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Numerical Modeling of Zestafoni City Dust Dispersion in case of Western Wind

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ABSTRACT

Dispersion of dust emited in the atmospheric air of Zestafoni city is numerically modelled and studied in case of weakt background western winds. Dust spatial distribution patterns are obtained, and the influence of orography, horizontal and vertical turbulence and advective processes on dust distribution in the atmosphere is analyzed.

Key words: dust, numerically modeling

1. Introduction

Pollution of national environmental objects and related health status of population even today remains one of the topical issues both in general and for Georgia. Ecological state of the environment is especially complicated in those places, where large industrial enterprises are located. Zestafoni city draws attention in this context, where the object of ferrous metallurgy – Georgian Manganese LLC and other smaller enterprises of this profile are situated. Major trunk highway and railway road connecting the East and Europe, as well as oil- and gas pipe-lines pass the mentioned territory. Thousands of big and small vehicles move back and forth everyday on Transcaucasus highway, which is component part of the Silk Road. As a result large quantities of dust, manganese and other solid and gaseous aerosols are emitted in the atmosphere.

Except the industrial and administrative functions this region has also economic, cultural-recreational and touristic importance. Zestafoni is known for high-quality grapes for production of champagne and dry wines. Especially is worth to mention cultural, touristic and recreational significance of Zestafoni city and its adjacent territories. Within a radius of 50 km from Zestafoni are located Tskhaltubo and Sairme – resorts of international importance, as well as tourist attractions – Borjomi-Kharagauli and Ajameti national parks, Sataplia, Prometheus cave etc. That is why the knowledge of dispersion and spatial distribution of polluting agents is of great practical importance in order to carry out environmental protection measures. Respectively, application of numerical modeling methods for dispersion of polluting agents in the atmosphere is very effective for solution of the mentioned problem.

In the works [1–12] non-stationary three-dimensional models of transfer-diffusion of substances in the atmosphere and methods of their numerical integration are elaborated. Models describe the processes of propagation, dynamics and kinetics of small admixtures and solid aerosols in the atmosphere.

2. Formulation of the Problem

In the presented work the propagation and distribution of a dust at easthern part of Imereti Region emited in an atmosphere of Zestafoni Town using the numerical model [12] are studied. For the purpose the area 94.4×72 km^2 of size is considered, in the centre of which Zestafoni Town is placed, while to the west the Kolchi Lowland, north and north-east the ridges of Racha and Likhi, south - the Meskheti Range are placed (Fig. 1). Orography height varies from 50 m to 2.5 km.

As it is shown by Fig. 1 the relief is very complicated here. That is why for proper description of atmospheric processes is convenient to use the relief follow coordinate system $\zeta=(z-\delta)/h$, where z is vertical orthogonal coordinate, $\delta=\delta_0(x,y)$, δ_0 - altitude of relief; h = H - δ ; $H(t,x,y)$ - tropopause height; t is a time; *x* and *y* – orthogonal coordinate axes directed to the east and north.

In the model [12] the Equation of atmospheric dust propagation in the taken (x, y, ζ) coordinate system is written in following form

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+(\tilde{w}-\frac{w_0}{h})\frac{\partial C}{\partial \zeta}=\mu\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+\frac{1}{h^2}\frac{\partial}{\partial \zeta}\nu\frac{\partial C}{\partial \zeta}\quad , \qquad (1)$$

where C is dust concentration in atmosphere u, v, w and $\tilde{w}$ are the components of wind velocity along x, y, z and ζ axes; w_o - rate of dust particle sedimentation determined according to Stoke's formula; μ and ν – kinematic coefficients of horizontal and vertical turbulence; values of wind velocity and turbulence coefficients in surface layer of atmosphere and in free atmosphere are defined by [12].

The data of National Environment Agency [13] are taken as the initial and boundary values of the monthly average concentrations at the height of 2 m in atmosphere in the territory Zestafoni.

