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INFLUENCE OF DIFFERENT FACTORS ON RELATIVE AIR HUMIDITY IN SZEGED, HUNGARY

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Summary – In this study the spatio-temporal distribution of relative air humidity, based on mobile measurements carried out in Szeged (Hungary), is discussed in detail. In the present work a ca. 8 km long cross-section of the urban area was examined consisting of every characteristic land-use type of city. Tasks include the determination and demonstration of mean humidity distribution and its daily characteristics as a function of urban, meteorological and anthropogenic factors. As the results show, strong connection can be detected between relative humidity and the above-mentioned parameters.

Key words: urban cross-section, relative humidity, urban, meteorological and anthropogenic factors, Szeged (Hungary)

1. INTRODUCTION

Air humidity conditions, among other factors, may affect for example human comfort, weather-related mortality (e.g. Kalkstein 1991, Saez et al. 2000) and air pollution induced respiratory diseases (e.g. Makra et al. 2008). However, the climate-modifying effect of urbanization is obvious for air humidity (e.g. Chandler 1967, Hage 1975, Landsberg 1981, Ackerman 1987, Kuttler 1998, Potchter et al. 2003). On the contrary, air humidity, especially relative humidity (RH), are still underinvestigated in urban climate research, compared to other parameters such as temperature (for case studies in Szeged, see e.g. Unger 1993, 1997, 1999) even if in recent years some investigations were carried out (e.g. Kuttler et al. 2007, Um et al. 2007, Liu et al. 2008).

In general the differences between the urban and rural values of relative humidity (ΔRH) have a diurnal and a seasonal cycle. A strong connection can be detected between ΔRH and the development of urban heat island (UHI) (e.g. Landsberg and Maisel 1972).

The aim of this study is to reveal the temporal dynamics of ΔRH during the night along a representative urban cross-section investigating mean distribution as well as two individual cases and to explain their features using urban, meteorological and anthropogenic parameters.

2. STUDY AREA AND METHODS

2.1. Location and conditions

The studied city, Szeged, is located in Central Europe (Fig. 1), in the south-eastern part of Hungary (46°15’N, 20°10’E) at 79 m above sea level on a flat plain.

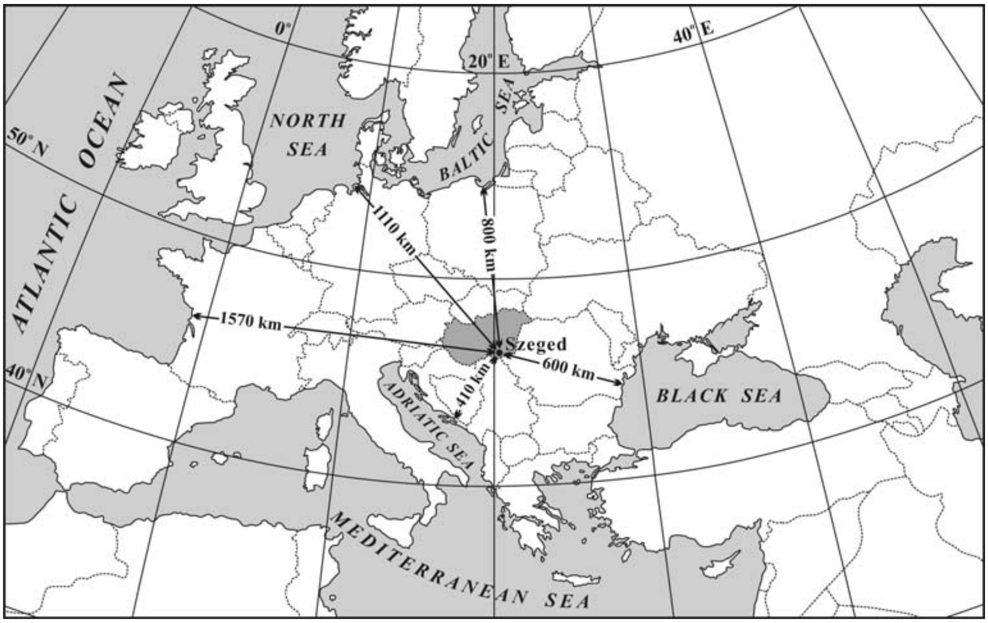

Fig. 1 Geographical location of Szeged in Europe and its distance from sea

The River Tisza passes through the city, otherwise there are no large water bodies nearby (the river is relatively narrow). According to its geographical features (Frisnyák el al. 1978, Mezősi 1983, Bárány-Kevei 1988) this area is especially suitable to study local and microclimatic characteristics.

