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REGIONAL AIR POLLUTION MODELLING

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1. Introduction

The greatest world concern nowadays is how to optimally design emission reduction strategies in order to reduce air pollution levels below regulatory thresholds. According to epidemiological studies high concentration of air infiltrated and air born pollutants, particularly ozone, have direct link with many health problems especially cardiovascular. Based on that knowledge ground level measurements of the most hazardous pollutants defined by Geneva and Kyoto protocols become regulatory based in a vicinity of every urban, industrial or protected area. Continuous monitoring link with on-line computer database offer possibility for future prognoses of pollution levels throughout certain geographic areas and fast decision-making of control mechanisms and ultimately for public notification.

Another issue concerning pollution levels is how transboundary or transcontinental pollution is transported due to certain synoptic and regional scale meteorological conditions. To answer that and similar questions relevant measurements have been conducted and information provided about directional influences of certain pollutants leading to reconstruction of direct emission sources or responsible mechanism. However, rise of computational power of today computers offers the use and evaluation of meteorological and air quality modelling tools to assess pollution levels by performing numerical simulations. One such simulation have been performed on specific episode (temporal and spatial) in order to achieve up-stated objectives and to gain insight into influence and connection between regional, mesoscale and local pollution levels.

2. Selection of the simulation episode

City of Rijeka and Kvarner area have been chosen as a prefered area of study. On one side reason for that statement is that Rijeka is an urban and at the same time industrial area offering great variations and almost continuous threshold air pollutant values. On the other side, due to its topographic complexity and multi-scale influence to the air pollution levels, it offers potential case for validation of air quality modelling systems. Analysis of measured and documented pollutant values for 2005. indicates the presence of three weekends of intense heat wave with stable meteorological conditions, [Fig. 1] and high levels of measured concentrations from which the one with the longest duration has been chosen. In order to minimize uncertainty of boundary and initial conditions, according to [1], the period of the chosen weekend, from 29th till 31st of July 2005, was extended for two days, leading to a final simulation episode from 27th till 31st of July 2005.