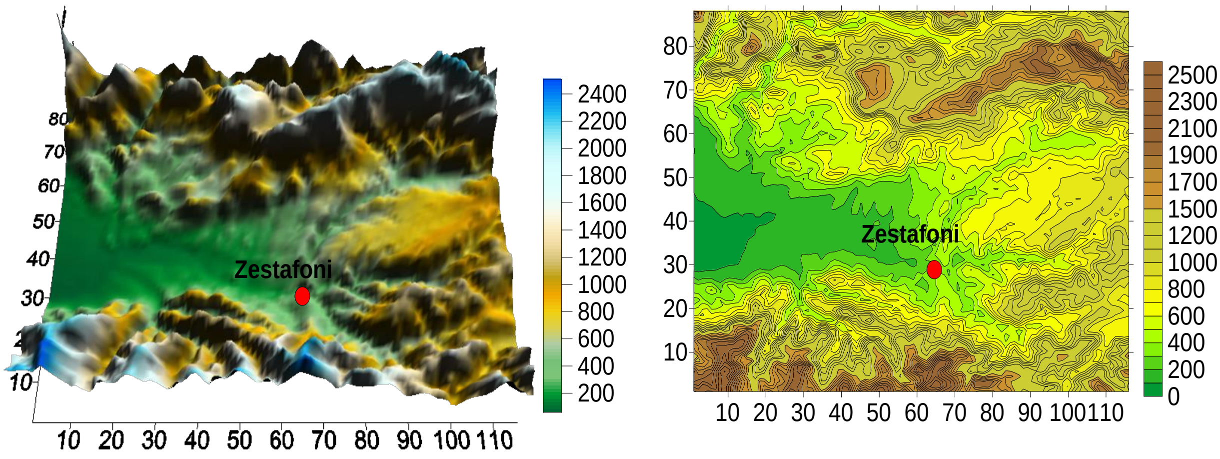

Fig. 1. The Zestafoni District topography and relief (heights in m).

Numerical integration of equation (1) with the use of corresponding initial and boundary conditions is executed using Crank-Nicolson method and using the splitting method and monotonous scheme [1]. The rectangular numerical grid with 118x90x31 points and the horizontal step equal to 800 m and the vertical step equal to 1/31 were used. In surface layer 17 vertical grid points with grid steps from 2 to 15 m are taken. Time step is 10 sec. The numerical integration is continued more than 2 days.

3. **Results of modeling**

Spatial distribution of dust concentrations in June during background weak western wind (1 m/c on z =10 m), when t = 16 hours, obtained by calculations, is shown on Fig. 2. Values are calculated in units of daily maximum allowable concentration (MAC = 0.15 mg/m^3) of dust.

As is seen from the Figure 2, dust concentrations at a height of 2 and 100 m are maximal at the territory of cities and in their direct vicinity (Fig. 2, a, b). In surface layer of the atmosphere dust cloud has the form of vertical deformed cylinder. Maximum concentration (1-2 MAC) is obtained directly in the vicinity of city at 2 km height, approximately in 12 km^2 area. This zone is gradually decreases with height increase and at 100 m height maximum concentration is obtained approx in 3 km^2 area. Dust is distributed both in windward direction and in the direction opposite to wind. Dust dispersion area in opposite direction is negligibly small that is caused by reciprocal action of horizontal turbulent and advective dispersion. To the contrary, in windward direction processes of advective and turbulent transfer have one and the same direction. Cloud form obtained by calculations shows that in the process of dust dispersion in surface layer of the atmosphere the share of turbulent diffusion and horizontal advection is roughly the same according to its value.

In the boundary atmospheric layer (Z > 100m) the area of dust distribution enlarges. Dust advection exceeds turbulent diffusion. As a result dust cloud becomes significantly deformed and takes oblong form, especially in the zones of local wind velocity increase – along the valleys of Kvirila and Chkherimela rivers (Fig. 2, c, d).

