

Numerical investigation of meso- and microscale diffusion of Tbilisi dust

A. Surmava^{ab}, L. Intskirveli^{a*}, V. Kukhalashvili^b, N. Gigauro^a

^aInstitute of Hydrometeorology at the Georgian Technical University, 150-a D.Aghmashenebeli Ave., Tbilisi, 0112, Georgia

^bM. Nodia Institute of Geophysics at the Iv. Javakhishvili Tbilisi State University, 1, M.Aleksidze Str., Tbilisi, 0171, Georgia

Received: 12 March 2020; accepted: 28 May 2020

ABSTRACT

Meso- and micro-scale processes of dust propagation in the atmosphere of the city of Tbilisi and its surrounding territory are modelled using 3D regional model of atmospheric processes and an admixture transfer-diffusion equation. Terrain-following coordinate system is used with the purpose of taking into account the impact of very complicated relief on the atmosphere pollution process. It is obtained via modelling that meso-scale propagation of the dust substantially depends on relief form of surrounding territory, background wind speed and its direction. In the second half of the day the mountain-and valley circulation process due to Tbilisi region relief in conditions of background light air causes a change of dust transfer direction in the lower 100m surface layer. The dust dissipated from Tbilisi city in the atmosphere is basically concentrated in lower 600 m of the boundary layer and it is propagated in the narrow zone with length about more than 80 km and width 20-24 km. Modelling of dust micro-scale diffusion process in Tbilisi city shows that the maximum concentrations 1.5-2.0 MAC are obtained from 3.00 p.m. to 9.00 p.m. in vicinity of central avenues and in the southern part of the city. The spatial dust distribution in the lower part of the atmospheric surface layer depends on vehicle traffic intensity, as well as on spatial distribution of highways, and micro-orography of the city and surrounding territories.

Keywords: Atmosphere, Pollution, Dust, Meso-scale, Micro-scale, Numerical Modelling.

*Corresponding author: Liana Intskirveli; E-mail address: intskirvelebi2@yahoo.com

1. INTRODUCTION

In big cities and industrial centers, the human health significantly depends on the atmosphere air purity level [1,2]. According to the World Health Organization “worldwide, ambient air pollution contributes to 7.6% of all deaths in 2016” [3]. Respectively, study of environmental objects pollution and its abatement is very important ecological and human task for healthcare. This problem is especially urgent for industrial centers and big cities that are featured by abundance of pollution sources. Tbilisi – an administrative center of Georgia and one of the biggest cities of the South Caucasus is no exception. Though, Tbilisi is not ranked among the world 500 most polluted cities [4], but according to the data of the Ministry of Environmental Protection and Agriculture of Georgia, dust and microparticle concentrations frequently exceed the maximum permissible levels [5]. Tbilisi is the main junction point of Great Silk road connecting Europe and Asia, and it connects Russia with Asia Minor as well. Thousands of heavy and light vehicles move everyday through it. Hundreds of thousands of cars drive on its narrow and compound shaped streets. Microparticles excretion from cars, dust emission from enterprises, pavement surfaces and other objects is the main source of the city pollution. Dust entering the atmosphere under action of variable dynamic fields formed due to complex terrain extends over the city, cultural and recreational zones located at surrounding territories and causes atmospheric air pollution and human health deterioration.

Currently, atmospheric air pollution studies using field measurements [6, 7] mathematical diagnostic and prognostic models [8-14] are carried out for many cities of the world.

In the presented article, for the first time the dust propagation kinematics in the atmosphere of Tbilisi and its surrounding territories will be studied. For these purposes a numerical model of mesoscale and local atmospheric processes in the Caucasus is used [13, 14].

