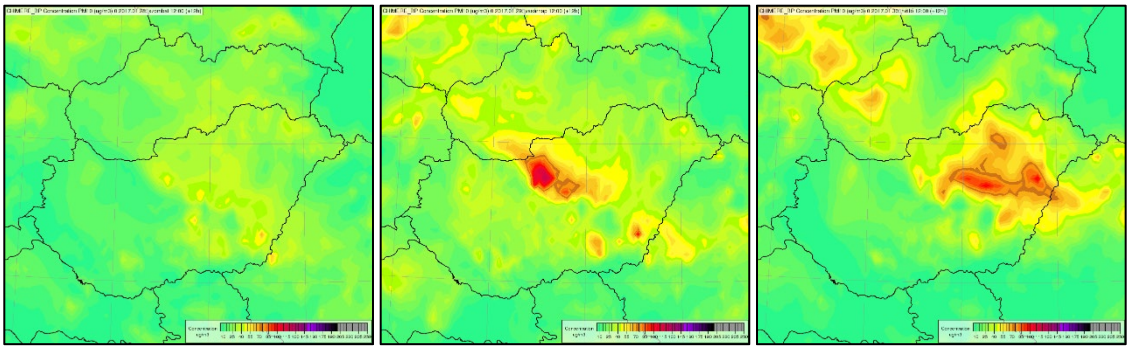

Figure 3. PM_{10} in the Carpathian Basin at 12 UTC from 28 to 30 January 2017.

Simulation results suggest that in this very special meteorological situation the model in some areas underestimated the real concentration values considerably. PM_{10} pollution was extremely high in the Sajó Valley, in the vicinity of the city of Miskolc, with the highest measured 1-hour average concentrations above 500 $\mu g/m^3$. Figure 4 shows time series of PM_{10} measured at 3 different stations in Miskolc and modelled values for a grid point in the territory of the city.

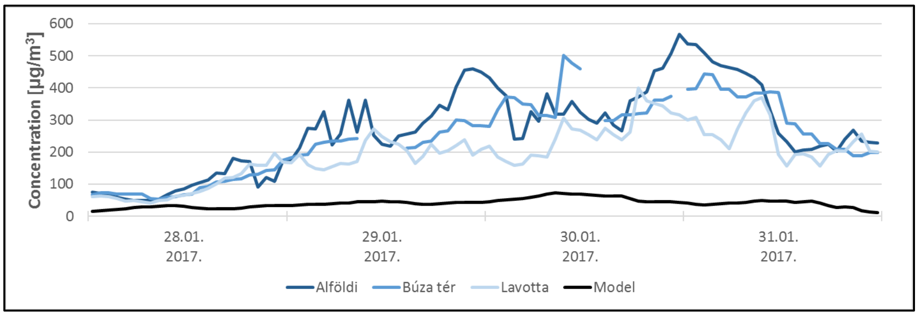

Figure 4. Measurement time series of PM_{10} at three different stations in Miskolc (blue) and model simulation results (black) for a grid point in the area of Miskolc from 28 to 31 January 2017.

Based on the results demonstrated in Figure 4 we can see that the model significantly underestimated the measurements around Miskolc. In the case of Budapest, however, we found that the simulation results were much closer to the measured values gained at 10 stations located sporadically in the area of the capital. Time series of PM_{10} measurements and modelled data for a grid point in Budapest are presented in Figure 5.

