Modeling Study of Atmospheric Boundary Layer Characteristics in Industrial City by the Example of Chelyabinsk

Lenskaya Olga Yu.*, Sanjar M. Abdullaev

South Ural State University, Chelyabinsk,

*ecolcsu@gmail.com

Introduction

- Chelyabinsk, one of the largest industrial cities of the South Ural (Russian Federation) with a population of more than 1 million, has experienced a significant urban expansion with increasing built-up areas, traffic and industrial activities. This results in modifications in the underlying surface properties and atmospheric circulations
- Because of limited observations, the urban heat island (UHI) and boundary layer structure in Chelyabinsk have not been systematically investigated. Numerical simulations allow to investigate these special distinct local weather phenomena
- In the recent release of the community mesoscale Weather Research and Forecasting (WRF) Model, version 3.4, the single-layer urban canopy model (UCM) was coupled to the ‘‘Noah’’ land surface model
- In order to investigate local weather phenomena WRF model was installed in September 2012 in Supercomputer Simulation Laboratory of South Ural State University (Chelyabinsk) on “Tornado SUSU" Supercomputer http://supercomputer.susu.ac.ru/en/computers/tornado/

In order to study urban boundary layer characteristics over Chelyabinsk metropolitan area we combine some instrumental observations and the coupled WRF/Noah/UCM model to define, in the first place, the horizontal and vertical configuration of Urban Heat Island during **winter anticyclonic weather**

1. Some Model and domain characteristics:

- Advanced Research WRF (ARW) dynamic solver
- grid spacing of domain is 2 km (45 × 40 grid points)
- WRF model was implemented with land-use data 0.5 km (30 s) spatial resolution
- vertical grid contains 35 full σ-levels from the surface to 50 hPa, of which the lowest 7 levels are below 1 km so as to have finer resolution in the PBL

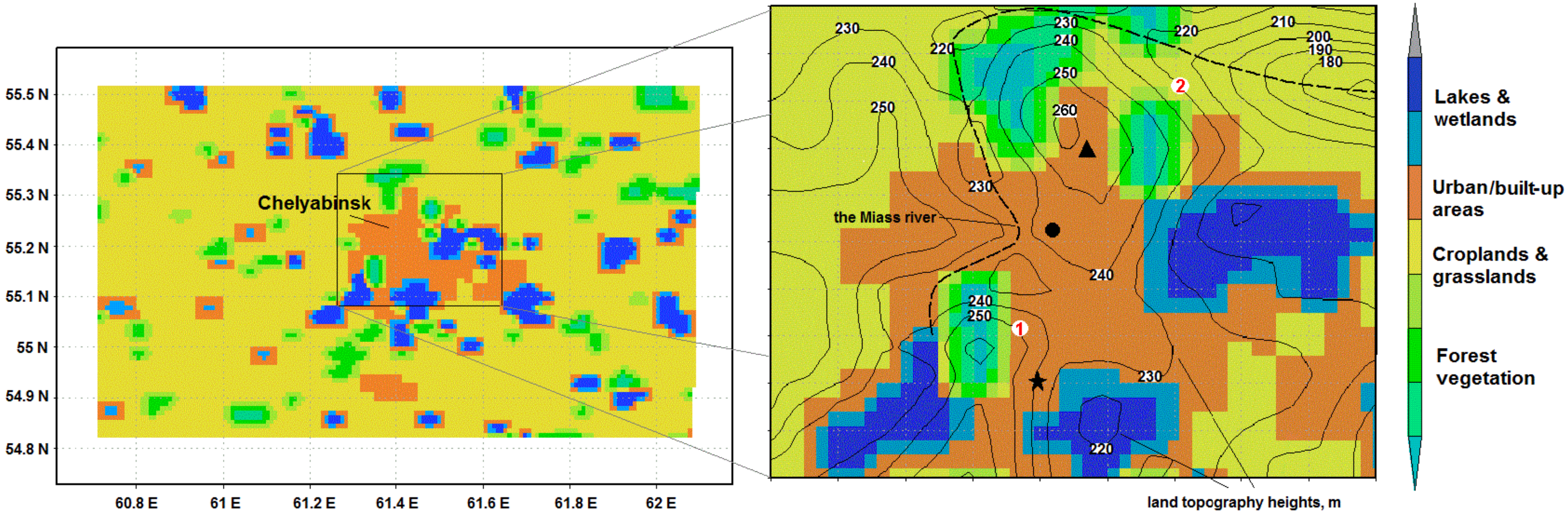


Figure 1. Area of application. 1- meteorological profiler, 2 – weather station

Some Model and domain characteristics (continuation):