2. STATEMENT OF THE PROBLEM

2.1 Mathematical statement of problem

Tbilisi has a complex terrain. From three sides it is confined by the Greater and Smaller Caucasus Mountain Ranges, while from the south-east side – by lowland. Terrain height in the city and surrounding territories varies from 300 m to 2 km (above sea level). In the city some of the small mountains and valley are located. Therefore, for correct description of the spatial-temporary evolution of the hydrometeorological fields and concentrations of polluting substance in the atmosphere over the complex terrain territory the following system of equations written in the terrain-following coordinate system is used [8]:

(a) For atmosphere:

$$\begin{aligned} \frac{du}{dt} &= -\frac{\bar{P}}{\rho} \frac{\partial \varphi}{\partial x} + lv + g(1 + 0.61q)\vartheta \frac{\partial z}{\partial x} + \frac{\partial}{\partial x} \mu \frac{\partial u}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial u}{\partial y} + \frac{1}{\rho h^2} \frac{\partial}{\partial \zeta} \rho v \frac{\partial u}{\partial \zeta}, \\ \frac{dv}{dt} &= -\frac{\bar{P}}{\rho} \frac{\partial \varphi}{\partial y} - lu + g(1 + 0.61q)\vartheta \frac{\partial z}{\partial y} + \frac{\partial}{\partial x} \mu \frac{\partial v}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial v}{\partial y} + \frac{1}{\rho h^2} \frac{\partial}{\partial \zeta} \rho v \frac{\partial v}{\partial \zeta}, \\ \frac{\partial \varphi}{\partial \zeta} &= \frac{g}{RT} (1 + 0.61q)\vartheta h, \\ \frac{\partial h}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} + \frac{\partial \tilde{w}h}{\partial \zeta} + \frac{1}{\rho} \frac{dp}{dz} wh &= 0, \\ \frac{\partial \vartheta}{\partial t} + u \frac{\partial \vartheta}{\partial x} + v \frac{\partial \vartheta}{\partial y} + \tilde{w} \frac{\partial \vartheta}{\partial \zeta} + Sw &= \frac{\partial}{\partial x} \mu \frac{\partial \vartheta}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial \vartheta}{\partial y} + \frac{1}{\rho h^2} \frac{\partial}{\partial \zeta} \rho v \frac{\partial \vartheta}{\partial \zeta} + \frac{L}{\rho C_p} \phi_{con}, \\ \frac{\partial q}{\partial t} + u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y} + \tilde{w} \frac{\partial q}{\partial \zeta} &= \frac{\partial}{\partial x} \mu \frac{\partial q}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial q}{\partial y} + \frac{1}{h^2} \frac{\partial}{\partial \zeta} v \frac{\partial q}{\partial \zeta} - \varphi_{con}, \\ \frac{\partial m}{\partial t} + u \frac{\partial m}{\partial x} + v \frac{\partial m}{\partial y} + \tilde{w} \frac{\partial m}{\partial \zeta} &= \frac{\partial}{\partial x} \mu \frac{\partial m}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial m}{\partial y} + \frac{\partial}{h^2} v \frac{\partial m}{\partial \zeta} + \varphi_{con}, \\ \frac{d}{dt} &= \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} + v \frac{\partial}{\partial y} + \tilde{w} \frac{\partial}{\partial \zeta}, \quad w = \frac{\partial z}{\partial t} + u \frac{\partial z}{\partial x} + v \frac{\partial z}{\partial y} + \tilde{w}h. \end{aligned} \quad (1)$$

(b) For active soil layer:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z} D(C) \frac{\partial C}{\partial z} - \frac{\partial E(C)}{\partial z}, \quad \frac{\partial T_{soil}}{\partial t} = K_{soil} \frac{\partial^2 T_{soil}}{\partial z^2}, \quad \text{at } \delta_0 > z > Z_{soil}; \quad (2)$$