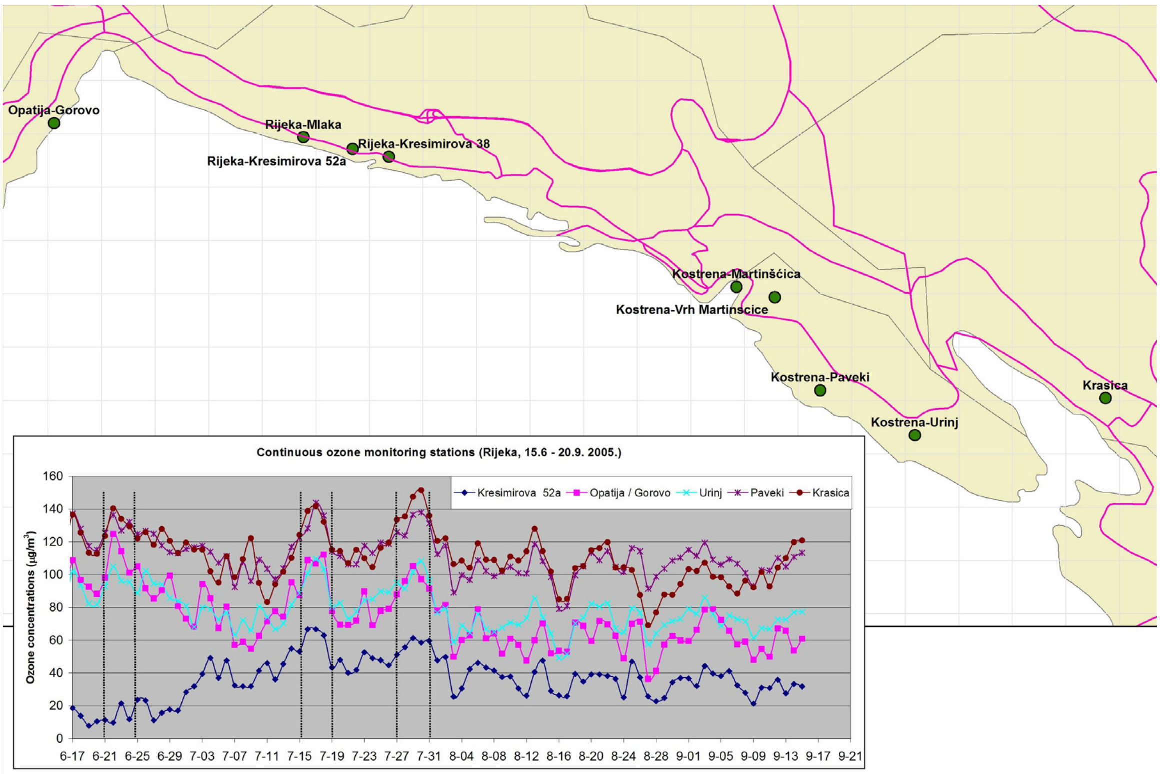

Figure 1. Ozone monitoring stations and summer concentration data covering wide Rijeka city area

3. Grid and domain configuration

Two nested domains have been constructed. First domain covered whole Northern Adriatic area with rectangular grid 300 x 300 km (100x100 nodes) while second, finer grid, covered Rijeka's basin with 50x50 km grid (50x50 nodes) where most of measured stations reside. Both domains stretche vertically from the terrain following bottom boundary layer up to the 100 mbar pressure surface through 18 layers with near surface biasing in order to account for local finer scale of emission sources and industrial stack heights.

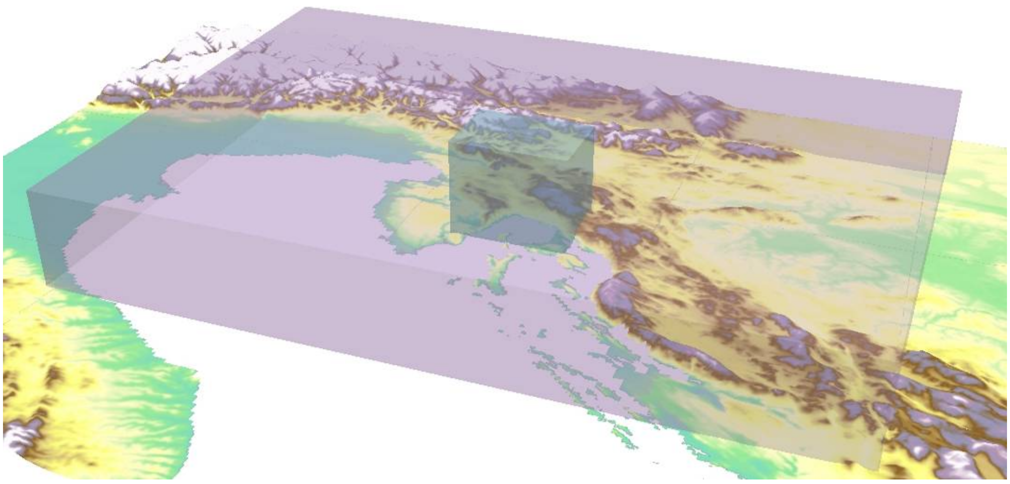

Figure 2. Grid representation used for meteorogical, air pollution modelling and emission inventory. Left figure shows two MM5 domains with horizontal resolution of 3 and 1 km, respectively.

