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Predictability analysis of the $PM_{2.5}$ and PM_{10} concentration in Budapest

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Abstract—The harmful effect of air pollution on human health have raised a series of concerns in recent years and imposed needs for accurate descriptions of air pollution levels in urban areas. This implies that tools supporting national pollution control and planning need to be developed including public web sites or other media, where citizens exposed to the air pollutants can catch urban background concentration data, predicted concentrations, or alerts. In recent years, PM_{10} episodes caused the most critical air quality problems in Budapest. Before the development of air quality forecasting systems, which help to predict the high PM_{10} concentration episodes, the main determinants have to be identified. In this work, the effect of long-range transport and meteorological conditions on PM_{10} concentration in Budapest was analyzed in detail, as well as the results of an existing air quality forecasting systems were evaluated in case of PM_{10}.

Key-words: air quality forecast, monitoring network, urban environment, emissions, meteorological parameters

1. Introduction

Climate, weather, and air quality have harmful effects on human health and environment. For centuries, people have selected their home where they could experience the most favorable environmental conditions. The Industrial Revolution brought great changes in energy usage and technological development. People moved in the cities in the hope of a better life, where the air was contaminated with different pollutants, depending on the current level of development of technology. The first big problem was the sulphur dioxide pollution, which was caused by the burning of coal. A few hundred years later, the widespread use of cars resulted in the increase of nitrogen oxides and tropospheric ozone concentrations in the

atmosphere. Nowadays, the high level of airborne particles concentration is considered seriously *(WHO,* 2011), especially in the winter season in Hungary.

Over the past few hundred years, we had to face also the changes in climate in parallel with the changes in air quality. The observed changes in climate, weather, and air quality continuously interact with each other: the pollutants are changing the climate, thus changing the weather, but also the climate impacts on air quality (*Bernard et al.,* 2001). The increasing number of extreme weather situations can occur as a result of climate change, which could create favorable conditions for rising of PM pollutant concentrations. In recent years, the PM_{10} episodes, which in many cases are associated with extreme weather situations, caused the most critical air quality problems in Budapest. The first step before developing a successful air quality forecast system is a detailed analysis of the meteorological background of the PM_{10} high-level situations (*Demuzere et al.*, 2009). Our investigation will focus on those episodes, which are caused by this pollutant, and on the long-range transport of the aerosol particles, which have also essential role in the formation of PM situation in Budapest.

The sum of all particles suspended in the atmosphere is referred to as PM (particulate matter). The particulates are classified according to their size and their capacity of penetrating the respiratory tract, causing harmful effects on people. The source of the particulate matter can be anthropogenic or natural. In urban environment, the most important causes of high PM_{10} concentration are traffic emissions, and in particular the use of diesel engines and motorcycles (*Sillanpää et al.,* 2006). Notable proportion is due to old tires and car brakes. During winter, emissions from domestic heating are added to the PM_{10} in larger amounts due to materials such as coal and wood.

Before developing an air quality forecasting system, which helps to predict the high PM_{10} concentration episodes, the main determinants (emission, meteorological conditions, and long-range transport) have to be identified. In this work, the effect of long-range transport and meteorological conditions on particulate matter in Budapest and Hungary was analyzed in detail.

Finally, the first results of the validation of the air quality prediction system of the Hungarian Meteorological Service are presented. In the evaluation work, the PM_{10} data detected by the air quality monitoring network of Budapest, as well as the forecasted air pollutant concentration values of the air quality prediction model system are used.

2. Analysis of the most important effects on PM concentration

Air quality of Budapest is determined by domestic and traffic emissions combined with the meteorological conditions. The effect of the long-range transport could also be essential. In this paragraph, the effect of emission, long-range transport, and meteorological conditions will be analyzed in detail.

2.1. Emission

The emission of PM_{10}, which has essential effect on the air quality of Budapest is determined by the industrial, traffic, and domestic heating activity in the area of Budapest. While the yearly variability of the industrial and traffic emissions are not significant, the domestic emissions increase in the winter season. All the mentioned emissions have weekly, daily and, especially for the traffic hourly variabilities. The different time variabilities of these emission sectors are reflected in the daily and yearly variability of concentration values of the PM_{10}.

2.2. Effect of the long-range transport on PM concentration

Effect of the long-range transport on the PM_{10} concentration was determined by the EMEP chemical transport model (*Simpson et al.*, 2012). With this examination only the yearly average of this effect could be analyzed. Sometimes the impact of the long-range transport can be negligible and sometimes it can be responsible for the episode situation. In this paragraph the effect of long-range transport on the PM_{10} and $PM_{2.5}$ in Budapest and Hungary will be analyzed in detail. The results will show how important this effect is and how we will able to put this information into an air quality forecasting system.

2.2.1. Short description of the EMEP model

Many types of air pollutants have been observed to travel far from their sources causing air quality problems (*EMEP Status Report,* 2012). Therefore, it is very important to begin the development of chemical transport models with investigating the long-range transport of the air pollutants. A representative of these types of models is the EMEP Eulerian long-range transport model (*Simpson et al.*, 2012). The model is an important tool to analyze both acidification and photo-oxidant activities in the air. The current version of the model working on a polar-stereographic projection, true at 60 N, has commonly been used, with grid-size of 50 km×50 km at 60 N. The standard domain has changed somewhat over the years, and was enlarged towards Eurasia in 2007. The model currently uses 20 vertical levels from the surface to the top of the model domain (currently: 100 hPa, 15 km). The 15 km high air column is divided into 20 levels in a form that the lower layer (3 km), which is relevant in the mixture of air pollutants, includes 10 levels, allowing the detailed examination of this air layer. The EMEP model uses a chemical pre-processor to convert lists of input chemical species and reactions to differential equations in Fortran code. The default chemical scheme, which is used in the open source version of the EMEP model, is the

EmChem09. This chemical scheme describes 137 reactions and 26 photochemical reactions between 72 chemical species. The model calculates the dry and wet deposition of the chemistry substances. The dry deposition flux is determined by using the deposition velocity, while the wet deposition processes include both in-cloud and sub-cloud scavenging of gases and particles.

