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Numerical Simulation of Dust Distribution in Kakheti and its Adjacent Territory

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ABSTRACT. Dust propagation at the territory of Kakheti in case of four basic meteorological situation and stationary pollution sources is studied with the use of regional model of atmospheric process development in the Caucasus and non-stationary three-dimensional equation of transfer-diffusion of passive admixtures. Numerical modeling is conducted in 236 × 180 km zone with 2 km permanent horizontal and variable vertical grid distances (from 2 to 300 m). Dust propagation existing in the atmosphere of Tbilisi and Rustavi, and in twenty other cities and major population centers of Georgia located in Kakheti and its adjacent territories is modeled at the territory of region. Distribution patterns of dust dissipated in the atmosphere are obtained at different level from the surface. It is shown that dust dissipated from cities in the atmosphere is basically concentrated in boundary layer. Maximum values of dust concentration are obtained from 100 m surface air layer. Spatial dust distribution region increases and concentration decreases along with height increase. Urban influence zone is determined. It equals 20-30 km for Tbilisi, approximately 10 km for Rustavi and for other cities does not exceed 2-4 km. Kinematics of dust propagation is studied. It is determined that in 2-100 m layer of atmosphere the process of turbulent diffusion take precedence in the process of dust propagation. From 100 m to 1 km the processes of diffusive and advective transfers are identical, while above 1 km the preference is given to advective transfer. A proposal is advanced regarding determination of background concentrations of dust at the territory of Kakheti. 0.05 MAC can be taken as background concentration of dust for territory adjacent to Tbilisi and Rustavi, while 0.01 daily MAC is selected for other territories. *© 2017 Bull. Georg. Natl. Acad. Sci.*

Key words: numerical simulation, equation of mass transfer, Kakheti air pollution, maximum allowable concentration

Kakheti is the eastern near-border region of Georgia. Its area is 11.3 thousand km^2. It is one of the most important parts of Georgia from the viewpoint of agricultural production and resort-recreational destination. That is why study of background pollution and propagation of polluting agents in Kakheti region is of great ecological importance.

Today there are no air polluting powerful enterprises of industrial purposes located on the territory of Kakheti. Pollution of the atmosphere takes place in big cities Tbilisi and Rustavi, and also resulting from regional propagation of polluting agents dissipated in the air atmosphere of small cities located in Kakheti and its adjacent territory.

Based on the fact that there are no ongoing observations over air pollution on the territory of Kakheti, the numerical modeling of background pollution may be considered as one of the main tools of study of ecological cleanness of atmosphere. For this purpose a numerical model of expected pollution of Kakheti region is represented and the level of background dust pollution of atmosphere is determined by means of this model.

The area of 236×180 km is considered, Kakheti is located between the Main Caucasus and Small Caucasus mountain chains. Orography height varies from 77 m to 3-4 km.

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

Equation for dust atmospheric propagation in the taken coordinate system will be written in the following form [1, 2]

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

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 factor in near-border layer of atmosphere and in free atmosphere are defined by means of regional model [3] of atmospheric process development in the Caucasus, while in atmospheric boundary layer of 100m in thickness – according to the methodology developed in [3] and [4].

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 data of National Environment Agency are taken as the initial and boundary value of concentrations at a height of 2 m in atmosphere at the territories of Tbilisi and Rustavi, while for territories of other cities, where the observations over dust pollution was not conducted, concentration values are calculated according to the given methodology [5]. Numerical integration is made on spatial grid comprising 118×90×31 points. Grid steps are 2 km in horizontal direction, while in vertical it varies from 2 to 300 m. Time step is 10 sec.

Results of modeling.

Spatial distribution of dust concentrations in June during background eastern wind, when t = 14 hours, obtained by calculations, is shown in Fig. 1. Values are calculated in units of daily maximum allowable concentration (MAC = 0.015mg/m^3) of dust.

