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Numerical Simulation of Dust Distribution in City Tbilisi Territory in the Winter Period

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ABSTRACT

Dust propagation at Tbilisi city territory in the winter period during western background light wind is modeled and analyzed using 3D regional model of atmospheric process evolution and via combined integration of admixtures transfer and diffusion equations. The motor transport moving at city streets and highways is the main source of atmosphere pollution. Basic peculiarities featuring dust spatial propagation processes under complex terrain conditions are explored. The role of complex terrain in the passive admixture's diffusion process is studied, urban zones with high dust pollution level are established, and the differences between air pollution spatial distribution in winter and summer seasons are determined. Time intervals, when high dust pollution level of the air is formed or air self-purification process occurs, are defined. Time and spatial change of dust concentration in the lower part of the atmospheric boundary layer is studied. It is obtained that 0.8-1.5 maximum allowable concentration (MAC) is registered at 9 AM and 6 PM at Gldani and Temqa district territories situated in the central and northeastern parts of the city.

Key words: *Numerical modeling, pollution source, dust distribution, western background wind, winter season.*

Introduction.

Tbilisi is one of the largest cities of the South Caucasus, an administrative and touristic center of Georgia. Tbilisi city relief is highly complex. City is confined from the west and the east by high-mountain massifs; from the north the narrow Mtkvari River gorge, and from the south the lowland territory connects it with the external space. Based on theoretical assumptions we suppose that the local air circulations formed under the influence of the city atmosphere don't promote city atmosphere self-purification process. Indeed, according to atmospheric air monitoring network data and other studies the dust concentration in Tbilisi atmosphere frequently reaches and, in some cases, exceeds maximum allowable concentrations (MAC) [1-7].

In order to elaborate air quality substantiated recommendations and carry out practical measures it is necessary to study theoretically the features of polluting agents time and spatial distribution in city atmosphere, especially during unfavorable meteorological conditions.

In the presented work, with the purpose of further extension of carried out researches [8-11], city atmosphere pollution level in winter period is studied via numerical modeling under conditions of western background light wind. A numerical model is used to describe the development of atmospheric processes and the spread of pollutants in the Caucasus [8].

Brief description of problem statement.

The 30,6x24 sq. km area of Tbilisi and surrounding territories is considered. In order to mathematically correctly describe the dynamic fields of atmosphere and meteorological parameters under conditions of complex terrain of the city a relief-following coordinate system (t, x, y, $\zeta = (z - \delta)/h$) is used. Here t is time, x and y are coordinates directed along parallel and meridian, ζ is a vertical non dimensional coordinate, $\delta(x, y)$ is a relief height above sea level), h = H - δ – 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

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

where, C – ingredients concentration; u, v, w and $\tilde{w}$ wind velocity components along the x, y, z and ζ axes, w_o – dust deposition rate, $F(t, x, y, \zeta)$ dust dissipation rate in the atmosphere by the source, μ and ν – coefficients of horizontal and vertical turbulence. Wind velocity components and coefficients of turbulence are calculated through numerical integration of equations given in [8] and formulas determining the coefficient of turbulence.

Dust dissipation in the free atmosphere and surface layer of the atmosphere is modeled through numerical integration of equation (1), using respective initial and boundary conditions. Numerical grid steps along the x and y axes equal to 300 and 400 m, and vertical step in the free atmosphere is 1/31 that roughly corresponds to 300 m. In the 100 m thick surface layers of the atmosphere a vertical step varies from 0.5 to 15 m, while time step is 1 sec. Calculations are made for 3-day period. A case of western light background wind under dry weather conditions of January is considered. Wind velocity varies from 1 m/sec (at 100 m height above the ground) to 20 m/sec (in the tropopause at 9 km altitude). Relative atmosphere humidity is 50%.

It is assumed that the atmosphere is polluted by a dust originated at city mains and streets due to motor transport traffic. Its quantity changes in time and is determined according to assessment of continuous surveillance materials and transport traffic intensity.