4. Air quality modelling system

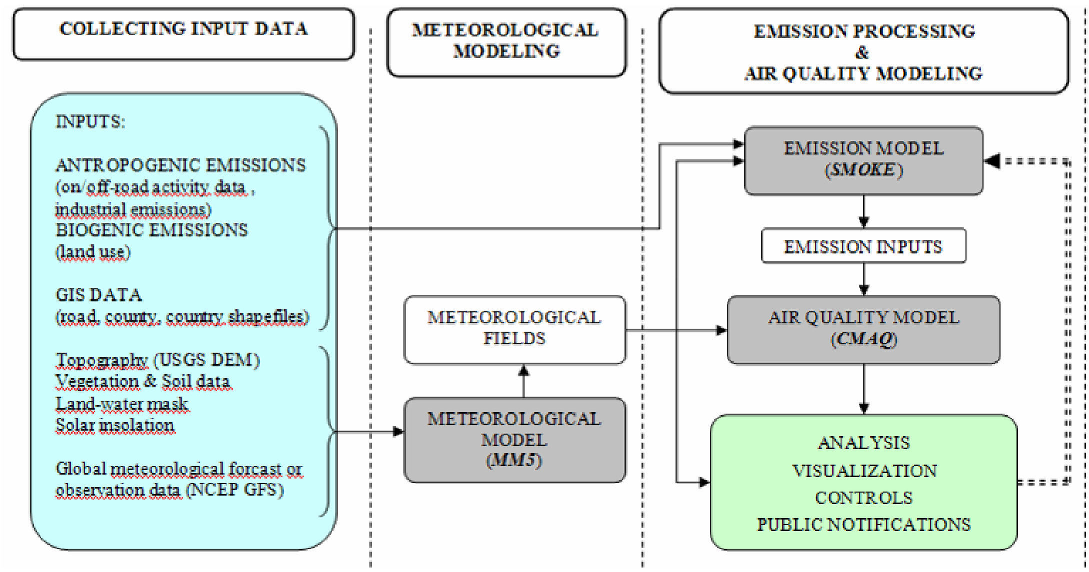

Figure 3. Structure of an air quality modelling system

Before detailed methodology will be elaborated it is needed to note the complexity and amount of labour input needed for such a simulation. Every process in presented flowchart (Figure 3) is an individual task completely separated form the others. The reason is open source scientific society, such as research societies in the fields of environmental protection. To couple or assemble them together different scripts and conversions had to be invented and processed and collection and analysis of inputted data had to be done, whether it be emission inventory data or inputs for meteorological model.

4.1. Meteorological model

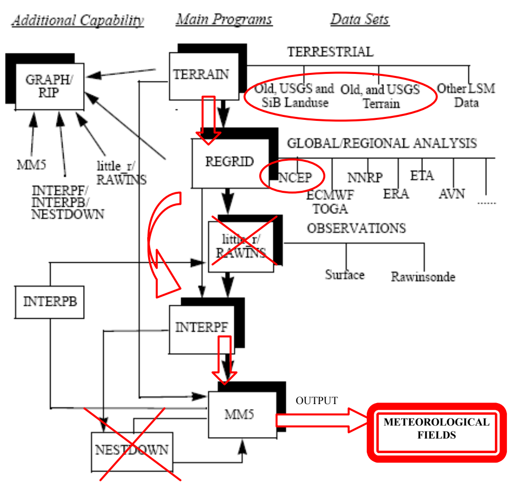

Figure 4. MM5 mesoscale modelling system

As shown in the self-explanatory flow chart (Fig.3.), meteorological modelling is pre-processing task crucial to obtain meteorological fields, for given geographic area and specific episode of study, needed as inputs to emission processing and air quality modelling. The Fifth-Generation NCAR / Penn State mesoscale modelling system *MM5* was applied on previously described rectangular domains. First part consists of collecting of gridded meteorological analysis data from global forecasting systems, regridding them to episode domain grids and finally interpolating them horizontally and vertically in order to prepare boundary and initial conditions. With prepared inputs a numerical weather prediction part of this modelling system, finite difference conservation equations solver (Navier-Stokes along with prognostic equations for water vapour and microphysical variables) can finally be started. It uses two-way nested technique for interpolation and feedback from coarser to finer domain and vice-versa.