Concerning large scale climatic partition, according to Köppen (1931) Szeged and its neighbourhood belong to the climatic region Cf (which means a temperate warm climate with a fairly uniform annual distribution of precipitation), while Trewartha (1943) classified it as belonging to the climatic region D1 (continental climate with longer hot season).

Nevertheless to partition the country into smaller climatic regions a special classifying method is needed, which considers the differences of water supply and of energy supply, which was successfully worked out by Péczely (1979). From the possible combinations of an aridity index and the vegetation period’s heat supply, 12 are realised in Hungary. Warm-dry climate is typical of Szeged and its surroundings (Fig. 2), namely the summer is hot, is prone to draughts, the duration of sunshine is abundant, the air humidity is relatively low as well as the clouds; in winter there’s little snowfall resulting in only a thin snow cover. As this not too wet, not too windy-cloudy weather helps the development of local climatic processes, we can say that Szeged offers remarkably good conditions to make experiments from which we can draw general conclusions.

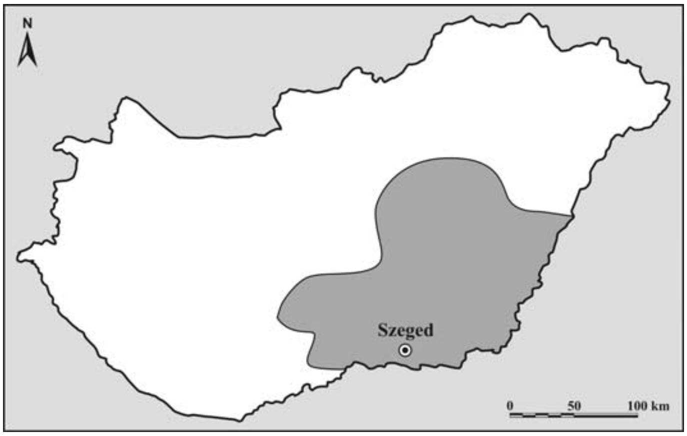

Fig. 2 Location of Szeged and warm–dry climate territory in Hungary (based on Péczely 1979)

2.2. Study area, cross-section and data collection

Szeged is the biggest settlement of the southeast of Hungary; its population was 167,000 person in 2008. The administrative territory of the city is 281 km^2 (most of which is situated on the right side of River Tisza), of which the real inner city and suburban area are only 25-30 km^2 The parts mentioned above mainly lie inside the circle dyke built to prevent floods; therefore our examinations were concentrated here (Fig. 3).

The city was rebuilt in the 19th century (because the so-called Great Flood in 1879 almost completely destroyed the earlier city) and its new structural speciality is the avenue-boulevard system. The advantage of this system is a clear, well-arranged city structure; its disadvantage lies in the traffic that is concentrated towards the city-core, causing heavier air-pollution (Gyöngyösi et al. 2009, Makra et al. 2009).

In the last 50 years (mainly in the period between 1968–1978 and to a lesser degree in 1978–1988) the structure of Szeged has been altered significantly due to the huge newly built blocks of flats in the outlying parts of the city. The city's significant structural-morphological types as well as their dimensions are shown in Fig. 3.

The area of investigation, the inner part of the administration district, was divided into 0.5 km x 0.5 km cells. The original study area consists of 107 cells covering the urban and suburban parts of Szeged. The outlying parts of the city, characterized by village and rural features, are not included in the network except for four cells on the western side of the area. These four cells are necessary to determine the temperature and humidity contrast between urban and rural areas. In the present study we use only 17 cells, which is a cross-section of the urban area including all the typical land-use types of Szeged (Fig. 3). It stretches from the rural area (cell 1) across zones used for industry and warehousing (cells 4-6), detached houses (7-8), the densely-built centre (9-12) and the large housing estates of tall concrete buildings set in wide green spaces (13-15) to the areas occupied by detached houses (16-17). The distance between the central points of the first (1) and the last (17) cells along the cross-section is about 8 km.

