ACTA UNIVERSITATIS LODZIENSIS
FOLIA GEOGRAPHICA PHYSICA 3, 1998

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THE MODEL OF WINTER NIGHT-TIME TEMPERATURE DISTRIBUTION IN ŁÓDŹ

MODEL NOCNEGO ROZKŁADU TEMPERATURY W ŁODZI W WARUNKACH ZIMOWYCH

In the paper a simply model of the UHI shape in Łódź during cloudless, winter night is presented. Decreases of the temperature in the city (dT_u) were calculated with the aid of rural temperature decreases (dT_r) basing on the relation: $dT_u = A \cdot dT_r$. This formula was applied to the city sectors (cells 500 × 500 m) with different urbanization ratio with the time step equal 10 min. Factor A was choosen empirically depending on wind speed and urbanization ratio. Additionally, in each iteration temperature field was smoothed proportionally to the wind speed. In spite of simplicity the model well describe temporal evolution and spatial distribution of the UHI.

INTRODUCTION

The urban heat island is the best documented atmospheric modification of the local climate by urbanization and industrialization. The fact that, in night, air temperatures are often higher in a city than in its surroundings countryside has been demonstrated beyoud doubt for many villages, towns and cities (Chandler 1970; Landsberg H. E. 1981; Oke 1974, 1979). Beside research focused on recognition and description of the phenomenon other studies construct various models to predict its behaviour. According to Bornstein (1986) urban climate models can be grouped into two categories: (1) urban canopy-layer models which examine microscale climate variation occurring below roof-level, (2) urban boudary-layer models which simulate mesoscale climate variation occurring above roof-level. The complexity of the urban environment causes that numerical simulations based on solving of the basic equation of atmospheric dynamic in such area are extremely difficult and time consuming. On the other hand, simple statistical models give a good approximation for some features of the urban climate, like the urban heat island. The aim of this work is to construct a simple statistical model of the spatial distribution of air temperature in near-surface layer in Łódź during the winter night basing on a nocturnal course of the temperature at the rural station.

THE AREA OF INVESTIGATION

Łódź is situated in central Poland in the area raised above sea level from 180 m in its western part to 235 m in its eastern part. The fact that the area of the city is relatively flat and there is no other geographical peculiarities (lakes, rivers, valleys, mountains, sea, etc.) is very convenient for study on processes leading to UHI formation and for models verification (Kłysik, Fortuniak 1997). The clear urban arrangement also answer this purpose. Regarding the population (ca 850 thousand) Łódź is the second biggest town in Poland with total built over area 80 km^2. There are no sky-scrapers in the centre but 15–20 m high buildings raised about 100 years ago. In new districts dominate very monotonous areas of blocks of flats ($\sim$ 15 m high) and detached houses. Characteristic for the industrial districts is that the roofs of not high production rooms occupy large areas. Greenery and vacant areas occupy together about 17% of the town. Such aragement gives very clear roof-level and allow precisely separate urban canopy-layer and urban boudary-layer.

DATA AND MODEL DESCRIPTION

Continuous meteorological observations in Łódź during the winter 1996/1997 allowed to select 17 nights (from the period 26 December 1996 to 4 February 1997) with the well developed urban heat island (UHI). The temperature values measured every 10 minutes at three stations (situated as Fig. 1 shows) were used to determine strength of the UHI. The data suggest a simple link between the rural and the urban temperature: decrements of the urban temperature dT_u in some time unit are proportional to the rural temperature decrements dT_r,

$$dT_u = A \cdot dT_r \qquad (1)$$

where A is some proportionality factor.

Construction of the model basing on this idea. The area of investigations (Fig. 1) was divided on 500 × 500 m cells and the factor of urbanization was determined for each cell. As a measure of urbanization a percentage of the entire artificial surface (pavements and streets included) was taken. For all cells the night temperature courses were calculated based on formula (1) using 10 min time steps. The proportionality factor, A, depends on the ratio of urbanization and wind speed. Moreover, the procedure smoothing the temperature field (the smoothing factor depending on the wind speed) was used after each iteration.