- A 48-h simulation (06:00 LST 08 Dec 2011 – 06:00 LST 10 Dec 2011) is conducted with the initial and boundary conditions from the National Centers for Environmental Prediction (NCEP, USA) operational Global Final (FNL) Analyses on a $0.5^0 \times 0.5^0$ lat/lon grid
- **Microphysics:** WRF Single-Moment 3-class scheme
- **Long/Shortwave Radiation** scheme : RRTM / Dudhia
- **Planetary Boundary layer:** Yonsei University scheme
- **Surface-layer physics option:** Monin–Obukhov scheme
- **Land Surface:** Noah Land Surface Model
- To take into account frozen lake areas the static data set **landuse_30s_with_lakes** was used
- **Urban Surface**: Urban canopy model: 3-category UCM option with surface effects for roofs, walls and streets.

2. Model Evaluation against Observation

2.1 Weather station

WRF predictions are in good accordance with measurements. Weather station is located in the site just north of Chelyabinsk (see Fig.1). Absolute difference of temperature and wind speed decreases as the model run.

The 48 h average values of temperature and wind speed are close to each other:

t_m = -15.3 ± 1.4^{0}C ; t_o = -14.1 ± 2.7^{0}C ; ws_m= 1.7 ± 1 m/s ; ws_0= 2.0 ± 1.6 m/s