The standard emissions input required by EMEP model consists of gridded annual national emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x =NO+NO_2), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), and particulates ($PM_{2.5}$, and PM_c, the latter being the coarse aerosol fraction, PM_{10}-$PM_{2.5}$). The particulate matter categories can be further divided into elemental carbon, organic matter, and other compounds as required. Emissions can be from anthropogenic sources (burning of fossil and biomass based fuels, solvent release, etc.), or from natural sources such as foliar VOC emissions or volcanoes.

The EMEP model has been adapted to run with meteorological fields calculated by a number of numerical weather prediction models, like the ECMWF IFS. In 2013, the data of the ECMWF IFS are available for forecasts with $0.125° \times 0.125°$ horizontal grid length and 137 vertical levels, and this model became the default meteorological driver.

2.2.2. Calculation of the long-range transport of PM_{10} concentration

For determining the long-range transport of the PM (particulate matter), the effect of the national emission from all countries in the EMEP model calculation area and the natural resources in the region were taken into account (*Gauss et al.,* 2012). The most important natural sources are the sea and the volcano, which have effect on the PM air quality conditions.

Our study was carried out for five years (2006–2010) in order to filter the variability of the weather as much as possible. Since the emission values show considerable variability from year to year (not only in case of Hungary), it is difficult to separate the effects of the weather from the effect of the emissions in the results.

First the proportion of the effect of the long-range transport was determined on the PM_{10} concentration in Hungary for five years (2006–2010). The results are summarized in *Table 1*.

On the basis of model calculations it was found that in annual average the transboundary sources are responsible for the 80% of the PM_{10} pollution formation in Hungary. According to *Table 1*, it can be said that in the last 5 years in Hungary, the PM_{10} emissions are significantly changed, and it could cause the variability in the quantity of the long-range transport.

Table 1. Fraction of transboundary contributions to PM_{10} concentrations in Hungary (unit: %) and the PM_{10} emission from Hungary (unit: Gg)

Years	Fraction of transboundary contributions (%)	Emission from Hungary (Gg)
2006	79	48
2007	83	36
2008	80	38
2009	79	48
2010	79	46

During the studied five years, trend in the change of the impact of the long-range transport could not be observed, the difference between the years can be mainly explained by changes in the PM_{10} emission of Hungary. In the years when the emission of Hungary was decreased significantly, the proportion of the long-range transport increased slightly. *Fig. 1* shows the spatial variability of the impact of long-range transport in Hungary between the years 2006 and 2010.

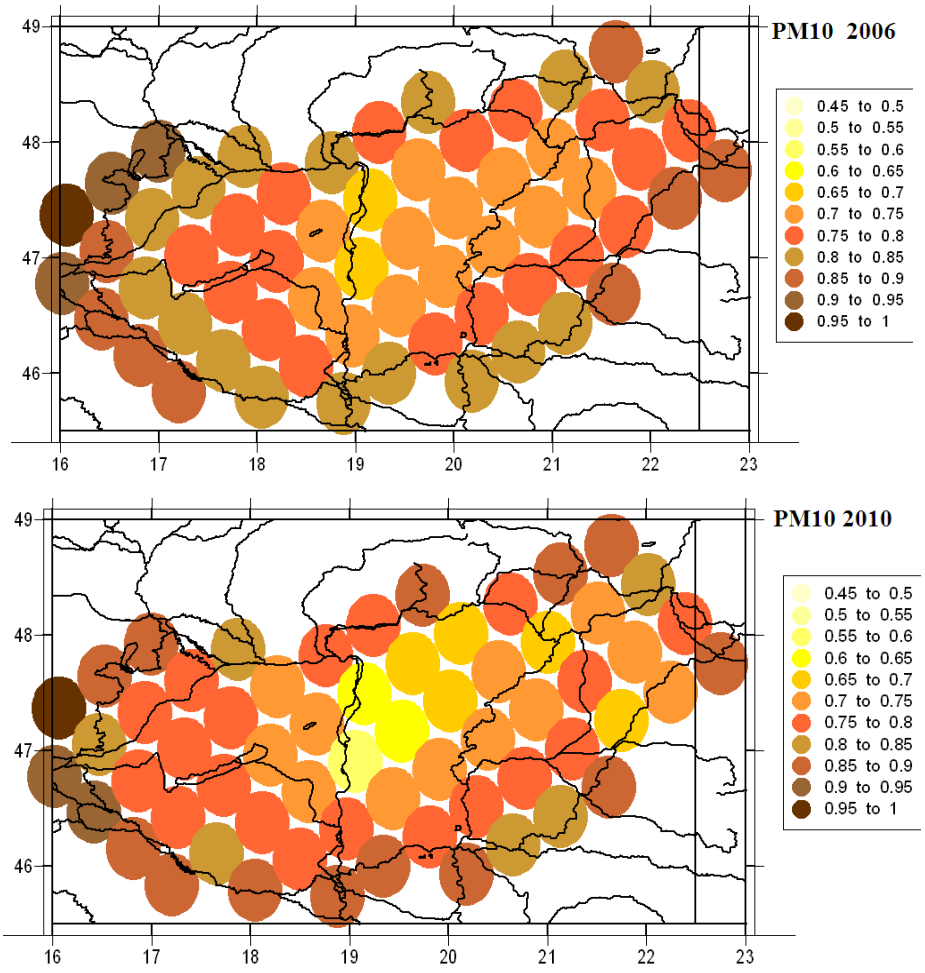

Fig. 1. Fraction of transboundary contributions to PM_{10} concentrations in Hungary in the years of 2006 and 2010 (unit: %).

