SZENT ISTVÁN UNIVERSITY

Analysis of expected air quality trends using new generation dispersion models

Theses of the doctoral (PhD) dissertation

Emese Homolya

Budapest
2020

Doctoral School

name: Doctoral School of Landscape Architecture and Landscape Ecology

research field: Agricultural engineering

head: **László Bozó, DSc**
Professor, Member of Hungarian Academy of Sciences
Szent István University
Faculty of Horticultural Science
Department of Soil Science and Water Management

Supervisor: **László Bozó, DSc**
Professor, Member of Hungarian Academy of Sciences
Szent István University
Faculty of Horticultural Science
Department of Soil Science and Water Management

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Approval of the Head of the Doctoral School Approval of the Supervisor

Table of contents

1. INTRODUCTION AND OBJECTIVES

Air pollution is a major environmental risk of our times, the reduction of which poses a great challenge on professionals and decision-makers equally. High concentrations of air pollutants may directly impair human health, ecosystems and the built environment and deposition processes may lead to harmful material getting into the surrounding environmental media – into the waters or soil – where it can cause further damage. Today a widening range of attention is given to air quality and we have more and more advanced methodologies to assess the current status and tendencies of, and the expected changes in air pollution.

The phenomenon of air pollution has been recognized long before the industrial revolution (Heidorn 1979). Contemporary descriptions suggest that poor air quality caused problems even in the middle age settlements, where the main causes behind the pollution were wood burning, certain domestic activities, noxious trades such as tanning and the decaying rubbish in the streets (Barker et al. 1961). In those times – although difficulties induced by smoke and obnoxious odours were commonly known – there existed scarce knowledge regarding the harmful effects of air pollution, therefore no effort was made to abate them. It was presumably the middle of the 19th century when the issue of air quality began to become more and more a point of scientific interest, however, it started getting raised attention only during the 20th century with the growing number of occurrences of London and Los Angeles type smog episodes.

In the latest decades the development of science and technology has brought about a major breakthrough in the field of air pollution research as well. There appeared organized measurement programs (EPA 2019, $EMEP_{web}$), more and more sophisticated trajectory and air quality models are available, our knowledge is constantly broadening concerning the physical and chemical background and the harmful effects of the phenomenon, moreover, international programs have been launched with the aim of reducing air pollution.

In this regard, the establishment of the United Nations Environment Programme (UNEP), following the UN conference held in Stockholm in 1972, stands as a milestone and from the end of the 70s on, a number of new international agreements – containing also commitments – arose, in which partners acknowledged their mutual interests in the handling of environmental problems (Faragó 2018). The monitoring of air pollution and the methodology of air quality assessments in Europe are supervised by the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP), initiated by the United Nations Economic Commission for Europe (UNECE) in 1977, which operates as a part of the Convention on Long-range Transboundary Air Pollution (CLRTAP) from 1983 onwards (EMEP MSC-W 2004).

Although the most accurate information regarding the actual conditions in the air is gained by direct measurements, a comprehensive assessment of air quality today requires the use of specific air quality models. Based on a mathematical interpretation of physical and chemical processes taking place in the air, air quality models define a relationship between the emitted pollutants and concentrations measured in the environment. Therefore, they provide a suitable way for the tracking of the dispersion, chemical reactions and deposition of air pollutants. Modern air quality models take many kinds of environmental processes into account and their evolving complexity makes it possible for them to describe the real behaviour of the natural systems more and more profoundly. However, no matter how sophisticated a model is, due to the high complexity of the natural systems and the feedbacks and non-linearities they involve, it is not able to describe all processes fully accurately, it is bound to use approximation and parametrisation in its methods. Simulations of the models are therefore generally accompanied by a certain amount of uncertainty that is dependent on the calculation methods, the accuracy of the input data, the geographical environment, the weather situation and the resolution as well. The better understanding we have regarding the behaviour, characteristics and the limits of our models, the more precisely we can define this uncertainty, which then provides us with the opportunity to estimate the expectable accuracy of our calculations beforehand.

My PhD work aims to analyse the Hungarian air quality from different aspects using up-to-date tools based on model simulations, where I focused primarily on weather elements that mostly influence dispersion processes in the air and their effects on concentrations evolving in the environment, modelling of critical air quality situations rising in special meteorological conditions and the expectable effects of anthropogenic emission reduction strategies. I chose the research topics to provide a comprehensive picture regarding the present-day methods of air quality assessment and their limits, the actual state of the Hungarian air quality and air quality analyses, and the opportunities and further challenges set by the modelling techniques. In the examinations – for the different tasks require different approaches – I basically used two methods. In the cases where the tracking of dispersion in the air was necessary, I used the French CHIMERE chemical transport model (CHIMERE 2017), while for the impact studies concerning the emission reduction measures, I applied the SHERPA air quality modelling tool (Thunis et al. 2016). My objectives are summarized in the following points:

- the collection of all the current and relevant information in the course of literature overview that are necessary for a comprehensive understanding of air quality, the methods applied in the assessments of air quality, the related regulations and the Hungarian relations,

- the adaptation of the latest version (2017) of the CHIMERE chemical transport model for a Hungarian domain and the installation of the SHERPA software,
- to perform a sensitivity analysis using the CHIMERE model in order to examine, to what extent and how the key meteorological elements affect the evolving concentrations in the course of the modelling process,
- the elaboration of a case study for a real Hungarian air pollution episode to explore the background and the probable causes behind it, and to test the model performance in such a special air quality situation,
- to examine the expectable environmental consequences of anthropogenic emission reduction measures in the area of Hungary and to analyse, to what extent the objectives set in the National Air Pollution Control Program may improve the Hungarian air quality concerning the $PM_{2.5}$ and the NO_2 pollution.

