Modelling Influence of Urban Territories on Meteorological Parameters that Affect Air Pollution Dispersion Using ENVIRO-HIRLAM: Vilnius Case Study

Introduction

The surface of urban areas differs from other territories in many parameters. These differences do have impact for boundary layer meteorological parameters (Mason V., 2006) which are especially important for dispersion of air pollutants (Daviesa F *et al.* 2007). This study concentrates on main meteorological parameters (which are important in air pollution dispersion processes) sensitivity to urban areas surface parameters such as surface roughness, albedo and anthropogenic heat flux. Vilnius agglomeration was selected for this study as it is the biggest urban area in Lithuania.

The most interesting cases are the extreme ones when the air pollution dispersion conditions are well (high wind), poor (calm wind conditions) and such events as heavy precipitation or stable atmosphere conditions occur. Different dates with different meteorological conditions were taken.

Methodology

The research version of numeric weather prediction (NWP) model Enviro-HIRLAM (Korsholm U. S *et al.* 2008) was used to carry out this study. Enviro-HIRLAM is the urbanized online integrated NWP-Atmosphere Chemical Transport Modeling version (ACTM) of HIRLAM NWP model. The parametrization schemes used for simulation runs are: Tiedtke convection and Sundqvist condensation scheme; CBR turbulence scheme (Cuxart *et al.,* 2000); ISBA (Interactions Soil-Biosphere-Atmosphere) land surface scheme (Noilhan *et al.,* 1996); Savijarvi radiation scheme (Savijärvi, 1989). The calculations are carried out using 40 vertical levels.

Table 1. LT1 modeling domain characteristics.

Longitude grid points: 250; Latitude grid points: 150;
Domain coordinates in rotated coordinate system:
South: 4.625; North: 6.711
West: 6.425; East: 9.911
Rotation of south pole:
Polon: 10 Polat: -40
Cell size: 1.4 x 1.4 km
Boundary points: 10 (Passive boundary points: 4)

Table 2. LT3 modeling domain characteristics.

Longitude grid points: 298; Latitude grid points: 220;
Domain coordinates in rotated coordinate system:
South: -4.5; North: -0.12
West: 11.5; East: 17.44
Rotation of south pole:
Polon: 0 Polat: -30
Cell size: 2 x 2 km
Boundary points: 10 (Passive boundary points: 4)

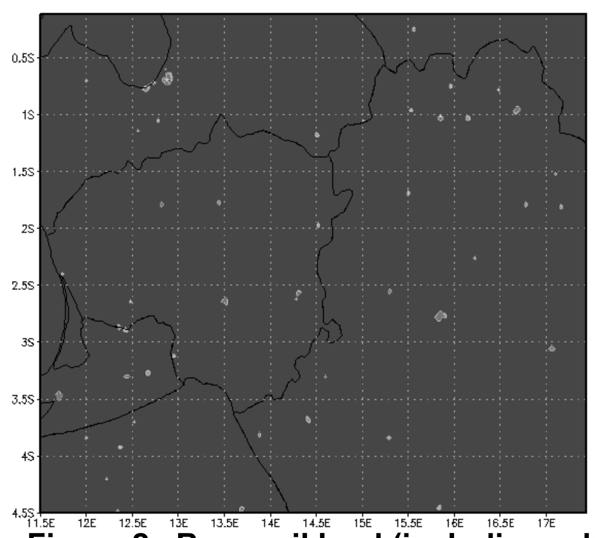

Figure 2. Bare soil land (including urban territories) fraction in LT3 modeling domain.

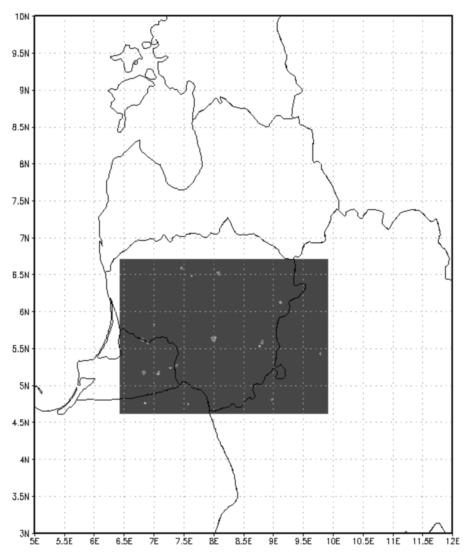

Figure 1. Bare soil land (including urban territories) fraction in LT1 modeling domain.