In the second part of this study, the proportion of the long-range transport was determined on the PM_{10} pollution formation in the air quality zones of Hungary (*Table 2*). The definitions of the zones are:

1. Budapest and its surroundings
2. Győr - Mosonmagyaróvár
3. Komárom – Tatabánya - Esztergom
4. Székesfehérvár - Veszprém
5. Dunaújváros and its surroundings
6. Environs of Pécs
7. Sajó Valley
8. Debrecen and its surroundings

Table 2. Fraction of transboundary contributions to PM_{10} concentrations in the zones of Hungary in different years (unit:%)

Years	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**
2006	69%	80%	78%	76%	68%	79%	72%	75%
2007	71%	86%	82%	80%	68%	84%	75%	77%
2008	68%	80%	76%	75%	65%	80%	71%	76%
2009	63%	76%	74%	73%	62%	80%	69%	77%
2010	65%	77%	74%	75%	58%	80%	67%	73%

According to *Table 2*, it can be said that the effect of the long-range transport on the PM_{10} concentration is the lowest in zone 1 (Budapest and its surroundings) and 5 (Dunaújváros and its surroundings), and the highest in zone 2 (Győr - Mosonmagyaróvár) and 6 (Environs of Pécs). Considering the country's size, this difference is mainly due to the significant spatial variability of the PM_{10} emission in Hungary. The largest industrial areas of Hungary located in zone 1 and zone 5 includes the area of our capital, where the combined effect of traffic and industries can cause high level PM_{10} emission.

2.2.3. Calculation of the long-range transport of $PM_{2.5}$ concentration

Further we determined the main contributor countries, which have significant effect on the $PM_{2.5}$ pollution formation in Hungary. *Table 3* summarizes the time variation of the national $PM_{2.5}$ emission of Hungary between 2006 and 2010.

Table 3. $PM_{2.5}$ emission from Hungary (unit: Gg).

Years	**$PM_{2.5}$ emission from Hungary (Gg)**
2006	29
2007	21
2008	23
2009	28
2010	32

Before preparing pie diagrams, the examined countries were placed into an order of magnitude based on how large the proportion of their contribution is to the $PM_{2.5}$ pollution of Hungary. The pie diagrams (*Fig. 2.*) show the proportion of the effect of Hungary and the 8 main contributor countries on the $PM_{2.5}$ concentration in the years of 2006 and 2010.

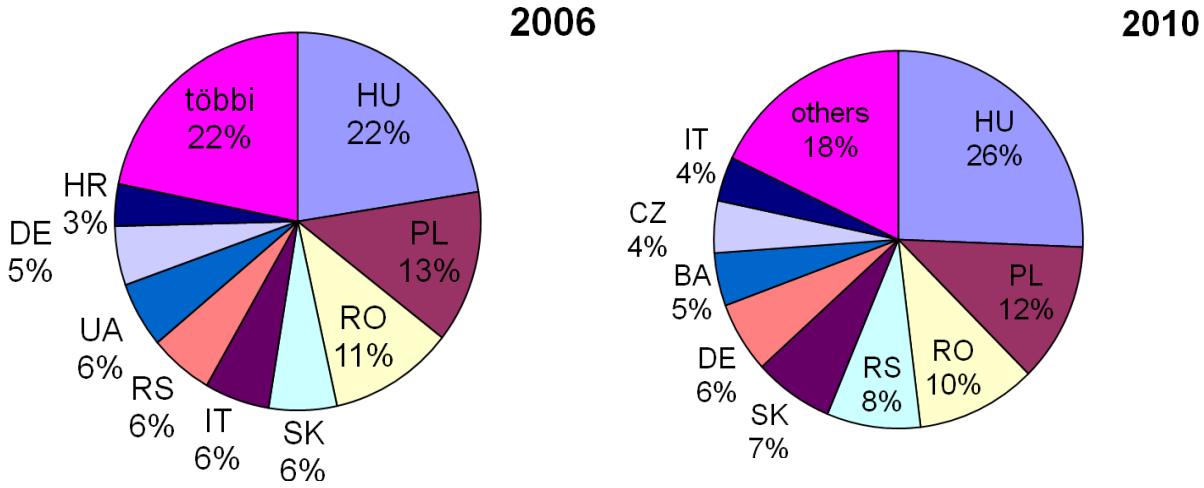

Fig. 2. Main contributors to concentrations of $PM_{2.5}$ in Hungary in the years of 2006 and 2010 (unit:%).

According to the pie charts, our homeland contributes to the $PM_{2.5}$ contamination in Hungary with 20–25%. It can be declared in general, that among the neighboring countries, the effect of Poland and Romania is considerable to the $PM_{2.5}$ contamination in Hungary, the combined effect of these two countries is comparable to the effect of Hungary. It can be said that the effect of Italy, Slovakia, Germany, and Serbia could also be considerable,

but the contribution of these countries to the Hungarian $PM_{2.5}$ contamination are essentially affected by the atmospheric conditions.