Numerical modeling results

Spatial distribution of dust concentration and wind velocity, obtained through calculation at 2, 100 and 600 m height from the earth surface, when t = 3 and 6 h, is shown in Fig. 1. Concentration is given in the units of one-off maximum allowable concentration (MAC = 0.5 mg/m^3).

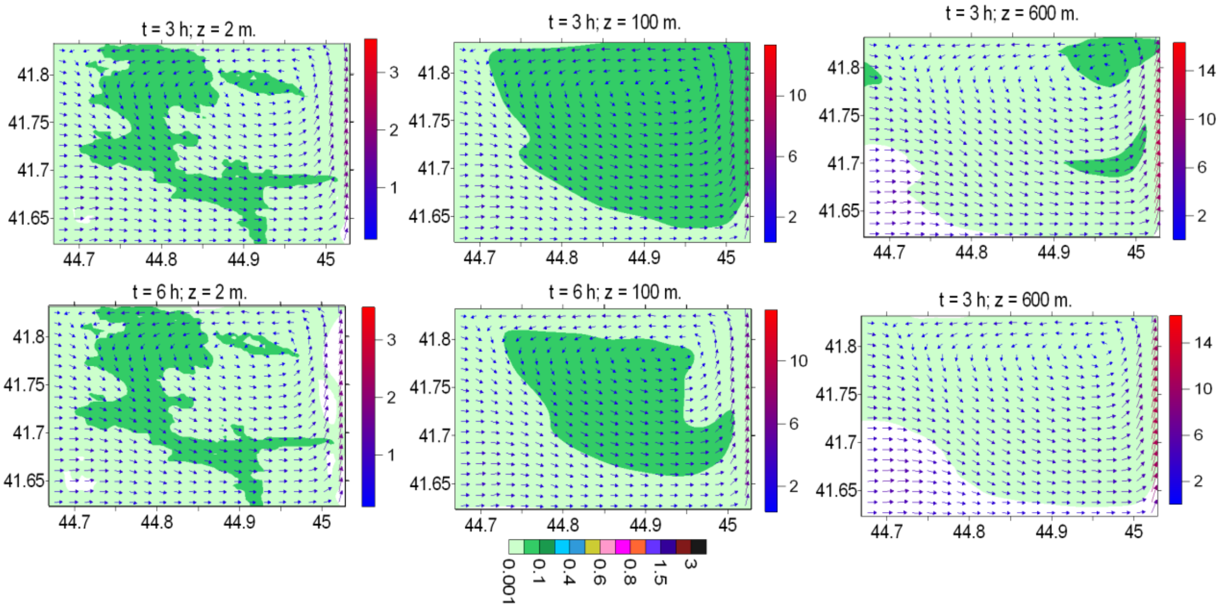

Fig. 1. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 3 and 6 h, at 2, 100 and 600 m height from the earth surface.

It is seen from Fig. 2 that in time interval from 3h to 6h the dust concentration at 2 m height from the earth surface is practically constant and slightly varies within 0.001-0.1 MAC. 0.01 MAC concentration is obtained at less urbanized territories adjacent to the city. At the central and densely populated (urbanized) territories of the city, dust concentration varies from 0.01 to 0.1 MAC. In the surface layer of the atmosphere dust concentration growths with height increase and at 100 m height it changes within 0.01-0.1MAC in the major part of the atmosphere. Afterwards dust concentration reduces with the further height increase and at 600 m height its value doesn't exceed 0.01 MAC. If we compare spatial distribution and quantitative values of concentration, we come to conclusion that the pollution level in nighttime hours of summer barely exceeds that obtained in winter period.

