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MAXIMUM AIR POLLUTION SIMULATION USING GENETIC ALGORITHM

Z. Mrša, and Z. Čarija

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1. Introduction

Good air quality is a prerequisite for the health and well-being of humans and ecosystems. The air pollution today presents major threat to the human health. The atmosphere can act as a means for transporting local pollution emissions to other locations, even long distances away and to other media (land and water). The urban areas, as well as industrial zones, with many air pollution sources, contribute most to the air quality deterioration. Most countries have enforced their Clean Air Act that regulates the air quality control and management to protect the population health and environment.

The region of the Rijeka municipality has very bad air quality (polluted above the regulatory boundary values). One of the main pollution sources is refinery plant near Rijeka. This was the reason for the maximum pollution analysis. The Rijeka refinery power plant and processing vessels and reactors emit, among others, significant amount of SO_2 pollutant. It is specially so when using high sulphor content fuel for power plant. Given the 17 point sources of SO_2 emission pollution resulting from high sulphor content in the fuel, the problem was to numerically simulate dispersion and distribution of SO_2 pollutant , as well as to find its maximum value in the nearby surroundings for the worst possible meteorological data, with given topography of the terrain. Special attention should be paid to the urban areas situated few km far from the power plant, which has third category of air quality (dangerous for health if temporary exposed) according to Report on environmental pollution in Republic of Croatia for 1998) [5]. Finally, different scenarios should be invented for pollution reduction, such as the alternative use of two different fuels, one expensive, with low and other cheap, with high sulphor content. The analysis of the height of the reconstructed power plant stacks on the pollution is carried out too.

2. Gaussian pollution dispersion model

By far the most frequently used approach to regulatory air quality modeling has been the Gaussian plume diffusion formulation. This approach stems from the fact that the well-known normal, or Gaussian, distribution function provides a fundamental solution to the classic Fickian diffusion equation. In the Gaussian plume model, the crosswind plume concentration distributions are taken to be Gaussian in form. This has been partially substantiated through field experiments for typical meteorological conditions. In the strict sense, Gaussian diffusion is valid only for long diffusion time and for homogeneous, stationary conditions. However, this type of model has been found to give useful results for many practical applications [6].

The Gaussian plume algorithm has the advantages of inherent simplicity, ease of use, flexibility and short computation time. For a steady-state Gaussian plume, the hourly concentration χ at downwind distance x (m) from the source and crosswind distance y (m) is given by eqn (1):

$$\chi = \frac{Q\,K\,V\,D}{2\,\pi\,u_s\,\sigma_y\,\sigma_z}\exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right], \tag{1}$$

where: Q, K, V and D are pollutant emission rate, scaling coefficient, vertical and decay term respectively, σ_y,σ_z standard deviation of lateral and vertical concentration distribution, dependent on downwind distance x, u_s mean wind speed (m/s) at release height [1].
The concentration is linearly dependent on emission value Q, so the pollution concentration field looks the same for different emissions, only maximum value and the scale depends on emissions.

3. Receptor and sources locations

The 17 sources were modeled at their real topographic locales with proposed SO_2 emissions. The stacks varied in height from 9.5 to 124 m, and were distributed through the whole refinery territory. The SO_2 emissions varied from 1 to 140 g/s coming from the sources such as refinery power plant, with highest emissions, to different refinery process plants.

To determine the maximum impact from given sources in the bigger surrounding for all possible meteorological conditions, the large number of receptor locations are needed across the modeling domain. Here we used 120x131 = 15720 receptor mesh with 100 x 100 m resolution, covering 12 x 13.1 km area centered at the power plant and including nearby urban areas. In the south-north direction (-15 to 60 deg) the terrain rises very steeply, which is the main reason for high surface pollutant concentrations in the refinery region for the south winds.

4. Meteorological data

The atmospheric conditions, besides terrain topography and emission intensity, determine the distribution of air pollution impacts for a particular area. While an unstable atmosphere disperses pollutants and thus causes a wider impact area, a stable atmosphere can cause pollutants to be transported further downwind in a long, narrow impact area. Here we varied meteorological data in the chosen intervals that result in highest pollution. The input meteorological parameters used by Gaussian dispersion models are the wind speed, wind direction, isolation (during daytime) or temperature gradient (night) , and the mixing height. Atmospheric stability category is then calculated from input data (6 possible values).