Boundaries and climate generation files (with urban fraction) for LT1 domain simulation run (date: 2009 January 29) were prepared from Danish Meteorological Institute NWP model HIRLAM operational runs (initialy resolution 15x15km downscaled to 5x5km). Boundaries and climate generation files (with the urban fraction) for LT3 domain (dates: 2009 March 14th and 2009 June 23rd) were prepared from operational Lithuanian Hydrometeorological Service NWP domain HLB8 (8x8km).

The included urbanization is made by modifying the roughness, albedo and anthropogenic heat flux for the grid cells that have urban fractions. The typical urban albedo of 0.15 was taken (15% of energy is reflected). It might be an extreme value for Vilnius since its agglomeration distinguishes itself as the one which has lots of forests, high, middle and low vegetation. However, the materials that are used for roof surfaces in Vilnius typically have lower albedo.

Surface roughness of 2 meters was taken as a standard surface roughness for Vilnius agglomeration area. It can be an extremely low value, but only the new downtown office buildings district can be taken with the higher values. Anthropogenic heat flux can be described as the heat released from all human related activities (power generating, transport, heating, cooking, using home appliances etc.) including metabolism. It is one of the most underestimated parameters that influences urban heat island and in some extreme cases can be higher than the sum of the solar radiation (Ichinose T *et al.* 1999). In the simulated case of Vilnius agglomeration area, the anthropogenic heat values that were used are 100W/m2 and 200W/m2 in different cases. Such high values were taken, because Vilnius has vast districts of residential buildings that can be up to 20+ floors and in the cold season the energy amount used heating can reach extremely high values.

Table 3. Definition of computed experiments.

Case Name	Date	Domain	Modifications	Dynamic time step	Forecast length
LT10129C			No modifications		
LT10129I	2009.01.29	LT1	Roughness 2m; AHF 100W/m^2; Albedo 0.15		
LT10129II			Roughness 2m; AHF 200W/m^2; Albedo 0.15		
LT30314C			No modifications		
LT30314I			Roughness 2m; AHF 100W/m^2; Albedo 0.15	60s	24 hours
LT30314II			Roughness 2m; AHF 200W/m^2; Albedo 0.15		
LT30623C	2009.03.14	LT3	No modifications		
LT30623I	2009.06.23		Roughness 2m; AHF 100W/m2; Albedo 0.15		
LT30623II			Roughness 2m; AHF 200W/m2; Albedo 0.15		

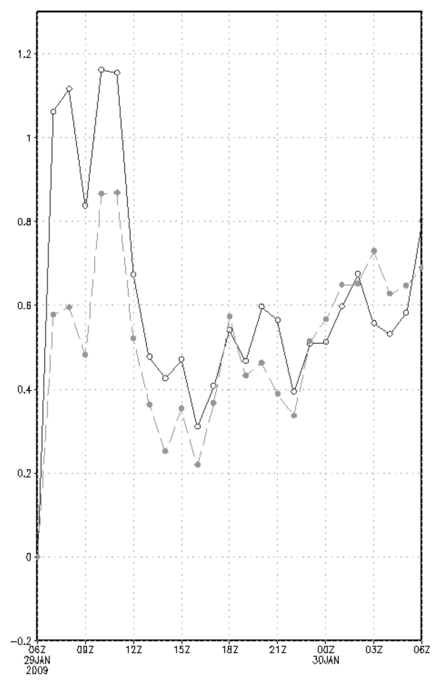

Figure 3. Temperature at 2m difference (vertical axis, °C) between control and modified runs. Solid line - LT10129II run and dashed line - LT10129I run.

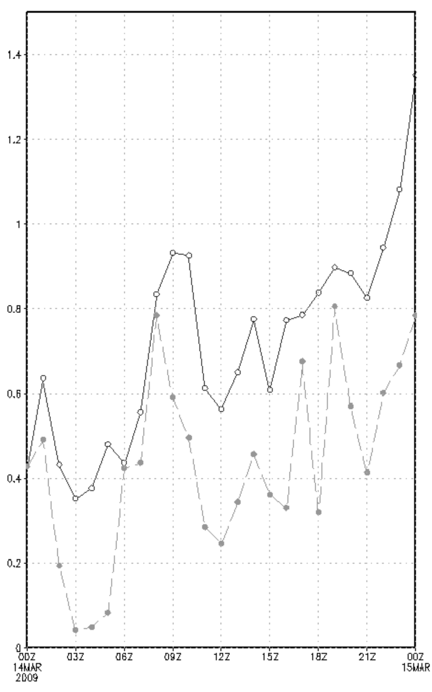

Figure 4. Temperature at 2m difference (vertical axis, °C) between control and modified runs. Solid line – LT30314II run and dashed line - LT30314I run.