After t = 6 h, the quantity of dust hitting the atmosphere increases along with quick growth of motor transport traffic intensity and rapid pollution of city atmosphere begins. When t = 9h, during first "rush-hour" situation, at 2 m height above the ground dust concentration is high in the proximity of city mains located in the northern part (Gldani, Temka districts) and the central (Vake and Saburtalo districts) parts of the city. Surface distribution of concentration obtained through calculations considerably differs from that obtained in summer period [12]. Maximum concentration value 1.2 MAC is obtained in the surroundings of the crossroad of Sarajishvili, Guramishvili avenues and Kerch street. Maximum value at Vazha-Pshavela and I. Chavchavadze avenues of Vake and Saburtalo districts equals to 0.7 MAC, while highest concentration at A. Tsereteli Avenue of Didube district reaches 0.9 MAC.

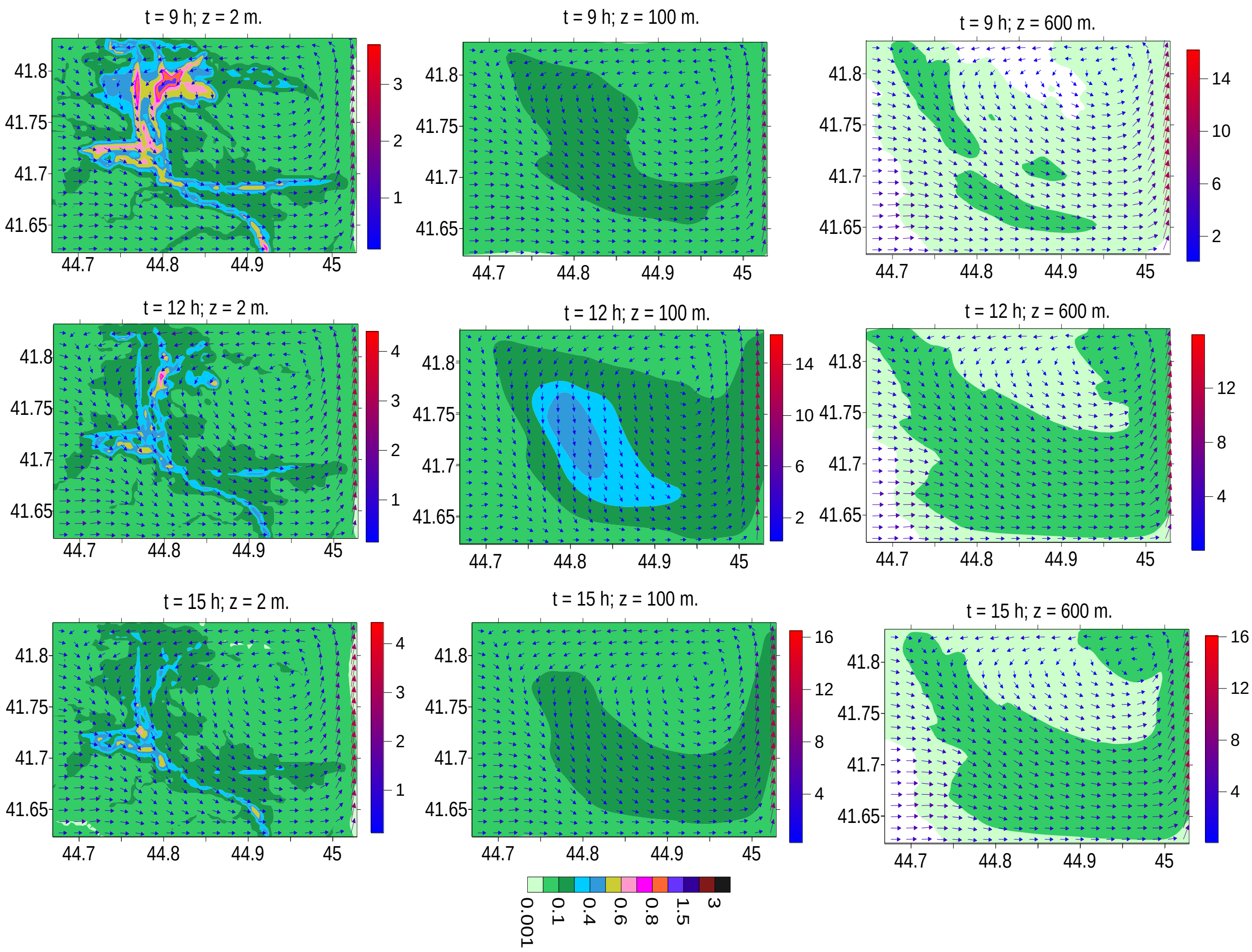

Fig. 2. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 9, 12 and 15 h, at 2, 100 and 600 m height from the earth surface.

In the time range from 10 AM to midday, under conditions of motor transport traffic constant intensity and dust dissipation constant speed, in the high pollution level area a considerable reduction of concentration is obtained at 2 m height (Fig. 2). Concentration decrease lasts until 3 PM. When t = 12 and 15 h, maximum concentration values vary within 0.6-0.8 MAC interval. The mentioned maximum concentrations are obtained at different urban territories distanced from each other, namely in Temka and Saburtalo districts.