4.1.1. MM5 Results

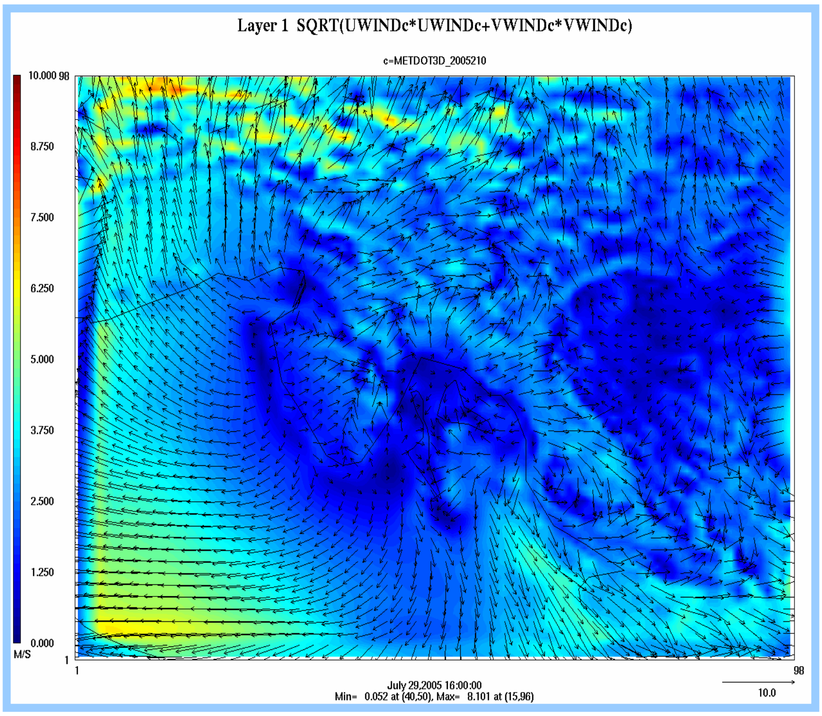

Figure 5. MM5 output meteorological fields showing near-surface wind velocity vectors with magnitude contours for D1 at 16:00 on 29th of July 2005.

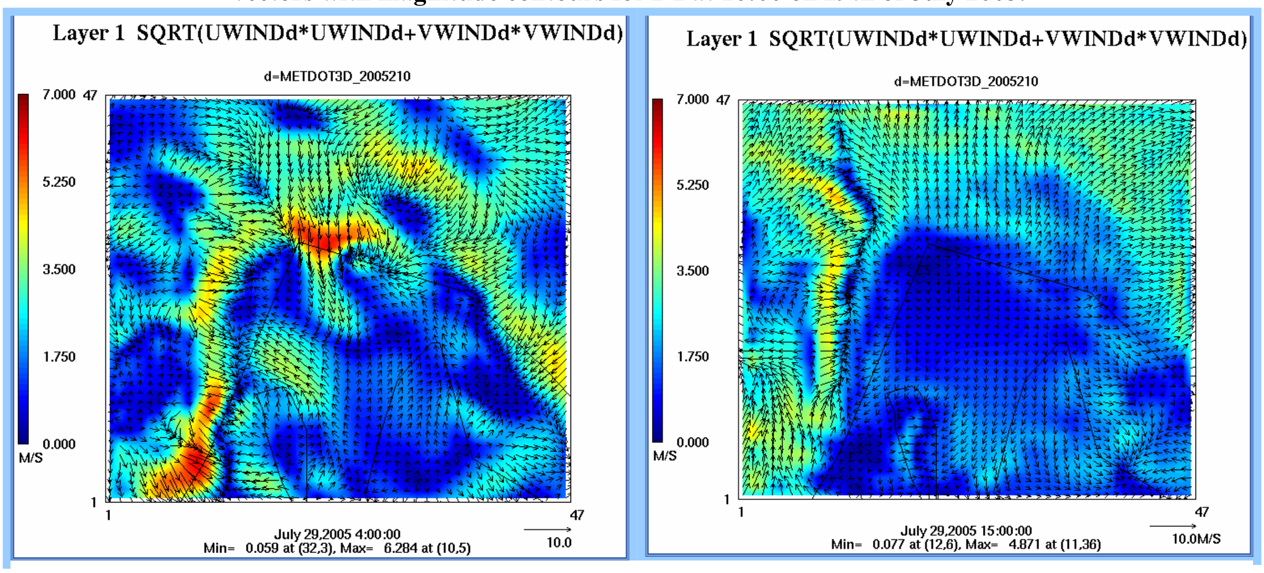

Figure 6. MM5 output meteorological fields showing near-surface wind velocity vectors with magnitude contours for D2. Two regimes of ground level circulations at 4:00 h (left) and 15:00 h (right) on 29th of July 2005. indicates strong terrain shape driven flows.