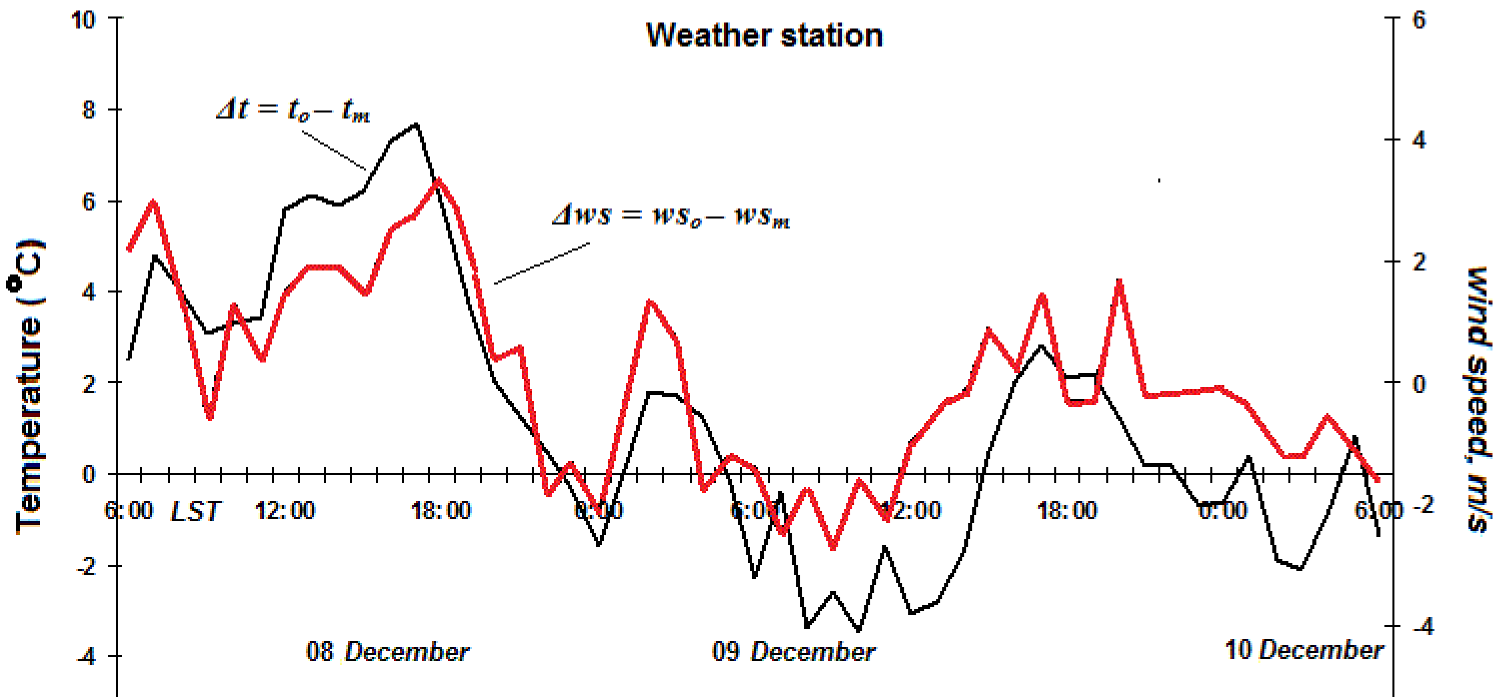


Figure 2. Air temperature and wind speed time series as calculated by WRF at 2 m (*t_m , ws_m*) and as measured (*t_0 , ws_0*)

2.2 Meteorological profiler

Meteorological profiler (MTP-5) is located in the center of Chelyabinsk (see Fig.1)

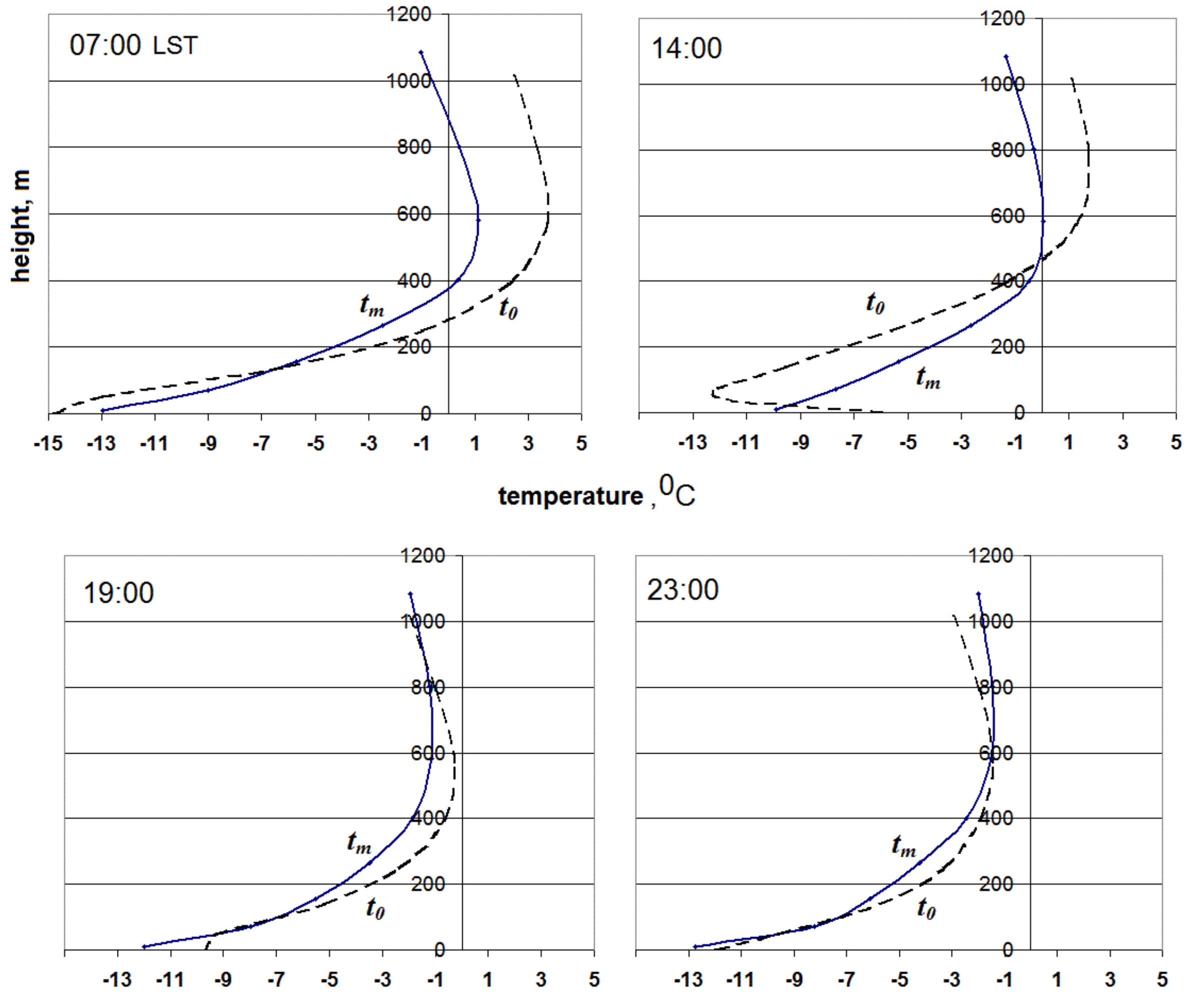


Figure 3. Boundary layer thermal stratification as calculated by WRF t_m and as measured by MTP-5 t_0

The cold anticyclone weather boundary layer thermal inversion is captured as by WRF and observation.