5. Genetic algorithm

We used genetic algoritm optimization tool. It is quite robust tool in producing near optimal solutions. It is derivative free method and can be applied to complicated objective functions with multiple local maxima [3],[4],[2]. Because of the varying terrain height and varying wind directions and speeds, even for the stationary pollution emissions multiple maxima of the surface pollution occur. Therefore the genetic algorithm technique is well suited for this problem. Each individual set of meteorological data is represented by chromosome with different gene lengths; 8, 6, 5 and 1-bit string encoding wind direction, speed, mixing height and temperature gradient respectively. The search intervals for given four variables are input data, given by their minimum and maximum values. The gene lengths can also be input data; those chosen here being best suited for required resolution of maximum location.

6. Results analysis

In the genetic algorithm every individual produce input meteorological data for computer code for the simulation of distribution and dispersion of pollutants accros the given terrain. Preliminary search resulted in following limits where maximum pollution occurs: wind speed 1-10m/s, direction 345°-60° (0 is north), mixing height 300 – 5000 m, temperature gradient –1 or 1. For given limits final detailed search with refined intervals gave maximum values. One population consisted of 20 individuals. The optimization was achieved with for 60 generations. The objective functional (fitness), which is maximized by the genetic algorithm optimization procedure, is the SO_2 surface concentrations at any of given receptors for all possible variations of meteorological data in given intervals. The cross-over and mutation probabilities were chosen 0,4 and 0,05 respectively in order to advance from parent to child generation. The generation history of adaptation is given in Fig.1, where generation mean, mean plus and minus one standard deviation curves are ploted versus the generation number. The results show that worst pollution occures at night, with stabile atmospheric condition, class 5 or 6, and low speeds 1 – 2 m/s and south winds 15-45 degrees. In these conditions the plume hits the steep terrain nearest to the stack, while difusion is still small, so that the concentrations are high.

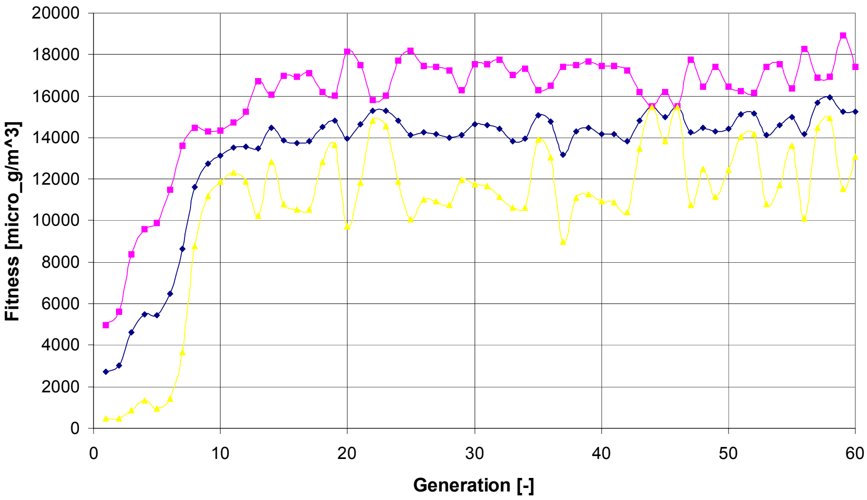

Fig. 1 The generation mean, mean plus and minus one standard deviation curves versus generation number

The mixing height, defining the reflection of the plume at upper boundary, has no practical influence in these conditions. From Fig. 1. it can be seen that the highest values of fittness was not significantly improved after 20 generations, so genetic algorithm optimization can be stoped after 20 iterations.

Figure 2. shows maximal surface pollution distribution in given terrain for worst meteorological data . Maxima occurs in the night for slow winds of 1 m/s, south-north direction 10°-12°, positive temperature gradient and high mixing heights 3880 – 5000 m.