2. MATERIALS AND METHODS

In the course of my PhD work I carried out the majority of the air quality analyses using the CHIMERE chemical transport model, however, for the assessment of the potential effects of the Hungarian emission reduction measures I applied the SHERPA air quality modelling tool. The two methods basically differ in the aspect that while SHERPA is a decision support system with a graphical interface specialized for the analysis of the effects of emission reduction measures, the CHIMERE model is a program system executable in a terminal, the source code of which is freely accessible and all input data files can be modified, thus making the model system more complex.

For the examinations with the CHIMERE model I chose a domain covering Hungary and extending to almost the whole territory of the Carpathian Basin to be the target area, with the borders of latitudes 45º and 50º and longitudes 14º and 25º (Figure 1). I defined the grid – that is freely specifiable in the model – the way that the spatial resolution fits that of the emission inventory data of EMEP – 0.1º – which corresponds to roughly 10 km in the region of the Carpathian Basin.

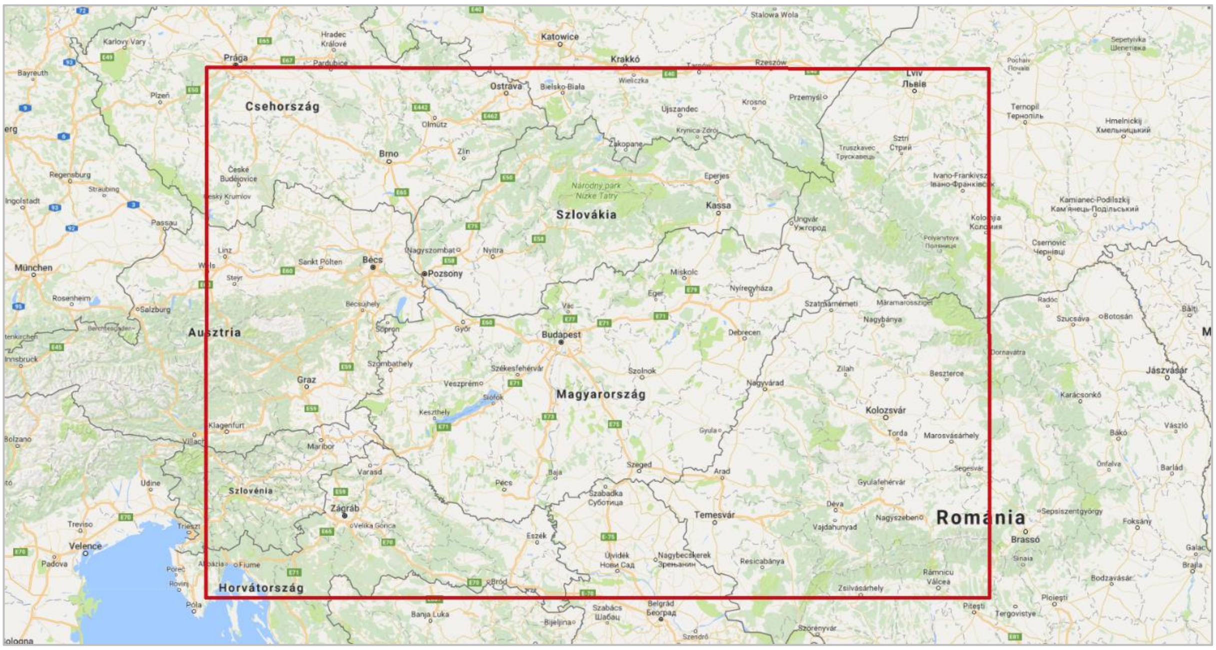

Figure 1: The target area for the analyses using the CHIMERE model

For the input emission data I used the gridded emission inventory of EMEP for the year 2015 in the simulations. I downloaded the data for nitrogen-oxides, volatile organic compounds, sulphur-dioxide, ammonia, fine aerosol particles ($PM_{2.5}$), coarse aerosol particles (PM_{10}–$PM_{2,5}$) and carbon-monoxide in a 0.1º spatial resolution. Data of biogenic emission was calculated by the

MEGAN model for the simulations, while data regarding terrestrial coarse particles originated from the USGS database.

Meteorological data were provided by the AROME numerical weather prediction model of the Hungarian Meteorological Service in a 1-hour temporal and the 0.1° spatial resolution of the EMEP grid. For CHIMERE, data is prepared by the built-in meteorological pre-processor, using the model's own diagnostic tool. Meteorological data files for the Carpathian Basin have been available from 8 February 2018 on. One file in the database contains data for one single day. Information concerning landcover is provided by the GLCF database.

CHIMERE yields concentration and deposition fields as results of the simulations in NetCDF file formats, from which data can be extracted using the appropriate tools. The graphical visualization in the form of maps – used for observing the spatial distribution of data – was in my thesis primarily implemented using the HAWK (Hungarian Advanced WorKstation) software owned by the Hungarian Meteorological Service and the Panoply application. I carried out file operations – such as basic mathematical conversions and extraction of data – with source codes in the C programming language and the CDO (Climate Data Operator) software. I managed the ordering, conversion and production of extracted data and other necessary ASCII files by writing suitable FORTRAN codes, while for the graphical presentation of data I used the Microsoft Excel and the LibreOffice Calc software. The execution of some procedures required the writing of bash scripts.

