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Numerical Modelling of Dust Propagation in the Atmosphere of Tbilisi City in Case of Western Background Light Air

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Abstract**—**Tbilisi, a large city of the South Caucasus, is a junction point connecting Asia and Europe, Russia and republics of the Asia Minor. Over the last years, its atmosphere has been experienced an increasing anthropogenic load. Numerical modeling method is used for study of Tbilisi atmospheric air pollution. By means of 3D non-linear non-steady numerical model a peculiarity of city atmosphere pollution is investigated during background western light air. Dust concentration spatial and time changes are determined. There are identified the zones of high, average and less pollution, dust accumulation areas, transfer directions etc. By numerical modeling, there is shown that the process of air pollution by the dust proceeds in four stages, and they depend on the intensity of motor traffic, the micro-relief of the city, and the location of city mains. In the interval of time 06:00-09:00 the intensive growth, 09:00-15:00 a constancy or weak decrease, 18:00-21:00 an increase, and from 21:00 to 06:00 a reduction of the dust concentrations take place. The highly polluted areas are located in the vicinity of the city center and at some peripherical territories of the city, where the maximum dust concentration at 9PM is equal to 2 maximum allowable concentrations. The similar investigations conducted in case of various meteorological situations will enable us to compile the map of background urban pollution and to elaborate practical measures for ambient air protection.

Keywords**—**Numerical modelling, source of pollution, dust propagation, western light air.

I. Introduction

Tbilisi is one of the biggest cities of the South Caucasus, an administrative and touristic center of Georgia. Protection of its atmospheric air from pollution is a critical ecological and social task. Some scientific works are devoted to the problem of Tbilisi atmospheric air purity. They reflect the experimental and theoretical studies of city atmosphere pollution [1]-[3].

Tbilisi has highly complex relief. The city is confined by high-mountain massifs from the west and east; a narrow Mtkvari valley connects it with the external space from the north and lowland territories – from the south. Based on theoretical propositions, we have to suppose that local air circulations formed under the influence of city relief do not promote the process of city atmosphere entire self-purification, especially in background western and eastern winds. That's why, to elaborate substantiated recommendations for atmospheric air purity improvement and to carry out practical measures, it is necessary to theoretically explore the peculiarities of time and spatial distribution of polluting agents in the city atmosphere, especially during unfavorable meteorological conditions. For this purpose, Tbilisi city pollution is numerically modeled and analyzed in the case of background eastern winds in works [4]-[6].

In the presented article, with the purpose of further extension of studies, the city atmosphere pollution is numerically studied in light background western winds. A numerical model of atmospheric processes' development and polluting agents' distribution in the Caucasus is used for these goals [4].

II. Brief Description of Problem Statement

The territory of Tbilisi and its surroundings 30.6x24 km^2 in the area is considered. To mathematically correctly describe the dynamic fields of atmosphere and meteorological parameters under conditions of complicated city topography, a relief-following coordinate system ($t, x, y, \zeta = (z-\delta)/h$) is used. Here t is time, x, y, and z are the Cartesian coordinates directed along parallel, meridian, and vertically upward, respectively, ζ is a vertical non-dimensional coordinate required at a right angle to relief surface, $\delta(x, y)$ is a relief altitude above sea level, $h = H - \delta$ – troposphere thickness, $H(t, x, y)$ – tropopause height.

The equation for dust concentration change in the selected coordinate system will be written in the following form

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

where C is an ingredient concentration; u, v, w and $\tilde{w}$ – parts of wind velocity along x, y, z, and ζ axes, w_o – dust deposition rate, $F(t, x, y, \zeta)$ is a rate of dust emission in the atmosphere; μ and ν – coefficients of horizontal and vertical turbulence. Wind velocity parts and coefficients of turbulence are calculated using numerical integration of the equation [3], [4].

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Dust dispersion is modeled in the free atmosphere and the surface layer of the atmosphere through numerical integration of (1) using corresponding initial and boundary conditions. Numerical grid steps are equal to 300 and 400 m along the x and y axes, respectively. A vertical step in the free atmosphere equals 1/31. In the atmosphere's 100 m thick surface layer, the vertical step varies from 0.5 to 15 m. Time step is 1 sec. Calculations are made for a 3-day period. A case of a western background light air under dry weather conditions of June is considered. Wind velocity changes from 1 m/sec (at 100 m height from earth surface) to 20 m/sec (in the tropopause, 9 km), relative atmospheric humidity is 50%.