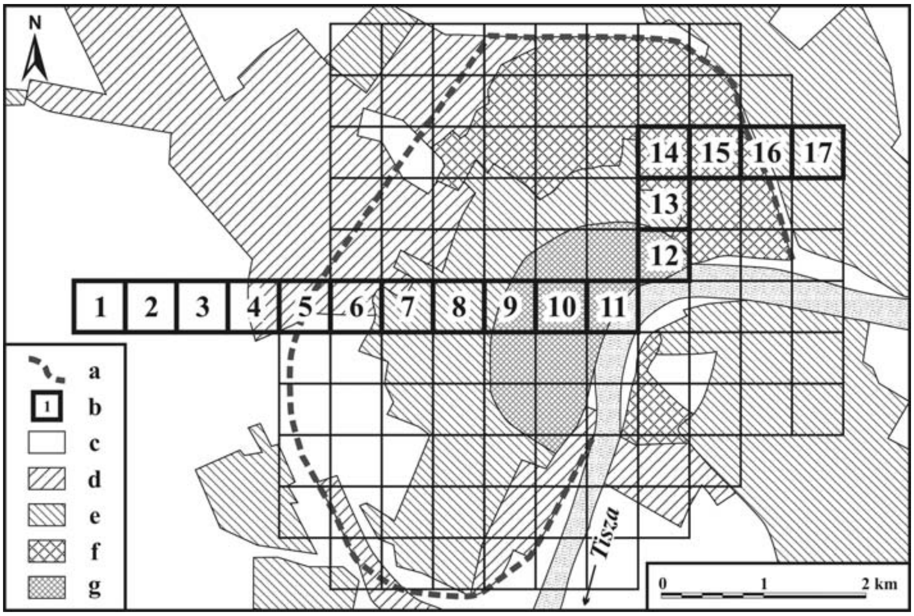

Fig. 3 Location of generalised land-use types, the original study area and the selected representative urban cross-section in Szeged: a) circle dyke, b) numbered cell of the selected urban cross-section c) agricultural and green area, d) industrial area, e) 1-2 storey detached houses, f) 5-11 storey apartment buildings and g) historical city core with 3-5 storey buildings

Table 1 Survey of mobile measurements along the cross-section in Szeged (April 2002 - March 2003)

No.	Date	Time of the sunset (CET)	Number of transects	Reference times
1	16-17. 04. 2002	18.27	10	19.00 – 04.00
2	22-23. 05. 2002	19.13	8	20.00 – 03.00
3	17-18. 06. 2002	19.33	7	21.00 – 03.00
4	10-11. 07. 2002	19.31	7	21.00 – 03.00
5	29-30. 08. 2002	18.24	9	20.00 – 04.00
6	10-11. 09. 2002	18.01	10	19.00 – 04.00
7	17-18. 10. 2002	16.50	10	18.00 – 03.00
8	14-15. 11. 2002	16.08	10	17.00 – 02.00
9	10-11. 12. 2002	15.53	10	17.00 – 02.00
10	15-16. 01. 2003	16.19	10	17.00 – 02.00
11	12-13. 02. 2003	17.00	10	18.00 – 03.00
12	17-18. 03. 2003	17.47	10	19.00 – 04.00

In order to collect temperature and relative humidity data for every cell during the night, mobile measurements were made on fixed return routes on an hourly basis along the cross-section between April 2002 and March 2003, 12 times altogether (Table 1).

In case of near-surface humidity investigations, moving observation is a suitable method to apply in further analysis (e.g. Chandler, 1962; Kopec, 1973; Mayer et al., 2003). To get some information on the temporal dynamics of UHI and ΔRH during the night, the measurements started at sunset and took about 7-10 hours (depending on the season), which means 7-10 transects. Return routes were needed to make time-based corrections, and one transect took about 50 minutes. Relative humidity data readings were obtained using a shielded sensor (LogIT) connected to a data logger (LogIT DCP Microdevelopments and SCC Research) for digital sampling. Data were collected every 10 s, so at a car speed of 20-30 kmh^{-1} the distance between the measuring points was 55-83 m. The sensor was mounted 0.60 m in front of the car at 1.45 m above the ground to avoid engine and exhaust effect. The speed provided adequate ventilation for the sensor to measure the momentary ambient humidity. The values logged at forced stops were omitted from the data set.