In order to estimate the influence of the stack height of the most influential stacks, these of the power plant, its variation is studied. The maximum surface pollution for the worst meteorological conditions for three different stack heights: original 35, 60 and 125 m are given on the Fig. 2 – 4. The linear regression of the maximum pollution concentration – y, as a function of stack height –x, was established in the form of

$$y = -121.53244262x + 18798.14140984 ,$$

showing that 80 m stack height would halve the maximum pollution concentration form 1600 to 800 $\mu g/m^3$ (see Fig. 5).

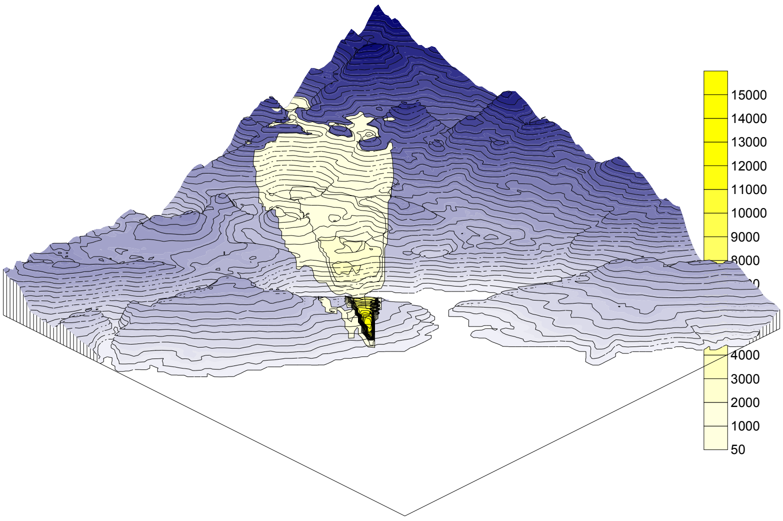

Fig. 2 The surface SO_2 concentration (μg/m^3) for worst meteorological conditions for original stack heights

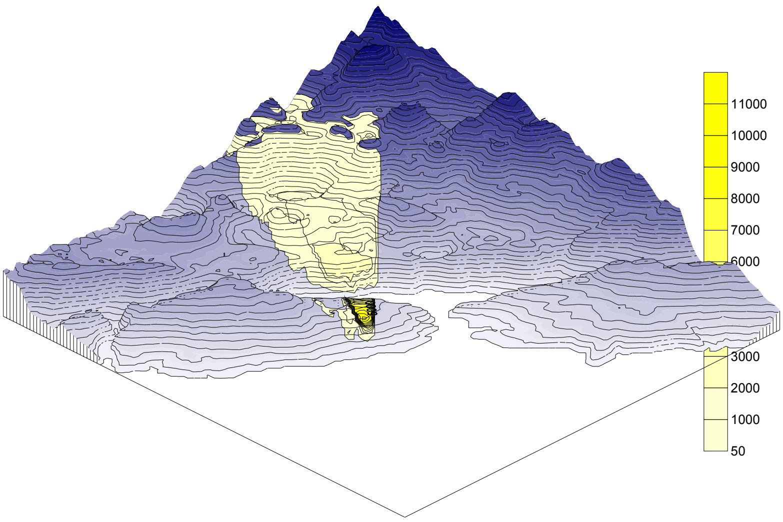

Fig. 3 The surface SO_2 concentration (μg/m^3) for worst meteorological conditions for 60 m stack heights

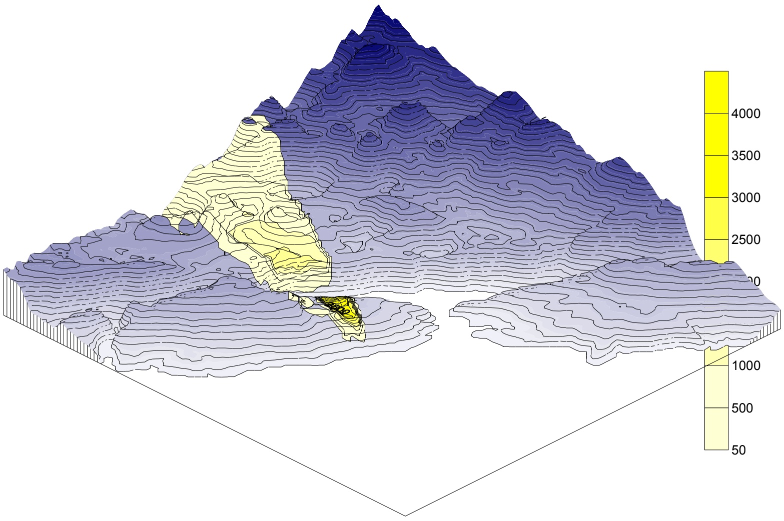

Fig. 4 The surface SO_2 concentration ($\mu g/m^3$) for worst meteorological conditions for 125 m stack heights