At 100 m from the earth surface a dust is distributed above urbanized territories of the city and its concentration values are equal to 0.3 MAC. The only exception is the concentration values (0.5 MAC) obtained at quite large territories above the central part of the city, when t = 12 h. At 600 m height above the ground the concentration doesn't exceed 0.1 MAC.

After 3 PM, at z = 2 m height, the second stage of dust pollution level increase begins, which lasts up to 8 PM (Fig. 3). Dust pollution level increases in 1 km thick area of the atmospheric boundary layer. This growth is especially intensive in the lower part of the surface layer in the surroundings of city mains located in the center of the city and its peripheries. In the northern part of Tbilisi (surroundings of Temka and Gldani districts), at 2 m height, dust concentration maximum value reaches and even exceeds 1 MAC, while in the central and southern parts of the city the maximum value equals to 0.8 MAC. At suburban areas, dust concentrations are within 0.2 MAC.

Dust vertical turbulent and convective transfer processes occur along with the increase of its surface concentration. Dust concentration growth in the upper part of the surface layer runs with approximately 3-hour phase lag. As a result, maximum concentration value, which is equal to 0.6 MAC is obtained at 100 m height, when t = 21h. At 600 m height from the earth surface dust pollution level is virtually unchanged and is less than 0.1 MAC.