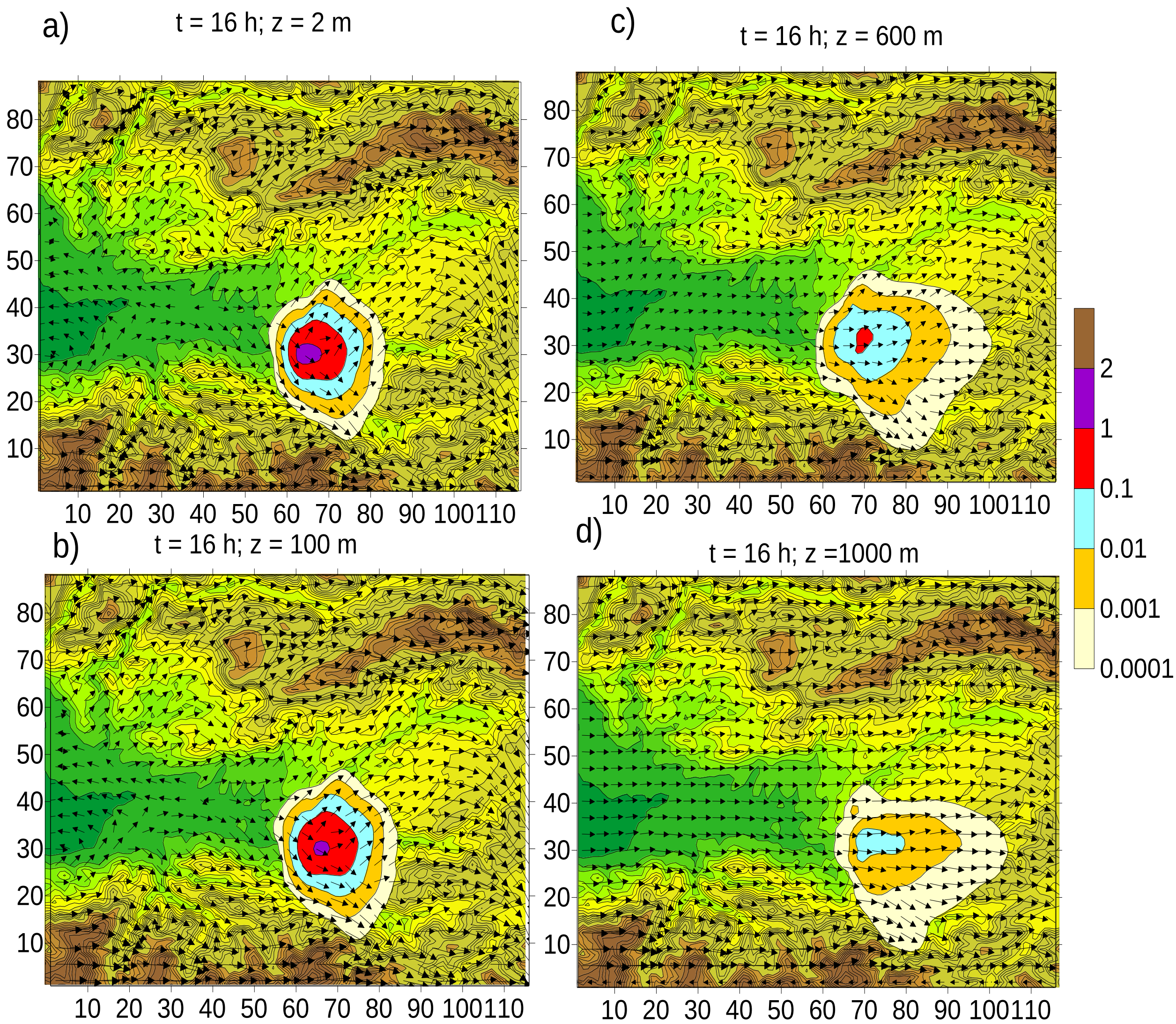

Fig. 2. Distribution of wind velocity and dust concentration C (in units of MAC) at z = 2, 100, 600 and 1000 m height from earth surface, when t = 16 h.

Mentioned effects are obviously seen on Fig. 3, where the distribution of zonal component of wind velocity and concentration of dust are shown in XOZ plane of zonal cross-section of atmosphere at 3 km height, which passes acros on Zestafoni (y=31). It is seen from Fig. 3 that dust is dispersed in 2 km surface layer of the atmosphere. 0,1-1 MAC concentration values are obtained in approx. 9 km long and 0,8 km thick layers of atmospheric air, 0,01-0,1 MAC values in 15 km long and 1,2 km thick layer and 0,01-0,001 MAC – in 20 km long and 2 km thick layer. In the windward side the dust is dispersed approx. at 5 km distance, while in the leeward side - at 20 km distance. Dust concentration distribution in the cloud is not uniform. Concentration is maximum in the central part of cloud and gradually decreases towards the periphery.

When t = 28h, dust distribution pattern in the atmosphere (Fig. 4) is qualitatively similar to distribution, which is shown on Fig. 2. The difference is quantitative one. During 12 hours took place dust transfer at larger territory and cloud becomes deformed according to daily variation of wind velocity. In 2-100 m layer dust was predominantly dispersed in north and south directions along the valleys of Kvirila and Chkherimela rivers. Above 100 m dust is dispersed basically in east and south-east directions.

