Final report

Analyses of the interactions between local air pollution and urban vegetation by in situ measurements and model simulations

This research project is a joint project in the cooperation between
(1) Department of Meteorology, Eötvös Loránd University (ELU), and
(2) Department of Floriculture and Dendrology and *Department of Soil Science and Water Management, Corvinus University of Budapest (CUB).*

1. Background

The atmospheric pollution under urban conditions causes serious human health disorders, however, related effects like discomfort and smog alerts both in winter and summer can cause complications in urban life. The evaluation of elements in a complex model requires in situ measurements on interaction, but such measurements and data are almost completely missing. The characterization of interactions in this system will provide a conducing framework for predicting microclimatic factors and useful data of urban drafting and planning urban tree plantations. Micrometeorological, plant physiological and atmospheric contamination measurements as well as detailed deposition, local scale dispersion and chemical models are intended to describe the status, the spatial and temporal variability, and the connections of the vegetation-atmosphere complex system in urban environment.

Considering the complexity of the theme, researchers of the two universities (ELU and CUB) decided to cooperate in this topic, the research is supported by National Scientific Research Funds (OTKA). (*Based on the government decision, Faculty of Horticultural Science, CUB was merged to Szent István University, Gödöllő. This process blocked the finacial funds for more than one year, and in 2016 a new contract was made with OTKA.*)

Our final report gives an overview on the results of cooperative research focusing the following main topics:

- **Measuring and modeling the tree canopy under urban conditions** (leaf area index, canopy size, leaf area).
- **Qantification of leaf gas exchange capacity and ecological services of urban tree**
- **Measuring and modelling the air pollution in the city in large spatial and temporal resolution.**
- **Contribution of urban trees to the diminishing of air pollution, quantification of dust removal capacity of urban trees**

2. Measuring and modeling activities during the project

During the project, different measuring and modeling activities were carried out in urban environment in connection with urban vegetation and air pollution. Leaf area index, trunk and leaf characteristics were measured in case of different species and different environmental conditions. Next to the measurements of the characteristics of trees, atmospheric variables (meteorological elements and concentration of air pollutants) were also detected at different locations and routes. Some of the applied instruments (LCi portable Photosynthesys System, Boreas BGS 06 module with gas sensors, TSI DustTrakII Aerosol monitor) have been provided in the frame of recent project. Table 1. contains the summary of our measurements during the project.

Applications and developments of different environmental models have been the second main pillar of the project. Our measurements provide the input dataset for the model simulations, but available data (obtained from Hungarian Air Quality Network and the meteorological station of Szent István University, Soroksár) as well as different soil and plant parameters from literature were also used by the models. Our modeling activities covered the estimation of the dynamics of several vegetation characteristics, simulation of dispersion of air pollutants on different scale and deposition of air pollutants over different vegetation types, as well as regional and urban climate simulations. The summary of our model simulations during the project can be found in Table 2.

Table 1. Measuring activities during the project

Measured values	**Equipment**	**Project results**
Leaf area index	AccuPAR LP-80 PAR/LAI ceptometer	Steiner et al., 2015
Tree characteristics (trunk and canopy volume, height)	Leica DISTO D510	Steiner et al., 2015
Leaf characteristics (leaf temperature, stomatal conductance)	LCi portable Photosynthesys System	Tóth et al., 2015 Ludányi, 2016 (thesis)
Microclimatological characteristics in different urban areas	Voltcraft HT-200 sensors, BOREAS sensors, TESTO 623 sensors	Dian et al., 2015 Pongrácz et al., 2017a Pongrácz et al., 2017b
Trace gas (CO, NO_2, O_3, VOC) concentration	Boreas BGS 06 module with gas sensors	Mészáros et al., 2016.
Particulate matter (PM2.5, PM10) concentration	TSI DustTrakII Aerosol monitor 8532	Mészáros et al., 2017a Mészáros et al., 2017b
Deposited heavy metal (Fe, Pb, Zn, Ni, Cu) content on leaves	AURORA AI 1200 AAS appliance	Hrotkó et al (2018) - submitted

Table 2. Modelling activities during the project

Modelling activity	**Applied model**	**Project results**
Trees characteristics	Regression based on measurements	Steiner et al., 2015
Stomatal conductance	TREX Deposition model	Ludányi, 2016 (thesis)
Urban scale modelling of air pollutants	WRF-Chem TREX Gauss	Kovács et al., 2015 Kovács et al., 2017 Leelőssy et al., 2017
Dispersion of air pollutants in local (street canyon) scale	Open FOAM	Molnár, 2017 (thesis)
Dry deposition of air pollutants	TREX deposition model	Mészáros et al., 2014 Mészáros et al., 2015a Ludányi, 2016 (thesis)
Regional and urban climate simulations	RegCM model WRF model	Göndöcs et al., 2017a Göndöcs et al., 2018

3. Summary of the results

3.1 Measuring and modeling the tree canopy under urban conditions

There is only little information in the literature on the performance of leaf growth and distribution within the canopy of trees and shrubs of different ages. In the frame of this project, we specified the dynamics of leaf area index (LAI) performance and other plant parameters in urban environment. The expected environmental services of urban trees are provided mainly by the leaf canopy, which shows yearly course and typical growth performance by tree ages (Hrotkó et al., 2014).

In our project we selected for the measurements from among *Acer, Fraxinus* and *Tilia* species and varieties around 5 trees from 8 age groups and measured trunk and canopy characteristics for setting up models for their growth over the lifespan. Further on we measured the leaf mass and LAI development over the season. The following tree parameters were investigated: trunk circumference, trunk height, tree height, crown diameter, crown projection area, crown volume and leaf area index (LAI). Data were collected in the middle of summer when tree growing stopped. Trunk circumference was measured by measuring tape at height 1 m above the ground. Crown diameter was measured perpendicularly in two directions (d_1, d_2) by measuring tape, as well. For measuring tree height (total height of tree from the base to the uppermost tip of tree) and trunk height (height of unbranched trunk measured from the base) Leica DISTO D510 laser distance meter was used. Crown projection area (A_c) was calculated with the following equation: $A_c = (d_1 / 2) \times (d_2 / 2) \times \pi$. Crown length ($l_c$) was determined as the difference between tree height and trunk height. For calculation of crown volume three different equations were used for spheroid, elongated spheroid and hemispherical crown (Hrotkó et al., 2004).

For measuring leaf area index (LAI) AccuPAR LP-80 PAR/LAI ceptometer (Decagon Devices, Inc.) was used. For correlation models LAI was measured on appointed specimens parallel with tree survey in the middle of summer. For following seasonal LAI development measurements were done monthly, in the sprouting and leaf falling period in every two weeks. This examination was done in Experimental Farm of Szent István University in Soroksár, Budapest.

Measurement process was as follows: one above-canopy PAR measurement was done on every tree. Number of measurements below the canopy depended on crown diameter: over 2 m eight, under 2 m four measurements were done. Measurements were distributed radially around the trunk. Value of below-canopy PAR was given as the mean of these measurements. LAI was measured on trees with trunk circumference over 15 cm.

Regression analysis was applied to evaluate the relationship between trunk circumference and crown volume, crown projection area, tree height and leaf area index. For statistical analysis different linear regression models were applied. Those data, which were outside of prediction intervals of the model at 95% confidence level were eliminated. Software IBM SPSS Statistics 22 was used for mathematical and statistical assessment.

Modeling the capacity of urban trees in environmental benefits (e.g. CO_2 sequestration, vapor release, shading, deposition of air pollutants) requires models on their growth characteristics and leaf canopy development. Around 40 trees with different age and measured trunk and canopy characteristics for setting up models for their growth characteristics over the lifespan. Regression analysis was used to evaluate the relationship between trunk circumference and crown volume, crown projection area, tree height and leaf area index. Statistically significant relationship was found between trunk circumference and crown volume, crown projection area and tree height (Fig.1.). Further on LAI development showed correlation to trunk circumference (Fig. 1), however LAI might be influenced by other factors (e.g. environmental and year effect) too.