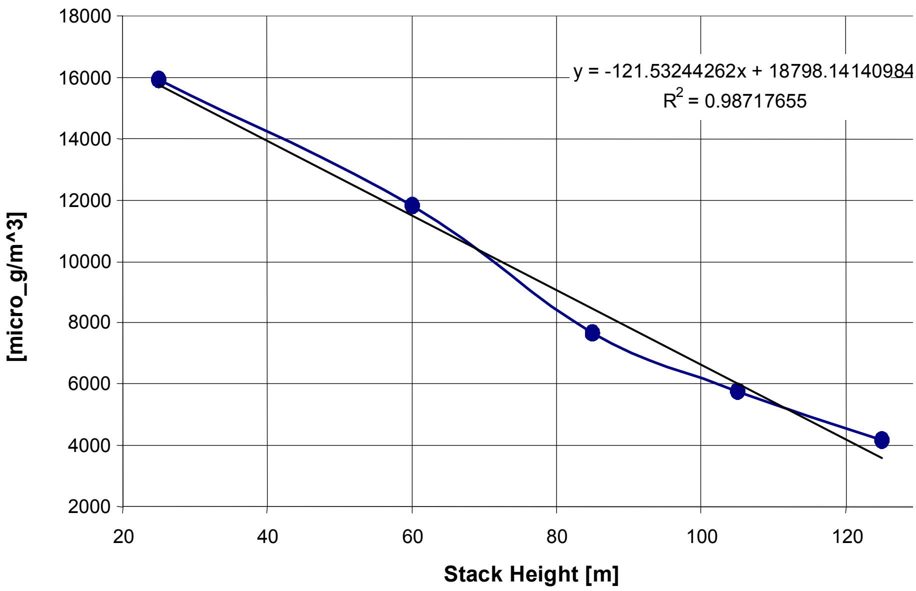

Fig. 5 The maximum surface SO_2 concentration ($\mu g/m^3$) for worst meteorological conditions and different stack heights

7. Conclusion

The town of Rijeka and its surroundings has third category of air quality, dangerous for human health, mainly due to emissions from nearby refinery and thermal power plant. The need for developing scenarios to avoid excessive pollution in unfavoranle meteorological conditions, motivated the study of evaluating maximum pollution for given emissions in various athmospheres. The Gaussian plume model was used to model SO_2 advection, disspersion and concentration distributions in the surrounding of Rijeka refinery. The genetic algorithm was used to find maximum pollution values within 12 km radius of surrounding terrain for all possible variations of meteorological conditions. Since the problem has many local maxima due to variable terrain height and wind directions genetic algorithm was the most suitable optimization technique. It was shown that 20 individuals population go through 20 generations to achive maximum pollution with cross-over and mutation probabilities 0,4 and 0,05.

The main conclusion is that proposed modelling of maximum pollution enables one to decide in which forecasted meteorological conditions the pollution is above accepted values and therefore determine the time interval when cheap law sulphur fuel should be used instead of cheap high sulphur fuel. The analysis of the influence of the stack height on surface pollution concentrations was carried out too, for all possible meteorological conditions and given pollutant emissions. The linear regression of the maximum pollution concentration, as a function of stack height, was established.

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Zoran Mrša, Prof. Dr. Sc.
Faculty of Engineering, University of Rijeka, 51000 Rijeka, Vukovarska 58, Croatia, Phone: 00385 51 651500 Fax: 00385 51 675818, e-mail: mrsa@riteh.hr

Zoran Čarija, Assist.
Faculty of Engineering, University of Rijeka, 51000 Rijeka, Vukovarska 58, Croatia, Phone: 00385 51 651500 Fax: 00385 51 675818, e-mail: zcarija@riteh.hr