Finally, the contribution of Hungary to the $PM_{2.5}$ contamination of the neighboring countries was examined. *Fig. 3* shows the results of this investigation.

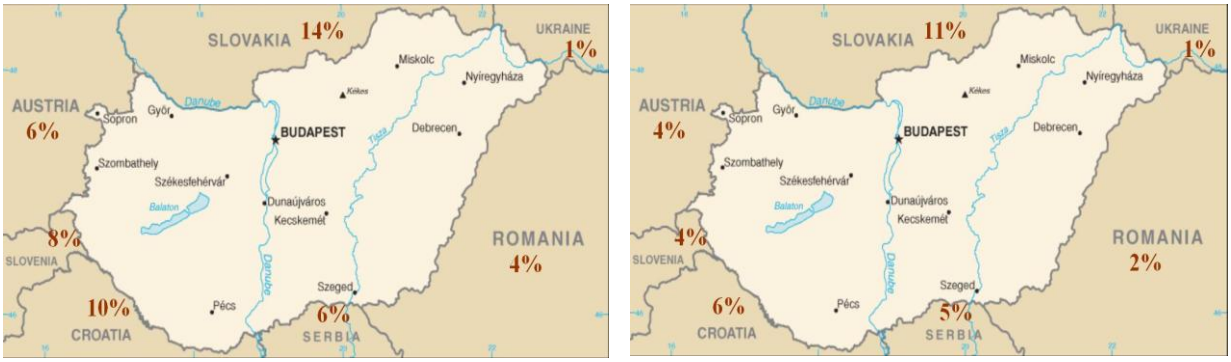

Fig. 3. Contribution of Hungary to the $PM_{2.5}$ contamination of the neighboring countries in the years of 2006 (left) and 2010 (right)(unit:%).

Comparing *Fig. 3* with the pie charts (*Fig. 2*), the amount of the contribution of the Hungarian $PM_{2.5}$ emission to the air pollution conditions in the neighboring countries is similar to their contribution to the Hungarian air pollution. The balance is positive only in the case of Romania, which means that Hungary receives much more particles from Romania than the amount was sent by Hungary to Romania. Hungary significantly pollutes the air of Slovakia, Croatia, and Serbia. Hungary contributes to the air pollution of these countries with 5–20%. The value of this rate depends on the meteorological conditions and the changes in the emission of these countries from year to year.

After specifying Hungary's contribution to the $PM_{2.5}$ air pollution in the surrounding states, it was possible to determine which countries are the net polluters of Hungary and, on the other hand, which countries are polluted by Hungary. The results of this investigation are summarized in *Table 4*.

According to *Table 4* it can be related, that Poland and Romania pollute Hungary much more, than Hungary pollutes these countries. In case of Slovakia the situation is inverse, because Hungary pollutes this country much more than Slovakia pollutes Hungary.

Finally, it was determined that from the particles emitted by Hungary 37 percent remain in the country and 63 percent cross the border of Hungary and increase the $PM_{2.5}$ contaminations of other countries. Considering the total emission of the modeling domain in case of Hungary the amount of aerosols particles arrive to the area of Hungary from outside sources are 30% more than those emitted by Hungary in all.

Table 4. The proportion of the received and sent polluted particles from the point of view of Hungary.

Year	Poland		Romania		Serbia		Slovakia	
	received	sent	received	sent	received	sent	received	sent
2006	13%	4%	11%	4%	6%	6%	6%	14%
2007	12%	2%	7%	4%	8%	5%	7%	9%
2008	7%	2%	10%	3%	8%	5%	6%	12%
2009	10%	3%	10%	3%	8%	5%	7%	11%
2010	12%	2%	11%	2%	8%	5%	7%	11%

The results of this investigation can be summarized as follows: the long-range transport is very determinant in Central Europe, and could not be neglected in the transport model calculations.

2.3. Effect of the weather conditions

PM_{10} concentrations exceed the threshold value mainly in winter and fall. In summer, high PM_{10} concentrations can be observed very rarely. We think, that the effect of special meteorological situations are determinant in the high level PM_{10} concentration formations (*Barmpadimos et al.*, 2011; *Mok* and *Hoi.*, 2005). In this paragraph we examine the effect of some meteorological parameters on the PM_{10} concentration. In Budapest, an air quality network of 10 stations detects the hourly concentration values of PM_{10}, we used this database.

2.3.1. Seasonal effects

Examining the past few years, it shows that high PM_{10} air quality conditions were observed especially in the winter semester. In order this statement could be supported by measurements we examined the PM_{10} data of the Gilice tér air quality monitoring station in Budapest. Those days were selected, when the daily average of the PM_{10} concentration values exceeded the limit value for the protection of human health (50 $\mu g/m^3$). The results of the study are shown in *Fig 4.*

Fig. 4 shows, that the exceedance of the limit values can be observed especially in fall and winter, in spring and summer this situation is very rare. The picture also shows a threshold value (red line) which means that the PM_{10} daily mean value may not exceed 50 $\mu g/m^3$ more than 35 times in a year. In the last years it was usual that the PM_{10} daily values exceeded the limit values for the protection of human health more than 35 times, except in 2009. *Fig 4* shows the result of the investigation only for the monitoring station „Gilice tér", but the situation is the same not only in Budapest, but in case of all of the Hungarian air

quality monitoring stations. How can we explain that high PM_{10} concentration levels can be observed in Hungary especially in fall and winter in Hungary? Due to the fact that the emission and the weather situation determine the PM_{10} concentration together, the seasonal variability of these two effects has to be analyzed. In the case of PM_{10}, the most significant emissions originate from the traffic and residential wood and cool combustion. From the two factors, only the residential combustion has essential seasonal variability.

