Numerical study of the air quality in the city of Sofia – some preliminary results

Ivelina Georgieva[1], Georgi Gadzhev[1], Kostadin Ganev[1], Maria Prodanova[2], Dimiter Syrakov[2], Nikolay Miloshev[1]
National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria[1]
National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia, Bulgaria[2]

INTRODUCTION

Recently extensive studies for long enough simulation periods and good resolution of the atmospheric composition status in Bulgaria have been carried out using up-to-date modelling tools and detailed and reliable input data (Gadzhev et al. 2011 a,b, 2012, 2013 a,b,c,d). The next step in atmospheric composition climate studies is performing simulations in urban scale. The simulations aim at constructing of ensemble, comprehensive enough as to provide statistically reliable assessment of the atmospheric composition climate of the city of Sofia – typical and extreme features of the special/temporal behaviour, annual means and seasonal variations, etc.

MODELING TOOLS

✓The simulations are carried out with the following set of models: US EPA Models-3 System:
✓- WRF (Shamarock et al. 2007) used as meteorological pre-processor;
✓- CMAQ - the Community Multiscale Air Quality System (Byun et al., 1998, Byun and Ching, 1999), being the Chemical Transport Model (CTM)
✓- SMOKE - the Sparse Matrix Operator Kernel Emissions Modelling System (CEP, 2003) – the emission pre-processor .

DOMAINS AND NESTING

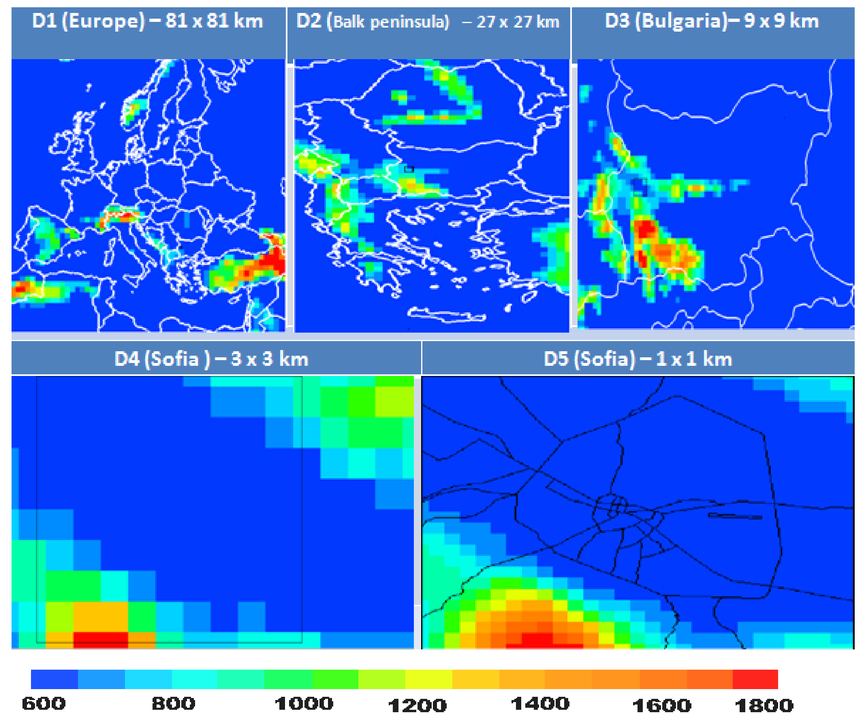
Meteorological data: NCAR 1ºx1º - in Grib1 format at every 6 hours
For 3 years (2010 to 2012) with Two-Way Nesting mod on

5 nested domains:
D1 (Europe) – 81 x 81 km
D2 (Balkan peninsula) – 27 x 27 km
D3 (Bulgaria) – 9 x 9 km
D4 (Sofia municipality) – 3 x 3 km
D5 (Sofia city) – 1 x 1 km

INPUT DATA

✓The large scale (background) meteorological data used is the NCEP Global Analysis Data with 1º x 1º resolution. WRF and CMAQ nesting capabilities are applied for downscaling the simulations to a 1 km step for the innermost domain (Sofia).
✓The national emission inventory is used as an emission input for Bulgaria, while outside the country the emissions are taken from the TNO inventory (A. Visschedijk et all., 2007).
✓Special pre-processing procedures are created for introducing temporal
profiles and speciation of the emissions.
✓The biogenic emissions of VOC are estimated by the model SMOKE.
A detailed description of the emission modelling is given in Gadzhev et al. (2013a).

Downscaling effect – relief
Terrain elevation (HT) [m] for D1 (81km), D2 (27km), D3 (9km), D4 (3km), D5 (1km)



RESULTS, COMMENTS

The most simple and natural atmospheric composition evaluations are the surface concentrations. By averaging over the whole simulated fields ensemble the mean annual and seasonal surface concentrations can be obtained and treated as respective "typical" daily concentration patterns. Plots of some of these "typical" annual, summer and winter NO_2, O_3 and $PM_{2.5}$ surface concentrations are shown in Figures 1, 2 and 3. The spatial, seasonal and diurnal variations in NO_2, O_3 and $PM_{2.5}$ surface concentration fields are very well manifested.