Calculated temperature profile is more smoothed probably due to inadequate static data resolution and therefore UCM used.

The difference is most pronounced in the morning.

3. Results and Discussion

3.1 Spacial configuration of UHI

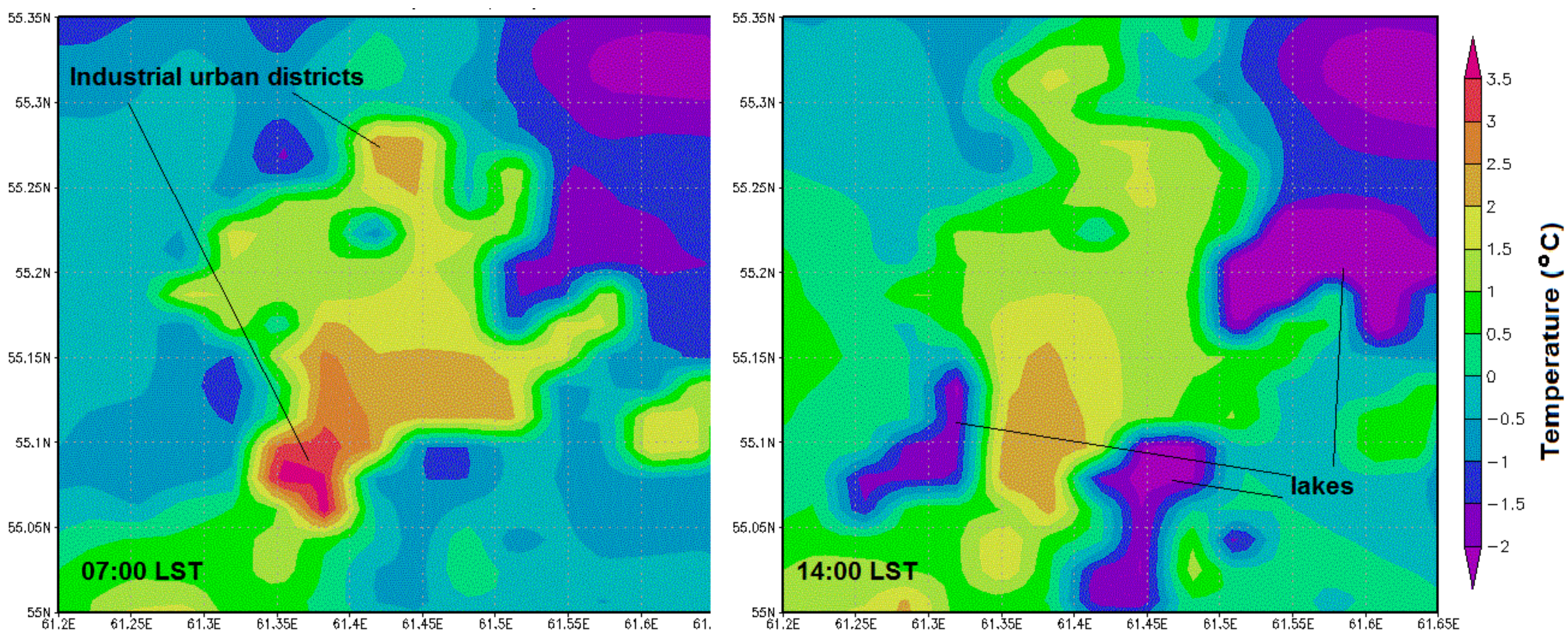


Figure 4. Modeling air temperature anomaly of 2 m heihgt relatively mean temperature over area of application at 7 and 14 h 9 Dec 2011

Spatial distribution of air temperature show enhenced warm areas over industrial urban districts ecpecially early in the morning

During simulation period the canopy layer over river valley remains cooler 1-2 °C than surrounding higher building up and industrial areas.