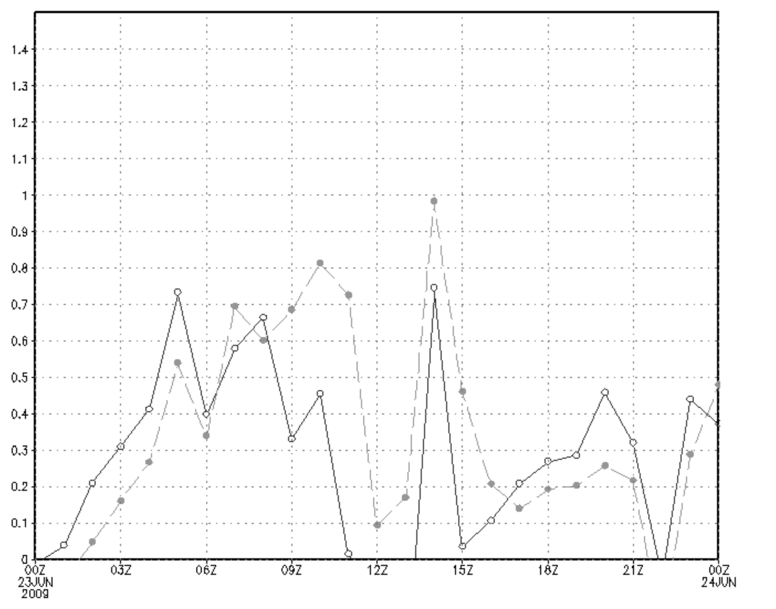

Figure 5. Temperature at 2m difference (vertical axis, °C) between control and modified runs. Solid line – LT30623II run and dashed line - LT30623I run.

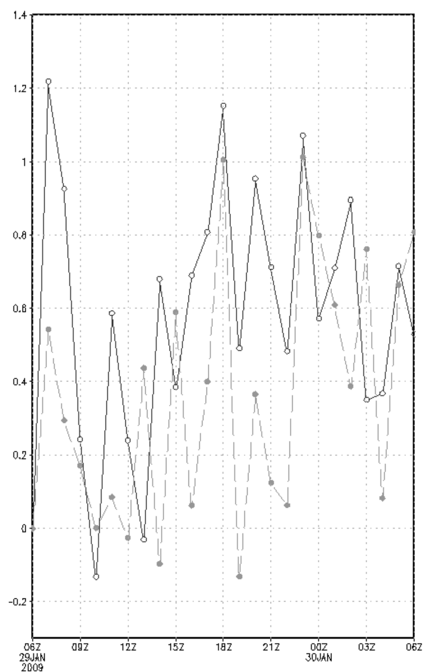

Figure 6. Wind speed at 10m difference (vertical axis, m/s) between control and modified runs. Solid line – LT10129II run and dashed line - LT10129I run.

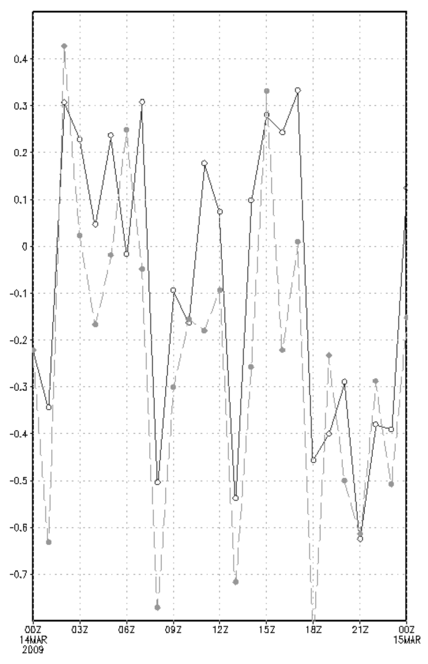

Figure 7. Wind speed at 10m difference (vertical axis, m/s) between control and modified runs. Solid line – LT30623II run and dashed line - LT30623I run.