It is assumed that the atmosphere is polluted by the dust that originated at city mains and resulted from motor transport traffic in the streets. Its quantity varies in time and is determined via assessment of stationary surveillance data and traffic intensity. Tbilisi relief is shown in Fig. 1. The distribution of pollution sources is marked in dark blue. Sources are situated at central city mains and urbanized territories.

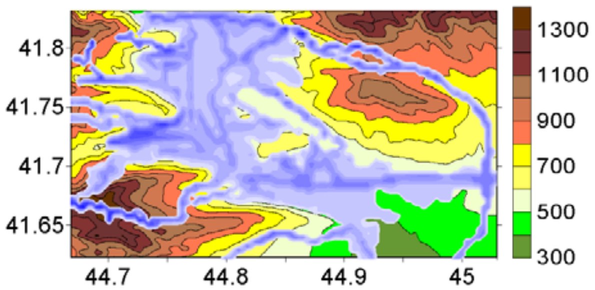

Fig. 1 Tbilisi terrain heights (m) and distribution of pollution sources. Accurate geographic coordinates are marked off the axes

III. Numerical Modeling of Results

In Fig. 2 is shown a spatial distribution of dust concentration and wind velocity obtained through calculations at 2, 100, and 600 m altitudes above the earth surface, when t = 0, 3, and 6 hours. Concentration is given in terms of one-off maximum allowable concentration (MAC = 0.5 mg/m^3). It is seen from Fig. 2 that dust concentration reduction takes place in 0-6 h time interval. When t = 0 h, dust concentration is relatively high at z = 2 m in the central and south-eastern parts of the city at territories located along the Mtkvari valley. The concentration value reaches 0.4 MAC in these places. With distance from high pollution area, the concentration gradually reduces, and its value in the peripheral parts of the city becomes equal to 0.001 MAC. The city atmosphere self-purification process lasts until t = 6 h. When t = 6 h, the maximum value of concentration 0.1 MAC is obtained in the vicinity of some places confined by orographic barriers.

Within 0-6 h interval, the vertical dust distribution is featured by a peculiarity – maximum values of concentration at 100 m height are higher than obtained at 2 and 600 m height. This effect probably is associated with the lifting of heated air in the second half of the day. Heated air mass brings along a dust mass and causes its accumulation in the upper limit of the surface layer. As a result, when t = 0 h, the concentration value reaches 0.7 MAC at 100 m height above the central part of the city. Over time, convective motion is getting weaker, and pollution level gradually reduces by diffusive and advective transfer. As a result, when t = 6 h, the maximum value of dust concentration drops to 0.1 MAC.