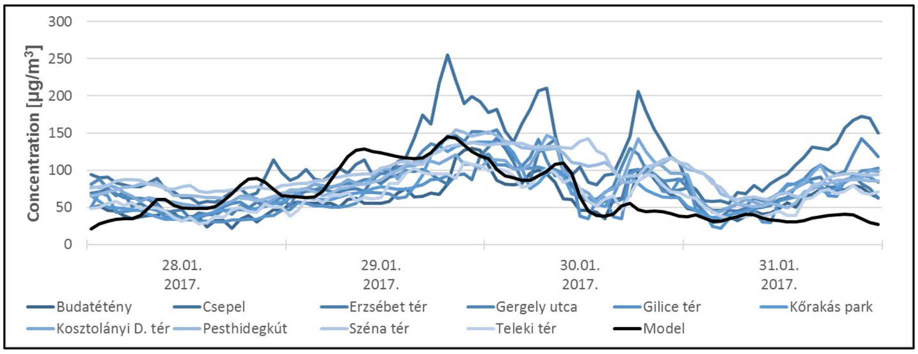

Figure 5. Measurement time series of PM_{10} at ten different stations in Budapest (blue) and model simulation results (black) for a grid point in the area of Budapest from 28 to 31 January 2017.

The ability of the model to describe a smog situation in a realistic way lies both in precise emission data and in an accurate weather forecast. Deviation of weather forecast data from the real meteorological situation leads to inaccurate modelled concentration levels, especially when it concerns meteorological variables that affect pollutant distribution dominantly. In the smog situation examined here, wind speed had a crucial role. Wind speed is responsible for the strength of advection and in the absence of a considerable wind, the amount of pollutants in the air increases rapidly. Figure 6 demonstrates measured and modelled wind speed values in Miskolc and in Budapest for the end of January 2017.

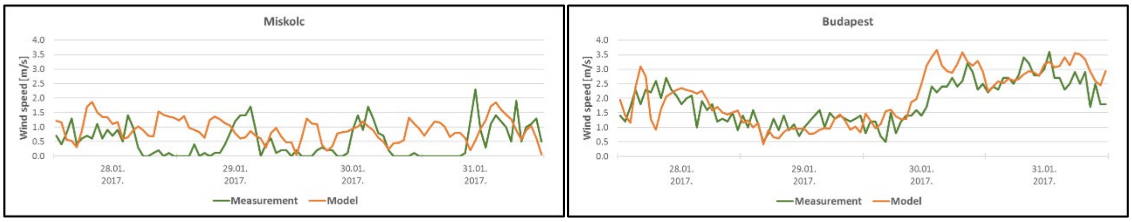

Figure 6. Measured and modelled wind speed data for Miskolc (Diósgyőr station) and Budapest (Pestszentlőrinc station) from 28 to 31 January.

Data on Figure 6 suggest that the tendencies of measured and modelled wind speed data were quite similar in the case of Budapest, however, differences in magnitude did occur. When measured wind speed approximated zero, which happened regularly in Miskolc, the model was usually not able to follow, leading to considerably higher average modelled wind speed in that area. We note that the geographical environment of Miskolc and the Sajó Valley does not favour weather forecast either, due to surface complexity. Since wind speed strongly affects the dilution of pollutants in the air and in model simulations, as we could see in the sensitivity analysis presented above (Figure 1), the inaccuracies in modelled wind speed data could probably largely contribute to the inaccuracies in PM_{10} concentration fields calculated by CHIMERE. Another factor which the model was unable to take into account, was the increase in the anthropogenic emission compared to the inventory, which occurred as a consequence of the very low temperature conditions.

CONCLUSIONS

In this study we presented a few examples for the way meteorological variables affect the transport and dilution of PM in the atmosphere and investigated a special meteorological situation that occurred in the Carpathian Basin and led to increased environmental concentrations of PM_{10}. We demonstrated how strongly wind speed and precipitation contribute to the dilution of particles in the air, while in low wind and dry weather conditions pollutants accumulate rapidly. At the end of January 2017, in an anticyclonic weather situation, a cold air cushion evolved over Hungary that involved very low temperature conditions, a low planetary boundary layer height, light winds and stable air. The consequence was a smog period with high PM_{10} concentrations that in some areas exceeded the 500 $\mu g/m^3$ value. Model calculations were carried out in order to simulate the smog episode using the CHIMERE chemical transport model and AROME weather forecast data. We found that in this very special case the model significantly underestimated the measured values in certain areas, probably as a result of the inaccuracies in weather data and the enhanced intensity of residential heating which the model could not take into account. This analysis suggests that local meteorology has a crucial role in the accuracy of air pollution modelling.

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