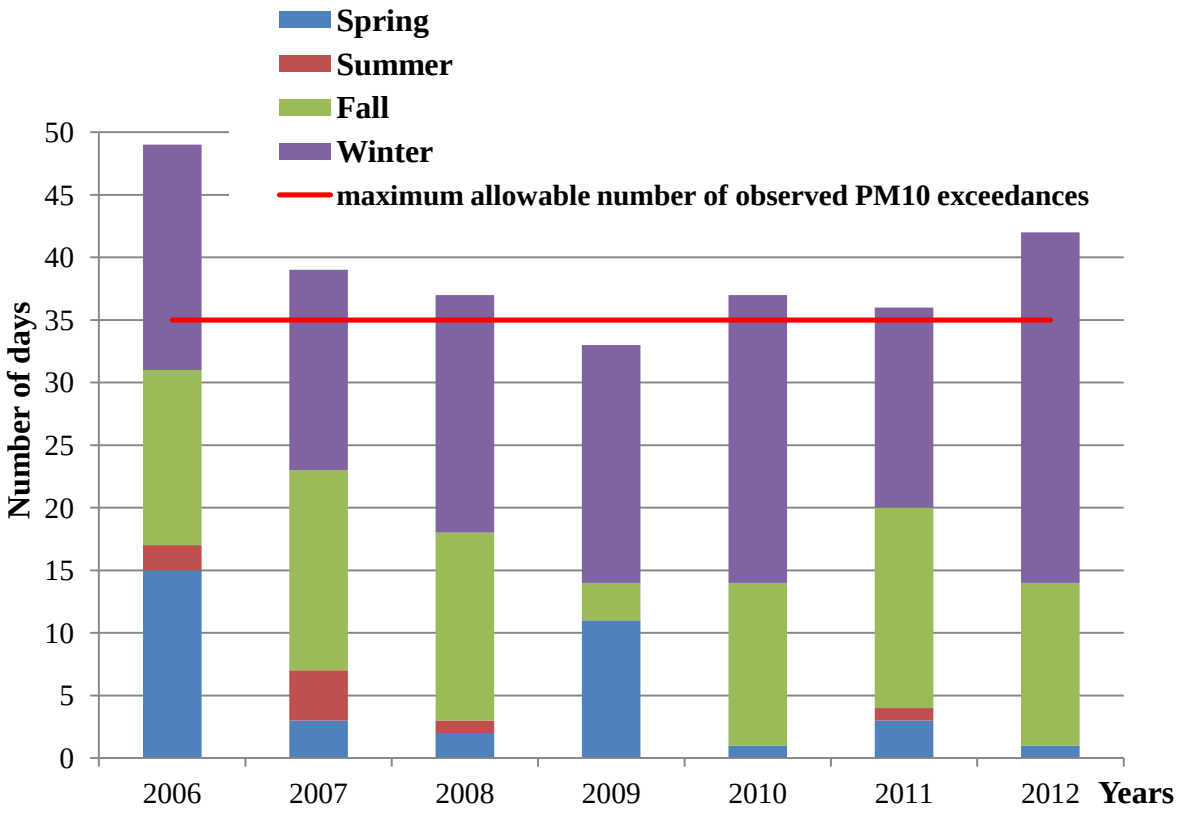

Fig. 4. Exceedance days of air quality threshold (health protection) values of PM_{10} (Budapest, Gilice tér, 2006–2010)

Beside the emission, weather situations also change from season to season in the Carpathian Basin. The typical weather situation, which favors the development of high PM_{10} concentration occurs primarily in the winter season. Furthermore, these weather situations, and meteorological parameters, which can be linked to these meteorological situations, will be examined in more detail.

Not the conventional meteorological measurements, but the grid point data of the numerical weather prediction models are used in the experiments, because we had to produce that type of parameters, which are not measurable or not possible to be calculated from the classical measurements. In this study we used the results of two different numerical weather prediction models to eliminate the

differences in the parameterization methods of the two NWP models (finally, in the results, there was no significant difference).

The features of the two numerical weather prediction models used in the examination are as follows:

AROME (Applications of Research to Operations at MEsoscale) is an atmospheric non-hydrostatic modeling system, which includes a state-of-the-art numerical weather prediction model and a data assimilation system. The horizontal resolution of the model domain is 2.5 km with 60 vertical model levels. The model is used primarily for ultra-short-term forecasting and runs at the Hungarian Meteorological Service's supercomputer four times a day.

WRF (Weather Research and Forecasting) is a versatile numerical weather prediction model, which was developed at the National Center for Atmospheric Research (NCAR) and U.S. National Oceanic and Meteorological Service (NOAA) in cooperation with many research institutes and universities. Operational WRF model used by the Hungarian Meteorological Service with high resolution (2.6 km) and non-hydrostatic configuration. The service runs four times a day on a supercomputer.