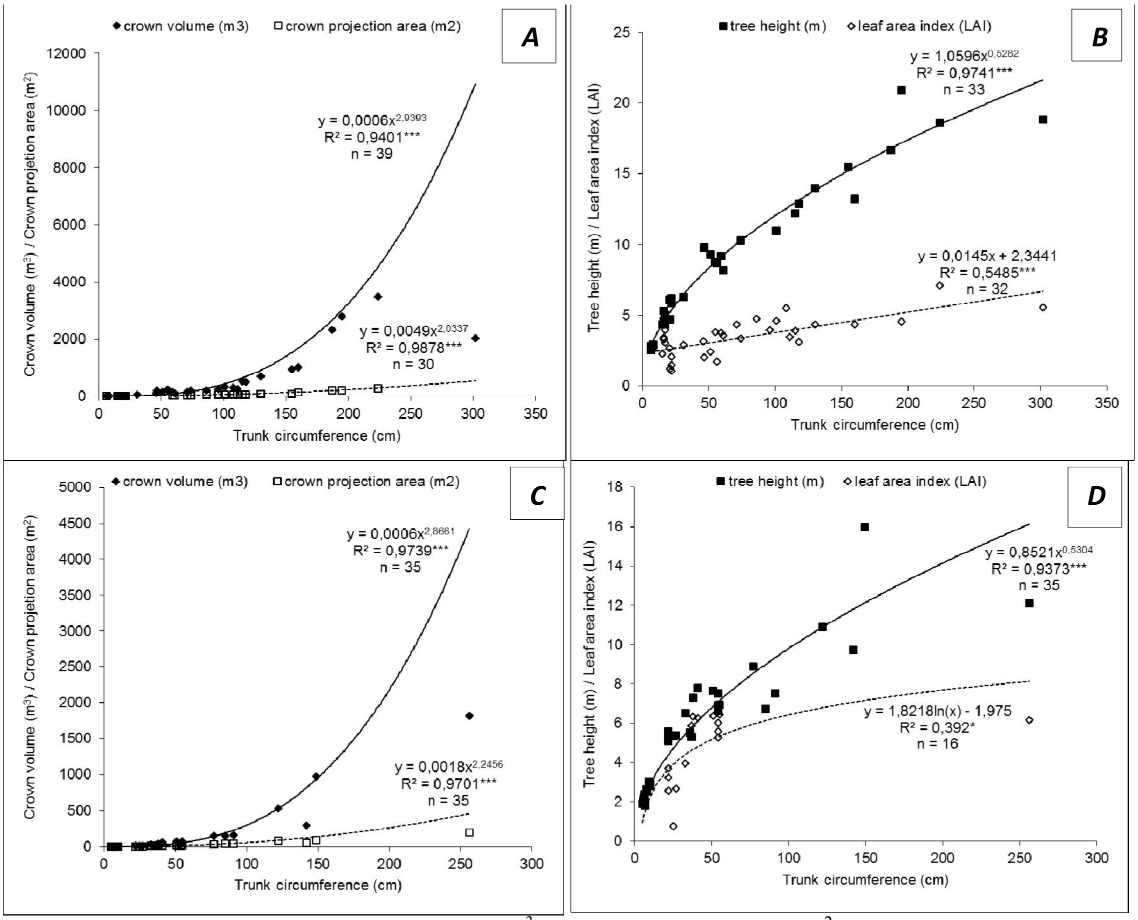


Fig. 1. Models of the correlation of crown volume (m^3), crown projection area (m^2), tree height (m) and leaf area index (LAI) in function of trunk circumference in the case of *Acer platanoides* L. (A-B) and *Tilia cordata* Mill. (C-D). (***: SL < 0.0001; *: SL < 0.01)

3.2. Leaf area index (LAI) development of investigated species over the season

On trees of four taxa (*Acer platanoides*, *A. platanoides* 'Globosum', *Tilia cordata* and *T. tomentosa*) seasonal course of leaf area index (LAI) was measured in 2013 and 2014. The LAI on two examined *Tilia* species showed very similar performance in both years. They had lower LAI in 2013 (peak around 3), while in 2014 both taxa had LAI maximum between 3.5 and 4. It can be well observed that there are significant differences in leaf falling period compared the two year, however sprouting was detected in the same time. *Acer platanoides* and *A. platanoides* 'Globosum' had much higher LAI maximum. It was next to 6 in case of *A. platanoides* in both years and between 7 and 8 in *A. platanoides* 'Globosum'. Later leaf falling can be detected on these taxa as well in 2014.

Our investigations show due to the strength of models that the measurements of trunk circumference explain well the development of the examined factors. Further on using our models provide useful data about canopy size development for such sophisticated modelling for the local scale simulations of the atmospheric dispersion of air pollutants among buildings and trees. Regarding geometry of different arrangement of buildings and trees, using our in situ collected data and functions, applicable in the model simulation simplifies the measurements need for the complex model of interactions in the "plant – air pollution – urban site" multiple system. Our results (Hrotkó et al., 2014) would assist for professionals (landscape architects, horticulture engineers) in urban planning with more detailed data on tree size development over the lifespan and LAI development over the season.

3.3. Qantification of leaf gas exchange capacity and ecological services of urban trees

Measurements were carried out in the vegetation period in urban sites, Buda Arboretum and Experimental Farm of Faculty of Horticultural sciences in second and third year (2014-2015). Measurements focused on photosynthetic activity of leaves on Fraxinus and Tilia trees (stomatal conductance, CO_2 fixation, transpiration, leaf temperature, air CO_2 concentration, PAR absorption on investigated leaves).

Knowledge about the CO_2 fixation and water vapour emission of trees and shrubs has to be confirmed with onsite instrumental examinations to get actual information. There are little reliable data about LAI values and photosynthetic activity of such trees and shrubs which are exposed to various stress factors (air pollution, drought, human impacts) in different environmental conditions. Urban climate, of course, creates special environmental conditions.

Water stress under urban conditions results in stomatal closure and reduced transpiration rates, decrease in the water potential of plant tissues, and diminish the photosynthesis. Stomatal control of leaf transpiration is considered as short term dynamic adaptation to water stress; the reduced transpiration contributes to avoiding decrease of leaf water potential. The above leaf gas exchange characteristics influence the drought adaptability and some major environmental benefits (CO_2 fixation, O_2 and vapor release) of urban trees. Since there are little and inconsistent data on drought adaptability of linden cultivars we aimed in this work to evaluate the leaf gas exchange, stomatal performance of leaves on different linden taxa under drought stress conditions in order to gain information on the diurnal course of stomatal conductance.

During our research we investigated the leaf gas exchange capacities of linden trees (Tilia taxa) and maple species and varieties with special emphasis to the different leaf color of maple varieties. The daily course of leaf gas exchange was investigated on four linden cultivars from *Tilia cordata* Mill., *T. tomentosa* Moench and *T. americana* L. in the summer season of 2014. Leaf gas exchange measurements were carried out on four linden (Tilia sp) cultivars, measuring leaf samples from 6:00 am to 18:00 pm repeatedly in every two hours. Using the measured data we calculated the daily course of transpiration and the daily water use of leaves. The following cultivars propagated by budding, were involved in the trial: Tilia americana 'Redmond', Tilia cordata 'Greenspire', T. c. 'Savaria', and T. tomentosa 'Szeleste'. The parameters of leaf gas exchange were investigated by using portable infrared gas analyzer (LCi, ADC BioScientific Ltd, UK). We measured the leaf gas exchange on four leaves from each tree, possibly with similar PAR exposition, according to the points of the compass, on each side of trees. Data of leaves from the same time intervals were averaged and statistically analyzed. Further on daily (from 6:00 AM to 8:00 PM) accumulated transpiration was calculated as product of time and mean values of the time intervals. Data were analyzed with SPSS 2.0, Repeated measures ANOVA and One-way ANOVA were used.

After the morning peak rapid stomatal closure was detected on leaves of *T. cordata* 'Savaria', and 'Greenspire'. At the beginning of summer stomatal conductance on leaves of *T. tomentosa* 'Szeleste' was the highest, while in the middle of summer the highest was on *T. americana* 'Redmond'. The transpiration resulted significant differences in daily water use on every days of measurements (early summer: *T. cordata* 'Greenspire': 2.4 $kg{\cdot}m^{-2}$; *T. tomentosa 'Szeleste'*, 4.1 $kg{\cdot}m^{-2}$, middle of summer: *T. cordata* 'Savaria': 0.6 $kg{\cdot}m^{-2}$; *T. americana* 'Redmond': 2.4 $kg{\cdot}m^{-2}$, late summer: *T. cordata* 'Greenspire': 1.2 $kg{\cdot}m^{-2}$; *T. americana* 'Redmond': 1.8 $kg{\cdot}m^{-2}$ of leaf area). Due to rapid stomatal closure *T. cordata* cultivars realized water savings.

The high stomatal conductance and transpiration capacity of *T. americana* 'Redmond' suggest good adaptability. The large cultivar differences in the performance of leaf gas exchange and water potential should be considered at evaluation of drought stress adaptability and environmental benefits (CO_2 fixation, O_2 and vapor release) of *Tilia* cultivars.

The leaves showed a diurnal course of stomatal conductance on summer sampling day (07.07. 2014) typical to water stressed plants: the daily maximum was around 8:30, than decreased to the minimum. The leaves of *T. cordata* 'Greenspire', 'Savaria' and *T. platyphyllos* 'Favorit' showed low level of stomatal conductance during the whole day. This strategy as a short term dynamic adaptation to water stress may efficiently contribute to the water saving. The largest conductance was measured during the whole day on *T. americana* 'Redmond', which is in correspondence with its low leaf temperature. Both *T. tomentosa* cultivars produced a second minor peak in the afternoon.