Such approach disregard the detailed urban conopy-layer processes consolidating all city influences into a single parameter – incraesed heat capacity. The increased heat capacity has here a complex meaning including not only greater thermal admittance of construction materials but also dynamical factors like redistribution of the energy in the relatively thick atmospheric mixing layer over the city or altered radiative processes coused

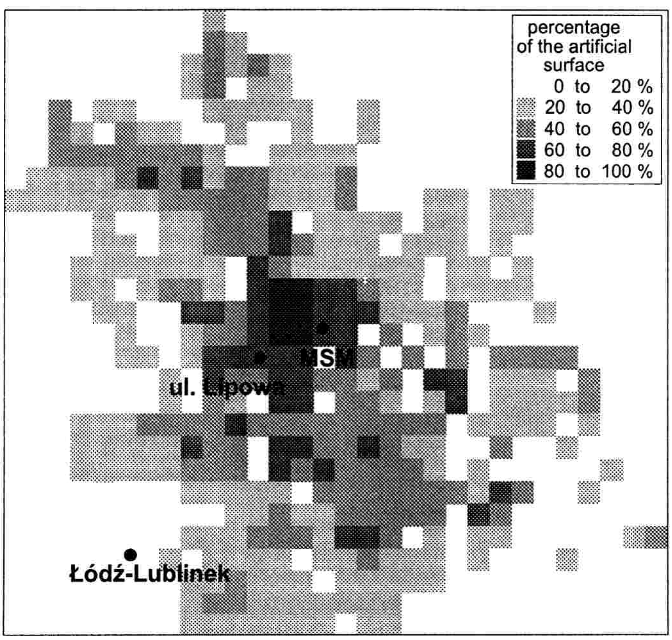

Fig. 1. The percentage of the entire artificial surface (pavements and streets included) for the area of investigation (size of cells 500 × 500 m)

Rys. 1. Procentowy udział wszystkich powierzchni sztucznych (wraz z powierzchnią ulic i chodników) dla analizowanego obszaru (rozmiary komórek 500 × 500 m) by atmospheric pollution or urban geometry. City may be trated as some kind of entirety (as in Fortuniak, Kłysik 1997) or divided on sectors with different urban structure – different heat capacity. Because of including dynamical proceses urban heat capacity depends not only on the features of the city but also on meteorological parameters like wind speed, cloudiness or stratification type. The smoothing procedure applied after each iteration represents energy exchange between cell.

RESULTS

Basing on the data from 17 selected nights the average nocturnal courses of the air temperature for analysed stations were calculated and the data from rural (Lublinek) station were used to calculate spatial distribution of the temperature in Łódź. Results were verified with the aid of data on urban stations (Lipowa and MSM). As it is shown at Fig. 2 computed urban temperature courses fits well to the measurements. Agreement is especially good in Lipowa case where instrumental shelter is situated at narrow street cross in typical dence build over area.

For MSM station similar as for Lipowa percentage of the artifical surface represents quite distinct conditions. The station is situated at street cross neighbouring to large parking place. Such parameter like street hight to wide ratio, sky view factor or roughness parameter are for both places complety different. Assigned factor of urbanization dose not take into consideration that kind of features hence model has to give worse estimation in at least one case. It dose not disqualify the basic idea of the model but points on other choice of urbanization factor for model improvement.

Figure 3 shows a clear dependence of the UHI shape on the wind speed. For the windless conditions one can observe a well developed, multi-cellular UHI, with distinguishable cliff, plateau and peak. Moreover, in this case large parks or other vacant areas creates cold „lakes" in the UHI structure. For the moderate wind the UHI getting week and takes more generalised form. Isotherms become smoother and temperature raise gradually from outskirts to the city centre. When wind exceeds 4 m/s thermal conrasts between urban and rural areas become insignificant. Temporal changes of the UHI also seem to be in a good agreement with the observation in Łódź (Fig. 4). In the evening UHI starts to form, grows during the night, and reaches its maximum before sunrise. At the beginning of the forming process small spots of warm air arise and next join together in smooth UHI.