Having averaged the approximately 15-20 measurement values by cells, time adjustments to the reference times (namely integer hours after sunset) were applied assuming linear humidity change with time, like in the case of temperature (Oke and Maxwell 1975). Consequently, we can assign one relative humidity value to every cell (central point) by transects. The ΔRH were determined by cells referring to cell 1, which was regarded as a rural cell because of its location outside of the city (Fig. 3).

ΔRH along the cross-section was investigated by the comparison of absolute and normalized values taking land-use, meteorological features and anthropogenic factors into consideration. The normalized value of a given cell in a given hour is the ratio of the ΔRH of that cell and the cell where the absolute ΔRH is the largest at that transect. Since meteorological conditions influence humidity, the comparison of spatial variation of humidity differences is more effective using normalized (dimensionless) values. Namely, the normalized feature is expected to be almost independent of the prevailing weather conditions; in any case it is expected to be dependent mainly on the surface factors (e.g. land-use features, distance from the city centre).

2.3. Built-up surface ratio

The ratio of the built-up surface (to the total cell area) by cells was determined by a vector and raster-based GIS database combined with the remote sensing analysis of SPOT XS images. The geometric resolution of the image was 20 m x 20 m. Normalized Difference Vegetation Index (NDVI) was calculated from the pixel values, using visible (V: 0.58-0.68 μm) and near infrared (IR: 0.72-1.1 μm) bands (Gallo and Owen 1999):

$$NDVI = (IR-V)/(IR+V).$$

The NDVI values range between -1 to +1 indicating the effect of green space in the given spatial unit. Built-up and other (water and vegetated) surfaces were distinguished using these values.

3. RESULTS

3.1. Built-up characteristic

Table 2 contains areal ratios (%) of the built-up area by cells along the cross-section. The largest built-up density (more than 90%) can be found around the centre (cells 9-10, see Fig. 3), but the variation from the urban edge to the core is not uniform. The proportion of the water surface is negligible except for cell 11 (River Tisza, see Fig. 3). Towards the eastern parts of the city a second high built-up density occurs (cell 15) where the large housing estates are located and the magnitude of the artificial surfaces remains rather significant in the eastern suburbs.

Table 2 On each isopleth Figs., due to the shape of the cross-section, the centres of cell-pairs located at a similar distance from cell 10 can be found at different aerial distances in reality. These real distances and the areal ratios of built-up areas (cell 10 = 90.5%) are shown here.

cell	distance (km)	built-up (%)	cell	distance (km)	built-up (%)
9	0.500	91.4	11	0.500	77.3
8	1.000	77.8	12	1.118	83.6
7	1.500	71.7	13	1.414	75.7
6	2.000	85.6	14	1.803	67.9
5	2.500	54.2	15	2.121	81.2
4	3.000	70.4	16	2.500	60.9
3	3.500	18.9	17	2.915	72.2

3.2. Mean relative humidity

Throughout the year we carried out 12 measurements altogether, with monthly frequencies. When calculating means, it was not possible to include results of the September-measurement due to some technical reasons. Thus, means were produced only for 11 occasions. Due to the differences of the durations of nighttime, meaning differences in the length of measurements, the number of observations changed (max. 10 in winter, while 7 in summer). Therefore, studying the mean change during the whole year, it is only possible to compare the first 7 hours of measurements. Figs. 4, 5, 6, 8 and 10 were produced by the 8.00 version of the Surfer (Surface Mapping System) software, applied linear variogram model, without multiplying the data.

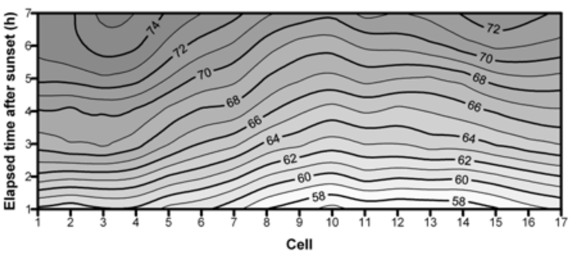

Fig. 4 Isopleths of the mean RH (%)