So, the UHI of Chelyabinsk is devided in two parts by river valley and is more enhenced early in the morning (in winter)

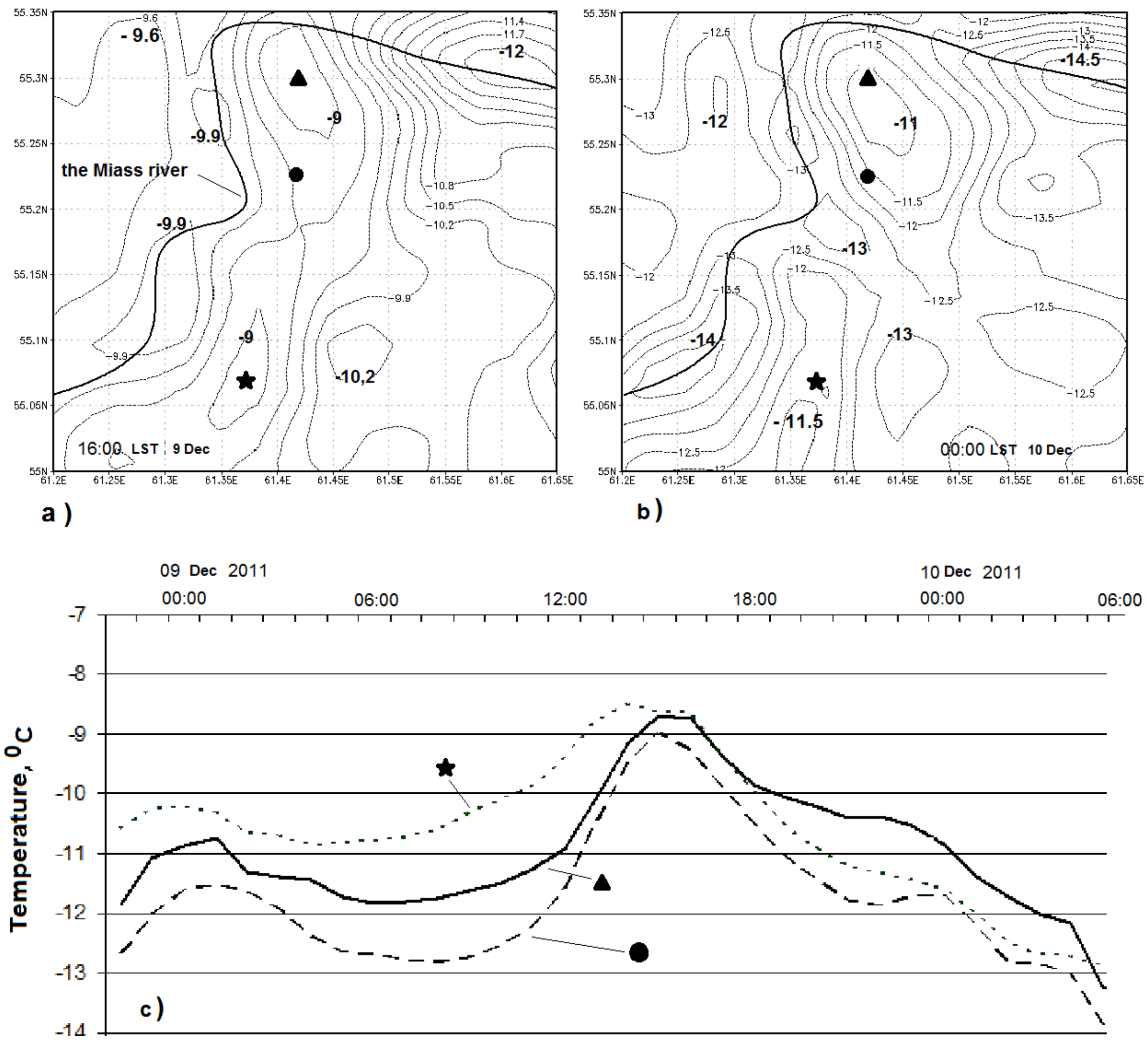


Figure 5. Air temperature field at 70 m above the ground in midafternoon (a) and midnight (b). Air temperature time series in different urban sites (c): highland industrial districts (asterisk and triangle) and river valley (circle)