where t is time; x , y and z are the axes of the Cartesian coordinate directed to the east, north and vertically upwards, respectively; $\zeta = (z - \delta)/h$ is the dimensionless vertical coordinate; $\delta(x, y)$ is the height of the relief; $h = H - \delta$; $H(t, x, y)$ is the height of the tropopause, which height is changed around 9 km; u, v, w and $\tilde{w}$ are the wind velocity components along the axes x, y, z and ζ , respectively; $\vartheta = (T' + \bar{T})/\bar{T}$, and $\varphi = (P' + \bar{P})/\bar{P}$ are the analogues of temperature and pressure, respectively; $\bar{T} = 300K$; T' and P' are the deviations of temperature and pressure from the standard vertical distributions $P'(t, x, y, z) = P(t, x, y, z) - \bar{P}(z) - \bar{\bar{P}}(t, x, y, z)$; $T' = T(t, x, y, z) - \bar{T} + \gamma z - \bar{\bar{T}}(t, x, y, z)$; T and P are the temperature and pressure of the atmosphere, respectively; $\bar{T} - \gamma z$ and $\bar{P}(z)$ are the standard vertical distributions of the temperature and pressure, respectively; γ is the standard vertical temperature gradient; $\bar{\bar{T}}$ and $\bar{\bar{P}}$ are the background deviations of the temperature and pressure from standard vertical distributions; T_{soil} is the soil temperature; q and m the mass content of the water vapor and cloud water; C is the volume content of soil water; $\rho(z)$ is the standard vertical distribution of the density

of dry air; g is the gravitational acceleration; R is the universal gas constant for dry air; C_p is the specific heat capacity of dry air at constant pressure; S is the thermal stability parameter; L is the latent heat of condensation; ϕ_{con} is the condensation rate; D is the diffusion coefficient of water in soil; E is the filtration coefficient of water in a soil; K_{soil} is the thermal diffusivity coefficients of soil;

$$\mu = \Delta x \Delta y \sqrt{2 \left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2 + 2 \left(\frac{\partial v}{\partial y} \right)^2} \quad \text{and} \quad v = (0.05 \Delta z)^2 \sqrt{\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 - \frac{g}{\rho} \frac{\partial \rho}{\partial z}}$$

are the horizontal and vertical turbulent diffusion coefficients, respectively [15, 16]. Where Δx , Δy and Δz are the numerical grid steps along the axes x , y , and z , respectively.

For the meteorological fields in the surface layer of atmosphere with thickness of 100 m there is used a parameterization method [17]:

$$\begin{aligned} \frac{\partial |\vec{u}|}{\partial z} &= \frac{u_*}{\chi z} \varphi_u(\zeta), \quad \frac{\partial p}{\partial z} = \frac{p_*}{z} \varphi_p(\zeta), \quad (p = \vartheta, q), \quad \zeta = \frac{z}{L}, \quad L = \frac{u_*^2}{\lambda \chi^2 \vartheta_*^2}, \\ |\vec{u}| &= \frac{u_*}{\chi} f_u(\zeta, \zeta_u), \quad p - p_0 = p_* f_p(\zeta, \zeta_0), \quad \zeta_u = \frac{z_u}{L}, \quad \zeta_0 = \frac{z_0}{L}, \quad \text{if } z \leq z_{\text{sur}}, \end{aligned} \quad (3)$$

where z_u – is the roughness; z_p – parameter, which depends on properties of underlying surface and is a known function; z_{sur} and z_0 – known constants; u_* – friction velocity; λ and χ – buoyancy parameter and von Kármán constant; $\varphi_u(\zeta)$, $\varphi_p(\zeta)$, $f_u(\zeta, \zeta_u)$ and $f_p(\zeta, \zeta_0)$ are the universal functions of similarity theory.

To describe the diffusion of contaminant in the atmospheric surface layer and in the free atmosphere, the following equation is used

$$\frac{\partial \text{Con}}{\partial t} + u \frac{\partial \text{Con}}{\partial x} + v \frac{\partial \text{Con}}{\partial y} + \left(\tilde{w} - \frac{W_{\text{sed}}}{h} \right) \frac{\partial \text{Con}}{\partial \zeta} = \frac{\partial}{\partial x} \mu \frac{\partial \text{Con}}{\partial x} + \frac{\partial}{\partial y} \mu \frac{\partial \text{Con}}{\partial y} + \frac{1}{h^2} \frac{\partial}{\partial \zeta} v \frac{\partial \text{Con}}{\partial \zeta} + \sigma \text{Con}, \quad (4)$$

where Con is the dust concentration; W_{sed} is an aerosol deposition velocity; σ is parameter of emission of the dust.