The above observation suggests considerable cultivar differences in adaptability to water stress conditions. Cultivars of *T. cordata* and *T. platyphyllos* showed an efficient short term dynamic adaptation to water stress by stomatal control, while cultivars of *T. tomentosa* and *T. americana* could maintain the transpiration of leaves on a relative higher level and produce a second peak after the midday drop. The high stomatal conductance and transpiration of *T. americana* 'Redmond' leaves support the drought tolerance of this cultivar. Maintaining the steady water status of *T. americana* 'Redmond' leaves requires double amount of water supply.

The performance of *T. tomentosa* and *T. americana* indicate that in the soil-plant-air complex of these species there might be a more efficient mechanism in water uptake or larger water reservation and supply capacity, which allows maintaining the higher level of transpiration. The above leaf gas exchange characteristics strongly influence the drought adaptability, ornamental value and the environmental benefits (CO_2 fixation, O_2 and vapor release) of the investigated *Tilia* cultivars under stress conditions.

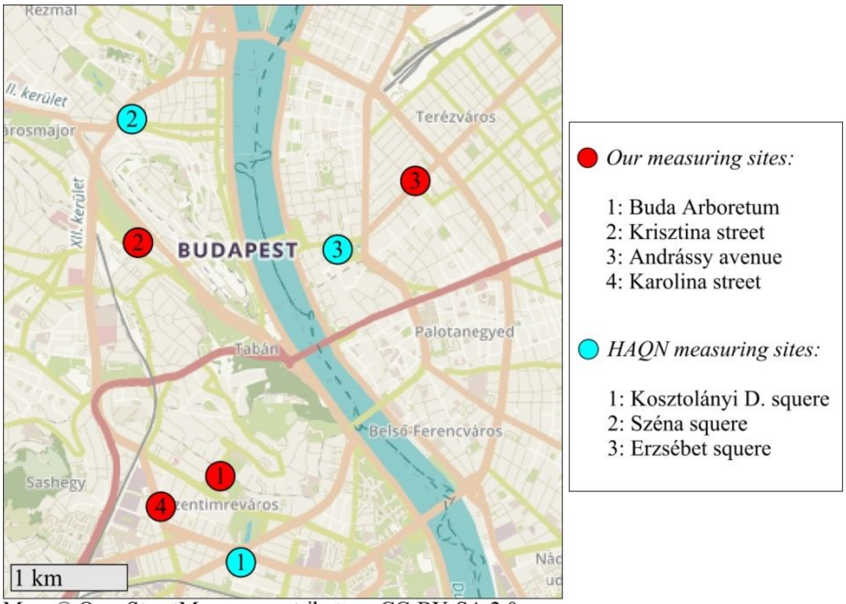
Conclusions on leaf gas exchange of trees

- Trees adopt to higher CO_2 concentration in ambient air with higher assimilation.
- PAR exposition should be considered, canyon effect of narrow streets reduce the tree efficiency.
- Higher PAR exposition increase the stomatal conductance and transpiration.
- Low leaf water potential reduces the stomatal conductance and tree efficiency in assimilation.
- Irrigation in urban green spaces improves the efficiency of trees carbon assimilation.

3.4. Contribution of urban trees to the diminishing of air pollution, quantification of dust removal capacity of urban trees

Measuring expeditions in the vegetation period in three selected sites and in Buda Arborétum (Fig 2.) were carried out in 2015 and in 2016. Leaf sample collection was made in all sites. For comparison with foliar dust deposit the PM10 pollution data from 3 measuring station of Hungarian Air Quality Network (HAQN) were also used.

The atmospheric pollution under urban conditions impacts the human health however, related effects like discomfort and smog alerts both in winter and summer can cause complications in urban life. The major source of urban air pollution is the traffic by emitting CO_2, CO, Cl^-, NO_x and dust, soot particles causing several environmental damages on vegetation, buildings and human health. Trees are very efficient in trapping atmospheric particles, which is especially important for urban areas. Plant leaves have been used as indicators and/or monitors of trace metal pollution.



Map: © OpenStreetMap.org contributors, CC-BY-SA 2.0

Fig. 2. Our measuring sites and measuring stations of Hungarian Air Quality Network (HAQN)

Dust deposition and its heavy metal content on leaves of three urban trees (*Acer platanoides* L. 'Globosum', *Fraxinus excelsior* L. 'Westhof's Glorie' and *Tilia tomentosa* Moench.) were investigated in three periods: May-June 2015, October-November 2015 and October 2016. Leaves were collected from the 7.5 ha large Buda Arboretum (low traffic) and from different streets of heavy traffic in Budapest. At each site five trees were sampled by collecting 6 leaves from each tree from the height of 2 to 3 meters. Samples were taken seven times in the spring and three times in the autumn. Dust deposit from leaves were removed by soaking the foliage in distilled water for 20 hours than being washed with ultrasound shaking. After removal of deposit leaves were dried to a constant weight, then their Pb, Fe, Ni, Zn and Cu content was measured using ICP AS equipment. The removed dust deposit was dried and after nitric acid – hydrogen peroxide treatment the Pb, Fe, Ni, Zn and Cu content was measured by using AURORA AI 1200 AAS appliance. The heavy metal (HM) deposit was calculated in mg m^{-2} leaf surface area.

From each sample the single leaf area on 10 leaves was measured, then the average leaf area for each species and each location was calculated. The leaf area was measured by AM 350 leaf area meter (ADC BioScientific Ltd, UK). Another 10 leaves subsamples were washed and soaked in 250 ml distilled water for 20 hours, then a 10 minute ultrasonic shaking was applied. The suspension containing dust and dry particles was evaporated, the weight of residue was measured again and chemically investigated by using concentrated nitric acid - hydrogen peroxide. Pb, Fe, Ni, Cu and Zn were determined by using AURORA AI 1200 AAS appliance.

Leaf samples after removal of dust and other deposited particles were dried in oven to constant weight. For analyzing the leaf metal content, the ground dry leaf samples were digested at 105 °C with 10 ml concentrated nitric acid (HNO_3) plus 4 ml 30% solution of H_2O_2, which was boiled until clearing. The contents of mineral nutrient elements in the two digestion solutions were measured using ICP atomic emission spectroscopy (ICP Thermo Jarrell Ash ICAP 61E equipment).

During the season of 2015, from period May-June to October-November the amount of dust deposit on leaves increased 3 to 7 times. The foliar dust deposition on the investigated three urban tree species weighed 48 – 380 mg m^{-2}. We found large differences in foliar dust deposition on leaves between the sampling periods and tree species but the differences between the locations of the same tree species in the same sampling period were not significant (Table 3.). This suggest that in dust removal capacity from urban air the leaf surface of trees in larger parks are similarly efficient as the trees along the heavy traffic charged streets.

The dust deposit in the 7 weeks long period from May to June was affected by rainfall reducing the dust deposition. The most efficient tree species in trapping dust on leaves was silver linden (Tilia), followed by Norway maple (Acer) and common ash (Fraxinus).

Table 3. Dust deposition washed off from leaves of different species in Budapest (mg m^{-2}): average of samples from seven (spring 2015) and three weeks (autumn 2015 and 2016).

2015	Acer Arbor		Acer Krisztina		Fraxinus Arbor		Fraxinus Andrássy		Tilia Arbor		Tilia Karolina	
May – June 2015	48.89	a	76.67	ab	51.28	a	59.31	ab	76.60	ab	88,05	b
Oct. – Nov. 2015	246.72	a	296.81	a	380.93	a	288.48	a	224.06	a	317.61	a
Oct. 5 – 19. 2016	51.32	a	81.30	ab	58.62	a	72.60	ab	77.79	ab	130.01	b

Note: means were separated by Duncan's Multiple Range test, values marked with different letters within rows are significant different at p=0.5.