The basis of the calculations in SHERPA comprises the gridded emission inventory prepared by the Institut National de l'Environnement Industriel et des Risques (INERIS) and the calculation results of the CHIMERE chemical transport model, however, due to its flexibility, the software is also capable of processing high resolution data produced on local levels. Emission reduction measures can be introduced on small regions – which for Hungary equal to the counties and the capital – in percentages, and the results can be visualized for the same regions with the use of the built-in tools of the software.

In the aspect of air pollution aerosol particles cause the main problems in Hungary, the majority of critical air quality situations rise as the consequence of the accumulation of PM_{10}. Therefore, in the course of my PhD work I focused my analyses primarily on PM_{10} pollution.

3. RESULTS

As a first step in my thesis, I collected the relevant and up-to-date information provided both on the national and the international levels that is necessary for a comprehensive understanding of the scientific basis of my work. I put special emphasis on, among others, the details concerning the field of air quality modelling, the related regulations aimed at the improvement of air quality and the evaluation of the current situation in Hungary.

I carried out a sensitivity analysis with the aim firstly to prove that the role of meteorology is significant in the formation of air pollution, moreover, to discover how this role is demonstrated by model simulations. The performance of a model may depend on the geographical domain, which makes the target area relevant in the process of investigating the model characteristics. I focused my analyses mainly on Hungary and the surrounding areas and so I chose the modelling area to cover roughly the Carpathian Basin. The sensitivity analysis – carried out using the CHIMERE model – proved to be an efficient method to demonstrate the strong effects of local meteorological parameters – including the parameters principally responsible for the dispersion and dilution processes of air pollutants, namely precipitation (Figure 2), wind (Figure 3) and planetary boundary layer height (Figure 4) – on the evolving concentrations in the environment. A definite change in the values of the examined meteorological parameters defined in the input data fields of the model leads to a consistent change in the concentrations we get as output fields of the simulations.

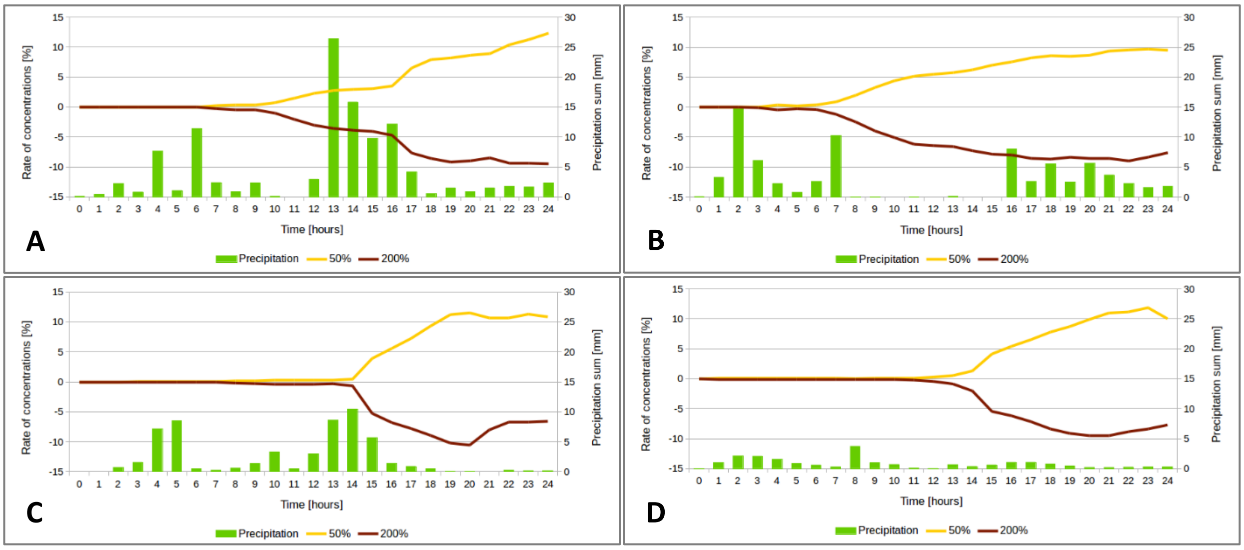

Figure 2: Daily trends of precipitation and the rates of concentrations gained in the simulations with the modified and the original meteorological parameters in the geographical locations of A) 18.9° – 49.3°, B) 19.0° – 49.6°, C) 17.6° – 48.9° and D) 19.0° – 48.8° longitudes and latitudes