Equation systems (1- 4) are solved numerically using initial and boundary conditions, which are selected according to the specific task. Numerical integration of first five equations of (1) is made using scheme [18], the fifth, sixth and seventh equations of (1) and (4) - with the use of Crank-Nicolson scheme and splitting method [8], equations (2) – with the use of Crank-Nicolson scheme, (3) are solved according to method given in [17].

2.2 Conditions of modelling

The two tasks are considered in frame of this work: 1. the mesoscale transfer of Tbilisi city dust; 2. local distribution and temporary variation of the dust in the city emitted into the atmosphere from vehicle traffic. The background hydrometeorological fields, parameters, boundary and initial conditions of the tasks are chosen so, that were possible to simulate the meteorological situation in case of the background stationary light air in June. The background wind speed grows linearly from 1m/s on $z = 2$ m to 20 m/s on $z = 9$ km.

In the first task the mesoscale transfer of the dust is simulated in the rectangular domain using calculated grid having $118 \times 90 \times 31$ points with horizontal step 2 km. The concentration $\text{Con} = 0.59 \text{ mg/m}^3$ is taken as the initial and boundary values at the height of 2 m from the earth surface in the atmosphere of the city [5]. Out of the city the initial concentration of the dust is equal to zero.

In the second task on modelling of the microscale dust distribution process, calculated grid has $103 \times 61 \times 31$ points with steps 300 m and 400 m along axes x and y , respectively. The initial dust concentration on the

height 2 m in the populated area is equal to 0.1 mg/m^3 , in the unpopulated area – 0. The initial and boundary conditions for the dust concentrations are determined using observational data. It was found that there is almost an linear dependence of dust concentration on the intensity of car traffic. It was also found that in the vicinity of the central motorways and streets, where intensity of car motion is about 1000 cars per hour, the dust concentration is approximately equal to 0.8-1.3 MAC.

In the both tasks 30 levels were taken vertically in the free atmosphere and 16 levels in the surface layer. The time steps were equal to 5 c and 1 c in the first and second tasks, respectively. Calculations were made for the period 72 h.

3 RESULTS OF MODELLING

3.1 Mesoscale transfer of dust

In Fig. 1 there are shown the field of dust concentration and wind velocity over Tbilisi Region for $t = 12$ and 24 h, at the 2, 100 and 600 m height above the ground surface obtained in case of the background stationary eastern light air. It is seen from Fig. 1 that at $t = 12$ h under action of the relief a change of directions of the local wind and of transfer of dust in the atmospheric boundary layer take place. Dust is predominantly distributed in north-west direction over the Kartli plain along the Mtkvari River. Pollution cloud has of ellipsoid-shaped form. On 2 m height a dust concentration 0.01-1 Maximum Allowable Concentration (MAC) is obtained at 10 km distance from the city, on 100 m height – at 15-18 km and on 600 m altitude – at 40 km distance.

Distribution of the dust concentration obtained through calculations and analysis of values of corresponding members of equations (4) shows that in the atmospheric surface layer the turbulent diffusion of dust is dominant. Above 100 m an advective transfer of dust grows and on the height 600 m and up from earth surface it becomes predominant. Analysis also shows that at $t = 24$ h, a local circulation related to daily temperature regime causes wind velocity vertical distribution change in the atmospheric boundary layer. During the evening and night-time, a convective ascension of warm air masses generated in the vicinity of Tbilisi takes place. Ascending warm stream is replaced further by the air cooled during night-time at surrounding mountain slopes. A formed mountain-and-valley circulation along with the local relief form generates north-west wind in 200 m lower atmospheric layer. Described thermodynamic processes lead to dust distribution direction change. In 200 m surface layer the dust is propagated in the direction opposite to background wind along the Mtkvari River valley over the Jeiran plain. Terrain impact on local circulation is gradually reduced with grows of height and in 600-1500 m layer of air the dust is transferred to the west – in the direction of background wind as a 16 km width narrow band. At 2 m height from the earth surface 0.01-1 MAC and 0.01-0.001 MAC concentrations are obtained in 6-10 km, and 20-24 km bands adjacent to city, respectively. In 100 m surface layer of the atmosphere an intensive vertical diffusive dust transfer influenced by vertical turbulence takes place and a dust pollution cloud with 0.1-1 MAC is obtained in the roughly 20 km length ellipsoid-shaped area above the city.