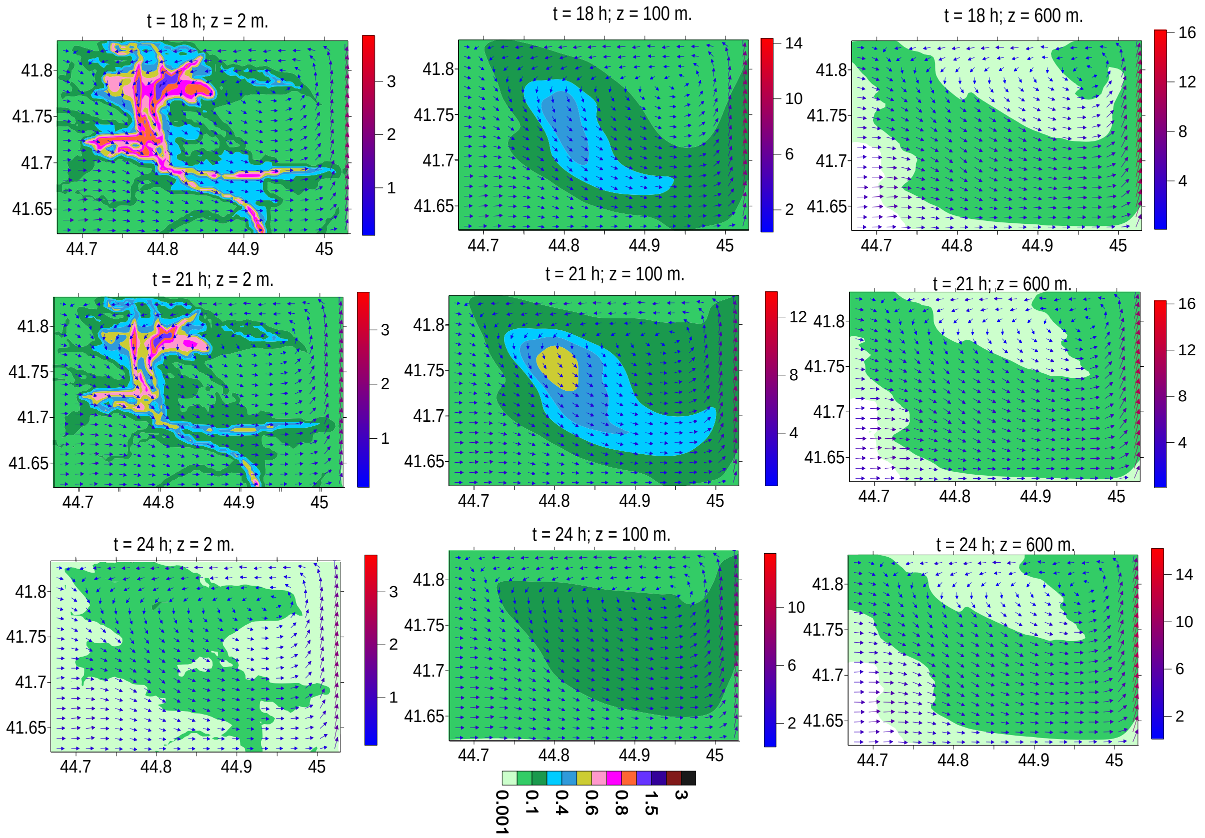

Fig. 3. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 18, 21 and 24 h, at 2, 100 and 600 m height from the earth surface

After t = 20h the stage of surface concentration reduction begins, which lasts up to t = 24h. Concentration value by this time is within 0.1 MAC at urbanized territory. At 100 m height from the earth surface, dust concentration roughly equals to 0.2 MAC. Calculations show that in case of constant wind, dust transfer and diffusion process has quasiperiodic character with 24h period.