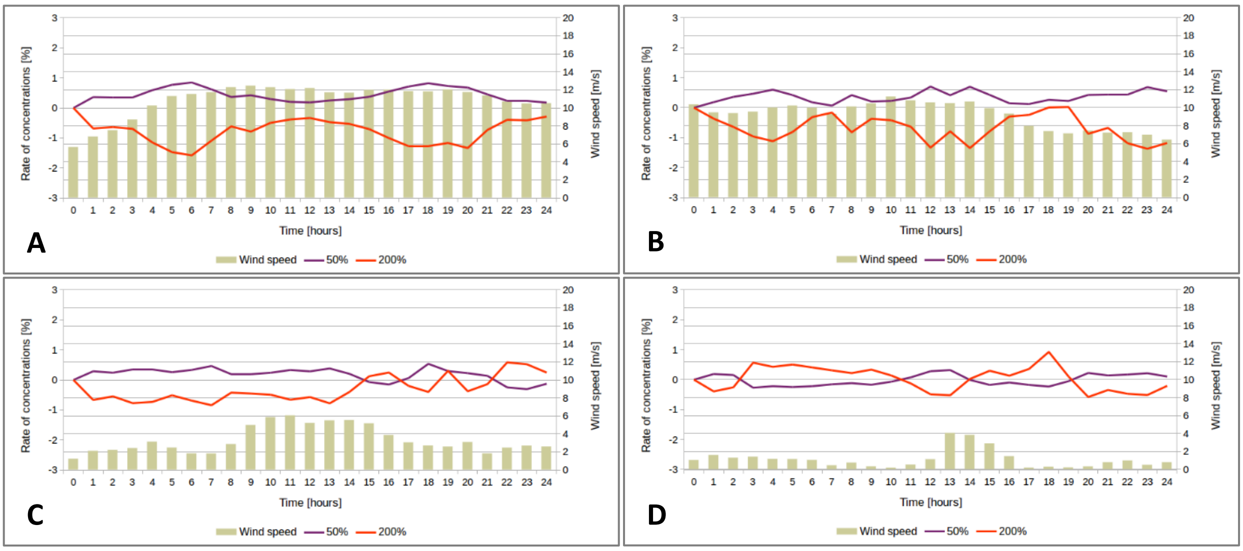

Figure 3: Daily trends of wind speed and the rates of concentrations gained in the simulations with the modified and the original meteorological parameters in the geographical locations of A) 23.3° – 45.2°, B) 18.3° – 46.9°, C) 21.3° – 48.0° and D) 14.8° – 45.9° longitudes and latitudes

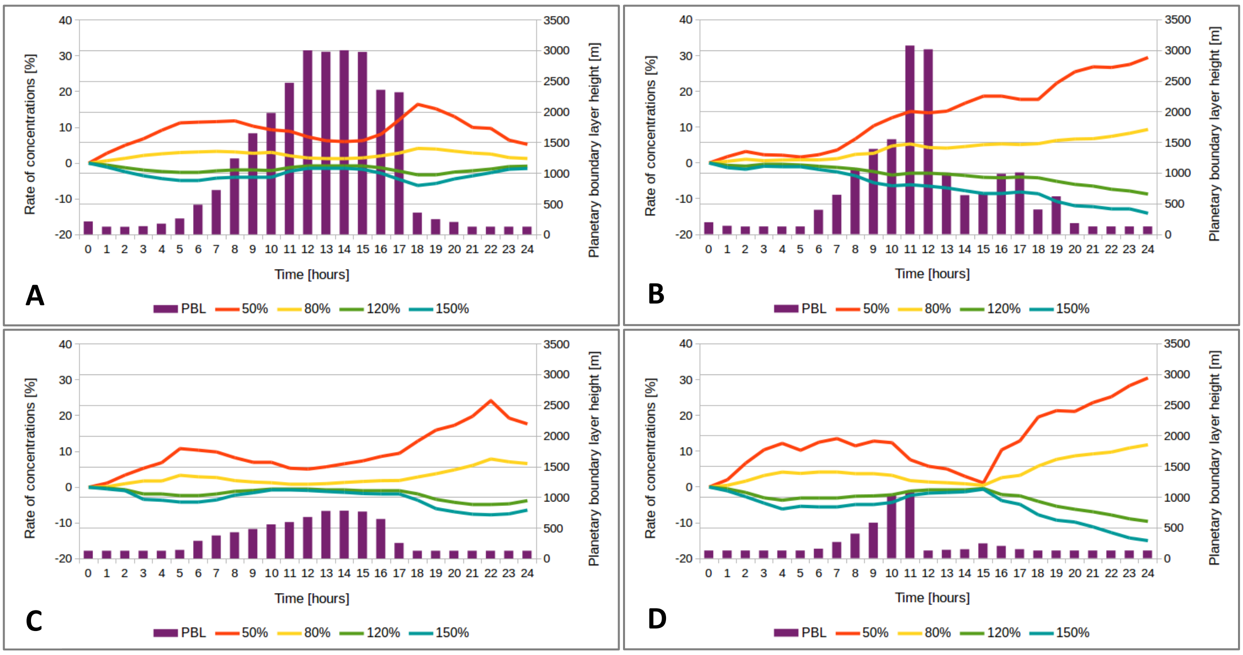

Figure 4: Daily trends of planetary boundary layer height and the rates of concentrations gained in the simulations with the modified and the original meteorological parameters in the geographical locations of A) 24.7° – 46.2°, B) 20.2° – 49.8°, C) 18.1° – 47.6° and D) 20.1° – 47.7° longitudes and latitudes

My results also suggest that generally winter weather patterns provide more favourable conditions for critical air quality situations coupled with high concentrations of PM_{10} to occur than summer weather patterns, which can basically be put down to the different emission and meteorological characteristics. Exploring the background of air pollution episodes more precisely is of high significance, since despite the general improvement in air quality during the latest years in Hungary, episodes coupled with concentrations that often exceed the thresholds considered harmful for the health continue to occur periodically and cause a major problem. In the course of my PhD work I elaborated a case study for the Sajó Valley in which I analysed a real air pollution episode – with exceptionally high PM_{10} concentrations in some places – that was connected to a special meteorological situation in wintertime. I found the main causes behind the episode to be the highly unfavourable meteorological conditions (Figure 5) and the enhanced intensity of anthropogenic emissions they induced.