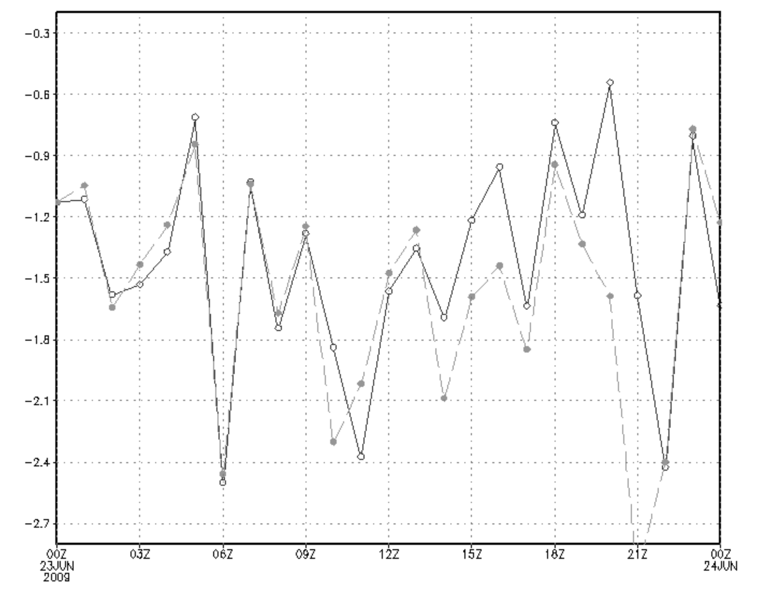

Figure 8. Wind speed at 10m difference (vertical axis, m/s) between control and modified runs. Solid line – LT30314II run and dashed line - LT30314I run.

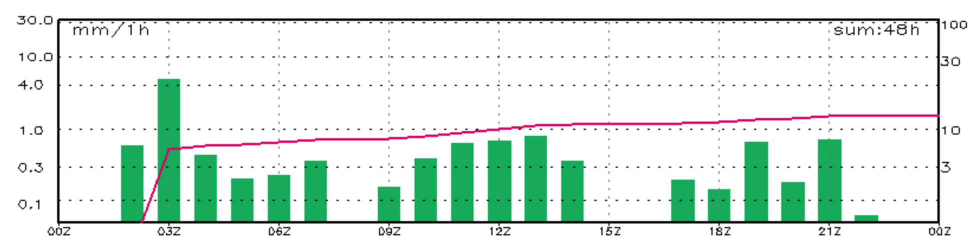

Figure 9. Precipitation at 2009-06-23, Control Run

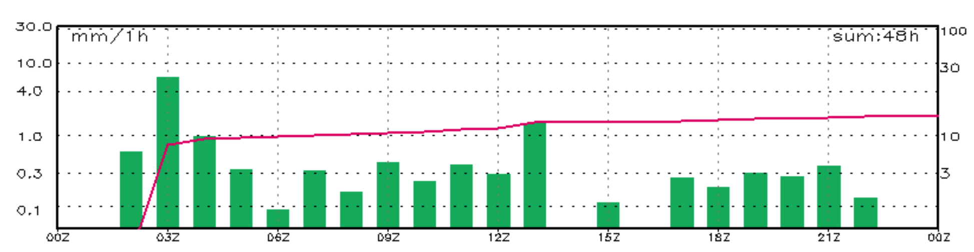

Figure 10. Precipitation at 2009-06-23, Modified Run

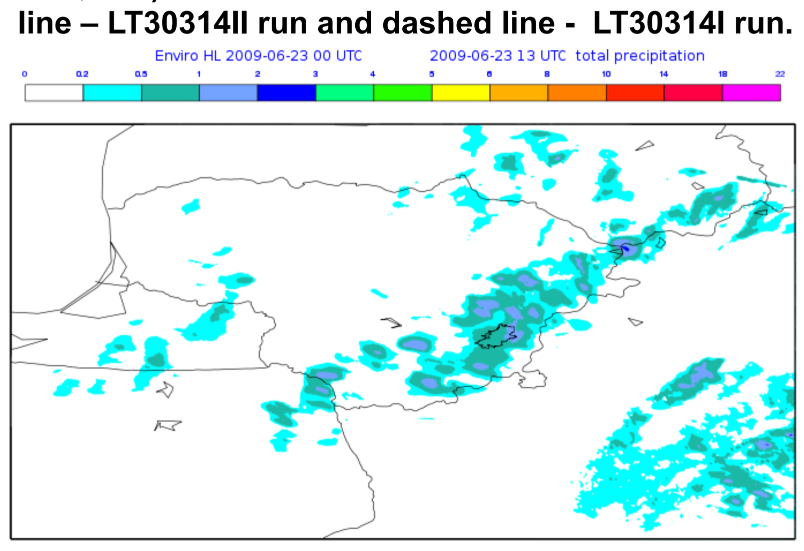

Figure 11. Precipitation at 2009-06-23 13 UTC, Control run.