Table 4. HM content of leaf dust deposit on urban trees in Budapest (mg m^{-2} leaf)

Species	*Acer platanoides* 'Globosum'				*Fraxinus excelsior* 'Westhof's Glorie'				*Tilia tomentosa*			
Location	Buda Arboretum		Krisztina Street		Buda Arboretum		Andrássy avenue		Buda Arboretum		Karolina Street	
Spring sampling 2015 (means of 19th to 25th week)												
Fe	0.27	ab	0.36	b	0.20	a	0.24	a	0.60	b	0.68	b
Pb	0.57	a	0.90	c	0.57	a	0.67	a	1.60	d	1.79	e
Zn	2.28	b	4.09	c	2.08	a	2.28	a	5.18	d	5.80	d
Cu	1.15	a	1.60	b	0.91	a	0.92	a	2.43	b	2.47	b
Ni	6.85	a	9.00	b	5.44	a	5.55	a	14.84	c	15.20	c
Total	11.12	b	16.94	c	9.20	a	9.66	ab	24.64	d	25.94	d
Autumn sampling 2015 (means of 44th to 46th weeks)												
Fe	3.29	a	7.63	ab	3.33	a	5.94	ab	7.34	ab	10.28	b
Pb	5.82	ab	7.26	b	4.01	a	4.28	a	10.39	c	11.63	c
Zn	0.32	ab	0.58	c	0.23	a	0.47	bc	0.82	d	1.05	e
Cu	1.78	a	2.55	ab	1.63	a	2.15	a	3.71	ab	4.45	b
Ni	1.50	a	1.88	ab	1.11	a	1.23	a	3.27	b	3.84	b
Total	12.71	ab	19.9	bc	10.32	a	14.05	ab	25.54	cd	31.25	d
Autumn sampling 2016 (means of 40th to 42nd week)												
Fe	2.90	a	4.54	ab	3.55	ab	4.44	ab	5.51	bc	7.31	c
Pb	3.55	a	4.90	a	4.99	a	4.55	a	7.10	a	6.63	a
Zn	1.16	a	1.54	a	1.14	a	1.24	a	2.39	b	2.98	b
Cu	0.20	b	0.38	c	0.06	a	0.13	ab	0.46	c	0.62	d
Ni	4.00	a	5.91	ab	4.27	a	4.25	a	10.11	bc	11.26	c
Total	11.65	a	17.16	ab	14.02	ab	14.61	ab	25.57	bc	28.81	c
Mean of totals of investigated HM elements of three sampling periods (2015–16)												
Mean	11.82	a	17.16	b	10.57	a	11.82	a	25.06	c	27.81	c

Note: means were separated by Duncan's Multiple Range test, values marked with different letters within rows are significant different at p=0.5.

We found significant differences in the heavy metal deposition on leaves of different species (Table 4.). We measured the lowest amount of HM deposition on *Fraxinus excelsior* 'Westhof's Glorie'. The measured HM depostition was higher on *Acer platanoides* 'Globosum', and twice as large on leaves of *Tilia tomentosa*. The proportion of HM deposition changed during the season. In early season we found outstandingly high amount of Ni in the HM deposition, while, in autumn the accumulating Pb and Fe made around 70% of the HM deposition. The deposition of Fe and Pb increased more than ten times by the end of the season, while the amount of other heavy metals in the deposition did not accumulate, but rather decreased. The amount of dust deposition on the leaves of common ash did not show any difference between the two locations. *Acer platanoides* and *Tilia tomentosa* had 10–20% higher deposition on their foliage at locations with heavy traffic. This means too that in larger parks the role of trees in removal of HM particulates is close to those that are located along the main traffic roads.

When compare our data to the PM10 concentration in the air of Budapest measured in three location close to our sampling places (measuring stations of Hungarian Air Quality Network) we can conclude that the extremely high foliar dust deposition in 2015 autumn is linked with a high PM10 concentration in the air (Hrotkó et al., 2018). Our results confirm that the leaves of urban trees are good indicators in the monitoring of air pollution.

In summary, we can state that our data on leaf dust deposit for Budapest are valuable and provides new information as an indicator of air pollution.

Conclusions:

- The dust deposit on leaves of urban trees indicate well the increased PM10 concentration in the air, however the performance of deposit is influenced by rainfall and retaining capacity of leaves. Highest dust deposit was in rainless period with high PM10 pollution in the air.
- Urban trees differ in their dust retaining capacity, highest was detected on silver linden trees, intermediate capacity was on Norway maple and lowest on common ash.
- The deposit of investigated five HM elements showed temporal differences in share (%) related to the total dust deposit: at average air pollution it was about 23.2–24.9%, while in the highest leaf dust deposit the share of HM (Fe, Pb, Zn, Ni, Cu) elements was 6.8 %.
- By the end of the season on autumnal leaves Fe and Pb deposit and their share (%) related to total dust increases more than ten times higher, while the other heavy metals did not show such an accumulation.
- Silver linden with its pubescent leaf surface proved to be most efficient in entrapping and retain dust and heavy metals, especially Pb and Fe, followed by Norway maple and common ash.
- The common ash did not show any difference between the locations, the Norway maple and silver linden showed little higher dust and HM deposition in the location charged by heavy traffic.
- As the autumn leaf samples after the foliar dust was washed off, showed increased Fe and Pb content, our results indicate that over the season leaves absorb Fe and Pb from the dust deposit on leaf surface.

3.5. Measuring and modeling the concentration of atmospheric pollutants in urban environment

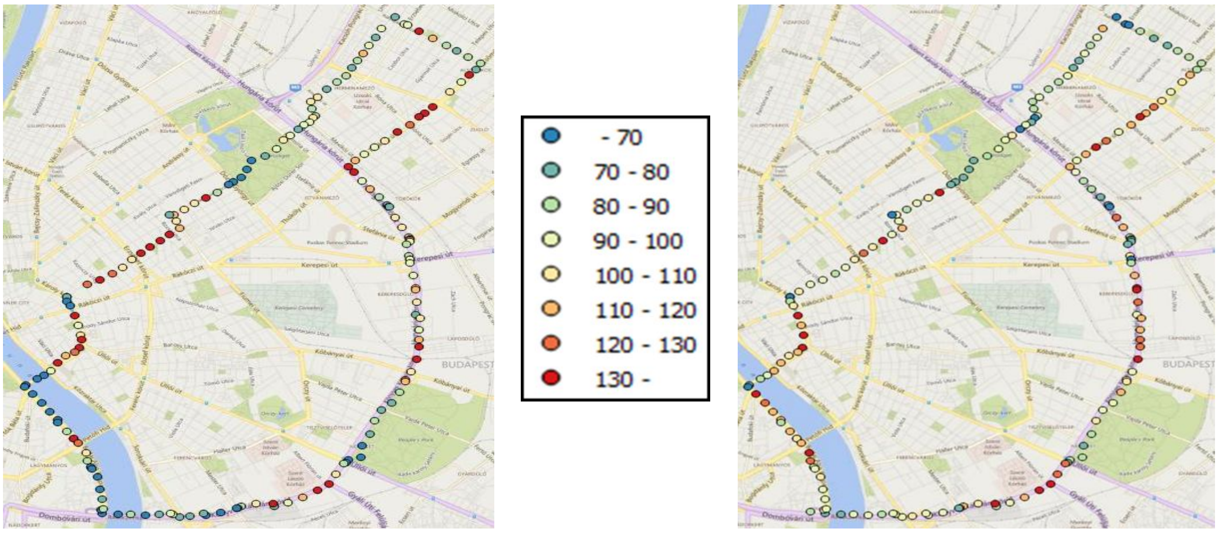
Mobile measurements:

Urban air quality is a major issue of European cities. At the same time, very few measurement data is available to estimate the air pollution risk of everyday urban road transport. A measuring campaign has been conducted with two portable gas monitors carried on bicycles in Budapest (Mészáros et al., 2016a,b). Few typical routes were selected from the domestic outskirts to the downtown area of Budapest, each ranging approximately 10 km in length. The concentration of NO_2, O_3 and CO was measured with 30 s temporal resolution along the way on several days. The spatial distribution of results clearly shows the impact of roads, parks, trees and the Danube river. Measured concentrations have been compared to the background values to estimate the fine-scale spatial variability of air quality. A one-day long measurement campaign has also been carried out in downtown Budapest. Results show large spatial variability of air quality, underlining the importance of vegetation and car-free streets.

High temporal resolution NO_2 and CO concentration measurements were carried out with two Boreas BGS-06 mobile gas analyzers mounted on bicycles, which contained the following detectors:

- Membrapor CO/MF-200,
- Membrapor NO2/M-20,
- Membrapor O3/M-5,
- Figaro TGS2602 VOC,
- Boreas Pt100 temperature and relative humidity sensor,
- L80-M39 Qectel GPS modul.

Measurement data was obtained with 2 seconds temporal resolution using a 30-second moving average window. Measurements were carried out regularly on two busy cycling routes (Fig 3.) of downtown Budapest. One of these routes crossed the City Park, then followed narrow street canyons, reached the river side, crossed a bridge and followed the river. The second route followed a wide 2×3 lane road with very high car and truck traffic.



a.) b.)