3.2 UHI circulations

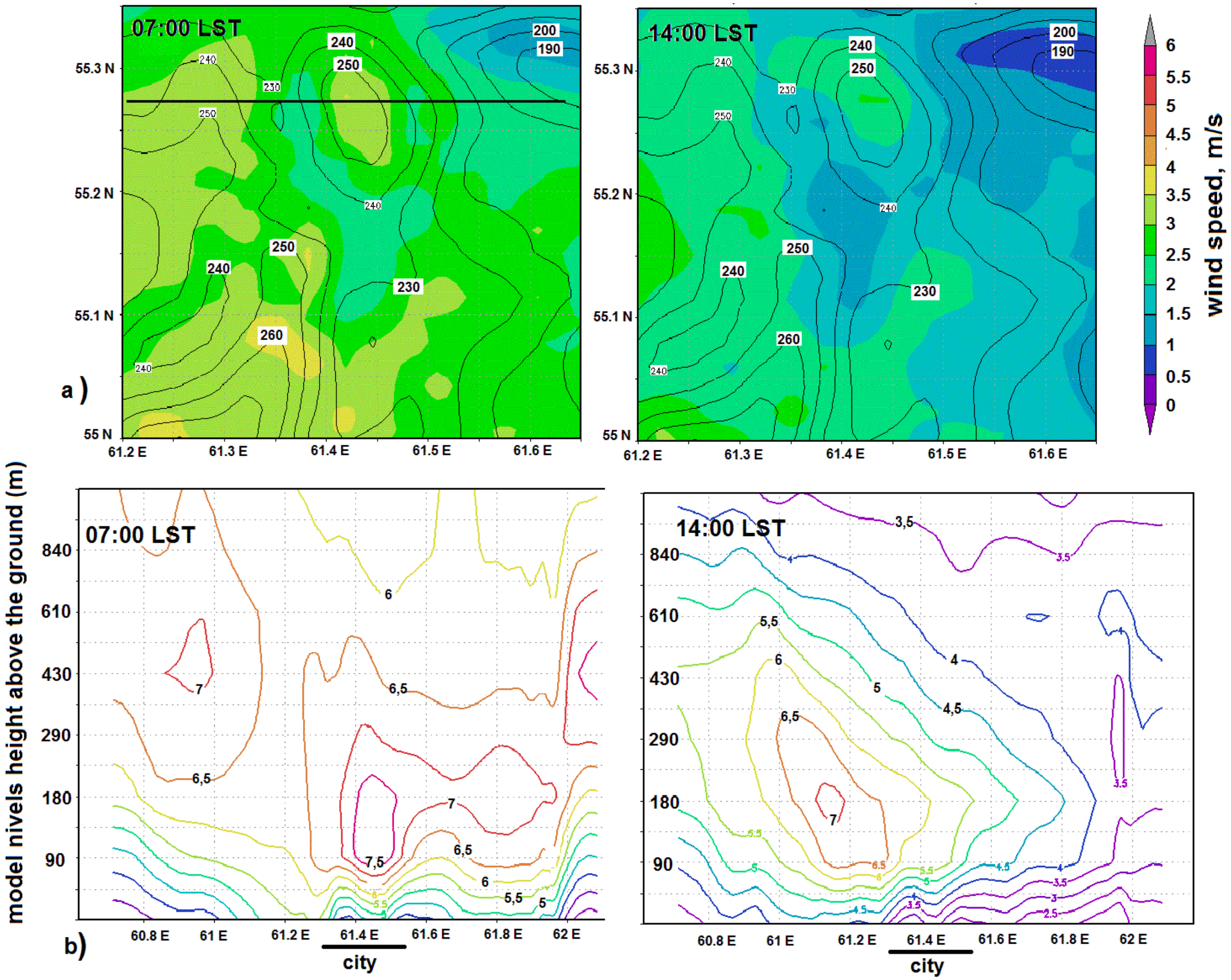


Figure 6. (a) Wind speed distribution (at 10 m) over the city and surrounding; solid lines – land topography heights. (b) Vertical cross section along 55.27 N (black line) of wind speed

During 8 – 10 Dec 2011 wind direction from SW was observed. So the city acts as mesoscale roughness; wind speed decrises to 14:00 LST due to mixing (Fig.6 a)

Wind speed cross section above metallurgical industrial district detects the jet achieving 7.5 m/s at the top of canopy layer (Fig.6 b)

Vertical extension of the jet is approximately 200 m

The simulation of air circulation reveals that at 7 h LST pronounced convergence zones (dark blue in Fig. 7a) coinside with river valley and frozen lakes where cold and more dense air outlet is present.