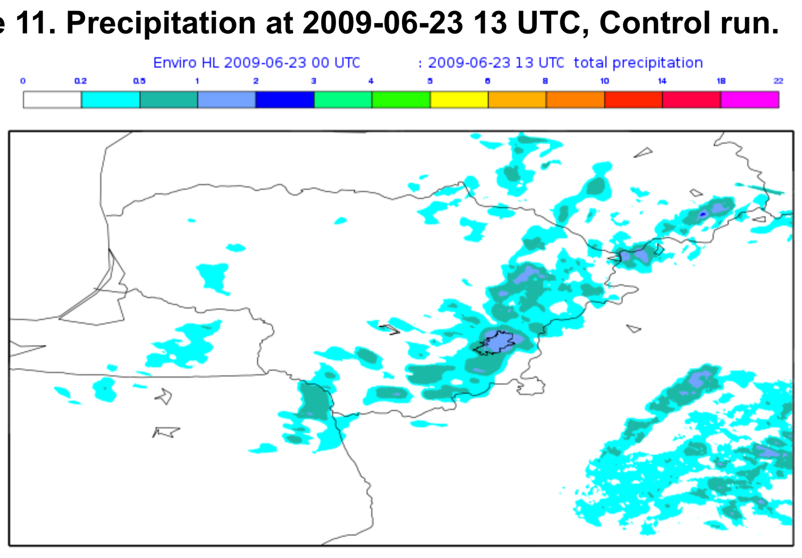

Figure 12. Precipitation at 2009-06-23 13 UTC, Modified run.

Results and analysis

Two fields: temperature at 2m and wind speed at 10m were taken for comparing and the differences between control and two modified runs can be seen in the following figures (figure 3, 4, 5, 6, 7, 8). The provided plots illustrate the difference in temperature and wind speed at the grid cell of Vilnius where the urbanization is the highest (that would be Žvėrynas district at the moment). Vertical axis in figures 3, 4, 5 - °C, temperature of modified runs – temperature of control run, so if less than 0 – control run temperature is higher.

It can be clearly stated, that in all cases the changes do affect the temperature by increasing it (except some hours on the 2009 June 23rd). The reason is clear – lower albedo means that more solar energy is absorbed. Higher anthropogenic heat flux sums up to higher sensible heat flux and it means that the energy available for heating the near surface air is higher. The surface roughness stops the wind so the lower wind speed would be expected, but by increasing albedo and anthropogenic heat flux there are more energy for air parcel heating/lifting and air movements can create significant turbulence as well.

The urban effect is seen up to 2 cells (in LT1 domain it is 2x1.4=2,8km) away from the heavy urbanized points. The same can be seen with the impact in height of the boundary layer. Already in the first layer (30-40 meters) the effect is near to zero.

The impact of urban territories on mentioned meteorological fields is not the same in all cases it might be difficult to evaluate the impact on air pollution dispersion conditions. The wind speed change of even 1 m/s when the measured speed is 3 m/s can mean big changes in pollutant concentration. However, the impact of urbanization can be negative too – the wind speed can become extremely low due to increased surface roughness.

Acknowledgments

The study was supported by Danish Meteorological Institute, MUSCATEN and MEGAPOLI.

Conclusions

- The modifications of the surface parameters in urban territories have impact the meteorological fields that affect air pollution dispersion. However, the impact in different cases is different.
- The temperature at 2m height is typically higher in modified simulation runs.
- The wind conditions can be higher in some cases and in some cases significantly lower (up to 2.7 m/s).
- The impact of urban territories in simulations is local (up to 2.8km and 30-40m height).

References

Cuxart, J., Bougeault, P. Redelsperger, J.-L., 2000. *A turbulence scheme allowing for mesoscale and large-eddy simulations.* Quarterly Journal of the Royal Meteorological Society, 126, 1-30

Daviesa F., Middletonb D.R., Boziera K.E. 2007, *Urban air pollution modelling and measurements of boundary layer height*, Atmospheric Environment, Vol. 41, Issue 19, 4040-4049.

Ichinose T., Shimodozono K., Hanaki K. 1999, *Impact of anthropogenic heat on urban climate in Tokyo*, Atmospheric Environment, Vol. 33, Issue 24, 3897-3909

Korsholm U. S., Baklanov A., Gross A., Mahura A., Sass B. H., Kaas E., 2008, *Online coupled chemical weather forecasting based on HIRLAM – overview and prospective of Enviro-HIRLAM*, HIRLAM Newsletter no 54, 151-168

Masson V., 2006 *Urban surface modeling and the meso-scale impact of cities,* Theoretical and Applied Climatology, Vol. 84, 35-45