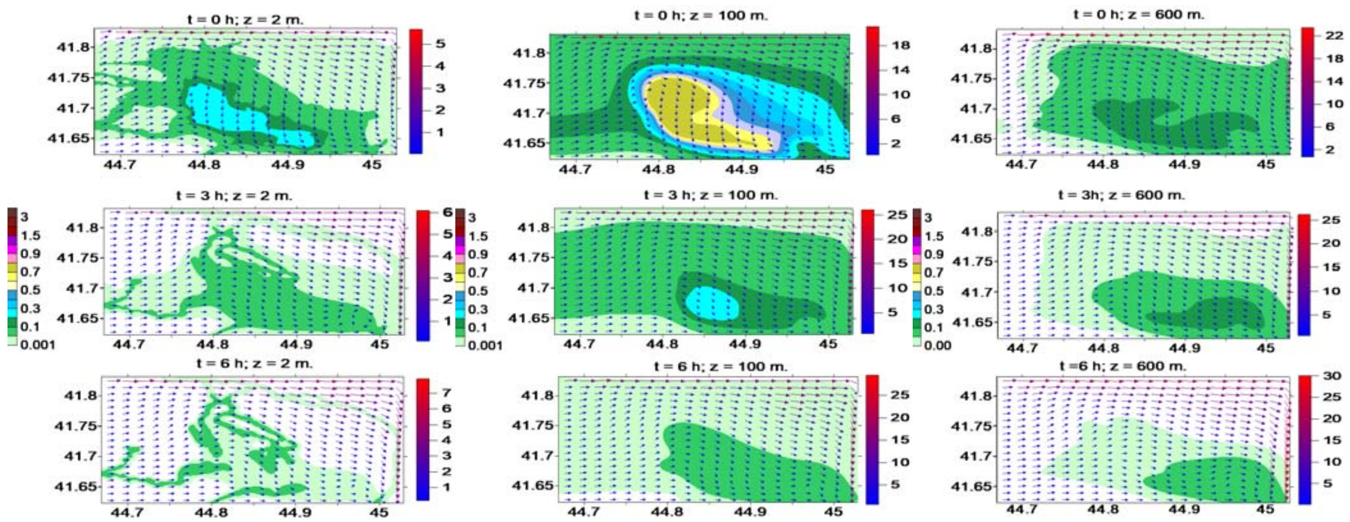

Fig. 2 Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 0, 3, and 6 h, at 2, 100, and 600 m height above the earth surface

After t = 6 h, the quantity of dust hit the atmosphere increases along with the rapid growth of motor traffic intensity. Quick pollution of city atmosphere takes place. When t = 9 h, dust concentrations at 2 m above the earth's surface increase directly in the surroundings of pollution sources and in their proximity – along with the city mains (Fig. 3).

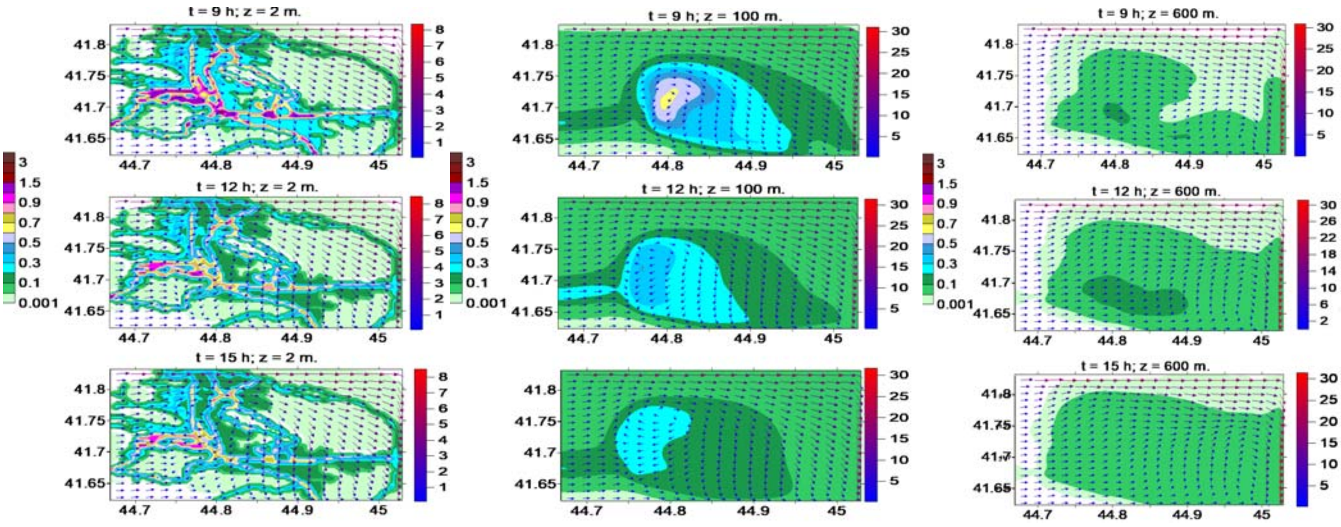

Fig. 3 Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 9, 12, and 15 h, at 2, 100, and 600 m height above the earth surface