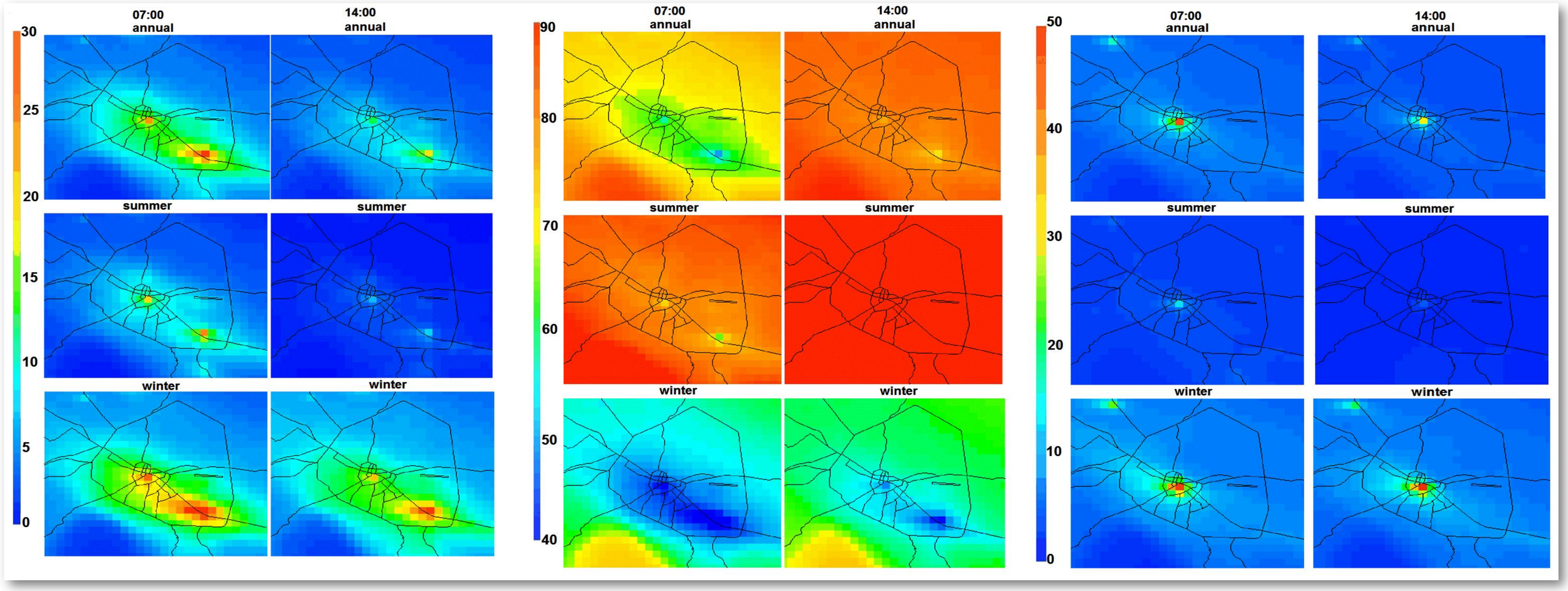


Figure 1, 2, 3
Surface NO_2, O_3 and $PM_{2.5}$ "typical" annual, summer and winter concentrations [µg/m3] in 07:00 and 14:00 GMT

Because the major NO_2 source in the city is the road transport (surface sources) the surface NO_2 concentrations are higher early in the morning and much smaller at noon (when the atmosphere is usually unstable, and so the turbulence transports the NO_2 aloft more intensively). For the same reasons the concentrations during the winter period are bigger than those in summer, or the annually averaged. The spatial distribution is significantly heterogeneous – the maximal concentrations are formed in the city centre and along the boulevard with most busy traffic.

The ozone in Bulgaria is to a great extend due to transport from abroad (Gadzhev et al. (2012, 2013 a,b,c,d)). This is the reason why the ozone concentrations early in the morning are smaller than at noon (less intensive transport from higher levels). The other reason is the ozone photochemistry, which explains both the higher O3 concentrations at daytime and during the summer and the O_3 gaps in the regions, where the NO_2 concentrations are large.

The surface $PM_{2.5}$ concentrations are bigger during the winter months than the summer. The main reason of this are probably the weather conditions. The sources from domestic heating could be another reason.