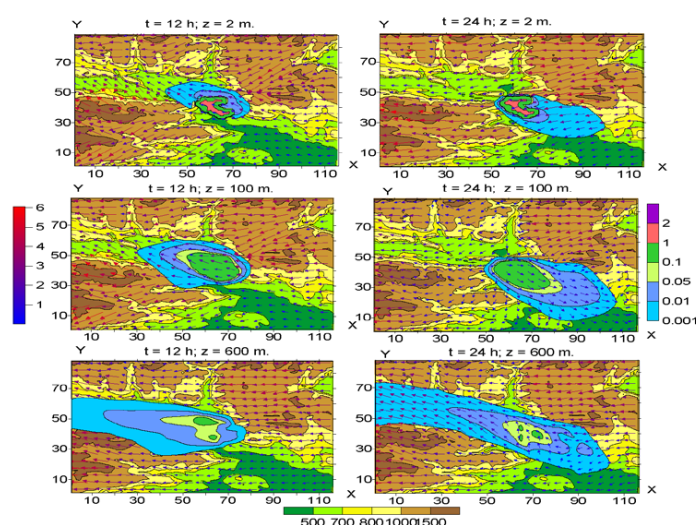
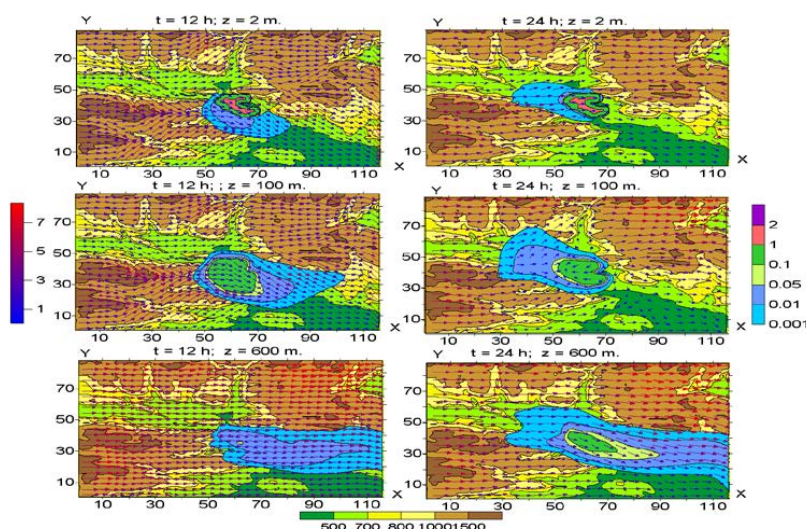


Fig 1. Terrain height (in m), dust concentration (in MAC) and wind velocity (in m/s) fields at 2, 100 and 600 m height from earth surface in case of background eastern light air, when $t = 12$ and 24 h.

Throughout the following 24 hours dust diffusion process is repeated quasi periodically, and dust transfer direction in the surface layer of the atmosphere alters from south-east to north-west direction during that time. Dust transfer in the upper part of the surface layer occurs to the west – in the direction of background wind. In case of weak background western wind (Fig. 2), by 12:00, a dust is mainly propagated in the direction of local wind that is formed in the vicinity of Tbilisi - in south and south-east directions. When $t = 24$ h, dust spreading direction in the surface layer of the atmosphere ($z < 100$ m) alters. Change in dust transfer direction is related to daily variation of dynamical and thermal meteorological fields in the surface layer of the atmosphere and occurrence of local vertical vortex. Above the surface layer of the atmosphere, wind velocity increases and dust propagation process is getting more intense. As a result, at the height of $z = 600$ m, 0.01 MAC concentration is obtained in a rectangular-shaped band with 40 km width and more than 100 km length.