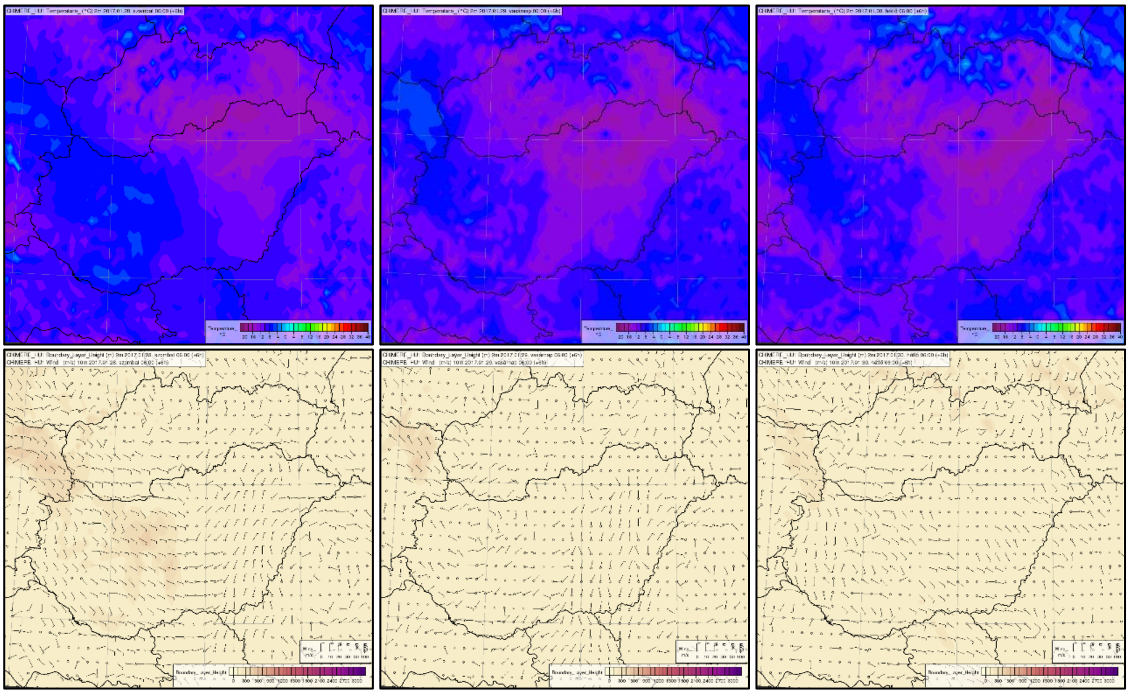

Figure 5: Temperature, wind speed and planetary boundary layer in the period 28–30 January 2017 (06 UTC)

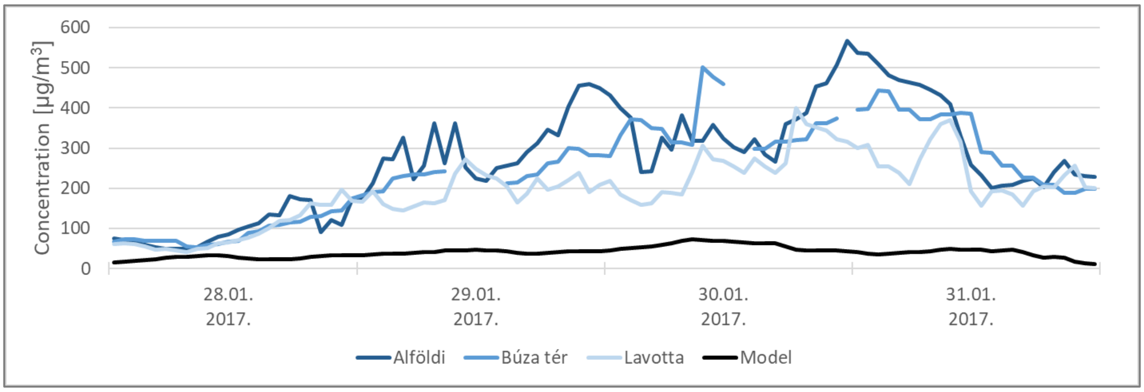

Figure 6: PM_{10} time series of measurements for three stations in Miskolc (blue lines) and model data for a grid point in the area of Miskolc (black line) between 28 and 31 January 2017

My experience concerning the model simulations was that in this special case the model significantly underestimated the real air concentrations (Figure 6), which fact proves the relevance of a basic understanding of the behaviour, characteristics and applicability of the model and suggests the necessity of the involvement of a professional in air quality analyses.

In the following phase of my work I focused on the investigation of the possible consequences of the reduction of anthropogenic emissions using the SHERPA software. I concluded that in developing strategies and measures aimed at reducing air pollution it is crucial to take sectoral differences into account, since the improvement in air quality due to a certain extent of emission reduction largely depends on the sectors we choose to focus the measures on. As the dominant emission sectors may differ spatially throughout the country and depend also on the pollutant, the efficiency of a measure may differ from place to place as well. Being a rather small country, Hungary is very much exposed to the effects of long-range transport (Figure 7), which does not make local emission reduction strategies less significant, however, it confirms the need of the handling of air pollution on the international level.