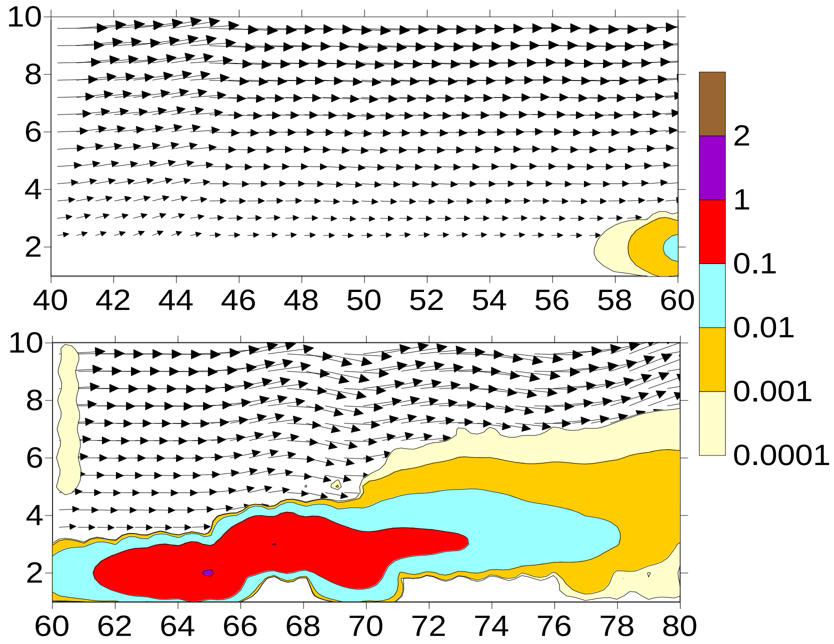

Fig. 3. Distribution of wind velocity zonal component and dust concentration C (in units of MAC) in atmospheric layer at 3 km height above Zestafoni city (y=31) in XOZ plane .