Showing the time and the distribution of relative air humidity along the cross-section, we should start with the annual mean data (Fig. 4). The isopleths clearly show that the city centre area (cell 10) is much drier (in the first hour after sunset the annual mean RH < 57%). A given value measured in the outskirts of the city (cell 1) can be observed only considerably later in the centre. Relative humidity grows in every section as hours go by (in accordance with the temperature decreasing), but the degree of shift in the inner parts of the city is continuously rising nearly all night. For example while the 64% mean relative air humidity appears 2 hours later in the centre than in the outer parts of the city, this same shift at 70% appears almost in a 3-hour delay. Isopleths at cell 11 show a little excess relative air humidity compared to its environment, which can be explained by the closeness of the water surface of the River Tisza (Fig. 3), as the ratio of water surface along the cross-section is the highest in this grid (11.4%).

Fig. 5 shows the differences in mean relative humidity. It is clearly visible that the inner part of town is drier than the outskirts, since the greatest negative differences occur over the inner city. The boundaries of drier areas, similarly to the “cliff” of the heat island, are quite sharp (here, however, a negative form develops), which appears as a continuous decrease from cell 4 to 9. This is caused by the fact that the ratio of artificial surfaces, namely industrial sites, rapidly increases from cell 4 which is followed by a higher density of built-up areas. In cells 9 and 10, typically to inner city structures, highly built-up areas can be found (Table 2). The driest is the centre (cell 10) where through the whole year, at least in the first 6 hours of measurements, there is a more than 5% mean difference in relative humidity; moreover, the greatest difference (-6.5%) can be found here, as well. While studying the shape of isopleths, the increasing impact of the River Tisza (11.4% water surface in the cell) over the relative humidity is well-recognisable at cell 11. The moderate decrease, extending northeast to the centre (cells 11-17) (Fig. 5), has two main reasons. On one hand, relatively to Szeged centre (cell 10), the distribution of built-up ratio among the cells is not symmetric. The mean built-up ratio (74.1%) of the 7 cells located east and northeast to the centre (cells 11-17) is higher than that of those 7 cells (3-9) located west to the centre (67.1% mean built-up ratio). This is caused by the fact that measurements ended up still inside of the northeastern part of the town (at cell 17), whereas the western edge of the cross-section is located outside of the town (Fig. 3). Another reason of this asymmetry is that, although on Fig. 5 the cells are located at a similar distance from each other, in reality the cells located northeast to the central cell (except for cell 12) are situated a bit closer to the centre (Table 2). The accumulation of the two phenomena, in their effect taking the same direction, well explains the asymmetric structure of relative humidity extending towards cell 17.

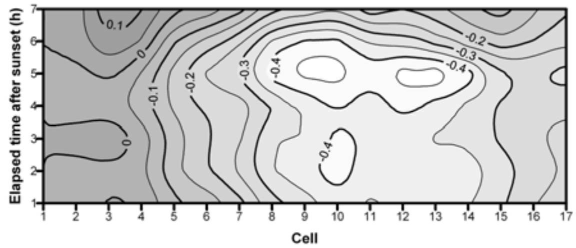

Fig. 6 Isopleths of the mean normalized ΔRH (dimensionless)

Mean ΔRH values are the highest in the second hour after sunset, but a secondary maximum also arises between the fourth and the fifth hours (Fig. 5). After the fifth hour a sudden decrease of the mean ΔRH begins both in the inner city and the suburbs. The main reason of this phenomenon is presumably that dew formation starts in these hours and thus, the air humidity of the outskirts starts to decrease.

Fig. 6 shows the mean of normalized values of differences in relative humidity. The great advantage of applying this method is that every case is taken into consideration with the same importance, and thus some individual cases with great humidity difference do not alter the general picture significantly. Excluding the effect of extremely high values, we get a different picture; compared to Fig. 5 (showing mean ΔRH values) the driest period most frequently occurs in the fifth hour after sunset.