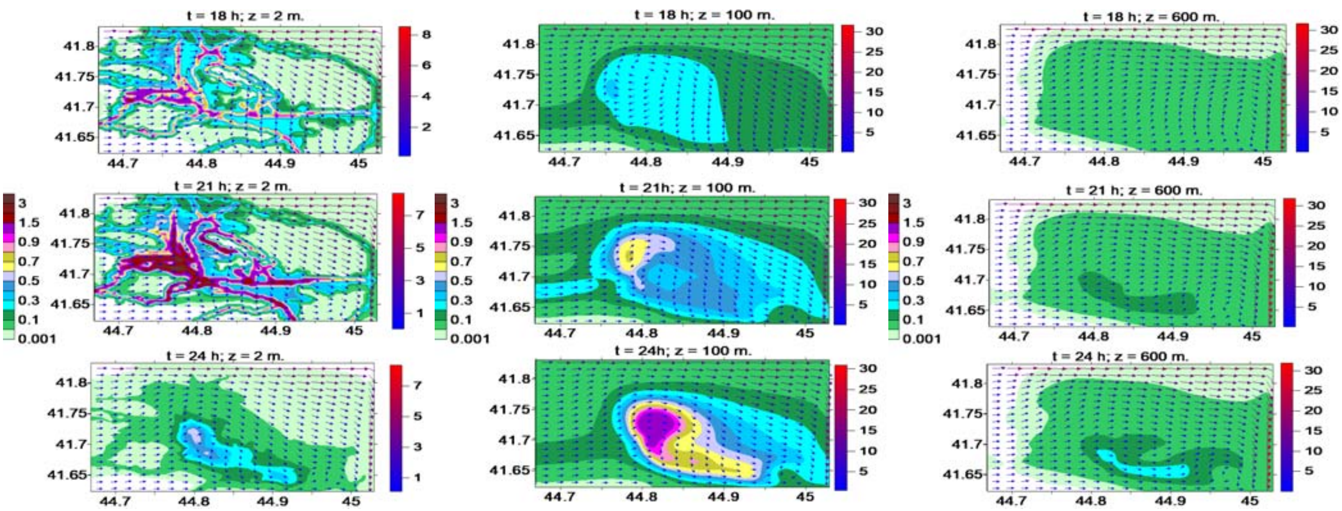

Fig. 4 Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 18, 21, and 24 h, at 2, 100, and 600 m height above the earth surface

Obtained distribution of concentration is similar to the distribution pattern taken in eastern light air [4]. At the same time, there is some difference. In particular, in the case of eastern background light air at 2 m height at 9 a.m., the high pollution areas (0.9-1.5 MAC) are located both in the central part of the city and in the vicinity of city mains in peripheral Gldani, Didube, Temka, and Didi Digomi districts.

In Western background wind, dust concentration values in these areas are significantly smaller and vary within 0.5-0.9 MAC wherein City center, Vake, Saburtalo, and Ortachala districts remain areas of high dusting. The mentioned difference between spatial distributions in western and eastern background light airs is caused by mutually antithetic effects of airflow and terrain interaction in the windward and leeward parts of orographic barriers.

Within a period between 9:00 and 15:00, the dust concentration is maximal at 9:00 and slightly reduces within an interval of 12:00-15:00. Saburtalo, Vake, Ortachala, and separate areas of Gldani Massive and Vakhtang Gorgasali Avenue are among the maximum pollution levels. Ground-level concentration growth is accompanied by its vertical diffusion formed from the local horizontal vortex and convective motion. At 100 m height above the earth's surface, the concentration is maximal at 9 a.m. (0.6 MAC) and gradually reduces with time.

After t = 15 h, at z = 2 m height, in contradistinction from the eastern background light air, the second stage of pollution level growth begins, which lasts until t = 21 h (Fig. 4). Pollution level increases in the 1 km thick boundary layer of the atmosphere. This growth is incredibly intense in the lower part of the surface layer, in the surroundings of city mains situated in the center of the city and peripheries. The highways of Georgian Military Road and Tbilisi by-pass road are the only exception. At 2 m height, the maximum value of dust concentration reaches and even surpasses 2 MAC in the central part of Tbilisi.

After t = 21 h, the stage of ground-level concentration reduction begins, which lasts until 6 a.m. The maximum value of ground-level concentration (0.7 MAC) coincides with t = 24 h, while in the ensuing moments it reduces to 0.1 MAC.

At 100 m height above the earth's surface, the concentration growth process is more longstanding and lasts until t = 24 h. At this time, the process of intense vertical convective transfer causes a rapid increase of pollution level up to 1.5 MAC at 100 m height.

Figs. 5 (a)-(c) show the vertical distribution of dust concentration in different moments. The dominant directions of dust propagation are seen from Fig. 5 and, respectively, one may determine the corresponding dynamic processes causing dust transfer. We can conclude that the local circulation processes taking place at the same territory but in different moments may have different nature – advective, convective, or turbulent-diffusive. Consequently, dust distribution forms vary, as well. Distribution is as follows: ground-level light convective (t = 9 h, Y =41.69°), developed convective (t = 24 h, Y = 41. 69° and Y = 41. 72°) and advective-diffusive (t =21 h, Y = 41.77°). In the 0-50 m layer, the process of convective dust transfer is dominant, while above 50 m an advective-diffusive transfer prevails.