2.3.2. Effect of the planetary boundary layer (PBL)

One of the most important parameter of the diffusion processes is the planetary boundary layer (PBL) height. The planetary boundary layer is defined as the part of the atmosphere that is strongly influenced directly by the presence of the surface of the earth, and responds to surface forcings with a timescale of about an hour or less (*Holton,* 1992). In the boundary layer the horizontal transport is dominated by the mean wind and the vertical by the turbulence. When pollutants are emitted into this layer, they dispersed horizontally and vertically because of the action of convection and mechanical turbulences until it becomes completely mixed.

The height of this layer cannot be measured directly, but many methods are known to determine it. In this work, two different numerical weather prediction models, AROME and WRF were applied to determine the PBL height values using different PBL parameterization schemes. In the Hungarian version of the WRF model, the BouLac PBL scheme (*Bougeault et al.,* 1989) was used to calculate the PBL height. The BouLac PBL scheme is classified as a one-and-a-half order turbulent kinetic energy (TKE) closure scheme, which determines the diffusion coefficients from the prognostically calculated TKE. In the Hungarian version of the AROME model, the top of the PBL height is determined by the momentum flux profile method (*Szintai* and *Kaufmann,* 2008). The top of the PBL is the height where the momentum flux value becomes less than 5 percent of the surface level momentum flux value.

Because the numerical weather prediction models determine the PBL height using different parameterization schemes, we determined the connection between the two differently determined PBL height, and the PM_{10} concentration values.

In our examination the hourly average PM_{10} concentration values were used, that are measured between October 27 and November 26, 2011 at the air quality monitoring station Gilice tér, and the hourly PBL height determined by the two mentioned numerical weather prediction models. The examined time period is the longest PM_{10} episode situation which has been detected since the PM_{10} measurements started in Budapest. *Fig 5* shows the relationship between the two parameters.

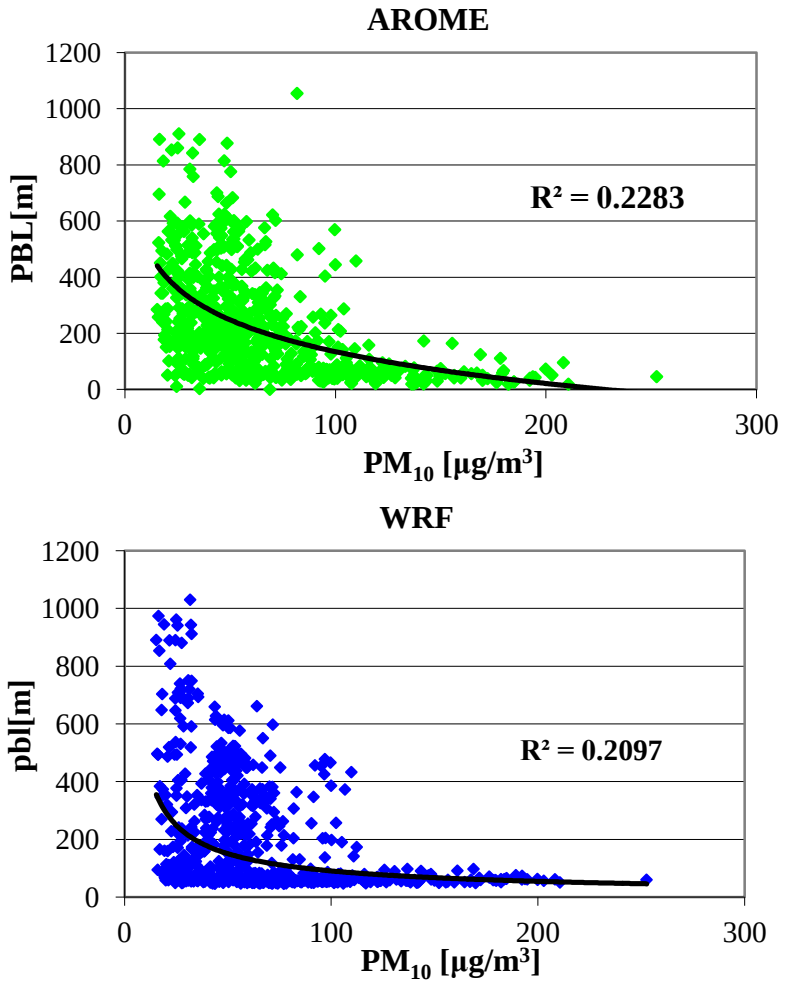

Fig. 5. The relationship between the height of the planetary boundary layer (PBL) and the PM_{10} concentrations (Budapest, Gilice tér).

According to *Fig. 5*, in case of high (>100 µg/m^3) PM_{10} concentration values the PBL heights were lower than 200m. Nevertheless, this statement is not true in another direction, because in case of low PBL height the PM_{10} concentration is not so high in every cases. Regression analysis was also performed to determine the connection between the PM_{10} concentration and PBL height hourly values. There is not big difference between the results of AROME and WRF models. The value of the regression is a little bit higher in case of AROME.

2.3.3. Effect of the stagnation index (SI)

Because the results of the analysis with the PBL height was not convincing to find the weather conditions resulting high PM_{10} concentration level, we took into the analysis other meteorological parameters. While the PBL height characterizes the intensity of the vertical diffusion in the atmosphere, the magnitude of wind speed and wind shear could be the index of the intensity of the horizontal diffusion. The SI index is the parameter (*Holst et al.* 2008), which characterizes the intensity of the horizontal and vertical diffusion in the lower layer of the atmosphere as it takes into account the height of the PBL and the wind speed in the surface layer. The SI index can be determined by this simple equation:

$$SI = \sqrt{\frac{10^6}{PBL \times |v|}}$$

Fig. 6 shows the relationship between the SI index and the PM_{10} concentration. According to *Fig. 6*, the relationship between the SI index and the PM_{10} concentration is slightly stronger, than the relationship between the PBL height and the PM_{10} concentration. Based on this study we can conclude that the weak mixing processes in the planetary boundary layer (low PBL heights and low wind speed) are responsible for the formation of high PM_{10} concentrations with 25%, and there is no big difference between the results, which was based on the WRF or AROME numerical weather prediction models.