Fig. 3. *Percent of route-mean concentration of a.) CO and b.) NO_2 in two different routes in Budapest*

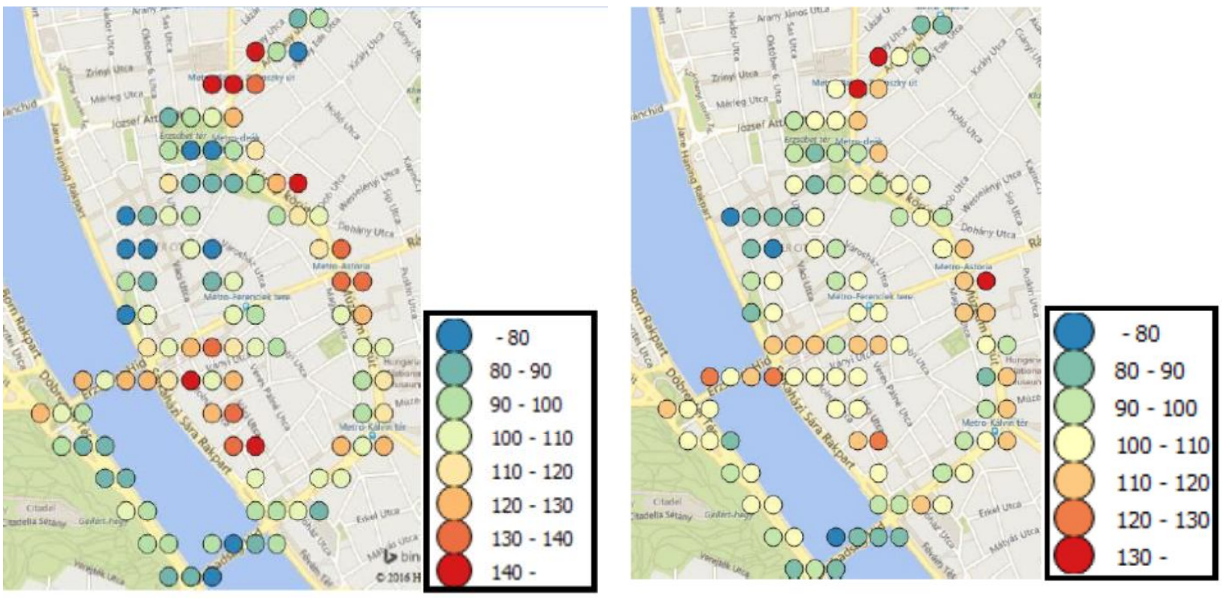
Besides these measurements, one-day long measurement campaigns were organized following the same route several times with both bicycles (Fig. 4). The 10-km long route within the city of Budapest covered narrow street canyons, pedestrian streets, the river side and two bridges.

Measurement uncertainty was assessed in two ways: correlating the two devices against each other and comparing the values with nearby air quality monitoring stations of the Hungarian Air Quality Network. The two devices showed >95% correlation for CO, NO_2 and ozone. Compared to the fixed station, the mobile device showed a general underestimation of 1–34%. This value is large for a regulatory application, but is smaller than or comparable to the fine scale spatial variability of air pollution. Uncertainty factors are the limited accuracy of the mobile device, the very large local concentration gradients in the urban environment and the different averaging intervals. However, the temporal and spatial trends of air pollution were clearly observable and the fine spatial structure of air quality could be revealed.

Results indicate the large importance of the distance between the cyclist and the car traffic. CO concentrations were larger on a 1-lane street than on a bike path only a few meters next to the 6-lane Hungária road, one of the busiest roads of the city. NO_2 concentrations, on the other hand, showed the opposite tendency, pointing out the direct exposure to primary road emission despite the relatively low traffic.

Urban green areas show significantly (20–40%) better air quality in terms of CO and NO_2 than the route average. However, the benefits are spatially constrained by high traffic roads alongside the green area. Concentration differences to as high as 60% were observed at the park boundaries within 100 m distance. Traffic reduction near parks has an increased importance to allow the cleaner air to extend into the street canyons (Fig. 3).

A one-day long measuring campaign was also organized following the same route several times with two bicycles. Our goal was to reveal the fine spatial structure of air pollution in streets. Therefore, results were post-processed to eliminate the large-scale daily variability and the possible bias of the mobile device. Results are presented in terms of relative difference compared to the route-mean concentration of the given hour of the day (Fig. 4.).



a.) b.)

Fig. 4. Average of percent of route-mean concentration od a.) CO and b.) NO_2. Measurements were carried out in the same route in 18 times in 23 March, 2016.

The main ventillation pathway of downtown Budapest is the Danube river. Concentrations could stay below or even above the route average depending on the traffic and the wind direction. In the one-day measurement campaign, the northern (Erzsébet) bridge with 6 lanes and very high traffic was 30–50% more polluted than the southern (Szabadság) bridge having 2 lanes and a tram rail.

Pedestrian and wide low-traffic streets showed the expected low concentrations. Surprisingly, a narrow street canyon to the south proved to be an air quality hotspot with very high concentrations. Even weak traffic could cause high pollution in a badly ventillated street. Hotspots with the worst air quality are located at junctions where slow and high traffic coincides with street canyons. Concentrations could exceed 140% of the route mean (Fig. 4.).

Another measuring campaign have been carried out on 26 Nov. 2016. This day, PM2,5 concentration was also detected by TSI DustTrakII 8532 Aerosol monitor (Mészáros et al., 2017a). Our results (Fig 5.) showing the effects of the vegetation, construction, traffic and environment on fine scale spatial variation of air pollution.

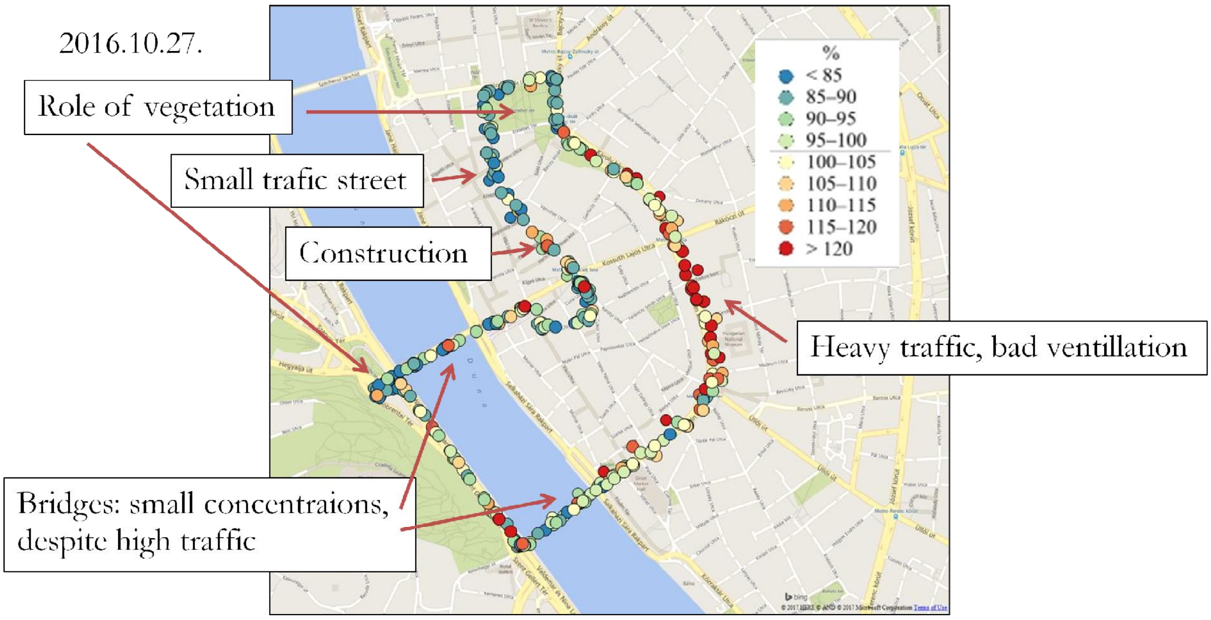


Fig. 5. Results of 3-hour continuous measurements in 27.10.2016 (9 round, each round is 5 km in the same route). Percent of rout-mean concentration of PM2,5

Model simulations:

During our modelling activity, the main goal was to simulate the transport and spatial distribution of atmospheric pollutants in an urban environment in order to make air quality forecasts for the city of Budapest (Kovács et al., 2015, 2017). For this task, we use the WRF-ARW meteorological model (*The Weather Research & Forecasting Model - Advanced Research WRF*, v3.6, 2014.) coupled with a chemistry transport model (WRF-Chem, v3.6, 2014.). Our simulations run on a triple-nested domain with the 30 km horizontal resolution mother domain over Central Europe. The first nested domain with a horizontal resolution of 10 km over Hungary, and the finest resolution domain representing the area of the city of Budapest with 2 km grid spacing. The WRF-Chem model is capable of simulating the emission and transport of gases and aerosols from anthropogenic and biogenic sources depending on the choice of the chemical mechanism package.