MM5 simulation results for a simulation on 29th of July 2005 are presented. Coarse D1 domain wind field indicates low pressure gradients around Kvarner bay and regional scale flows while finner D2 domain resemble terrain specific or local scale phenomena: terrain canalizations, mountain ridge conflicting wind streams and local low pressure gradient areas, ideal for accumulation and formation of pollutants.

4.2. Emission data processing

Air pollution can be described as infiltration of high concentrations of emissions from terrestrial sources (primary pollutants) to lower troposphere leading, through a series of photochemical mechanisms, to formation of secondary air-born pollutants. According to this, emission inputs to air quality model need to be as realistic as possible. The majority of national emission inventories in Europe rely on annual temporally and spatially averaged values of categorized emission sources. In order to use such database and to incorporate it to a model and domain of interest, different scale of conversions have been performed for different emission source categories (point, area, mobile, etc.): temporal profiles from annual to modelled time step scale, spatial profile from spatial agglomeration to specific gridded values and speciation profiles for conversion from ensemble emission measurements to particular species data fractions. Although such profiles rise from accustomed means of how different industrial processes or other emission sources work, data obtained in this way have lower resolution and, as such, being used as course domain inputs to account just for transboundary or regional scale pollution formation and transport and as input files for finer domain initialization.

Finer resolution emissions have been achieved using continually monitored point source and on-road specific hourly based emissions. To account for biogenic emissions and their high correlated impact on formation of secondary pollutants, high resolution land use and land cover GIS maps need to be used and incorporated into emission model. Biogenic emissions have not been used due to lack of emission data.

SMOKE (*Matrix Operator Kernel Emissions Modelling System*) proved to be a reasonable modelling system choice. It is basically emission processor that uses matrix formatted profiles and emissions and generates model-ready emission input files through a series of sparse matrix and vector multiplications.