3.2 Microscale transfer of dust

For study the micro-scale mechanism of the dust propagation in city the calculations in the 30.6 km x 24.0 km area are made. Tbilisi is located in the center of this area. In Fig. 3 Tbilisi orography and pollution source distribution is shown. Actual geographic coordinates are placed on the axes.

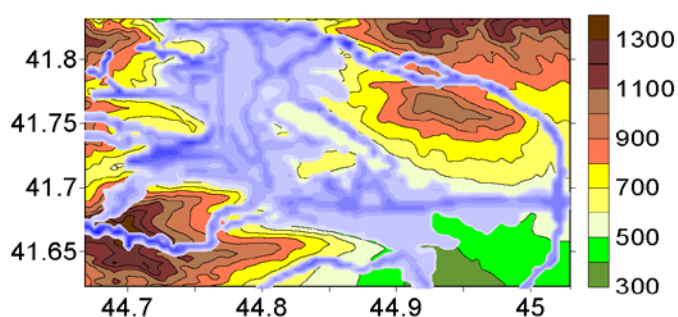


Fig. 3. Tbilisi relief (in m) and of the pollution sources (blue zone and lines) fields.

In Fig. 4 the distribution of dust concentration and wind velocity obtained by calculation at the height of $z = 2$ m from earth surface for 24 hours of the first day are shown. It is seen from the figure that concentration is minimal at the town territory when $t = 6$ h. At that time the maximum value of concentration varies in interval of 0.3-0.5 MAC at three less populated territories – in vicinity of Tbilisi Sea, south-east and south-west parts of considered area. At the central and densely populated territories of the city, concentration of dust is within 0.1-0.2 MAC. From $t = 6$ h to $t = 12$ h in the central part of the city and near the town mains, a concentration rapidly increases with grow of intensity of vehicle traffic.