The WRF-Chem model requires meteorological, static terrain and emission input data. For the meteorological data, we used 3 hour temporal resolution output data from the GFS model (0,5°×0,5° horizontal resolution prior to 2015, and 0,25°×0,25° horizontal resolution after 2015). The static terrain data was added to the WRF model. Using different emission datasets, the dispersion of air pollutants (gases and aerosol particles) in various weather situations were simulated. An example for NO concentration field estimated using traffic emission data is presented in Fig 6.

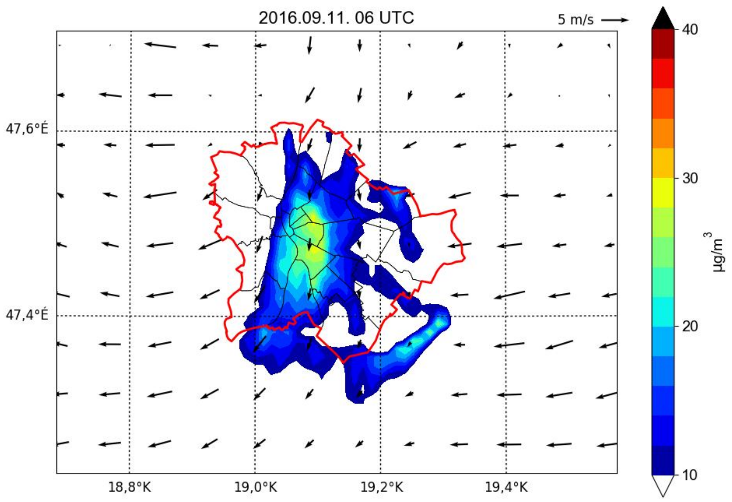
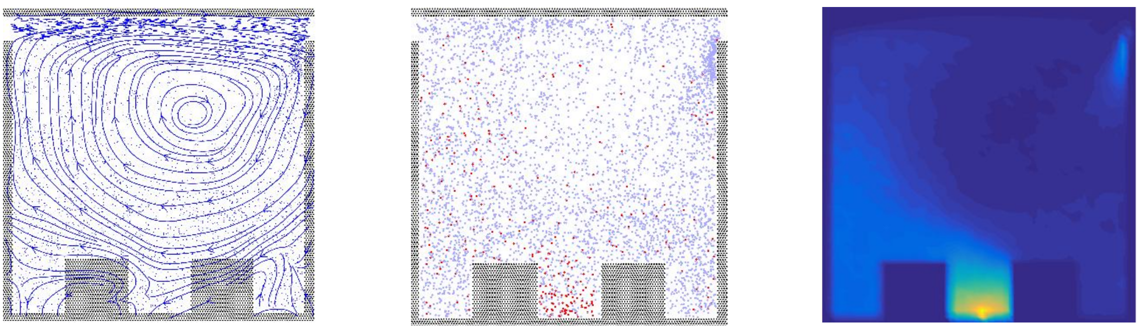


Fig. 6. Surface NO concentration simulated by WRF-Chem model for 11. Sept.2016. 06 UTC using traffic related emission.

In microscale (less than 1 km) dispersion problems, the interaction of the atmospheric flow with surface obstacles changes significantly the flow velocity profile, thus the spatial distribution of pollution can completely differ from that over a flat terrain. As a consequence of complex building configurations, the concentration values can change by an order of magnitude due to the disturbance of atmospheric flow. NWPs do not have sufficient resolution to resolve this pattern, therefore a more detailed simulation was implemented to simulate the distribution of radionuclides and other pollutants (e.g., smoke, toxic substances) among the buildings or trees of an urban or industrial site.



a.) b.) c.)

Fig. 7. Street canyon simulation using Dissipative Dynamics Simulation in case of rectangular obstacles. (a) generated streamlines with particles (blue), (b) distribution of particles (air particles – blue; air pollutants – red), (c) concentration distribution of air pollutants.

The dynamics of the fluid flow, is usually simulated by the Navier-Stokes equations, which are mathematically partial differential equations with appropriate initial and boundary conditions. In the complex three-dimensional domain the application of boundary conditions can be a challenging task. Additionally, these calculations are computationally expensive and time consuming. In the framework of this project we developed a street canyon model (Fig. 7.) using DPD (dissipative particle dynamics) method. To achieve inflexible collision between particles new types of forces should be introduced - dissipative and random forces - which make the system dissipative, but conserve the mass and momentum. If the time integration is accurate then the DPD model conforms the Navier-Stokes equation.

Besides the above mentioned model simulations, the effect of climate change on urban environment under the episodes of heat waves using a fine resolution non-hydrostatic numerical model was also investigated (Göndöcs et al., 2018). The analysis focused on selected heat wave episodes from the RegCM simulations during three periods (past:1971–2000; future: 2016–2045 and 2061–2090). The simulations were carried out for Budapest with the WRF model coupled to multilayer urban canopy parameterisation. With our updated land use and urban characteristics database, the model was able to reproduce the Urban Heat Island with a fine horizontal resolution, and also its spatial structure.

3.6. Development, refinement and application of a sophisticated deposition model

For the purpose of estimating the environmental load caused by atmospheric pollutants, a sophisticated deposition model has been developed and applied (Fig. 8.). This model describes the deposition velocity and deposition flux of ozone over different surfaces by a resistance network. Resistance terms are described in the soil-vegetation-atmosphere system as the function of radiation and energy balance, water balance, and the physical properties of the soil, the vegetation and the atmosphere.

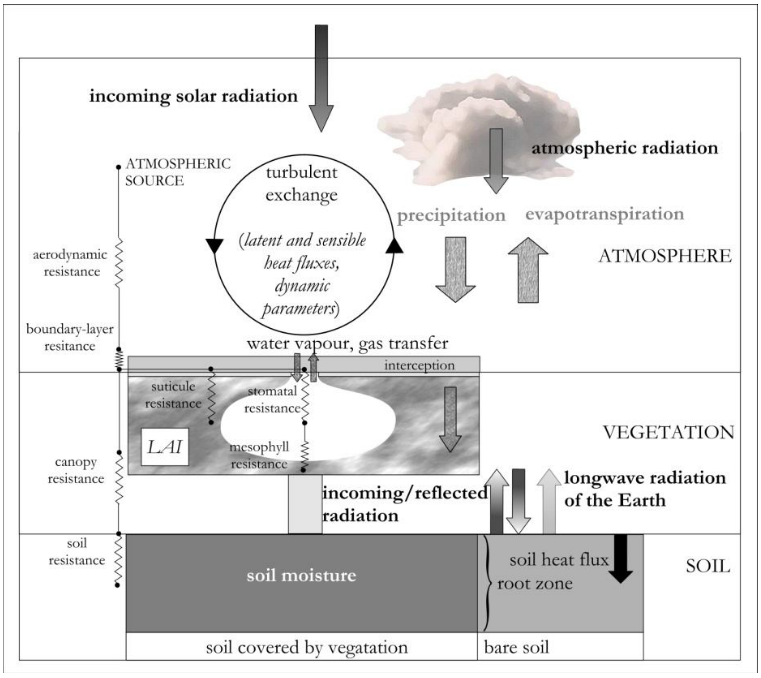


Fig. 8. Flow chart of the deposition model

During our investigation, this detailed deposition model was developed and refined for urban vegetation (Ludányi, 2015) to utilize the results of our micrometeorological and plant physiological measurements. Model calculation focused on the near surface ozone to describe the yearly variation of the deposition flux over different urban surfaces (Fig. 9.)