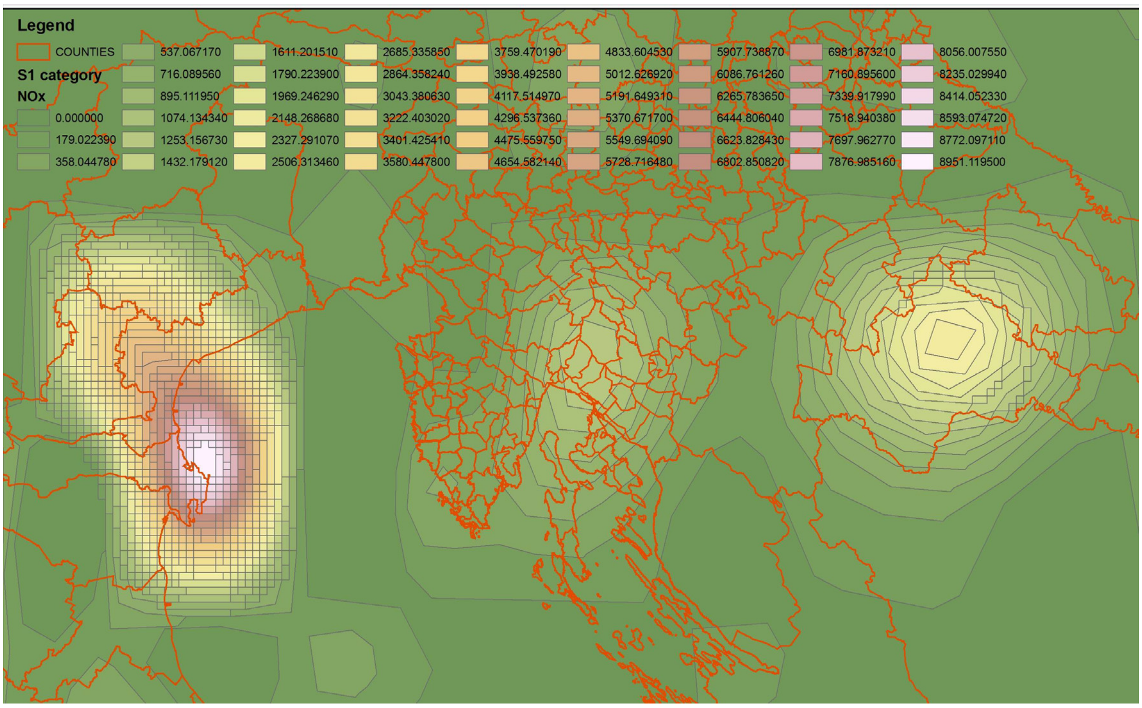

Figure 7. EMEP yearly averaged NOx concentration (Gg/y) from S1 category following SNAP-97 nomenclature (S1 - Combustion in energy and transformation industries (stationary sources)) based on European countries national emission inventories used as input for course domain along with other pollutants and categories.

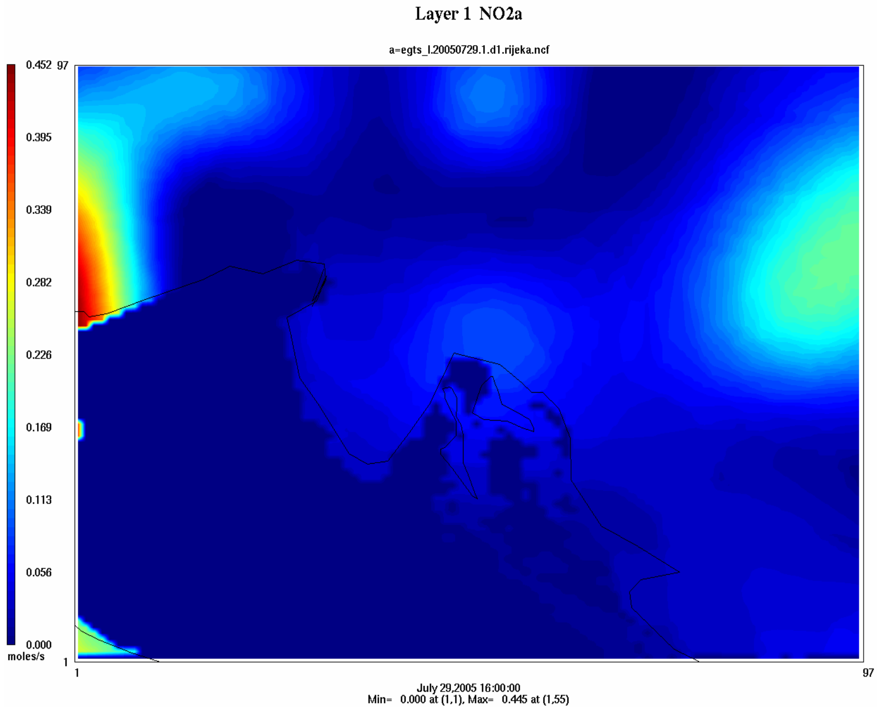

Figure 8. Domain 1 emission input data. Figures shows NO2 gridded concentrations from stationary S1 sources (moles/s) on 29th of July 2005 at 16:00 from EMEP NEI database according to Figure 7