Stream lines at Fig. 7b reflect the influence of city and its surrounding on air circulation: the divergence above metallurgical urban district at the north and the convergence in the south where there are three frozen lakes.

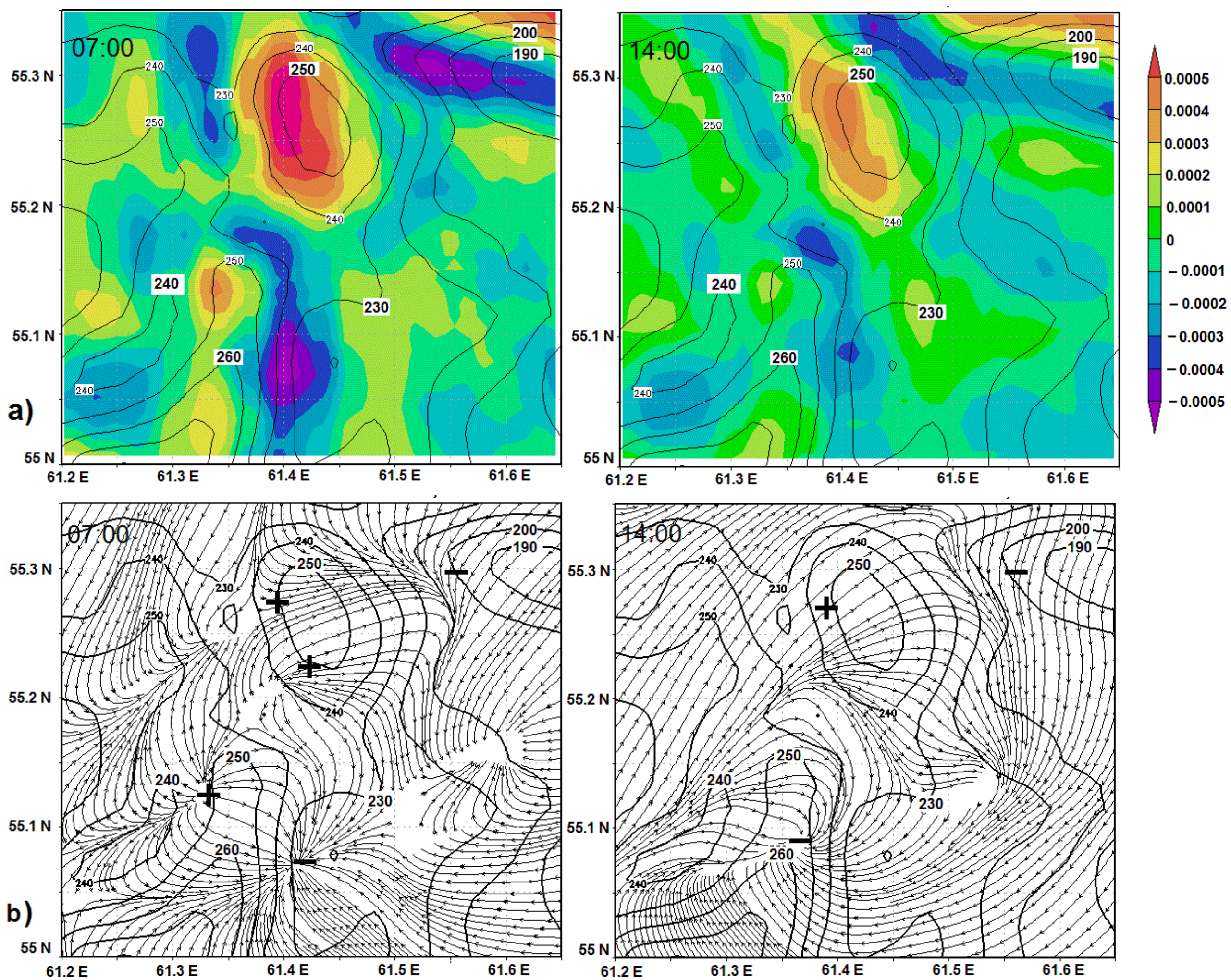


Figure 7. (a) The simulation of divergence field (s^{-1}) at 07 and 14 h LST 30 m above the ground. (b) The wind stream lines at 90 m; the position of positive and negative divergence is shown. Solid lines – topography heights (m).