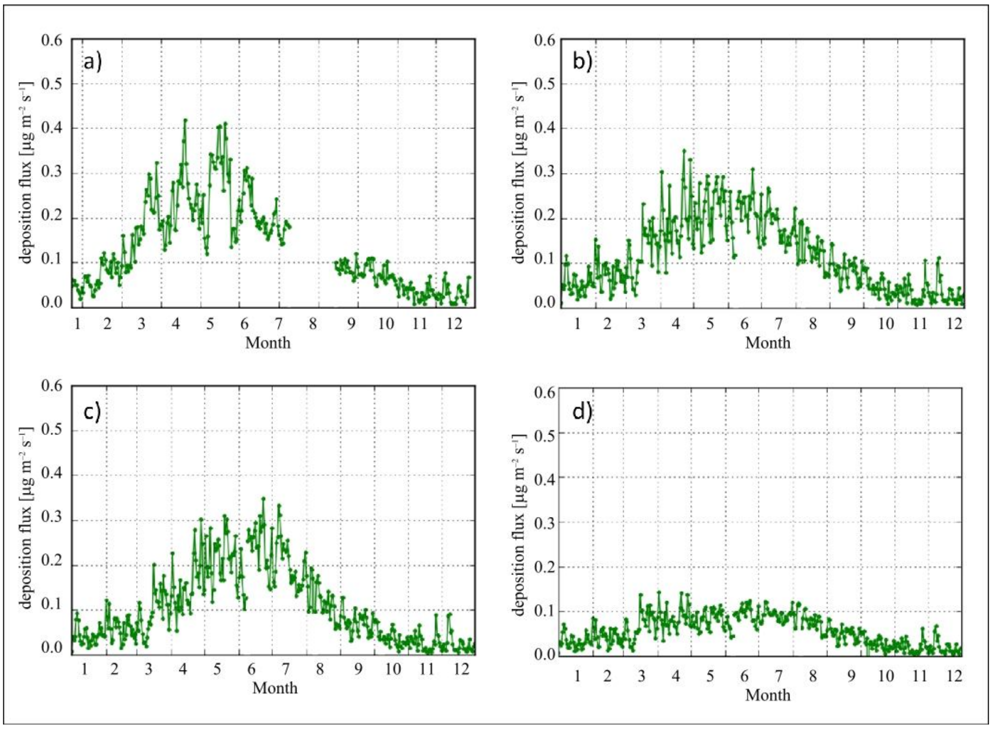


Fig. 9. Deposition flux of the near-surface ozone during 2013 calculated by deposition model over different surfaces: a.) suburb orchard, b.) downtown mixed trees, c.) downtown grass, d.) downtown pavement

4. Conclusions:

Considering the huge ecological services of urban trees, our conclusion is that urban planning, landscape planning and horticulturist should shift for a new paradigm in urban tree application, green space planning.

In future's urban planning, the creation of smart city conditions should be emphasized, which maximize the environmental usefulness and utilize the ecology services of urban trees, instead of the simplified requirements, adopting trees to urban conditions (Table 5.). This would need a strong cooperation between urban planning, landscape architecture and horticulturists.

Table 5. Suggestions for future urban planning

Adopting trees to urban conditions?	***Create smart city conditions for maximal tree usefulness and maximize ecology services!***
• Small canopy and root system fit well to architecture of buildings and utility lines. • Drought tolerant trees spare on water. • Small trees fit well into canyon like streets. • Small canopy doesn't disturb the „architectonic beauty" of facade.	• Large trees, shade providing canopy, healthy leaf surface. • Irrigation of trees instead of cooling pavement and tram rails. • Maximize transpiration capacity. • Maximize CO_2 sequestration and tree lifespan. • Avoid allergenic pollen.

5. Conference participations

In the following we summarize the conference participations and the presented results during the project (Table 6.).

Table 6. Participations in national and international conferences

Conference	Site	Date	Project results
Plants in Urban Areas and Landscape	Nitra, Slovakia	2014.05.14–15.	Steiner et al., 2014 Szaller et al., 2014 Tóth et al., 2014
A Meteorológiai TDK 2014. évi nyári iskola	Szigliget, HU	2014.08.26–28.	Mészáros et al., 2014
International Student Conference on Environmental Protection and Rural Development	Szolnok, HU	2014.09.26–27.	Langfeld et al., 2014
XXI. Növénynemesítési Tudományos Napok	Martonvásár, HU	2015.03.11–12.	Steiner et al., 2015a
XII. Magyar Aeroszol Konferencia	Szeged, HU	2015.03.18–20.	Kardos et al., 2015
VI. Magyar Tájökológiai Konferencia	Budapest, HU	2015.05.21–23.	Angyal et al., 2015
Aghriculture for life – Life for Agriculture	Bucharest, Romania	2015.06.04–06.	Steiner et al., 2015b
17th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes	Budapest, HU	2016.05.09–12.	Kovács et al., 2016
A Meteorológiai TDK 2016. évi nyári iskola	Hercegkút, HU	2016.08.23–25.	Leelőssy et al., 2016 Mészáros et al., 2016a
16th EMS / 11th ECAC conference	Trieste, Italy	2016.09.12–16.	Mészáros et al., 2016b
5th International Scientific Horticulture Conference	Nitra, Slovakia	2016.09.21–23.	Iváncsics et al., 2016 Steiner et al., 2016a
III. International Symposium on Horticulture in Europe	Chaina, Greece	2016.10.17–21.	Steiner et al., 2016b Steiner et al., 2016c
XIII. Kárpát-medencei Környezettudományi Konferencia	Kolozsvár, Romania	2017.04.05–08.	Angyal et al., 2017
XIII. Magyar Aeroszol konferencia	Pécs, HU	2017.04.19–20.	Kardos et al., 2017 Mészáros et al., 2017a
European Geosciences Union General Assembly 2017	Vienna, Austria	2017.04.23–28.	Göndöcs et al., 2017b Pongrácz et al., 2017b
17th EMS / 12th ECAC conference	Dublin, Ireland	2017.09.04–08.	Lagzi et al., 2017
Plants in Urban Areas and Landscape	Hokovce, Slovakia	2017.11.08–09.	Hrotkó, 2017 (plenary speaker)
43. Meterorológiai tudományos napok	Budapest, HU	2017.11.23–24.	Mészáros et al., 2017b

References (our selected publication during the project):

Angyal Zs., Kardos L., Sepsi P. (2015): A városi zöldfelületek hatásának vizsgálata a levegőminőség szempontjából. VI. Magyar Tájökológiai Konferencia kiadvány 4–9.

Angyal Zs., Sepsi P., Sütöriné-Diószegi M., Magyar L., Gyeviki M. Hrotkó K. és Kardos L. (2017): Budapesti légszennyezettség jellemzése díszfák leveleire rakódott szennyezés alapján. XIII. Kárpát-medencei Környezettudományi Konferencia, Kolozsvár, 2017. április 5-8. Tanulmánykötet, pp. 130-135. ISSN 1842-9815

Dian Cs., Pongrácz R., Dezső Zs. és Bartholy J. (2015): Városklimatológiai mérési expedíció Budapest IX. kerületében. Egyetemi Meteorológiai Füzetek. 26. 15–21.

Göndöcs J., Breuer H., Pongrácz R., Bartholy J. (2017a): Urban heat island mesoscale modelling study for the Budapest agglomeration area using the WRF model. *Urban Climate*, 21, pp. 66-86. DOI 10.1016/j.uclim.2017.05.005

Göndöcs J., Breuer H., Pongrácz R., Bartholy J. (2017b): Regional dynamical downscaling for urban environment to estimate the potential impact of climate change. Geophysical Research Abstracts, Vol. 19, EGU2016-13964. http://meetingorganizer.copernicus.org/EGU2017/EGU 2017-13964.pdf (poster)

Göndöcs J., Breuer H., Pongrácz R., Bartholy J. (2018): The effect of climate change on urban environment under the episodes of heat waves using a fine resolution non-hydrostatic numerical model. Geophysical Research Abstracts Vol. 20, EGU2018-586.

Hrotkó K. (2013): Városi fák környezeti hasznának vizsgálata. Előadás a „Közterületeink növény- és talajvédelme” c. tudományos konferencián. 2013. december. 10. FŐKERT Nonprofit Zrt.

Hrotkó K. (2017): Methods for evaluation of environmental usefulness of urban trees. Plants in Urban Areas and Landscape. International Scientific Conference, Nitra Agricultural University. Hokovce, 2017.11.08–09.

Hrotkó, K., Steiner, M., Forrai, M., Tóth, E. G., Vértesy, M., Leelőssy, Á., Kardos, L., Sütöriné D. M., Magyar, L. and Mészáros, R. (2014): Investigations on environmental benefits of urban trees at Corvinus University of Budapest. Plants in Urban Areas and Landscape, Slovak Agricultural University, Nitra, Faculty of Horticulture and Landscape Architecture, 24-27 pp. ISBN 978-80-552-1262-3.

Hrotkó, K., Gyeviki, M. Sütöriné, D. M., Magyar, L., Mészáros, R. and Kardos, L. (2018): Heavy metals in dust deposit on leaves of urban trees in Budapest. (In preparation)

Iváncsics, V., Hrotkó, K. and Sütöri-Diószegi, M. (2016): The survey of *Quercus* species and varieties in Buda Arboretum. Scientific proceedings of the 5th International Scientific Horticulture Conference 2016. 09. 21-23., Slovak University of Agriculture in Nitra, 2016, pages 27-33. ISBN 978-80-552-1571-6

Kardos L., Sepsi P., Sárközi E., Steiner M. és Hrotkó K. (2015): Budapest levegőminőségének részleges jellemzése a városi díszfák levélmintáinak vizsgálata alapján XII. Magyar Aeroszol Konferencia, Szeged, 2015. március 18–20. Előadások kivonatai. 44-45. old. ISBN 978-963-306-364-4

Kardos L., Sepsi P., Magyar L., Gyeviki M., Sütöriné-Diószegi M. és Hrotkó K. (2017): Budapesti légszennyezettség jellemzése 2015-2016. évi levélminták alapján. A XIII. Magyar Aeroszol Konferencia előadás-kivonatai. XIII. Magyar Aeroszol Konferencia, Pécs, pp. 73-74. ISBN 978-963-429-127-5

Kovács A., Mészáros R., Leelőssy Á. és Lagzi I.L. (2015): A WRF-Chem modell tesztelése pontforrásból származó légszennyező terjedésének vizsgálatára. Egyetemi Meteorológiai Füzetek. 26. 49–53.