2.3.4. Effect of the wind speed

The analysis so far basically studied the effect of the intensity of the atmospheric diffusion processes on the PM_{10} concentration. However, the atmospheric processes may be relevant in terms of the region from where the polluted air arrived to the area of the measuring point. In this respect, the effect of wind direction is essential. Using this analysis, clean and dirty sectors could be separated in the area of the monitoring station, and changes in the emission intensity and compositions could be inferred.

In this analysis, PM_{10} data detected by the air quality monitoring station Gilice tér, as well as the measured meteorological data between January 9, 2006 and February 14, 2012 are used. In case of this examination we halved the day to daytime and nighttime. *Fig. 7* shows the dependence of the PM_{10} concentrations on the wind direction in daytime and nighttime. The results are significantly different in the different parrt of the day. For daytime episode situation, the effect of traffic emission from the direction of M5 highway can be observed, while nighttime the effect of domestic heating from the direction of the residential district can be observed.

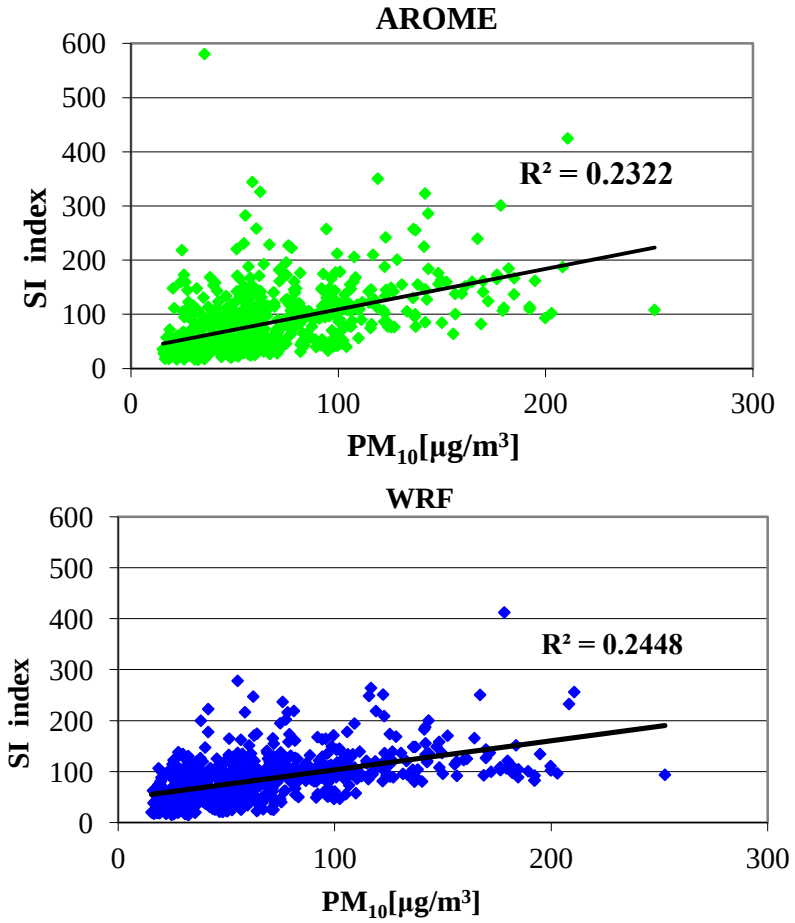

*Fig. 6.*The relationship between the SI index and the PM_{10} concentrations. (Budapest, Gilice tér).