Precise verification of the model is impossible basing of the data from three stations only. However, as it is shown at Fig. 4 for two selected nights, modelled temperature profiles fit well to the observations at the measurement points. The model works particularly well after midnight of 1997 New Year's Eve and for the first half of night of 2/3 February. It corresponds to the very week wind speed. In the second case (2/3 February) the urban/rural temperature differences evolute in more typical manner (O k e 1982) reaching maximum not just before the sunrise (as at Fig. 2) but much earlier, about 1.00 h. It is a moment when temperature at rural station stops to fall down and remaines unchanged until sunrise. At the same time urban temperature still decrease. This suggest that the urban temperature descent is caused by energy exchanged between warm urban and cold rural air. Shape of the modelled temperatures in the city center is similar rather to the rural than to the urban temperature course. It is a consequence of formula (1) and may be avoided by using a more sophisticated smoothing formula describing mixing processes between cells.

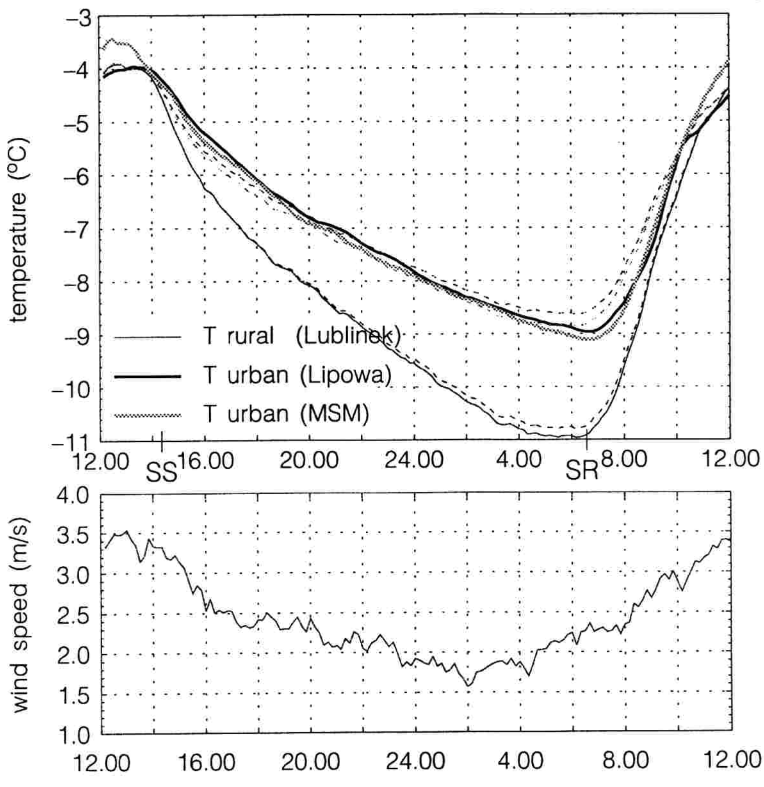

Fig. 2. Nocturnal air temperature courses (averaged values from 17 selected nights from the period 26 December 1996 to 4 February 1997) at three stations in Łódź – measured (solid line) and modelled (dashed line) values

Rys. 2. Nocny bieg temperatury powietrza na trzech posterunkach pomiarowych w Łodzi (wartości uśrednione dla 17 wybranych nocy z okresu od 26 grudnia 1996 do 4 lutego 1997) – wartości mierzone (linie ciągłe) i modelowane (linie przerywane)