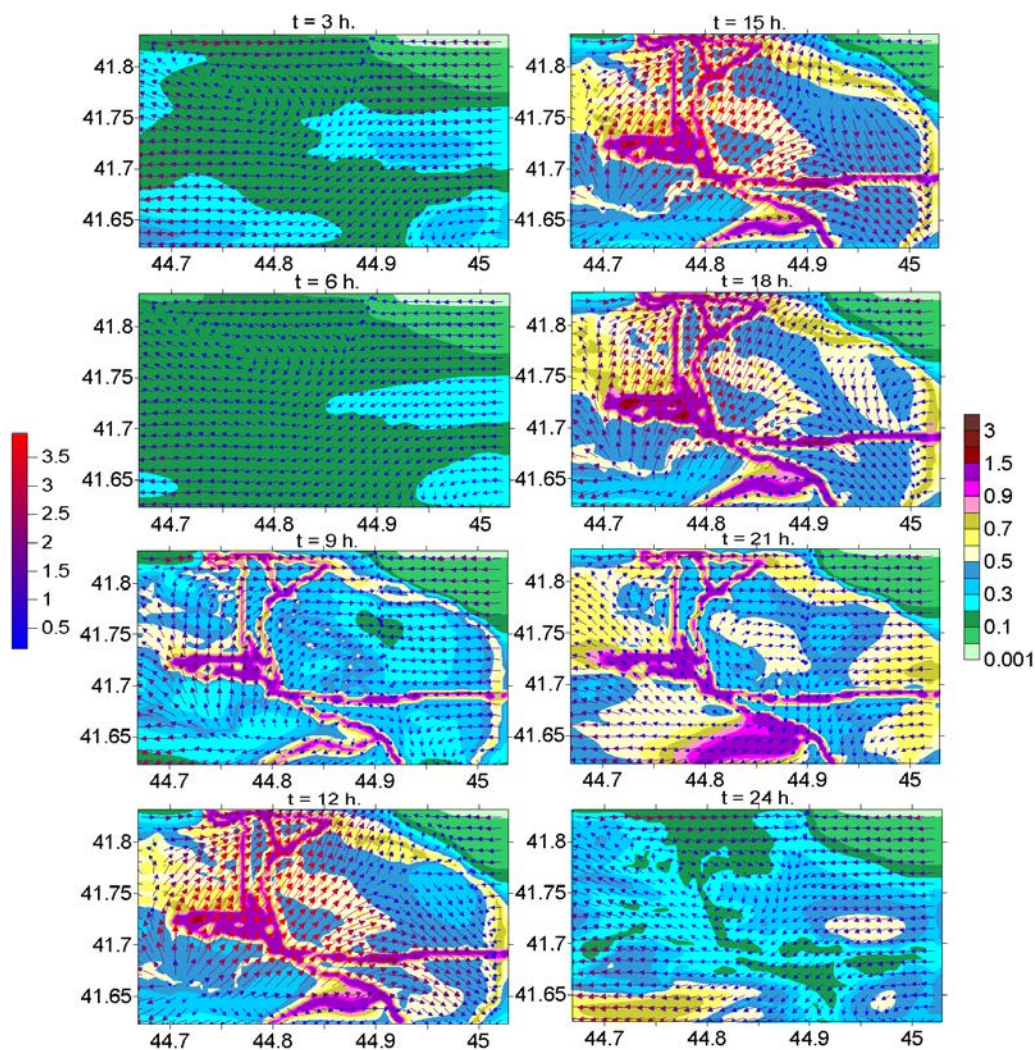


Fig. 4. Dust concentration (in MAC) and wind velocity (m/s) fields at the territory of Tbilisi at 2 m height from earth surface in case of background eastern light air, when $t = 3, 6, 9, 12, 15, 18, 21$, and 24 h.

Maximum values of concentration 1.5–2 MAC are obtained in vicinity of mains and central parts of city from 3 p.m. to 9 p.m. In these parts of city, despite the constant character of vehicle traffic intensity, slow rate of concentration growth and extension of square of relatively severely polluted areas takes place. Areas with severe dust pollution have different forms. Their shape and location depend on the value of surface wind velocity and form of relief (Fig. 4). Closed circulation systems, as well as convergence and divergence areas in the neighborhood of mountains confining separate urban districts are formed. As a result, dust redistribution and accumulation take place in some windward areas of the terrain.

From 9 p.m. to 12 p.m. concentration values are getting smaller. This reduction is non-uniform and is not proportional to vehicle traffic intensity change. Dust pollution drastically falls near the town mains at lowland territories of the central part of the city, and less sharply reduces in the neighborhood of inclined slopes of mountains confining the mentioned territory. Dust accumulation occurs in lowland urban districts. After 12 p.m. hours a quasiperiodic change of dust concentration field takes place.

Calculations had shown that at the height of $z > 2$ m a spatial dust distribution in the surface layer of the atmosphere is similar to the distribution shown in Fig. 4. At the same time, concentration slightly falls in 50 m surface layer of the atmosphere. Above 50 m, concentration change is more intense. In the atmospheric boundary layer ($z > 600$ m) a united dust cloud is formed, shape and propagation direction of which depends on local wind velocity. Small concentrations of Tbilisi dust (< 0.001 MAC) reach the upper part of the atmospheric boundary layer and lower layers of free atmosphere.

4. CONCLUSION

Tbilisi dust pollution impact on contamination of surrounding territories in cases of light eastern and western background winds is studied using numerical modeling. Dust propagation area and urban impact zones are determined. Influence of complex terrain on dust migration direction is studied. It is obtained that in case of light wind a local relief form causes daily variations of dust propagation direction.

It is shown, that the vertical turbulent diffusive dust distribution in the surface layer of the atmosphere is predominant compared to advective dust propagation. Above the surface layer the role of advective dust transfer gradually increases. As a result, in the surface layer of the atmosphere dust is propagated to several dozens of kilometers in the form of narrow and long rectangular-shaped stream. It is obtained that in case of light background wind Tbilisi dust creates 0.01-1 MAC and 0.001-0.01 MAC concentrations in zones adjacent to the city with width 6-10 km and 20-24 km, respectively.

Kinematics of distribution of dust generated by motor transport on the territory of Tbilisi is investigated. Diurnal variation of spatial dust distribution is studied. Based on the analysis of wind velocity and concentration fields it is shown that a spatial distribution of severely polluted areas depends on the location of town mains, on one hand and on local atmospheric circulation systems formed due to daily variations of thermal regime, on the other. Comparison of concentration values obtained through modelling with experimental measurement data showed satisfactory correlation.