As is seen from Fig. 1, dust concentration at a height of 2 and 10 m is maximal at the territory of cities and in their direct vicinity (Fig.1. a, b). In horizontal direction the dust is propagated only at small distances. In particular, at 2-4 km distance, from the point of pollution the value of concentration 10 times increases, while at 20-30 km distance 10^2-10^3 times less than concentrations at the territories of the cities. Such distribution is caused by smallness of horizontal turbulent and advective transfer and shows us the limits of urban exposure from the viewpoint of surface air pollution. Impact area is different for different directions and depends on orography. Horizontal dust transfer mainly occurs along the gorges, both in case of Tbilisi, Rustavi and other cities.

Processes of vertical, horizontal turbulent diffusion, advective and convective transfer become intensive in the area at a height of 10-600 m from earth

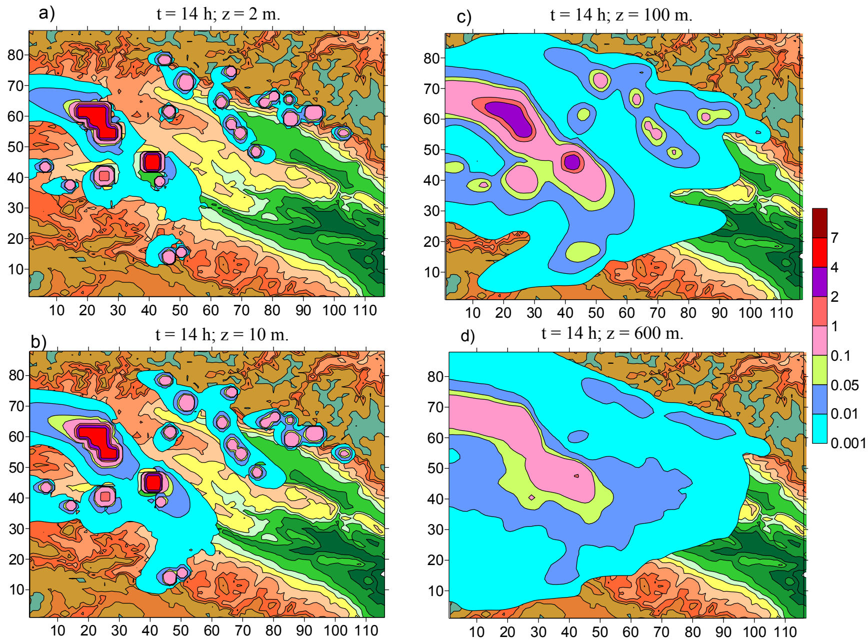

Fig. 1. Distribution of isolines of dust concentration C in MAC at height of z = 2, 10, 100, 600 m the background of eastern winds, when t = 14 hours.

surface. As a result the dust propagates at large territory, mostly in western direction.

Along with the height increase the maximum concentrations decrease (Fig.1 c, d). When z = 100 m, two zones of maximum concentration are formed: one (2-4 MACs) in the vicinity of Tbilisi and Rustavi and second (1-0.1 MAC) in the neighborhood of Alazani River. Orography influence on dust pollution form is gradually reduced and at a height above 600 m the form of dust pollution zone is predominantly determined by wind direction and velocity.

Calculations showed that in case of background western winds the kinematics of propagation of received dust pollution is qualitatively similar to the one described above. Basic difference is the form of dust pollution cloud. Dust pollution zone formed in 1 km layer of atmosphere is a single cloud, which has a trail oriented in background wind direction in atmospheric zone 100 m in thickness. Zone with maximum concentration is formed above Tbilisi and Rustavi. When z > 100 m, dust cloud takes single ellipse-like form.

In case of background northern winds (Fig.2) three dust pollution zones are formed in air layer 2-100 m in thickness. One of them is Tbilisi, Rustavi, Marneuli, Gardabani and Bolnisi, second is the zone of Azerbaijan cities and the third is the zone of Shida Kakheti cities. In the first and second zones the advective transfer of dust occurs in north-eastern direction, while in the third zone – in the south-western direction. Maximum dust pollution takes place in the neighborhood of Tbilisi and Rustavi. Away from the cities the level of dust pollution rapidly decreases and at a distance of 20-30 km the concentration value is within 0.05-0.01 MAC. Dominance of advective transfer over diffusive transfer is characteristic for the third zone. As a result we have dust propagation at the most part of territory of Kakheti. At heights of z > 100 m the role of turbulent diffusion becomes prevalent and we receive a single dust cloud formed above the central part of the region.