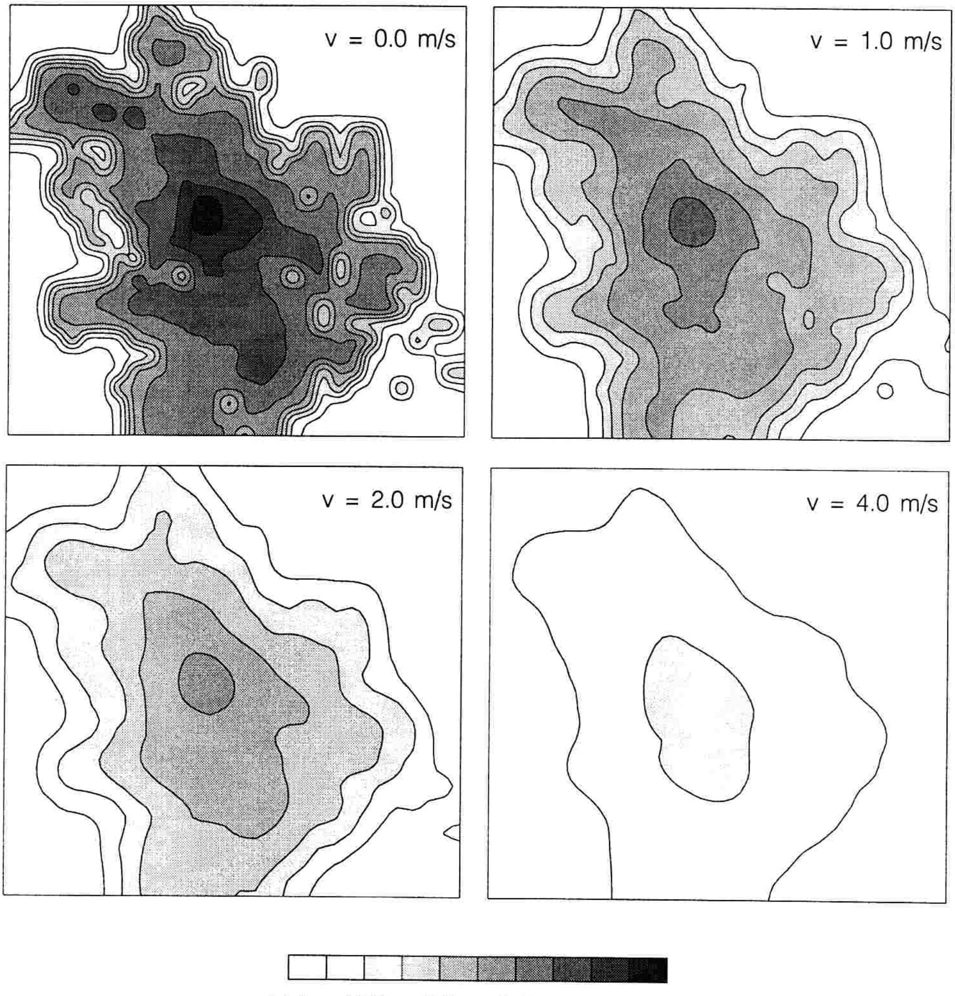

Fig. 3. Dependence of the modelled UHI shape on the wind speed at 7.00 local time (maximum of the UHI intensity) for the rural temperature profile taken as at Fig. 2

Rys. 3. Zależność modelowanego rozkładu temperatury w Łodzi od prędkości wiatru o godz. 7.00 czasu lokalnego (maksymalna intensywność UHI). Profil temperatury za miastem jak na rys. 2