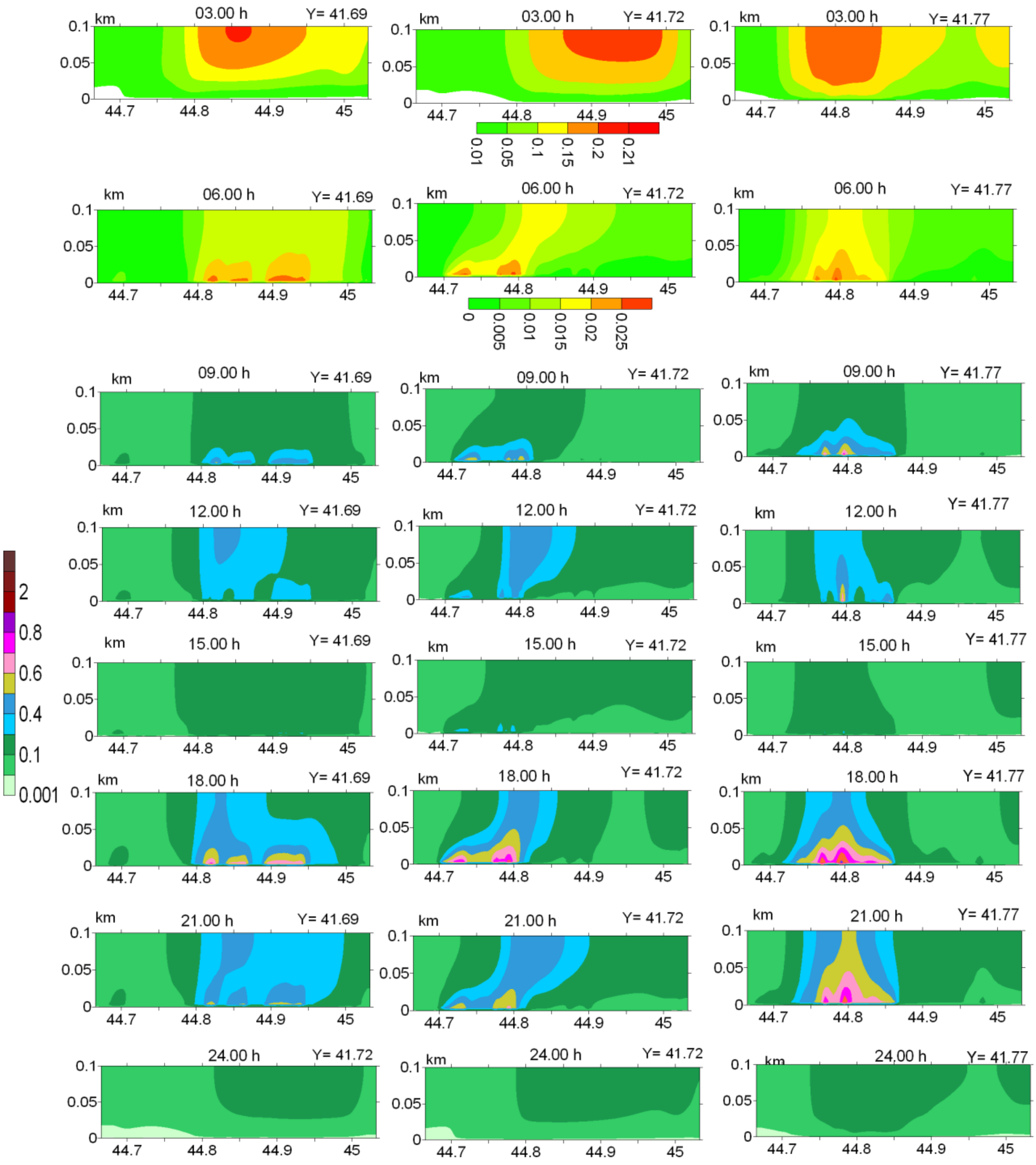

Fig. 4. Dust concentration (MAC) distribution within a day in the surface layer of atmo-sphere in three vertical planes located along the parallel (Y= 41.69°, Y=41. 72° and Y=41. 77°).

In Fig. 4 there is shown dust concentration vertical distribution in the surface layer of atmosphere, in three vertical cross-sections drawn along the parallel, with three hour time interval. It is seen from Fig. 4 that from the midnight to 6 AM an atmospheric dust is transferred to the upper part of the surface layer of atmosphere. From t = 6h dust pollution areas start to form near the underlying surface. At following points of time, a surface dust is propagated in vertical and horizontal direction. Intensive vertical dust transfer starts at t = 18h and lasts until t = 21h. Dust cloud form points at the convective mechanism of its origination. Prevailing directions of dust propagation are seen in Fig. 4 and from there we can determine respective dynamic processes causing dust transfer. We can conclude that local circulation processes at the same territory may have different character at different points of time, namely advective, convective or turbulent-diffusive.

Conclusion

Motor transport-induced dust pollution change kinematics in winter period at the territory of Tbilisi is explored in case of western background wind. Diurnal pattern of dust spatial distribution and its propagation peculiarities are studied. Through analysis of wind velocity and concentration fields it is obtained that spatial distribution of heavily dust polluted areas depends on city mains location, on one hand and on dynamic impact of relief, and local circulation systems formed by daily change of thermal regime at underlying surfaces, on the other.