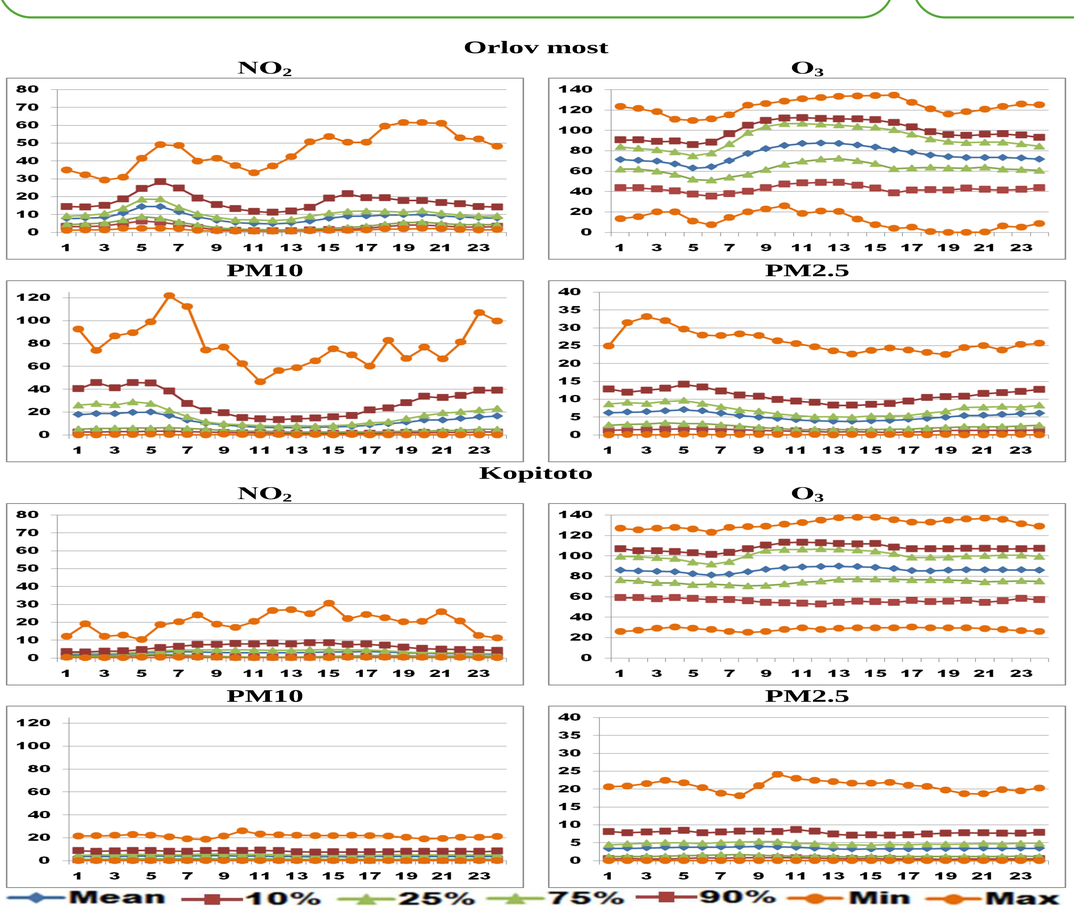


Figure 4. Diurnal variations of the annual NO_2, O_3 , PM_{10} and $PM_{2.5}$ surface concentrations [µg/m3], for the typically urban site "Orlov most" and the mountain site "Kopitoto".

An example of spatial and diurnal variations of the annual ensembles of surface NO_2, O_3, PM_{10} and $PM_{2.5}$ behaviour in two points – the typically urban site "Orlov most" and the mountain site "Kopitoto" is shown in Figure 4. The curves show the imaginary concentrations for which the probability of the simulated ones to be smaller is respectively 25, 75, 10 and 90%.
Thus the band 25-75 contains 50% and the band 10-90 - 80% of the possible cases.
The NO_2, PM_{10} and $PM_{2.5}$ concentrations at "Kopitoto" are much smaller as those at "Orlov most", while the O_3 concentrations at both sites are of similar values. For the "Orlov most" site the O_3 concentrations reach maximum around noon, when NO_2 and PM concentrations tend towards local minimum. This is quite natural having in mind the traffic and atmospheric stability diurnal course. On the contrary for the "Kopitoto" site the NO_2 concentrations reach maximum around noon, probably due to the more intensive turbulent mixture and the slope wind effect. The PM_{10} and $PM_{2.5}$ concentrations at "Kopitoto" do not have such a significant diurnal variations.

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CONCLUSIONS

The demonstrations, presented in the present paper are just a first glance on the atmospheric composition status of the city of Sofia. What can be seen so far is that the results does not defy the common sense and does not oppose the schematic concepts about how the air pollution near earth surface is formed. The numerical experiments are still going on, but when accomplished they will produce a huge volume of information, which have to be carefully analyzed and generalized so that some final conclusions can be made. It is planned computer simulations to be made for different emission scenarios, so that the contribution of different source categories to the atmospheric composition climate of Sofia can be evaluated.
The air pollution pattern is formed as a result of interaction of different processes, so knowing the contribution of each for different meteorological conditions and given emission spatial configuration and temporal behaviour could be interesting. Therefore the CMAQ "Integrated Process Rate Analysis" option will be applied to discriminate the role of different dynamic and chemical processes for the air pollution formation in the city of Sofia. These results have still to be generalised and carefully analysed.