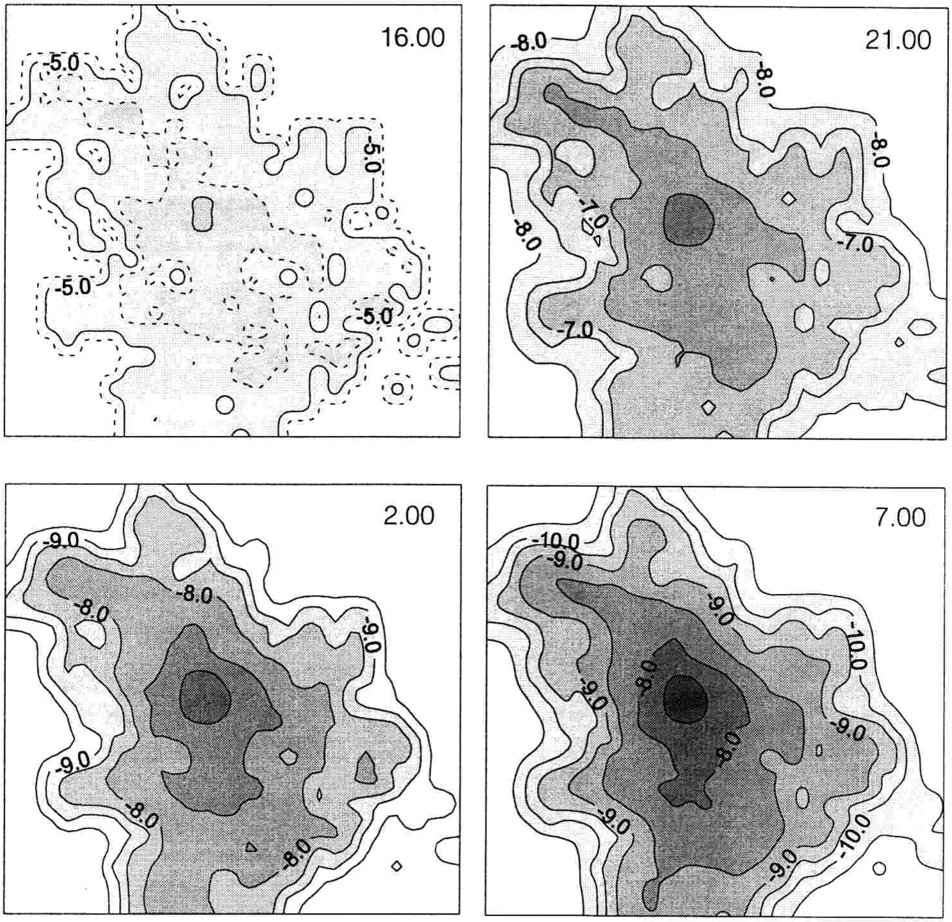

Fig. 4. Temporal evolution (16.00, 21.00, 2.00, and 7.00 h of local time) of the modelled UHI for the wind speed equal 1 m/s and the rural temperature profile taken as at Fig. 2 (solid isotherms every 0.5°C)

Rys. 4. Rozwój UHI (godz. 16.00, 21.00, 2.00 i 7.00 czasu lokalnego) przy prędkości wiatru 1 m/s. Profil temperatury za miastem jak na rys. 2 (izotermy poprowadzono co 0,5°C)