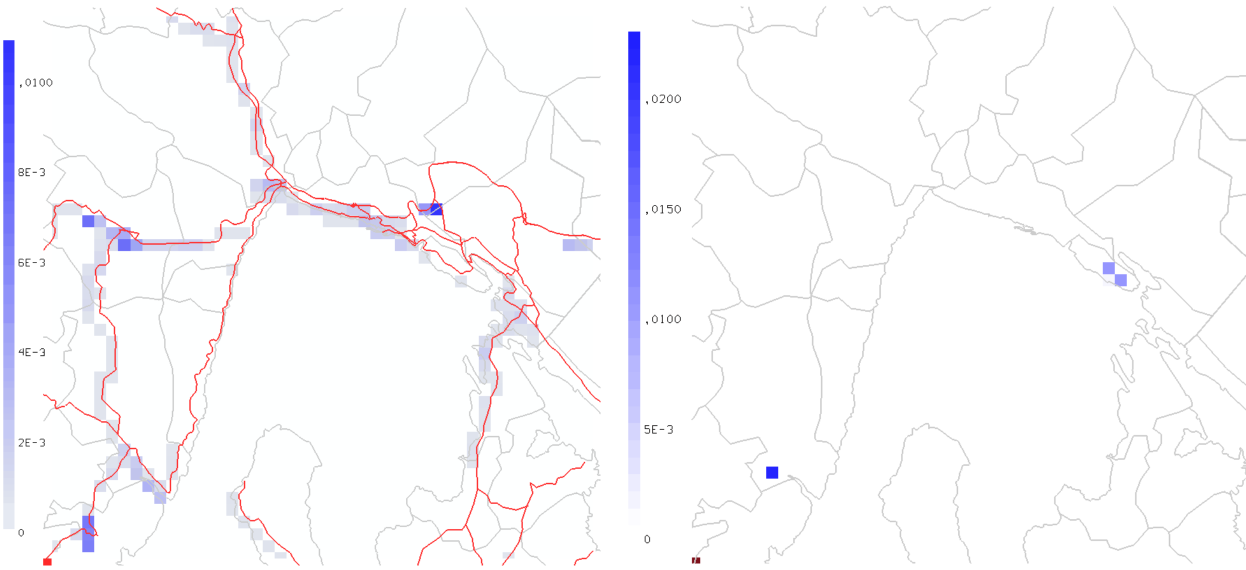

Figure 9. Domain 2 emission input data. Figures shows NO2 gridded concentrations (moles/s) on 29th of July 2005 at 16:00 from mobile on-road sources (*left*) and from power plant chimneystacks (point sources) (*right)*

4.3. Air quality model

A chemical transport model (CTM) is central module of an air quality model. CMAQ *Model3* CTM is fully compatible with MM5 meteorological fields and emission inputs from SMOKE and capable of simulation physical-chemical processes in order to produce three-dimensional concentration fields for different pollutants. It contains initial and boundary condition generators and modules for explicitly treating horizontal and vertical advection and diffusion, dry and wet deposition algorithms as well as Carbon-Bond IV chemical mechanism. Simulation was set according to domain's grid definitions and results can be seen on Figure 10, Figure 11 and attached movie for a simulated 30th of July 2005.

4.3.1. CMAQ Results

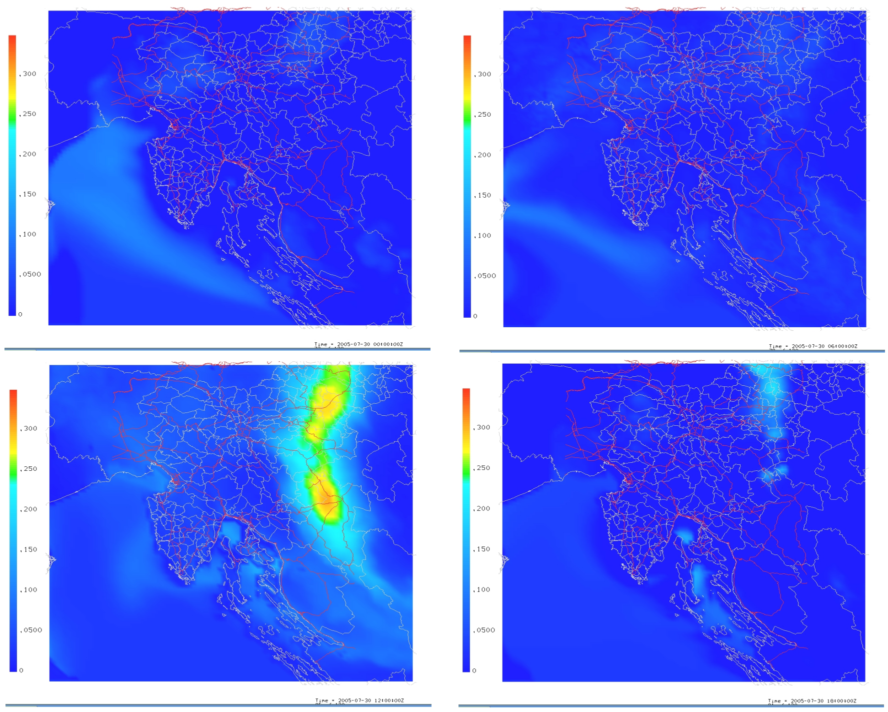

Figure 10. CMAQ ozone concentration (ppmv) contour plots for D1 domain for simulated hours at 00, 06, 12 and 18 h, respectively, on 30th of July 2005.