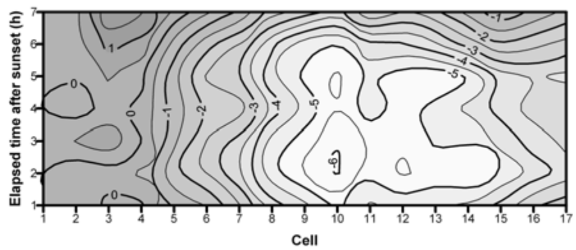

Fig. 5 Isopleths of the mean ΔRH (%)

On the isopleth map obtained by normalization, the areas with more frequent appearance of low humidity values throughout the year are better presented. Such areas are located along the cross-section between cells 8 and 14, practically in the most built-up parts of the town. Its temporal appearance can be well correlated with the mean UHI intensity, resulting from the parallel temperature measurements, whose maximum value also appeared in the 5th hour especially in cells 8 and 9 (Sümeghy 2004).

3.3. The night of 17-18 June 2002

The previous day was a warm summer day with a maximum temperature over 28ºC. The sky was clear and a light wind (1.8-3.6 ms^{-1}) blew. After sunset (19.33 CET) the wind weakened and its speed was below 2 ms^{-1} most of the time except for the early morning hours (about 2.5 ms^{-1} one hour before sunrise). The wind direction was NW in the first hours after sunset (1-2 hours), then it shifted to N (3-4 hours) and in the rest of the night the wind blew from E-NE (5-7 hours). During the night an anticy-clon (see Fig. 7 signed with M) centering over Hungary prevailed in the region with an air pressure over 1020 hPa. At night the sky remained clear and the temperature dropped under 17ºC).

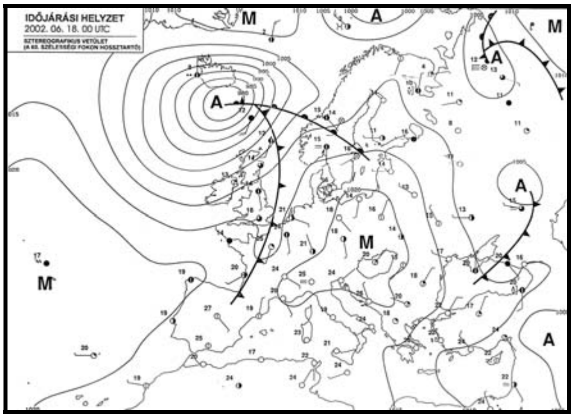

Fig. 7 Weather conditions in Europe during our measurements (Source: B Sallai 2002)

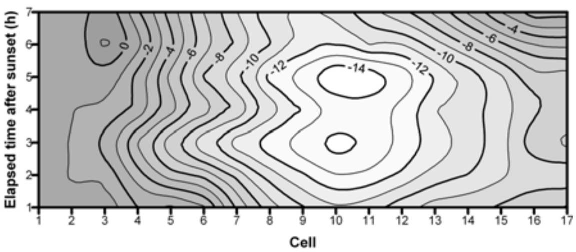

Fig. 8 Isopleths of ΔRH (%) during the night of 17-18 June 2002

Taking the short summer nights into consideration, the number of measurement turns was 7. Temperature measurements, carried out parallel, showed the formation of a strong UHI with a maximum of more than 4.5ºC. Peculiarities of the ΔRH field structure (Fig. 8) can be explained clearly by the above-mentioned gradual changes of wind direction and speed. The sudden change, occurred in the 5th to 7th hours after sunset to the northeast, can also be explained by the wind strengthening and turning towards northeast; thus taking the cooler and more humid rural air mass to the block-house district. This caused a significant decrease in ΔRH (5% in cells 15-17 within 1.5 hours).

3.4. The night of 12-13 February 2003

The previous daytime hours were cold winter hours with a maximum temperature of -3ºC and with an almost clear sky. After sunset (5.00 PM) the sky remained perfectly clear.

During the night the temperature sank under -18ºC, and the wind was very light (max. 1 ms^{-1}).

The wind direction was NW in the first hours after sunset (1-3 hours), then it shifted to W (4-10 hours). An anticyclon (see Fig. 9 signed with M) centering N from Hungary prevailed in the region with an air pressure between 1030 and 1035 hPa. The surrounding rural areas were covered with compact icy snow, while some parts of the city (mainly the streets and parking lots) were cleared and the remaining snow was soiled and partly piled.