Acknowledgement

This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) [FR-18-3667].

REFERENCES

- [1] Ji, S., Cherry, C.R., Zhou, W., Sawhney, R. et al., Environmental justice aspects of exposure to PM_{2.5} emissions from electric vehicle use in China, *Environ. Sci. Technol.*, 49 (2015) 13912-1392.
- [2] Ikenna, C. E., Hemkens, L.G., Bucher, H.C., Hoffmann, B. et al., *Environ Health Perspect.*, 123(5), pp. 381–389, (2015) 381-389.
- [3] Mortality and burden of disease from ambient air pollution-WHO.
https://www.who.int/gho/phe/outdoor_air_pollution/burden/en/ Accessed on: 17 Dec. 2019.
- [4] List of most polluted cities by particulate matter concentration.
https://en.wikipedia.org/wiki/List_of_most-polluted_cities_by_particulate_matter_concentration.
Accessed on: 17 Dec. 2019.
- [5] Environmental pollution, <http://nea.gov.ge/ge/service/garemos-dabindzureba/7/biuleteni/>. Accessed on: 17 Dec. 2019.
- [6] Amato, F., Pandolfi, M., Moreno, T., Furger, M., et al., Sources and variability of inhalable road dust particles in three European cities. *Atmos. Environ.*, 45 (2011) 6777–6787.
- [7] Kutenev, V.F., Stepanov, V.V. & Azarov, V.K., About real Particulate Emissions from Road Transport, *Ecology*, 4 (81) (2013) 45-47 (in Russian).
- [8] Marchuk, G.I., Mathematical modeling in the environmental problem. Gidrometeoizdat, Leningrad, 1982 (in Russian).
- [9] List of atmospheric dispersion models.
https://en.wikipedia.org/wiki/List_of_atmospheric_dispersion_models. Accessed on: 17 Dec. 2019.
- [10] Air Pollution Models. <http://envs.au.dk/en/knowledge/air/models/>. Accessed on: 17 Dec. 2019.
- [11] Long J., Cheng S., Li J., Chen D., Zhou Y. et al., A Monitoring and Modeling Study to Investigate Regional Transport and Characteristic of PM_{2.5} Pollution, *Aerosol and Air Quality Research*, 13 (2013) 943-956.

- [12] Shlichkov, V.A., Malbakhov, V.M. & Leghenin, A.A., Numerical Modeling of Atmospheric Circulation and Transfer of Contaminating Impurities in Norilsk Valley. *Atmospheric and Oceanic Optic*, 18 (2013) 490-496 (in Russian).
- [13] Kordzadze, A., Surmava, A. & Kukhalashvili, V., Numerical investigation of the air possible pollution in case of large hypothetical accidents at some industrial territories of the Caucasus. *J. of the Georgian Geophysical Society*, 16 B (2013) 13-23.
- [14] Gigauri, N.G. & Surmava, A.A., Spatial Distribution of the Local Meteorological Fields and Dust Concentration in Kakheti Atmosphere in Case of the Northern Background Wind. *J. Georgian Geophysics Soc.*, Issue B, Physics of Atmosphere, Ocean and Space Plasma, 20 B (2017) 11-23.
- [15] Zilitinkevich S. S., Monin A. S. Turbulence in dynamic models of the atmosphere. Leningrad, Nauka, Leningrad (1971) (in Russian).
- [16] Marchuk G. I., Kochergin V. P., Sarkisyan A. S., et al., Mathematical models of ocean circulation. Nauka, Novosibirsk, 1980 (in Russian).
- [17] Kazakov, A.L. & Lazriev, G.L., On Parametrization of Atmospheric Boundary Layer and Active Soil layer. *Izvestia. Atmospheric and Ocean Physics*, 15 (1978) 257-265 (in Russian).
- [18] Shuman F.G. & Hovermale L.R., An Operational Six-Layer Primitive Equation model. *J. of Applied Mechanics*. 7 (1968) 525-547.