Comparison of dust concentration spatial and time distribution in winter period with that obtained through calculation for summer one, shows not only their similarity, but also points at substantial qualitative difference between them. Distinctions are manifested in different location of high dust pollution areas, maximum dust pollution level occurrence time, and dust vertical and horizontal distribution. Differences between concentration distribution in case of the same background wind can be explained by the seasonal character of local hydrometeorological fields formation. In particular, Tbilisi city relief, in case of western background light wind, generates local cyclonic vortex in winter, and anticyclone vortex in summer. These vortices, due to diurnal change of thermodynamic fields in the surface layer of atmosphere, experience periodic variations of shape, velocity field and location during a day. The mentioned circumstance has an effect on dust transfer-diffusion process and causes differences in spatial distribution of concentration fields between the winter and summer periods.

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References

[1] http://air.gov.ge/reports_page.

[2] Kharchilava J.F., Lomaia O.V., Bukia G.N. The Conditions of Aerosols Formation and Accumulation in Cities, in Proc. 3th Int. Aerosol Conf., Kyoto, Japan, Pergamon, 24-27 September, 1990, v. 2, pp. 986-989.

[3] Amiranashvili A.G., Gzirishvili T.G. Aerosols and Ice Crystals in the Atmosphere. Tbilisi, Metsniereba, 1991, p. 113 (in Russian).

[4] Amiranashvili A.G., Chikhladze V.A., Kharchilava J.F.,. Buachidze N.S, Intskirveli L.N. Variations of the Concentrations of Dust, Nitrogen Oxides, Sulphur Dioxide and Ozone in the Surface Air in Tbilisi in 1981-2003, in Proc. 16th Int. Conf. on Nucleation&Atmospheric Aerosols, Kyoto, Japan, 26-30 July, 2004, pp. 678-681.

[5] Amiranashvili A., Bliadze T., Tsikhladze V. Photochemical smog in Tbilisi. Monograph. In Proc. of Mikh. Nodia Institute of Geophysics, Part 63, 2012, p. 160 (ISSN 1512-1135).

[6] Kirkitadze D., Nikiforov G., Chankvetadze A., Chkhaidze G. Some Results of Studies of Atmospheric Aerosols in M. Nodia Institute of Geophysics in the Recent Three Decades. Trans. of Mikheil Nodia Institute of Geophysics (ISSN 1512-1135), v. 66, pp. 178-185, Tbilisi, 2016 (in Russian).

[7] Intskirveli L., Gigauri N., Surmava A., Kukhalashvili V., Mdivani S. Study of Tbilisi atmospheric air pollution by PM-particles and dust, in Proc. Of Scientific conference "Modern problems of ecology", Tbilisi-Telavi, Georgia, 26-28 September, 2020, vol. 7, pp. 252-255 (ISSN 1512-1976).

[8] Surmava A., Intskirveli L.,Kukhalashvili V., Gigauri G. Numerical Investigation of Meso- and Microscale Diffusion of Tbilisi Dust. Annals of Agrarian Science, v. 18, No. 3 2020, pp. 295-302.

[9] Surmava A., Kukhalashvili V., Gigauri N., Intskirveli L., Kordzakhia G. Numerical Modeling of Dust Propagation in the Atmosphere of a City with Complex Terrain. The Case of Background Eastern Light Air. Journal of Applied Mathematics and Physics, v. 8, No.7, 2020, pp. 1222-1228. https://doi.org/10.4236/jamp.2020.87092.

[10] Kukhalashvili V., Kordzakhia G., Gigauri N. , Surmava A., Intskirveli L. Numerical Modelling of Dust Propagation in the Atmosphere of Tbilisi City: The Case of Background Eastern Gentle Breeze. Journal of the Georgian Geophysical Society, v. 23(1), 2020, pp. 46 -50.