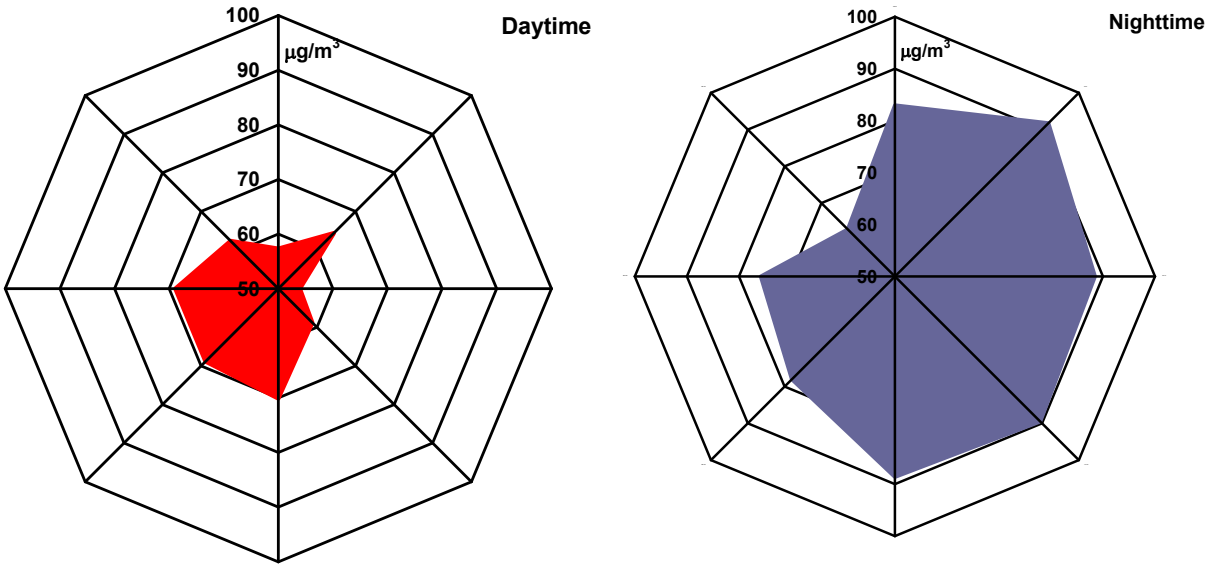

Fig. 7. Wind direction dependency of the PM_{10} concentrations in episode situations for daytime and nighttime. (Budapest, Gilice tér).

Based on *Fig. 7*, it is likely that during the day the traffic emission and during the night the domestic heating is the primary source of PM_{10} pollution in the area of Gilice tér station. It is worth to compare the highest average concentration values, which was detected in daytime and nighttime. During the day, the average hourly maximum concentration was 70 $\mu g/m^3$, while at night it was 90 $\mu g/m^3$, which could be explained with the low boundary layer at night, but it is possible that the level of emissions from residential combustion is greater than the traffic emission.

3. Validation of the PM_{10} forecast for Budapest

The Hungarian Meteorological Service adopted a chemical transport model to forecast the concentration values of the main pollutants. The forecasting tool is an integrated system of the WRF meteorological and CHIMERE chemical transport models. The air quality prediction system has been operating since June 1, 2010, which means, that there are longer than 2-year data sets to evaluate how it is working. In the validation work the PM_{10} data detected by the air quality monitoring network of Budapest, as well as the forecasted air pollutant concentration values of the air quality prediction model system are used. The values of NMSE (normalized mean square error) and correlation were determined for the PM_{10} pollutants and for the grid points, where the air quality monitoring stations are located. NMSE is a typical statistical indicator of the overall deviations between predicted and measured values. Low values mean, that the model is well performing both in space and time. The correlation coefficient is a measure of how well the predicted values from a forecast model "fit" the real-life data. The values indicate that the best forecast can be expected in the area of Honvéd utca monitoring station (the correlation value is 0.53) and the worst in the area of Pesthidegkút monitoring station (the correlation value is about 0.15) for PM_{10}. *Table 5* shows all the results of this examination.

The results of this evaluation work shows, that the PM_{10} concentration prediction is not so good. There is big lack in the emission input data base calculated for $PM_{10,}$ mainly in the domestic heating, which is reflected in the case of Pesthidegkút monitoring station, for which the values of NMSE and correlation are very bad. Presumably there are some problems with our traffic emission data base, and sometimes the NWP model is not able to predict well the essential meteorological parameters, which have effect on the PM_{10} concentration (*Saide et al.*, 2011).

In the future we plan to develop our emission database, determine new boundary conditions. We hope, that this investigation will result in an improvement in the PM_{10} forecast.

Table 5. NMSE and correlation values of the PM_{10} prediction

Station	NMSE	Correlation
Csepel	0.97	0.39
Erzsébet tér	0.35	0.49
Gergely utca	0.40	0.45
Gilice tár	0.57	0.31
Honvéd	0.31	0.53
Kőrakás park	0.14	0.36
Kosztolányi tér	0.36	0.33
Pesthidegkút	0.88	0.15
Széna tér	0.50	0.35
Teleki tér	0.45	0.49
Tétényi út	0.64	0.19

4. Conclusion

In this study, we tried to determine the contribution of the effect of the long-range transport and meteorological conditions to the Hungarian PM_{10} and $PM_{2.5}$ air pollution. In case of the long-range transport, the study tool was the EMEP chemical transport model, and the results of this model calculations were the bases of examination.

The conclusions drawn from the calculations are:

- In Hungary, the contribution of the long-range transport to the PM air pollution is 70–80%.
- The effect of the long-range transport shows significant spatial variability, the most important part is the western frontier of Hungary, and the smallest is the central part of the country.
- Among the European states, Romania and Poland are the greatest polluters of Hungary's atmosphere.
- Particles emitted by Hungary contribute significantly to the PM pollution of Slovakia, Serbia, and Croatia.
- 37% of the particulate matters emitted by Hungary remain in the country, and 63% cross the border of Hungary and increase the PM contaminations of other countries.
- In case of Hungary, the aerosol particles arrive to the area of Hungary from outside sources are 30% more than the particles emitted by the country in all.
- The reasons of the formation of PM_{10} related to high air pollution situations are: unfavorable weather conditions and increasing emission of the domestic heating. Among the meteorological parameters, the effect of the SI index is the most significant.

A dispersion modeling system was developed by the Hungarian Meteorological Service to predict the air quality in Budapest for 48 hours. The core of this system is the CHIMERE chemical transport model. Beside the CHIMERE's built-in emission database, also own emission data (point sources, traffic count) for Budapest are used during modeling. It was shown that the quality of the results depends on the quality of the weather forecast, the long-range transport, and the emission database. It was also demonstrated that there is a lack in the emission input database calculated for PM_{10}. Long-term transport of the pollutants seems to play an important role during concentration calculations. Validation of the system also confirms these statements.

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