Kovács A., Mészáros R., Leelőssy Á. and Lagzi I. (2017): Air pollution modeling in urban environment using WRF-Chem model. 17th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. pp. 367–370.

Lagzi I., Leelőssy Á., Mészáros R. and Göndöcs J. (2017): Autoregressive temperature and air quality prediction in Budapest in the winter of 2016-2017. EMS Annual Meeting Abstracts Vol.14, EMS2017.

Langfeld É., Sárközi E., Sepsi P., Kardos L. és Hrotkó K. (2014): Nagyvárosi légszennyezettség jellemzése levél- és ágminták vizsgálata alapján. In: 20th International Student Conference on

Environmental Protection and Rural Development. Szolnok, 09.26-09.27.2014. p. 33. 1 p. (ISBN:978-963-89935-1-9)

Leelőssy Á., Mészáros R., Kovács A. és Lagzi I. (2016): Légköri diszperzió modellezése különböző skálákon. Egyetemi Meteorológiai Füzetek. 27.100–105.

Leelőssy Á., Mészáros R. and Lagzi I. (2017): Spatial and temporal pattern of pollutants dispersed in the atmosphere from the Budapest Chemical Works industrial site. Időjárás / Quarterly Journal of the Hungarian Meteorological Service 121:(2) 101–115.

Ludányi E., 2015: Légszennyező anyagok ülepedésének modellezése városi környezetben. Thesis. Supervisors: Mészáros R., Leelőssy Á., Steiner M. Eötvös Loránd University Department of Meteorology, Budapest. pp. 46.

Mészáros R., Lagzi I.L., Leelőssy Á., Ludányi E.L., Kovács A. és Szabó Z, (2014): Légszennyezés-meteorológiai kutatások az ELTE Meteorológiai Tanszékén. Egyetemi Meteorológiai Füzetek. 25. 118–122.

Mészáros R., Ludányi E. és Leelőssy Á. (2015a): A felszínközeli ózon száraz ülepedésének modellezése városi környezetben. Egyetemi Meteorológiai Füzetek. 26. 70–75.

Mészáros R., Leelőssy Á., Lagzi I.L. (2015b): Levegőkémiai modellezés az ELTE Meteorológiai Tanszékén. Egyetemi Meteorológiai Füzetek. 26. 64–69.

Mészáros R., Csapó P., Boda B. és Leelőssy Á. (2016a): Légszennyezettségi viszonyok mérése Budapesten kerékpárra szerelhető mérőrendszerrel. Egyetemi Meteorológiai Füzetek. 27. 106–111.

Mészáros R., Leelőssy Á., Csapó P., Boda B., Kovács A. and Lagzi I. (2016b): Monitoring of atmospheric trace gases in Budapest by mobile measurements. EMS Annual Meeting Abstracts: EMS2016-501. 16th EMS / 11th ECAC conference. Trieste, 2016.09.12–16. 2016.

Mészáros R., Leelőssy Á., Kovács A. és Lagzi I. (2017a): PM2,5 koncentrációjának meghatározása kerékpáros mérésekkel Budapesten. XIII. Magyar Aeroszol Konferencia, Pécs, pp. 73-74. ISBN 978-963-429-127-5

Mészáros R., Leelőssy Á., Lagzi I., Kovács A. és Csapó P. (2017b): Levegőkémiai mérések és modellezés lokálistól regionális skáláig. 43. Meterorológiai tudományos napok: Mikro- és mezoskálájú légköri folyamatok modellezése. Budapest, 2017.11.23–24.

Molnár A.E. (2017): Légköri szennyezőanyagok keveredése városi környezetben. Thesis. Supervisors: Mészáros R. és Leelőssy Á. Eötvös Loránd University, Department of Meteorology, Budapest. pp. 51.

Pongrácz R., Dian Cs., Incze D., Kurcsics M., Dezső Zs. és Bartholy J. (2017a): Budapesti városklimatológiai helyszíni mérések elemzése. *Légkör*, 62., pp. 126-129. (2017/3. szám)

Pongrácz R., Bartholy J., Dezső, Zs., Dian, Cs., Incze, D. and Kurcsics, M. (2017b): Analysing the daily cycles of temperature and humidity differences between downtown and suburban environment in Budapest. *Geophysical Research Abstracts*, Vol. 19, EGU2016-15717.

Sepsi P., Incze D., Steiner M., Sütöriné Diószegi M., Hrotkó K. és Kardos L. (2015): Légszennyezés jellemzése levélminták vizsgálata alapján. Tudomány és Innováció a lokális és globális fejlődésért. Szent István Egyetemi Kiadó, 27-31. ISBN 978-963-269-512-9

Steiner M., Tóth. E.Gy., Sütöriné D.M. és Hrotkó K. (2013): Hárs fajták leveleinek gázcseréje különböző időjárási viszonyok mellett. Előadás a "Közterületeink növény- és talajvédelme c. tudományos konferencián. 2013. december. 10. FŐKERT Nonprofit Zrt.

Steiner, M., Tóth, E. Gy., Juhász, Á., Sütöriné D.M., and Hrotkó, K. (2014): Stomatal responses of drought and heat stressed linden (*Tilia* sp.) leaves. Plants in Urban Areas and Landscape, Slovak Agricultural University, Nitra, Faculty of Horticulture and Landscape Architecture, 7-10 pp. ISBN 978-80-552-1262-3.

Steiner M., Vértesy M., Sütöriné Diószegi M. és Hrotkó K. (2015a): Fiatal hársfák lombkoronájának fényabszorpciós képessége. XXI. Növénynemesítési Tudományos Napok, MNE és az MTA ATK kiadványa, Szerk. Veisz Ottó, 152. oldal. ISBN 978-963-8351-43-2

Steiner, M., Vértesy, M., Sütöri-Diószegi M. and Hrotkó, K. (2015b): PAR absorption ability of the canopy of young linden (Tilia sp.) trees. UASVM Bulletin, Bucharest. Series B, Horticulture. Vol. LIX, 405-408. Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

Steiner, M., Sütöri-Diószegi, M. and Hrotkó, K. (2016a): Growth characteristics of urban trees in Budapest. Scientific proceedings of the 5th International Scientific Horticulture Conference 2016.

09. 21-23., Slovak University of Agriculture in Nitra, 2016, pages 122-131. ISBN 978-80-552-1571-6

Steiner, M., Sütöri-Diószegi, M. Vértesy, M. and Hrotkó, K. (2016b): Estimated CO2 sequestration capacity of Maple (Acer sp.) and Linden (Tilia sp.) trees.III. International Symposium on Horticulture in Europe. Book of Abstracts. 2016. 10. 17-21. CIHEAM MAI Chania, Greece. 185.

Steiner, M., Vértesy, M. and Hrotkó, K. (2016c): Leaf gas exchange characteristics and leaf water potential of drought stressed Linden (Tilia sp.) trees. III. International Symposium on Horticulture in Europe. Book of Abstracts. 2016. 10. 17-21. CIHEAM MAI Chania, Greece. 127.

Szaller, V. Szabó,V., Sütöriné D. M., Magyar L. and Hrotkó, K. (2014): Urban Alley Trees in Budapest. Plants in Urban Areas and Landscape, Slovak Agricultural University, Nitra, Faculty of Horticulture and Landscape Architecture, 27-30. pp. ISBN 978-80-552-1262-3.

Tóth, E. G., Vértesy, M., Sütöriné D. M., Steiner, M. and Hrotkó, K. (2014): Growth and phenological observations on Hungarian and foreign Linden varieties. Plants in Urban Areas and Landscape, Slovak Agricultural University, Nitra, Faculty of Horticulture and Landscape Architecture, 93-95 pp. ISBN 978-80-552-1262-3.

Tóth, E. Gy., Juhász, Á., Sütöriné D.M., Steiner, M. and Hrotkó, K. (2015): Leaf gas exchange characteristics of drought stressed linden trees. Applied Ecology and Environmental Research, 13(4):1109-1120. ISSN 1589 1623 (Print) ISSN 1785 0037 (Online) DOI: http://dx.doi.org/10.15666/aeer/1304_11091120