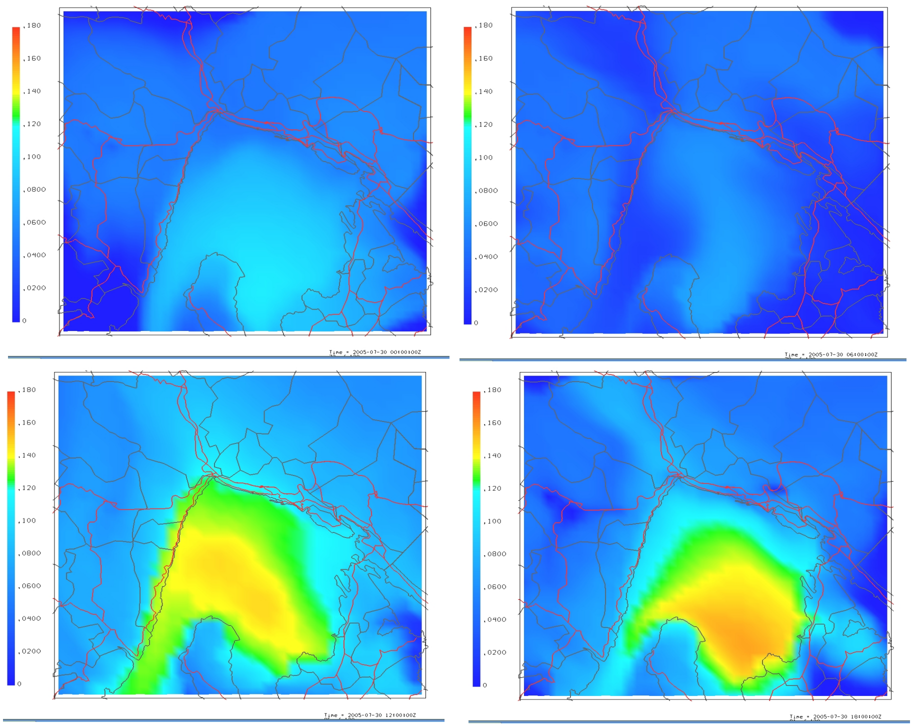

Figure 11. CMAQ ozone concentration (ppmv) contour plots for D2 domain for simulated hours at 00, 06, 12 and 18 h, respectively, on 30th of July 2005.

5. Conclusion

Presented air quality modelling system has been constructed as a framework for the assessment of deposition and air quality for studied Rijeka and larger regional areas. Meteorological model showed ability to resolve fine scale fields. According to [3], further refinement of horizontal and vertical domains' resolution wouldn't yield better results. We can conclude that present grid definition is fine enough to explain and describe meteorology driven pollution transport and accumulation. Using sophisticated visualization tools different periodic spatial patterns of pollution concentrations have been identified and correlated to meteorological local scale phenomena. It was shown that horizontal advection influences formation of topographic canalizations of pollution from and to the boundary of finer domain. Stable atmospheric condition in Rijeka basin allowed the formation of high ozone concentration field covering whole basin during daytime and showing periodicity for other simulation days.

However, emission inventory was scarce. Lack of urban city, biogenic emissions and finer temporal resolution data suggest that no real correlation between observation data at present state can be achieved. Further refinement should be performed on emission input data along with completing emission inventory for specific cases if not for whole national coverage.

Finally, operational air quality modelling system has opportunity in near future because it is European Commission primary goal, presented in Framework7 and EC Directives, to join individual efforts in the fields of sustainable development and environmental protection from the local communities to state directives and European community.

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