[11] Kukhalashvili V., Gigauri N., Surmava A., Demetrashvili D., Intskirveli L. Numerical Modelling of Dust Propagation in the Atmosphere of Tbilisi City: The Case of Background Eastern Fresh Breeze. Journal of the Georgian Geophysical Society, v. 23(1), 2020, pp. 51 -56.
[12] Surmava A., Intskirveli L., Gverdtsiteli L. Numerical modeling of dust distribution in the atmosphere of Tbilisi. I.A case of weak background wind from the west. Proceedings of the M. Nodia Institute of Geophysics, vol. LXXII, 2020, p. 89-96.

ქ. თბილისის ტერტორიაზე ზამთარში მტვრის გავრცელების რიცხვითი მოდელირება

ა. სურმავა', ლ. გვერდწითელი, ლ. ინწკირველი, ნ. გიგაური

რეზიუმე

ატმოსფერული პროცესების ევოლუციის 3D რეგიონალური მოდელისა და მინარევების გადატანა - დიფუზიის განტოლების ერთობლივი ინტეგრირებით რიცხობრივად მოდელირებული და გაანალიზებულია მტვრის გავრცელება ქ. თბილისის ტერიტორიაზე ზამთრის პერიოდში დასავლეთის ფონური სუსტი ქარის დროს. ატმოსფეროს დაბინძურების ძირითად წყაროს წარმოადგენს ქალაქის ქუჩებსა და მაგისტრალებზე მოძრავი ავტოტრანსპორტი. გამოკვლეულია ძირითადი თავისებურებანი რომლებიც ახასიათებენ რთული რელიეფის პირობებში მტვრის სივრცეში გავრცელების პროცესს. შესწავლილია რთული რელიეფის როლი პასიური მინარევების დიფუზიის პროცესში, დადგენილია ქალაქის მაღალი დამტვერიანების ზონები, აღმოჩენილია განსხვავებები რომლებიც არსებობენ ზამთრისა და ზაფხულის სეზონებში ატმოსფერული ჰაერის დამტვერიანებების სივრცულ განაწილებებს შორის. განსაზღვრულია დროის ინტერვალები, როდესაც ფორმირდება ჰაერის მაღალი დამტვერიანება ან ხდება ჰაერის თვითდასუფთავების პროცესი. შესწავლილია ატმოსფეროს სასაზღვრო ფენის ქვედა ნაწილში მტვრის კონცენტრაციის დროსა და სივრცეში ცვლილება. მიღებული იქნა, რომ 0.8 - 1.5 ზღვრულად დასაშვები კონცენტრაცია (ზდკ) მიიღება დღის 9 და 18 -ზე ქალაქის ცენტრალურ და ჩრდილო -აღმოსავლეთ ნაწილებში მდებარე გლდანისა და თემქის რაიონის ტერიტორიებზე.

Численное Моделирование Распространения Пыли Зимой на территории г. Тбилиси

А. Сурмава, Л. Гвердцители, Л. Инцкирвели, Н. Гигаури

Резюме

Исследовано распространение пыли на территории города Тбилиси в зимний период при фоновом слабом западном ветре с использованием региональной трехмерной модели эволюции атмосферных процессов 3D и интегрирования уравнения переноса-диффузии примесей. В модели автомобильный транспорт рассматривается как основной нестационарный источник загрязнения, от которого в атмосферу выбрасывается пыль. Путем численного моделирования показано, что процесс загрязнения атмосферного воздуха пылью протекает в четыре этапа и зависит от интенсивности автомобильного движения, микрорельефа города и расположения автомобильных магистралей. Исследованы особенности распространения пыли в зимний период года, роль сложного рельефа при диффузии пыли, определены зоны высокого запыленности, выявлены различия между пространственными распределениями пыли в зимний и летный периоды года. Определены интервалы времени, когда формируются зоны высокого запыления воздуха или происходит самоочищения городского воздуха. Получено, что зоны высокой запыленности с концентрациями 0.8-1.5 предельно допустимая концентраций формируются с 9 ч. утра до 6 ч вечера на территориях Глданского и Темкинского районов.