During the background southern winds, local circulation system of air current originated by orography creates complicated picture of dust propagation. Back flow formed in Mtkvari River valley and in Jeiran field causes dust propagation in southern direction in 1 km boundary layer of atmosphere. Afterwards the wind changes its direction and dust transfer occurs

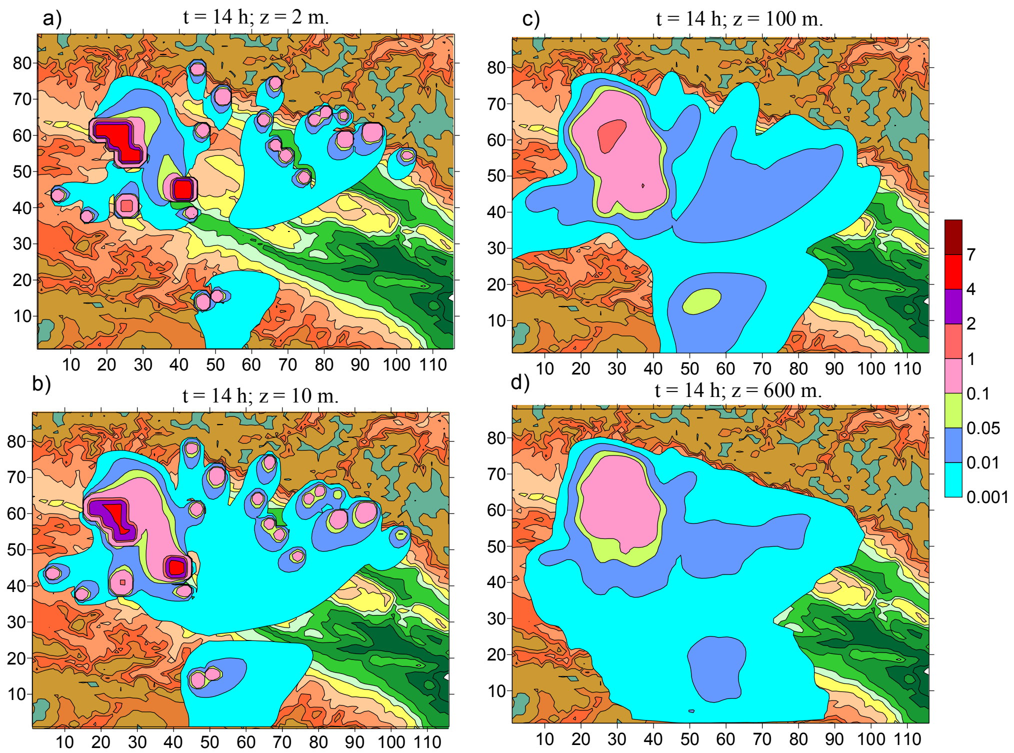

Fig. 2. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m during background northern winds, when t = 14 hours.

in north-eastern direction. Increased air turbulization related to rapid change of velocity causes dust propagation throughout the whole territory of Kakheti.

In the described numerical experiment, dust pollution zones of upper part of boundary layer of atmosphere (z>1000m) are represented by single cloud in the form of elongated ellipse formed under influence of orography and directed along local wind. Maximum concentration in dust cloud is getting smaller along with the increase in height from 0.01 to 0.0001 MAC, when z = 1 and z = 3 km.

Numerical experiment is conducted for various meteorological situations. Calculations were made for stationary and non-stationary sources. Analysis of calculation results enables us to study features of background pollution of the territory of Kakheti.