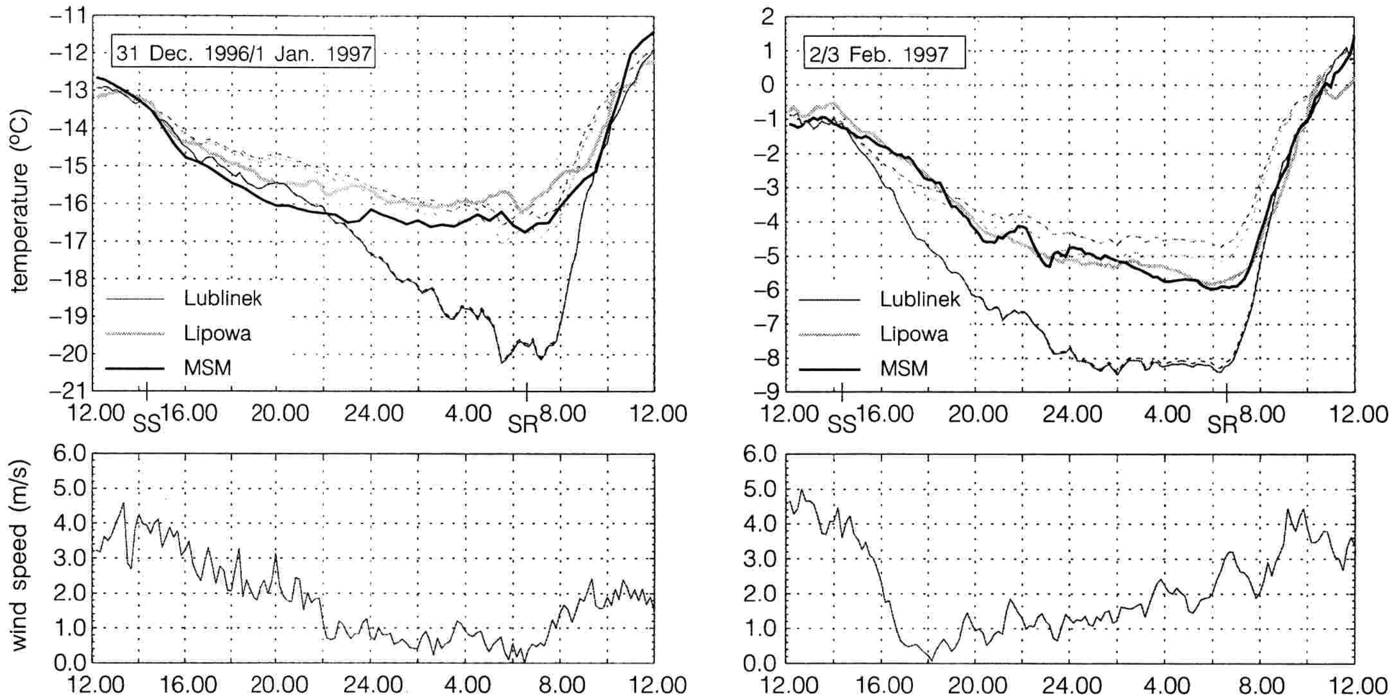

Fig. 5. Examples of the nocturnal courses of the temperature at three stations in Łódź (measured values – solid line, modelled values – dashed line) – a good agreement between measured and modelled values is noticeable

Rys. 5. Przykładowe przebiegi temperatury powietrza w nocy na trzech posterunkach pomiarowych w Łodzi (mierzone wartości – linia ciągła, modelowane – linia przerywana) – widoczne duże podobieństwo mierzonych i modelowanych profili

CONCLUSIONS

The spatial distribution of the UHI in Łódź as well as its temporary evolution could be estimated with the aid of a very simple statistical model. In spite of the simplicity of the model results show a good agreement with the measurements. Construction of the model suggests that the increased heat capacity of the city is a crucial factor for the UHI forming. The UHI shape and strength is determined by such meteorological parameters as daily temperature amplitude (rural temperature course), wind speed and cloudiness. More precise estimation of the dependence of the parameter A on wind speed and cloudiness should be done to improve a model. Other improvements could be done by more sophisticated procedure for smoothing temperature field and by choosing a different factor of urbanization.

This work was supported by the State Committee for Scientific Research under grant 6P04E 036 08.

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STRESZCZENIE

Opracowanie zawiera prosty model przestrzennego zróżnicowania miejskiej wyspy ciepła w Łodzi podczas bezchmurnych, zimowych nocy. Zmiany temperatury powietrza na terenie miasta (dT_u) obliczone zostały na podstawie spadków temperatury na obszarach zamiejskich (dT_r) z wykorzystaniem zależności $dT_u = A \cdot dT_r$. Formułę tę stosowano dla poszczególnych sektorów miasta (komórki 500 × 500 m) o różnym stopniu urbanizacji, z krokiem czasowym równym 100 min. Współczynnik A dobrany został zależnie od prędkości wiatru i stopnia urbanizacji. Dodatkowo po każdym kroku iteracji stosowano procedurę wygładzającą pole temperatury zależnie od prędkości wiatru. Mimo prostoty, model w zadowalający sposób opisuje zarówno przestrzenny rozkład temperatury, jak i czasowy rozwój miejskiej wyspy ciepła (rys. 2–5).