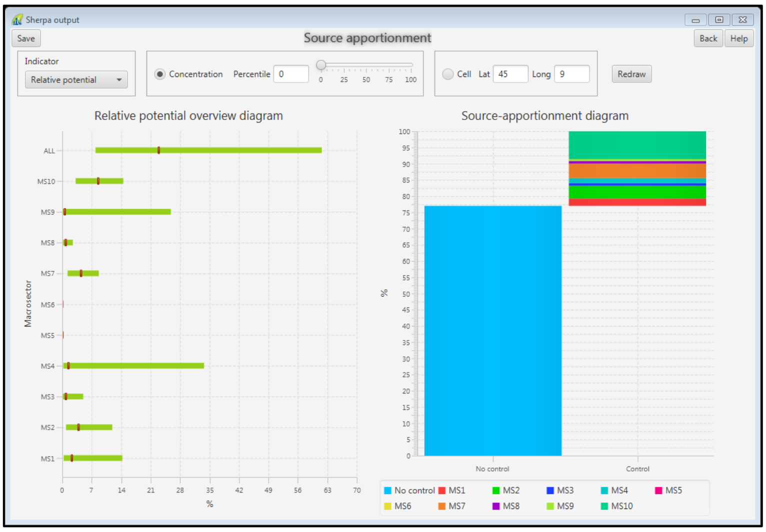

Figure 7: The main sources of PM_{10} pollution in Hungary

The National Air Pollution Control Program summarizes the current goals of Hungary to improve air quality in the country. The Program names the policies and measures that are necessary to be introduced in order to accomplish the obligations assigned by the EU and it also provides a quantified estimate regarding the expectable effects of these measures on the emissions, meaning that it defines the probable extent of the reduction in the emissions for each measure together with the sectors concerned. Based on this information I examined the possible environmental consequences of the goals specified in the National Air Pollution Control Program.

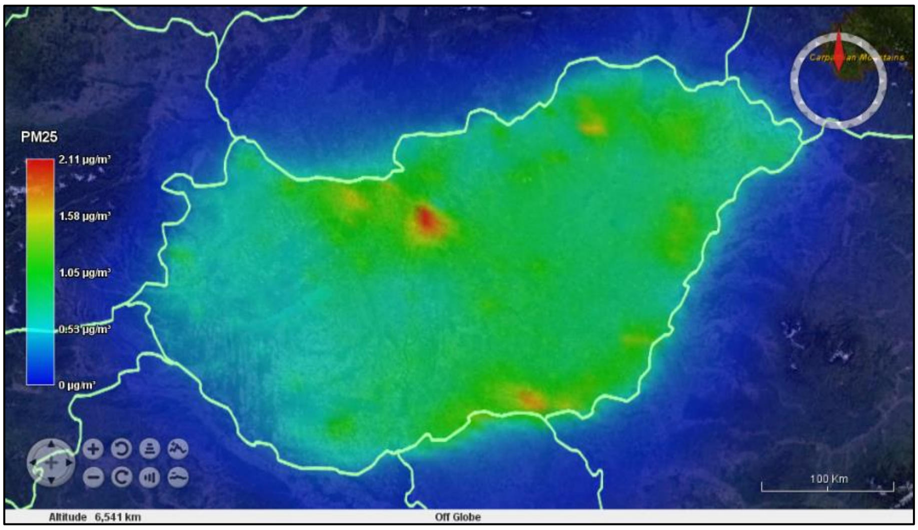

Figure 8: Spatial distribution of the expectable improvement in the mean annual $PM_{2.5}$ pollution due to the planned emission reduction measures after 2030 in Hungary

Results suggest (Figure 8) that an improvement in air quality due to the reduction of local emissions is evident. This improvement in the annual average values – that we have as results – might seem relatively small regarding the numbers, however, considering the tendencies in a year, on shorter time scales it may become much more pronounced. Furthermore, the effects of long-range transport, which contribute significantly to the current air pollution levels in Hungary, must not be neglected. However, in case the neighbouring countries also succeed in meeting their assigned emission reduction obligations, this effect is expected to diminish, which will in turn enhance the role and the importance of local emissions.

4. NEW SCIENTIFIC RESULTS

In my PhD work I chose the analysis of air quality in the Carpathian Basin to be the main objective, including the setting up of a methodological background necessary for a comprehensive analysis, the studying of the role of key meteorological parameters influencing the dispersion processes in the air, the exploring of the causes behind critical air quality situations evolving under special weather conditions and the examination of the expectable effects of planned emission reduction measures. Such comprehensive analyses in the field of air quality are unprecedented for the Carpathian Basin. The following theses summarize the most important results of my work.

1. My results concerning air quality analyses carried out for the area of the Carpathian Basin confirm that local meteorology affects the concentrations of pollutants in the environment significantly, which fact is well detectable by model simulations. Results of both the meteorological sensitivity analysis and the case study representing critical air quality situations evolving under special meteorological conditions suggest that – although local emissions determine the quantity of air pollutants fundamentally – the accumulation of pollutants is largely dependent on the prevalent weather conditions. The CHIMERE model proved to be a suitable tool for the studying of these relations, based on unified input emission data it is capable of tracking the effects of the different meteorological conditions on the concentrations evolving in the atmosphere.

2. Precipitation, wind speed and planetary boundary layer affect pollutant concentrations in the air significantly. The sensitivity analyses that I carried out demonstrate these effects well. An increase in the quantity of precipitation leads to the decrease of concentrations and a decrease in precipitation causes the concentrations to rise. According to the simulations having carried out with the CHIMERE model a 200% and a 50% change in the quantity of precipitation brings about a +/– 10% change in the PM_{10} concentrations in the air after 24 hours. The very same phenomenon is observable also in the deposition fields, a larger amount of precipitation washes out a larger amount of pollutants to the ground and a smaller amount washes out a smaller amount. Based on the results a 200% and a 50% change in the quantity of precipitation may induce a +/– 40% difference in the deposition fields compared to the deposition field in the original simulation. Through the model simulations I showed that the quantity of precipitation is related to the amount of pollutants accumulating in the air and that washed out to the ground. Model calculations suggest that the effect of precipitation on the changing of air pollutant concentrations can dominantly be demonstrated on local levels.