Discussion

Dust propagation on the territory of Kakheti in case of four basic meteorological situation and stationary pollution sources is studied in the Caucasus with the use of regional model of atmospheric process development and non-stationary three-dimensional equation of transfer-diffusion of passive admixtures. Through modeling the dust concentration pictures are obtained which qualitatively coincide with the dust distribution based on physical arguments.

It is shown that in 10 m zone of surface layer of atmosphere the dust propagation is determined by horizontal and vertical turbulence. At a height of 100 m the processes of advective transfer make significant contribution along with turbulence into dust propagation, while in upper part of boundary layer of atmosphere the dominant role is attached to advective transfer of dust.

By means of the obtained results the following values of background concentration can be determined: 0.05 MAC can be taken as the background concentration for 20-30 km region adjacent to Tbilisi and Rustavi, while for other cities – 0.01 MAC.

In this model the fields of velocities and vertical turbulence in the surface layer of atmosphere are described for uniform relief. That's why it is expedient to further develop a model with the use of different parametrization methods of the surface sub-layer of atmosphere.

There are no ongoing natural observations over air pollution at the territory of Kakheti, and therefore it is impossible to determine quantitative accuracy of obtained results. With the aim of determination of modeling accuracy it is planned to carry out experimental measures and their comparison with modeling results.

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გეოფიზიკა

კახეთისა და მის მიმდებარე ტერიტორიაზე მტვრის გავრცელების რიცხვითი მოდელირება

ა. სურმავა*, ლ. ინწკირველი**, ნ. ბუაჩიძე**

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კავკასიაში ატმოსფერული პროცესების განვითარების რეგიონალური მოდელის გამოყენებით და პასიური მინარევის გადატანა - დიფუზიის არასტაციონარული სამგანზომილებიანი განტოლების რიცხვითი ინტეგრირებით კახეთის ტერიტორიაზე შესწავლილია მტვრის გავრცელება ოთხი ძირითადი სინოპტიკური სიტუაციისა და დაბინძურების სტაციონარული წყაროების შემთხვევაში. რიცხვითი მოდელირება განხორციელებულია 236 × 180 კმ^2 არეში, 2 კმ მუდმივი ჰორიზონტალური ბიჯით და 2 - დან 300 მ-მდე ცვლადი ვერტიკალური ბიჯით. მოდელირებულია ქ.ქ.თბილისის, რუსთავისა და ასევე კახეთის რეგიონში და მის მიმდებარე ტერიტორიებზე განლაგებული ოცი ქალაქისა და მსხვილი დასახლებული პუნქტების ატმოსფეროში არსებული მტვრის გავრცელება რეგიონის ტერიტორიაზე.

მიღებულია ატმოსფეროში გაფრქვეული მტვრის განაწილების სურათები მიწის ზედაპირიდან სხვადასხვა დონეზე. ნაჩვენებია, რომ ქალაქებიდან ატმოსფეროში გაბნეული მტვერი ძირითადად კონცენტრირებულია სასაზღვრო ფენაში. მტვრის კონცენტრაციის მაქსიმალური მნიშვნელობები მიღებულია ჰაერის მიწისპირა 100 მ ფენაში. სიმაღლის ზრდასთან ერთად იზრდება მტვრის სივრცული გავრცელების არე და მცირდება კონცენტრაცია. განსაზღვრულია ქალაქების გავლენის ზონები. ის ქ. თბილისისათვის შეადგენს 20 - 30 კმ, ქ. რუსთავისათვის - დაახლოებით 10 კმ-ს, ხოლო სხვა ქალაქებისათვის არ აღემატება 2 - 4 კმ-ს. შესწავლილია მტვრის გავრცელების კინემატიკა. მიღებულია, რომ ატმოსფეროს 2 - 100 მ ფენაში მტვრის გავრცელების პროცესში უპირატესი მნიშვნელობა გააჩნია ტურბულენტური დიფუზიის პროცესს. 100 მ-დან 1 კმ-მდე დიფუზიური და ადვექციური გადატანის პროცესები ტოლფასია, ხოლო 1კმ-ის ზევით უპირატესობა

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