Urban Heat Island over the Coastal City

I. Marinin and V.Shnaydman

Odessa State Ecological University (Ukraine), vives@matrix.odessa.ua
Rutgers-State University of New Jersey (USA), volf@envsci.rutgers.edu

The goal of this contribution is the quantitative description of the influence of the urban heat island and the large roughness on the atmospheric boundary layer structure over the sea-shore city. This aim is realized by combining the data of meteorological observations with atmospheric boundary layermodeling for Odessa (Ukraine) settled on Black Sea shoreline.

The urban dataset was obtained from a network of 8 remote sensors of the air temperature at 2 m height above the surface. It was completed by observations at 3 urban and suburban meteorological stations and 6 rural stations in the area of 50 x 50 km including 3 observational sites at the coast of the Black Sea.

We used the atmospheric boundary layer (ABL) model which included two- equation turbulence closure scheme [Shnaydman et all]. Appliance of the third level closure scheme with the turbulent kinetic energy and dissipation equations led undoubtedly to better and more detail construction of ABL structure especially when dealing with areas with a large horizontal variability of temperature and roughness.

Urban heat island (UHI) was detected as the area of higher (positive UHI) or lower (negative UHI) air temperatures over urbanized territory in comparison with suburban and rural ones. Naturally UHI is characterized with large roughness. In general a positive UHI was observed mostly in the evening (19 UTC). Mean temperature in the city was of 1,5–2 °C higher than in rural during the period of October-March and the largest intensity of the evening positive UHI got 4,6 °C in January. A positive UHI showed less intensity in the morning. The negative UHI was observed in April–September at 07 UTC when the urban area was 1,5–2 °C cooler than the rural one. The monthly mean intensity of the negative UHI got maximum 3,7 °C of the absolute difference values in July. The temperatures in the urban area were 1–1,5 °C higher (or lower) than the horizontal mean temperature of the calculation domain. Larger differences were observed for the small zones of the urban development.

The distribution of the wind velocity, temperature and turbulence parameters was calculated for 50x50 km domain, centered on the city. The contribution of urban heating and large roughness influence mechanisms on the ABL space structure over the coastal city was estimated from
the results of two numerical experiments.

The quantitative estimation of large roughness influence on the distribution of the wind and turbulence parameters was obtained in the first experiment. In this experiment the temperature on the 2 m was set by a constant horizontally averaged value in entire calculation domain. It allowed to exclude the urbanheat input and to evaluate theroughness contribution only.

The effective roughness lengths for the urban development were determined with the account of the building density and height. The distribution of the roughness lengths showed a large horizontal variability with a "plateau" of 0.5–0.7 m and "peaks" above 1.0 m abruptly falling down to the sea. Maximal urban roughness length was got as much as 1.7 m. In the rural area it was given with the value of 0.20 m.

The large values of the roughness created the increased values of friction velocity which were 0.25-0.40 m/sec. The amount of friction velocity increase in 1.2-1.5 times and roughness length rise in 2.5-3.5 times led to decrease the surface wind in 1.3-1.7 times. It lowered the wind blow along the streets and promoted the air pollution. The large values of the roughness essentially increased the parameters of turbulence. TKE were 0.4-0.6 m^2/sec^2 and 0.5-1.2 m^2/sec^2 accordingly in the rural and urban territories. The coefficients of turbulence were 1.5-2.5 times greater in urban place than in rural one and were equal 15-22 m^2 /sec. These results were obtained for the conditions of neutral stratification.

In the second experiment the modeling was initialized with the observed near-surface temperature field. The second experiment was resulted with the space distribution of meteorological fields and turbulence parameters due to the action of heating and roughness effects. The land–sea contrast of –5 °C and +9 °C were normally observed at 7 UTC and at 19 UTC. These contrasts produced a land breeze of 2–2.5 m s^{-1} and a sea-breeze of 5 m s^{-1}, respectively when the geostrophical wind was small. A positive UHI is typically non-stable with the maximal surface heat flux laid in limits 20–25 W/ m^2. The coefficients of turbulence and TKE were equal 25-40 m^2 / sec and 0.8-2.5 m^2/sec^2 . The negative surface heat flux with 15-20 W/ m^2 absolute value was calculated for negative UHI . The coefficients of turbulence and TKE were equal 8-12 m^2 /sec and 0.4-1.0 m^2/sec^2 . The ABL above the water area was stable.

Let's underline that the second experiment results reproduced the influence of horizontal gradients of temperature formed with the natural horizontal temperature differences and created with UHI contrasts. So the subtraction of the first experiment results from the second experiment ones allowed to obtain the baroclinic wind vectors. The introduction of the UHI with the intensity 7 °C produced the flow baroclinic component in the limits 1.0-1.5 m/s on 50 m .The negative UHI with the same intensity produced the baroclinic flow component in the limits 0.3-0.5 m/s on the same height. The layer of the UHI baroclinic flows is capped by 100 m.

The changes of turbulence parameters produced by the UHI contribution were different for positive and negative UHI. The positive UHI differences of TKE and turbulence coefficients were positive and the equal 0.3-1.3 m^2/sec^2 and 10-18 m^2 /sec. The negative UHI differences of TKE and turbulence coefficients were negative and their absolute values laid in the limits of 7-10 m^2 / sec and 0.1-0.2 m^2/sec^2 .

In conclusion we would like to underline that quantitative description of the influence of the urban heat island on the seashore was obtained by using stationary 3-dimensional ABL model with two-equation turbulence closure scheme. The results given reassure that the developed approach can be successfully applied for the reconstruction of the temporal dynamics of ABL over the urbanized territory what is needed for the solution of the air pollution problem for the coastal cities.

Reference

Shnaydman, V., L. Berkovich, and S. Stepanenko 2006: Atmospheric Boundary Layer Modeling, *Ukrainian Hydrometeorological Journal*, No. 1, pp 2-27.