The effect of wind speed is similar to that of precipitation in the aspect that the strengthening of wind causes the accumulated air pollutants to diffuse, thereby leading to an improvement in air quality and vice versa, decreasing wind speeds favour the accumulation of pollutants and induce a decline in air quality. However, according to model simulations using CHIMERE, the magnitude of the changes in PM_{10} concentrations is smaller than in the case of precipitation, a 200% and a 50% change in wind speed brings about around 1–2% change in air concentrations. Results show that differences in the concentration fields due to the modified meteorology are more pronounced in the case of higher wind speeds than they are in the case of lower wind speeds. It is well trackable in model simulations that by low wind speeds pollutants start accumulating in the air rapidly. The effects of wind speed extend to a larger area than those of precipitation.

Pollutant concentrations in the environment are largely affected by the height of the boundary layer as well. My results show that an increasing boundary layer height is coupled with the decrease of pollutant concentrations and, on the other hand, a decrease in the planetary boundary layer height leads to a definite increase in concentrations. According to simulation results of CHIMERE the difference between concentration values of the original simulations and of those in which the height of the boundary layer had been modified to 50% and 150% may reach +30% and –15%, respectively. It is apparent that the response of the model is stronger for the decrease than the increase of the boundary layer height, which means that the accumulation of air pollutants is more intense with the lowering boundary layer than the dilution of pollutants is when the boundary layer height increases.

3. In the course of my PhD work I elaborated a case study in which I examined the processes behind a real critical air quality situation coupled with remarkably high PM_{10} concentrations. I demonstrated that the formation of the air pollution episode was primarily induced by unfavourable meteorological conditions such as low wind speed (1–2 m/s during the whole examined time period), a stable atmosphere and extremely low temperature conditions (temperatures at night dropped below –10 ºC throughout a large area of the country) connected to a weather situation called the cold air cushion, which triggered residential combustion and thereby led to intensifying anthropogenic emissions. In the resulting air pollution episode, the highest measured PM_{10} concentration exceeded the 500 μg/m³ value. I applied the CHIMERE model to analyse the episode more in detail and I found that the model was unable to detect the real environmental consequences and significantly underestimated the real air concentrations. In those areas where air pollution reached the highest levels, the difference between the measured and the modelled concentrations rose to multiple (even 5 to 10) times. I identified the underestimation of the emission fields – the increase in the real emission values compared to the inventory – and the imprecision of the input meteorological data as the main causes behind the differences.

Despite the potential imprecisions in cases of special meteorological situations similar to the one presented above, the CHIMERE model is capable of demonstrating that basically winter weather situations favour the evolvement of air pollution episodes coupled with high PM_{10} concentrations more than summer weather situations, which can mainly be put down to the different emission patterns and the weather characteristics.

4. By analysing the potential effects of emission reduction measures concerning PM_{10} and NO_2 pollution I showed that the expectable improvement in air quality largely depends on the emission sectors on which we focus the measures. According to the examinations carried out using the SHERPA air quality modelling tool, a 10% reduction of PM emission in the sector of residential combustion may lead to an improvement more than 1.5 times higher in air quality than that in the sector of road transport for the area of Budapest. NO_2 pollution, on the other hand, can be lessen more effectively by the limitation of road transport, where a 10% reduction in NO_x emissions is expected to bring about an improvement in air quality 2.5 times higher than the same reduction in the sector of residential combustion.

In Hungary today I identified the sectors of residential combustion, road transport and agriculture as the main emitters, however, the determining emission sectors may differ from region to region in the country and from pollutant to pollutant.

5. My analyses carried out using the SHERPA software confirm the preceding research results (Ferenczi et al. 2017) according to which the effect of long-range transport is significant in Hungary. However, the magnitude of this effect differs from place to place in the country and from pollutant to pollutant. Based on the results calculated by SHERPA, 77% of PM_{10} and 33% of NO_2 pollution – as spatial averages for the whole territory of the country – originates from sources outside the borders. Although the effects of long-range transport cannot be limited on local levels, they can be abated as a result of the large-scale improvement in air quality due to local emission reduction measures implemented to comply with the international obligations.

6. My results concerning the analysis of the effects of the emission reduction measures set in the National Air Pollution Control Program suggest that the planned measures are expected to lead to a significant improvement in air quality country-wise and also beyond the borders. Based on calculations carried out using the SHERPA software the maximum value of the expectable decrease in the annual mean $PM_{2.5}$ concentrations for the 2020–2029 time period is 0.64 $\mu g/m^3$, and the same value in the case of NO_2 is 1.22 μg/m^3. Further improvement in air quality is expected due to the planned emission reduction measures beyond 2030: the maximum value of the decrease in the annual mean concentrations is 2.11 μg/m^3 for $PM_{2.5}$ and 2.31 μg/m^3 for NO_2. In this respect $PM_{2.5}$ pollution indicates a more intense decline with time than NO_2 does. It is important to note that the values that we get as results of the calculations are changes in annual averages, the effects may significantly differ depending on, among others, the interannual distribution of emissions and on weather patterns. It is well observable that the improvement in air quality is considerably more pronounced in urban areas than it is in the background. Furthermore, it is necessary to separate the local effects from the effects of long-range transport, since the abatement of the latter by all means requires international cooperation.

5. CONCLUSIONS AND RECOMMENDATIONS

In the course of my PhD work I carried out analyses for the region of the Carpathian Basin and Hungary using the CHIMERE chemical transport model and the SHERPA air quality modelling tool. Results confirm that the chemical transport model is suitable for the detailed examination of the relationship between air pollutant concentrations and the meteorological elements. Through model simulations I demonstrated that a local accumulation of air pollutants significantly depends on the current meteorological conditions. A modification of the values of key meteorological variables that dominate in the dispersion processes – such as precipitation, wind speed and planetary boundary layer height – brings about a consistent change in air concentrations.