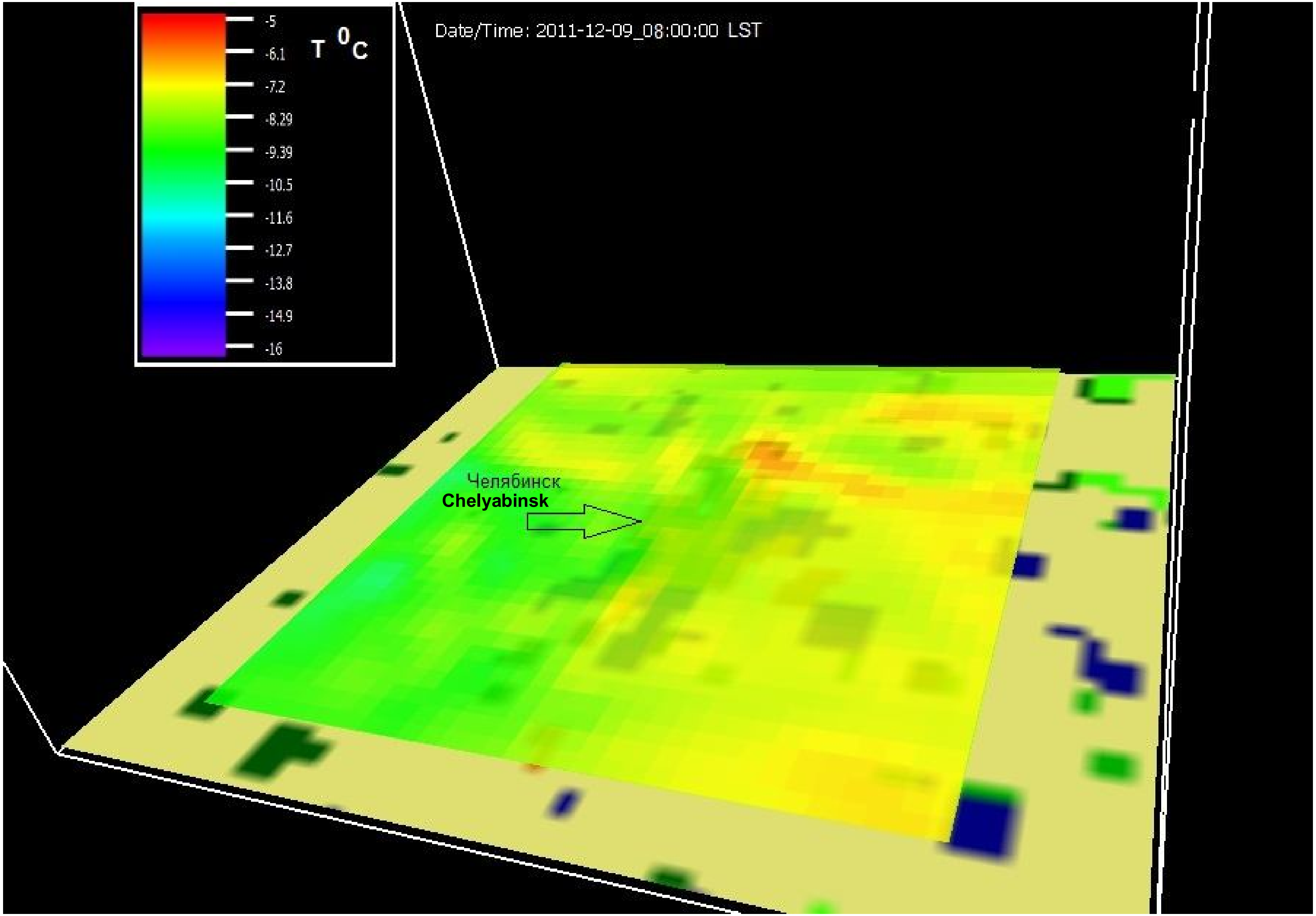
4. Conclusions

1. The WRF/Noah/UCM simulations satisfactorily depict the UHI of Chelyabinsk in winter anticyclone weather conditions. In spite of small altitude differences the relief forms affect the UHI configuration

2. The temperature contrast is more enhenced during early in the morning

3. The doublet structure of positive and negative divergence in surface wind fields was observed

4. In certain synoptic conditions model simulation reveals the jet at the top of canopy layer above metallurgical urban district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