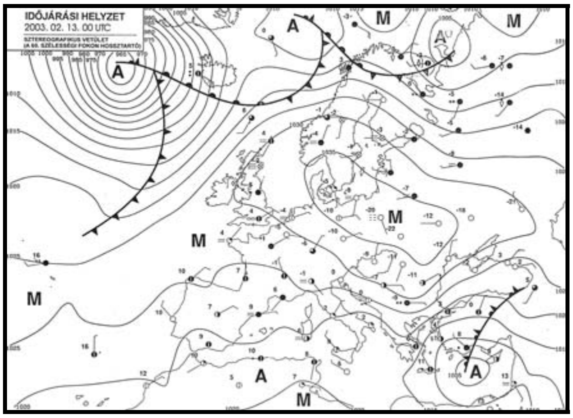

Fig. 9 Weather conditions in Europe during our measurements (Source: B Sallai 2003)

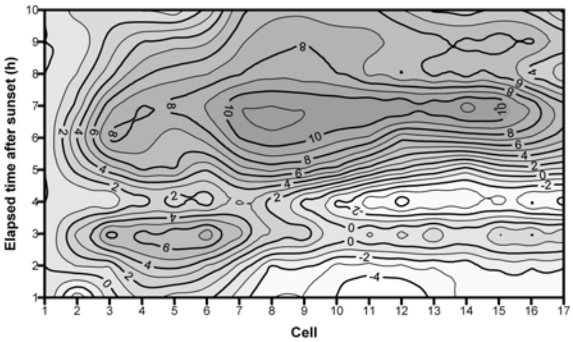

Fig. 10 Isopleths of ΔRH (%) during the night of 12-13 February 2003

Due to the long winter nights, the number of measurement turns was 10. The temperature measurement carried-out parallel detected a very strong UHI, of which the maximum almost reached 8ºC. In the same time a (positive) difference of 11% in relative humidity occurred over the inner city (Fig. 10). This could be caused on one hand by the fact that the significantly higher urban temperature (which however stayed well under 0ºC) encouraged the evaporation of the surface covered by deep snow, while the -20ºC in the outskirts did not. On the other hand, in the severe coldness extra humidity was added from combustion sources (traffic, heating) in the city as a surplus. Fig. 10 shows that the structure extending towards east-northeast, beyond the above-mentioned characteristics of the town, is the result of the winds turning towards W.

4. CONCLUSIONS

The following conclusions are reached from the analysis presented:

- In agreement with the results of the previous research, relative air humidity reached lower values inside the town than in the outskirts (in close connection with the UHI phenomenon). Therefore the driest inner parts of the city are sharply separated from the outer, more humid areas.

- As time advances, relative humidity increases in the outer and inner areas (in accord with the decrease of temperature), but in the inner parts of city the same relative humidity values appear later.
- ΔRH values usually increase until some hours after sunset and then after some time a decrease starts.
- Spatial structure of the ΔRH field is strongly influenced by urban parameters.
- In some situations this structure is influenced by urban parameters, however, it can also be affected by meteorological factors and anthropogenic effect. In some special cases the relative humidity of the town can be much higher than that of the outskirts.
- The usefulness of the normalized values in the investigation of the cross-section relative humidity distribution in the urban area is proved. It came to light that the highest ΔRH values most frequently occur in the fifth hour after sunset.

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REFERENCES

Ackerman B (1987) Climatology of Chicago area urban-rural differences in humidity. J Climatol Appl Meteorol 26:427-430

B Sallai M (ed) (2002) Időjárási napijelentés. [Daily Weather Report. (in Hungarian)] OMSZ, Budapest 18. June 2002

B Sallai M (ed) (2003) Időjárási napijelentés. [Daily Weather Report. (in Hungarian)] OMSZ, Budapest 13. Feb 2003

Bárány-Kevei I (1988) Talajföldrajzi vizsgálatok Szeged környékén. [Studies on soil geography on Szeged area. (in Hungarian)] Alföldi tanulmányok 12:25-34

Chandler TJ (1962) Temperature and humidity traverses across London. Weather 17:235-241

Chandler TJ (1967) Absolute and relative humidities in towns. Bull Amer Meteorol Soc 48:394-399

Frisnyák S, Futó J, Göőz L, Kormány Gy, Moholi K, Pápistáné Erdős M, Süli-Zakar I (1978) Magyarország földrajza. [Geography of Hungary. (in Hungarian)] Tankönyvkiadó, Budapest

Gallo KP, Owen TW (1999) Satellite-based adjusments for the urban heat island temperature bias. J Appl Meteorol 38:806-813