Concerning the examined weather elements, the general conclusion can be deducted that they fundamentally influence the formation of air pollution and affect air concentrations significantly. Wind speed, being in connection with the intensity of mixing processes in the air, the quantity of precipitation and the height of the planetary boundary layer are all inversely proportional to the amount of pollutants in the air. Weather situations coupled with low wind speed, low boundary layer height and the absence of precipitation favour the accumulation of air pollutants the most. On the other hand, stronger winds, precipitation and an increase in the boundary layer height cause concentrations to decrease. Due to the related general weather characteristics and emission patterns the effect of temperature can also be demonstrated indirectly. Based on my results the role of local meteorology is therefore significant in the formation of air pollution. The more knowledge we have about the relationship between local weather and the evolving air concentrations, the more accurate assessments we are able to accomplish regarding both the current air quality and air quality forecasts. Therefore, a detailed exploration of these relations is of fundamental significance. Naturally, the geographical environment, that makes the individual local conditions diverse, is also an important factor in this issue. The Carpathian Basin is unique in this respect with strong characteristics as a basin, but within its boundaries very different local conditions may exist owing to the diverse topography, that is necessary to be taken into account. My analyses for the Carpathian Basin point out some fundamental features, however, in favour of the more accurate air quality assessments for Hungary, further examinations – focusing also on local levels – are recommended to be carried out concerning the relations between local meteorology and air concentrations.

With a case study elaborated for the Sajó Valley I showed an example weather situation – called a cold air cushion – in which the calculations of the air quality model may become considerably inaccurate. A cold air cushion generally forms over a valley and is coupled with anticyclonic air movements and inversion in the upper atmosphere which may lead to extremely high pollutant concentrations in the environment due to a very low planetary boundary layer height, weak mixing processes in the air, very low temperature conditions and the accompanying increase in residential combustion. The effect of topography also has a crucial role in a case like this. I identified the main cause behind this critical air quality situation to be the combination of the highly unfavourable weather characteristics and the significant increase in anthropogenic emissions compared to the inventory, which latter is the basis for model calculations. The investigation of similar cases is essential in order to explore weather situations in which we can only reservedly rely on the results of air quality models. Being aware of the limitations of our models and the situations in which their calculations might become imprecise, and knowing what to expect concerning the differences between the real situation and the model results – whether the model over- or underestimates the real concentrations – make it possible for us to add an uncertainty to the results and also to make a more accurate assessment of the current situation by taking the expectable inaccuracies into account, based on which we can introduce more adequate measures.

The treatment of the issue of air pollution on international levels brought about the development of tools that provide a unified investigation method for the air quality of individual areas and the expectable effects of measures aiming to reduce emissions. Through my analyses using the SHERPA software I demonstrated that the expectable effects of emission reduction measures depend on the emission sectors for which we introduce the measures. Considering the different areas in the country the dominant sectors contributing to the total local emission may differ from place to place and from pollutant to pollutant. The sectors on which it is worth the most to focus the limitation of the emissions mainly depend on local conditions. It is therefore suggested to carry out preliminary investigations, prior to the planning of the emission reduction strategies, concerning the way an improvement in air quality can be achieved the most effectively, or rather the emission sectors to concentrate on.

As a result of the implementation of the emission reduction measures planned for the next few decades and detailed in the National Air Pollution Control Program, a clear improvement in the Hungarian air quality is expectable. This improvement may seem slight according to the results calculated using the SHERPA tool, however, it is important to take into account, that these values are annual averages, in an interannual time period the differences may be much more pronounced. Another fact that is necessary to be taken into consideration is that due to its relatively small area, the effect of long-range transport is significant in Hungary, which means that a considerable proportion of the Hungarian air pollution originates from sources outside the borders. However, this fact does not make the importance of local measures negligible. The abatement of local emissions can only be attained through local restrictions, besides, as a result of the reduction of local emissions the amount of air pollutants transported further to other places also decreases, and therefore the area pollutes its environment less intensely. The effect of long-range transport makes it necessary to extend the endeavours aimed at the improvement of air quality to as large areas as possible, therefore, an international cooperation in order to abate the cross-border air pollution is of fundamental significance.

6. PUBLICATIONS

PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

Articles in journals

Homolya. E., Ferenczi, Z. (2018): A levegőminőség elemzésének egy új lehetősége: SHERPA. Légkör, 63, 3, pp. 112–117.

Homolya, E., Rotárné Szalkai, Á., Selmeczi, P. (2017): Climate impact on drinking water protected areas. Időjárás, 121, 4, pp. 371–392. IF: 0,49.

Rotárné Szalkai, Á., Homolya, E., Selmeczi, P. (2016): Ivóvízbázisok klíma-sérülékenysége. Hidrológiai Közlöny, 90, 2, pp. 21–32.

Articles in international conference proceedings

Ferenczi, Z., Homolya, E., Bozó, L. (2020): Detailed assessment of a smog situation detected in the Sajó valley, Hungary, pp. 351–356. In: Mensink, C., Gong, W., Hakami, A. (Editors): Air Pollution Modeling and its Application XXVI, Springer International Publishing, Springer Nature Switzerland AG, ISBN 978-3-030-22054-9, ISSN 2213-8684, doi: 10.1007/978-3-030-22055-6, 490 p. 36th International Technical Meeting on Air Pollution Modelling and its Application, Ottawa, Canada.

Ferenczi, Z., Homolya, E. and Bozó, L. (2019): Evaluation of the performance of CHIMERE chemical transport model in fog situations over Hungary. 19th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Bruges, Belgium.

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