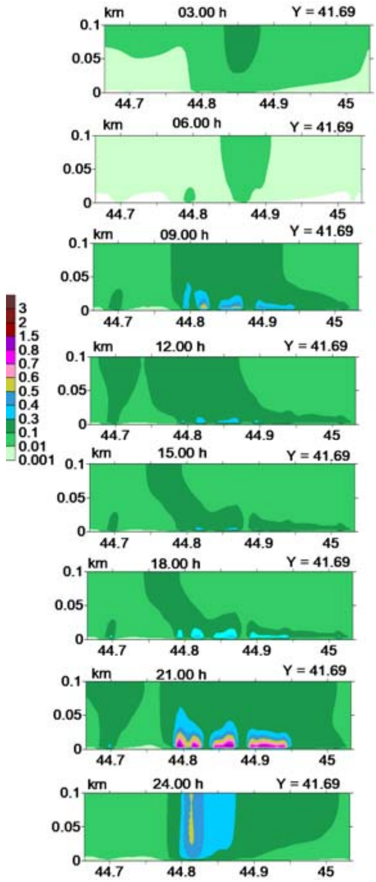

Fig. 5 (a) Dust concentration (MAC) distribution within 24 hours in the surface layer of the atmosphere in three vertical planes located along a parallel (Y = 41.69°)

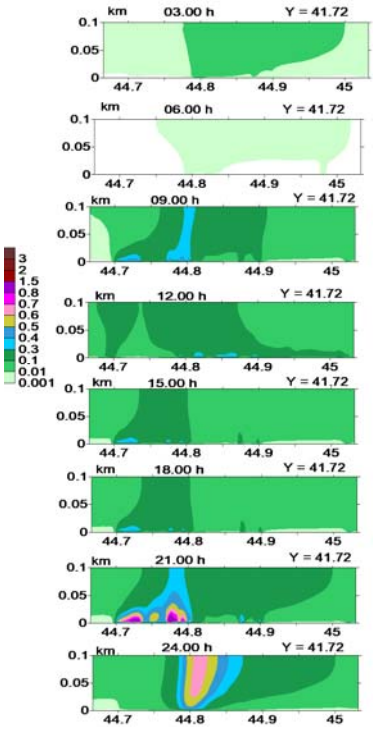

Fig. 5 (b) Dust concentration (MAC) distribution within 24 hours in the surface layer of the atmosphere in three vertical planes located along a parallel (Y = 41. 72°)

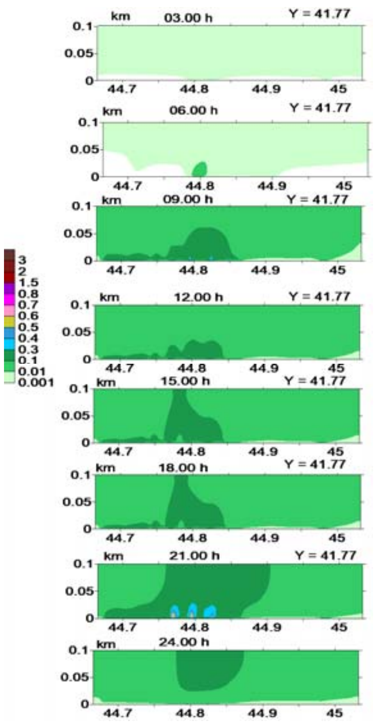

Fig. 5 (c) Dust concentration (MAC) distribution within 24 hours in the surface layer of the atmosphere in three vertical planes located along a parallel (Y = 41. 77°)

IV. Conclusion

Kinematics of dust change originated by motor transport at the territory of Tbilisi is explored in case of light background western wind. Diurnal patterns of dust spatial distribution and propagation peculiarities are studied. It is obtained that in the process of dust concentration change in the atmosphere, four stages can be singled out in the heavily polluted areas: 21.00-6.00h – atmosphere self-purification; 6.00-9.00 – the rapid growth of concentration; 9.00-15.00 – slight reduction or constancy of concentration; 15.00-21.00 – concentration growth.

Based on the wind velocity and concentration fields analysis, it is accepted that the spatial distribution of heavily polluted areas depends on the location of city mains, on the one hand, and local circulation system formed due to dynamic influence of the relief and daily variations of the thermal regime at the underlying surface, on the other. The differences are revealed that may have a place in the spatial distribution in light eastern and western background winds.

Acknowledgment

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