Gyöngyösi AZ, Weidinger T, Makra L, Baranka Gy (2009) Application of a dispersion model for Szeged, a medium sized Hungarian city: a case study. Fresenius Environmental Bull (accepted)

Hage KD (1975) Urban-rural humidity differences. J Appl Meteorol 14:1277-1283

Kalkstein LS (1991) A new approach to evaluate the impact of climate on human mortality. Environ Health Perspect 96:145-150

Kopec RJ (1973) Daily spatial and secular variations of atmospheric humidity in a small city. Int J Climatol 17:187-196

Köppen W (1931) Grundriss Der Klimakunde. Walter De Gruyter–Co, Berlin

Kuttler W (1998) Stadtklima. In: Heyer E (ed) Witterung und Klima. Teubner, Stuttgart-Leipzig. 328-364.

Kuttler W, Weber S, Schonnefeld J, Hesselschwerdt A (2007) Urban/rural atmospheric water vapour pressure differences and urban moisture excess in Krefeld, Germany. Int J Climatol 27/14:2005-2015

Landsberg HE (1981) The Urban Climate. Academic Press, New York

Landsberg HE, Maisel TN (1972) Micrometeorological observations in an area of urban growth. Bound Lay Meteorol 1:61-63

Liu W, You H, Dou J (2008) Urban-rural humidity and temperature differences in the Beijing area. Theor Appl Climatol DOI 10.1007/s00704-008-0024-6

Makra L, Tombácz Sz, Bálint B, Sümeghy Z, Sánta T, Hirsch T (2008) Influences of meteorological parameters and biological chemical air pollutants on the incidence of asthma and rhinitis. Clim Res 37:99-119

Makra L, Mayer H, Mika J, Sánta T, Holst J (2009) Variations of traffic related air pollution on different time scales in Szeged, Hungary and Freiburg, Germany. Physics and Chemistry of the Earth (accepted)

Mayer H, Matzarakis A, Iziomon MG (2003) Spatio-temporal variability of moisture conditions within the Urban Canopy Layer. Theor Appl Climatol 76:165-179

Mezősi G (1983) Szeged geomorfológiai vázlata. [Geomorphology of Szeged. (in Hungarian)] Alföldi tanulmányok 7:59-74

Oke TR, Maxwell GB (1975) Urban heat island dinamics in Montreal and Vancouver. Atmos Environ 9:191-200

Péczely Gy (1979) Éghajlattan. [Climatology. (in Hungarian)] Nemzeti tankönyvkiadó, Budapest

Potchter O, Cohen P, Yaakov Y, Bitan A (2003) The climatic behavior of various types of urban parks in coastal Mediterranean city during the summer – the case of Tel Aviv, Israel. In: Klysik K, Oke TR, Fortuniak K, Grimmond CSB, Wibig J (eds) Proceed. Fifth Int. Conf. on Urban Climate, Vol. 2, University of Lodz, Lodz, Poland. 281-284

Saez M, Sunyer J, Tobias A, Ballester F, Antó JM (2000) Ischaemic heart disease and weather temperature in Barcelona, Spain. Eur J Public Health 10:58-63

Sümeghy Z (2004) A szegedi városi hősziget területi és időbeli eloszlásának térképezése térképezése és elemzése. [Evaluation and mapping of spatial and temporal distribution of the urban heat island in Szeged. (in Hungarian)] PhD thesis (manuscript), University of Szeged, Szeged, Hungary

Trewartha GT (1943) An Introduction to Weather and Climate. McGraw-Hill, New York

Um H-H, Ha K-J, Lee S-S (2007) Evaluation of the urban effect of long-term relative humidity and the separation of temperature and water vapor effects. Int J Climatol.27/11:1531-1542

Unger J (1993) The urban influence on the diurnal and annual patterns of absolute humidity in Szeged, Hungary. Acta Climatologica Univ Szegediensis 27:33-39

Unger J (1997) Városklimatológia – Szeged városklímája. [Urban climatology – Urban climate of Szeged. (in Hungarian)] Acta Climatologica Univ Szegediensis 31B, Urban Climate Special Issue

Unger J (1999) Urban-rural air humidity differences in Szeged, Hungary. Int J Climatol 19:1509-1515