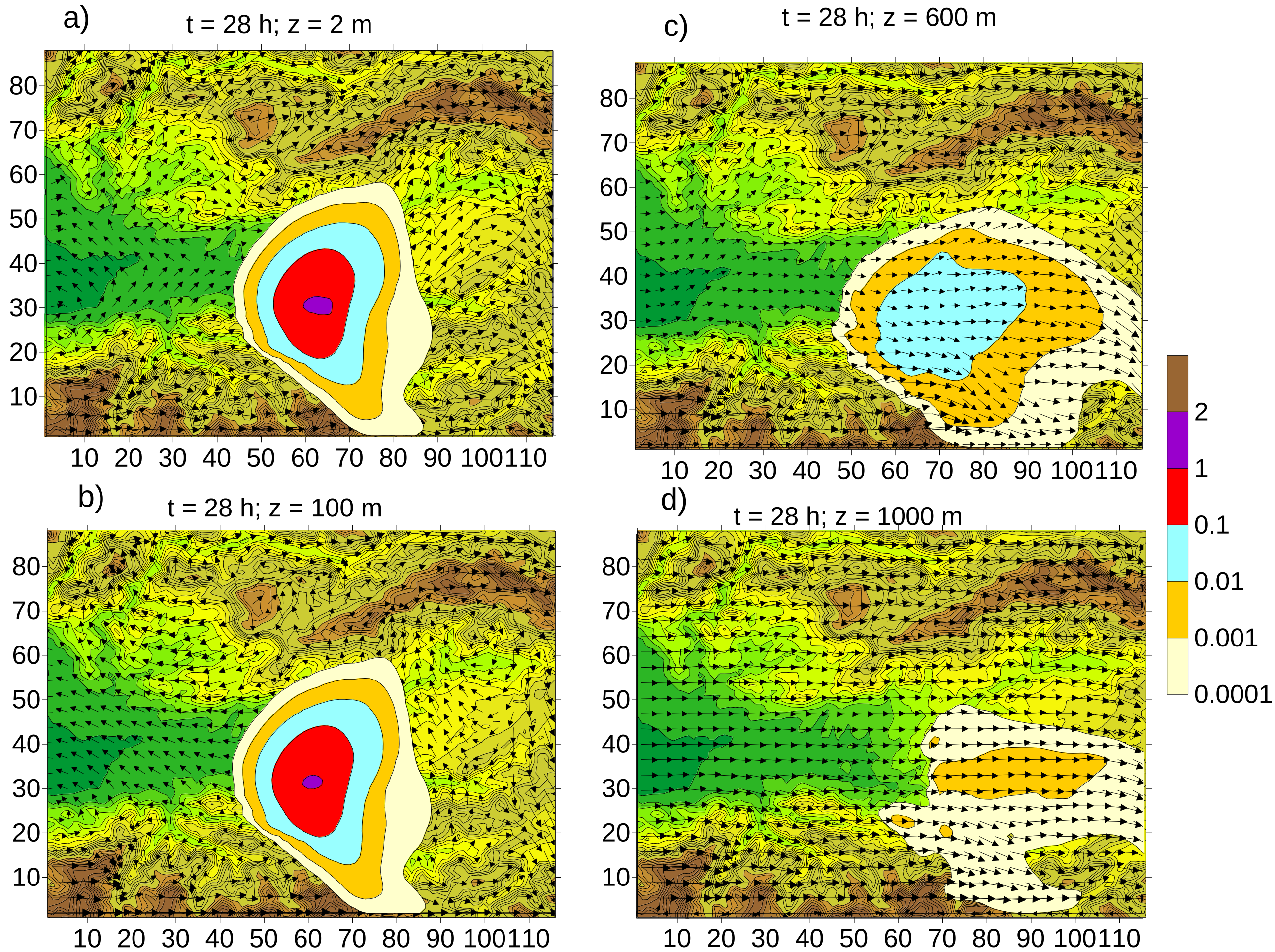

Fig. 4. Distribution of wind velocity and dust concentration C (in units of MAC) at z = 2, 100, 600 and 1000 m heights, when t = 28 h.

Along with horizontal dust transfer occurs dust deposit at the earth surface. On Fig. 5 is shown surface density of the dust deposited on the surface during 24 hours. It is seen that at 200 km^2 territory adjacent to Zestafoni the dust quantity deposited on 1 sq.m. area varies from 200 mg to 1 mg.

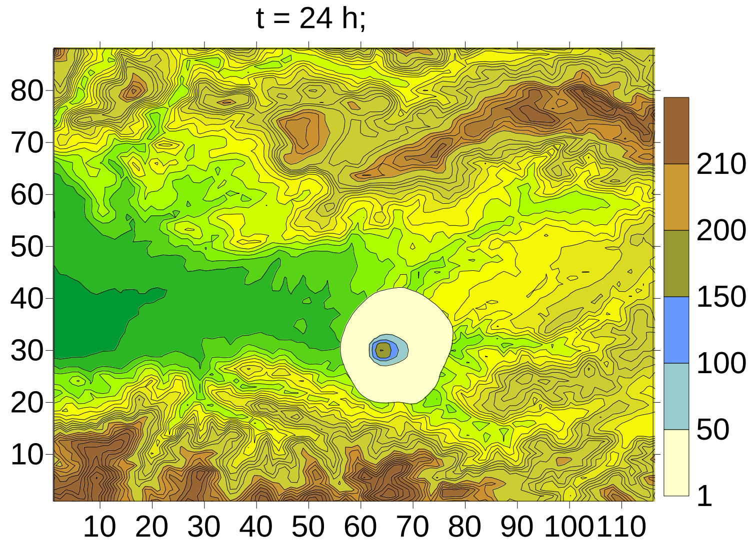

Fig. 5. Surface density of the dust deposited on the soil (mg/m^2).

3. Conclusion

Thus, a carried out numerical modeling has manifested some meteorological peculiarities, which are characteristic for dust dispersion process under urban conditions in Zestafoni region. In case of light western winds dust concentration in 100 m surface layer of the atmosphere above Zestafoni is roughly the same. Above the surface atmospheric layer this concentration rapidly decreases and at 3 km height becomes equal to zero. In vertical profile dust concentration is bigger in the centre of cloud and is getting smaller towards the periphery.

Orography causes deformation of pollution cloud. On the windward side of Likhi ridge, due to orography influence dust dispersion eastward is inhibited and starts to shift predominantly in north-east and south-east directions along the valleys of Kvirila and Chkherimela rivers. At that, on the windward side of the ridge upward movement caused by orography decreases dust sedimentation process. As a result the density of deposited dust at large distances from dust pollution sources is negligible.

Comparison of results obtained by calculations with actual results is very important. Natural observations at the territory adjacent to Zestafoni are scheduled for this end.

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ქ. ზესტაფონის დამტვერიანების გავრცელების რიცხვითი მოდელირება დასავლეთის ქარის შემთხვევაში

ა. სურმავა

რეზიუმე

რიცხობრივად მოდელირებული და შესწავლილია ქ. ზესტაფონში არსებულიი მტვერის გავრცელება ფონური სუსტი დასავლეთის ქარის შემთხვევაში. მიღებულია მტვერის სივრცული განაწილების სურათები, გაანალიზირბულია ოროგრაფიის, ჰორიზონტალური და ვერტიკალური ტურბულენტობისა და ადვექციური პროცესების გავლენა მტვერის გავრცელებაზე ატმოსფეროში.

Численное моделирование распространения запыленности воздуха г. Зестафони при западном ветре

А. Сурмава

Резюме

Численно смоделировано и изучено распространение в воздухе городской пыли г. Зестафони при фоновом западном ветре. Получены картины пространственного распределения пыли, проанализированы влияния орграфии, горизонтальной и вертикальной турбулентности и процесса адвекции на диффузию пыли в атмосфере.