Journal of the Georgian Geophysical Society,
Issue B. Physics of Atmosphere, Ocean and Space Plasma, v.19B, 2016, pp.18-25

Spatial Distribution of Dust Concentration in Kakheti Atmosphere in Case of Nonstationary Sources of Pollution

[1]Aleksandre A. Surmava, [2]Natia G. Gigauri

[1]M. Nodia Institute of Geophysics, I. Jvakhishvili Tbilisi State University; Institute of Hydrometeorologi,Georgian Technical University, Tbilisi; aasurmava@yahoo.com.
[2]Georgian Technical University,Tbilisi.

ABSTRACT

Using a regional model of atmospheric process in the Caucasus and equation of transfer-diffusion of passive contaminant the distribution patterns of dust dissipated in the atmosphere of Kakheti are obtained.
It is shown that dust dissipated from cities in the atmosphere is basically concentrated in boundary layer. Maximum values of dust are concentrated in 100 m surface air layer. Spatial dust distribution region increases and concentration decreases along with height increase. Urban influence zone is determined. It equals to 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.

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

1. Introduction

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 at 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 atmosphere of small cities located in Kakheti and its adjacent territory.

Based on the fact that there are no ongoing observations over air pollution at 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 is represented the numerical model of expected pollution of Kakheti region and the level of background dust pollution of atmosphere determined by means of this model. The polluted air of the cities of Kakhety and in the vicinity of Georgia and Azerbaidjan are taken as the sources of contaminant in model. The presented article is a firs try of investigation of Kakheti air pollution

2. **Goal setting**. The area 236×180 km of size is considered, in the centre of which Kakheti is placed, while to the west, north and north-west are located the Main Caucasus and Small Caucasus mountain chains, while to the south-east is placed Shirvan steppe. 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 is convenient to use the relief succeeding 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 following form [1, 2]

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

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 Caucasus, while in atmospheric boundary layer 100m in thickness – according 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 temporary variation of concentration in the cities is following:

$$C(t,x_i,y_i,z_0) = \begin{cases} C_{min}(t\,x_i,y_i,z_0) & \text{if} \quad 24n \le t \le 24n+6 \\ C_{min}(t,x_i,y_i,z_0) + \Delta C\sin(0.5\pi(t-6)/3) & \text{if} \quad 24n+6 < t < 24n+9 \\ C_{max}(t,x_i,y_i,z_0) & \text{if} \quad 24n+9 < t < 24n+21 \\ C_{min}(t,x_i,y_i,z_0) - \Delta C\sin(0.5\pi(t-21)/3) & \text{if} \quad 24n+21 < t < 24(n+1) \end{cases}$$

where $C_{min}(t,x_i,y_i,z_0)$ and $C_{max}(t,x_i,y_i,z_0)$ are the maximal and minimal concentrations of pollutant substance in the points of source; x_i and y_i are the coordinate of cities; index i denotes the city, $\Delta C = C_{min}(t,x_i,y_i,z_0) - C_{max}(t,x_i,y_i,,z_0)$, z_0 = 2 m; $C_{max}(t,x_i,y_i,z_0)$ and $C_{min}(t,x_i,y_i,z_0)$ are equal to 0.8 and 0.2 parts of the monthly mean concentration in city i, respectively. The data of National Environment Agency [5] are taken as the initial and boundary value of the monthly mean 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 given methodology [6].

Numerical integration is made on spatial grid comprising of 118×90×31 points. Grid steps are 2 km in horizontal direction, while in vertical it varies from 2 to 15 m in the surface layer, and from 15 to 300 m in the boundary area and free atmosphere. Time step is 10 sec.

Dust dispersal in Kakheti region is modeled in case of air non-stationary pollution sources. Climate conditions corresponding for June are taken. Meteorological situation corresponds with western stationary winds, when the velocity of geostrophic background winds is 1 m/sec at the height of 10 meters. The speed linearly increases along with height and reaches 23 m/sec at a height of 9 km.

3. **Results of modeling.** Results obtained by calculations are shown on Fig. 1-Fig. 7. On these figures, the values of concentration are calculated in units of daily maximum allowable concentration (MAC = 0.015mg/m^3) of dust.

On Fig. 1 and Fig. 2 is shown the distribution of dust concentration in the atmosphere at different heights in the midnight (t = 0 hour), 4 hours after beginning of dispersal. As is seen from drawings, dust concentrations are virtually equal in atmospheric surface layer at a height of 2 and 10 meters. Dust is basically concentrated at urban territories and rapidly decreases with the increase of distance from cities. The value of horizontal gradient of concentration is depended on local orography adjacent to source and on the direction of background wind.

In case of Tbilisi city the concentration at a height of 2 meters from earth surface and at 2 km distance decreases 10-30 times, while at 2-20 km distance dust content reduces from 0,1 MAC (maximum allowable concentration) to 0,01 MAC.

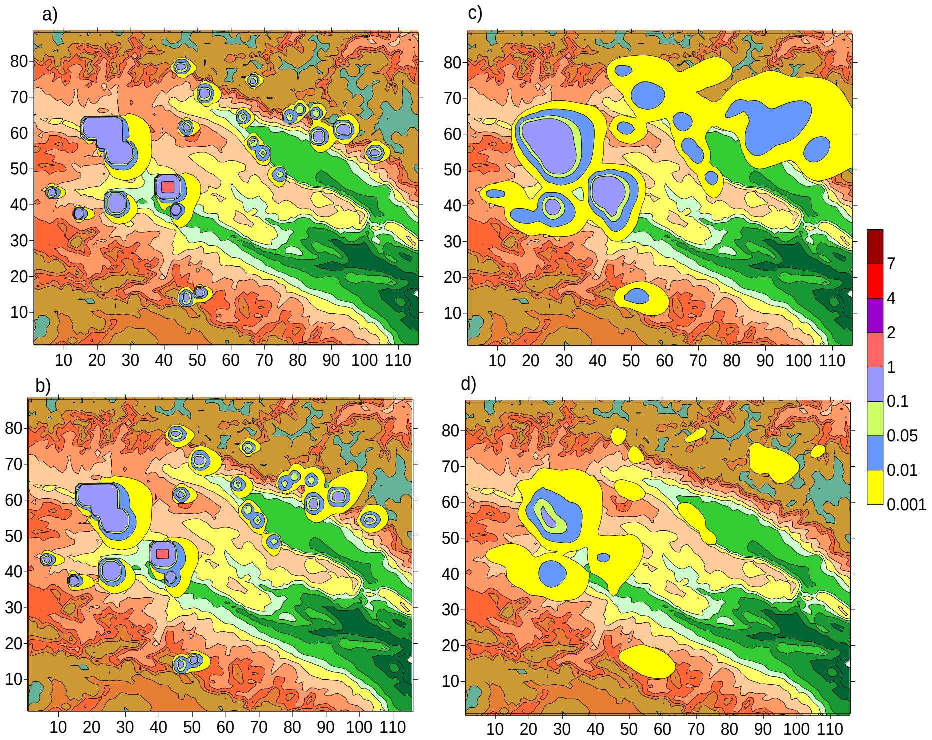

Fig. 1. Dust concentration in atmosphere at the height of z = 2 – a), 10 – b), 100 – c) and 600 - d) meters, when t = 0 hour.

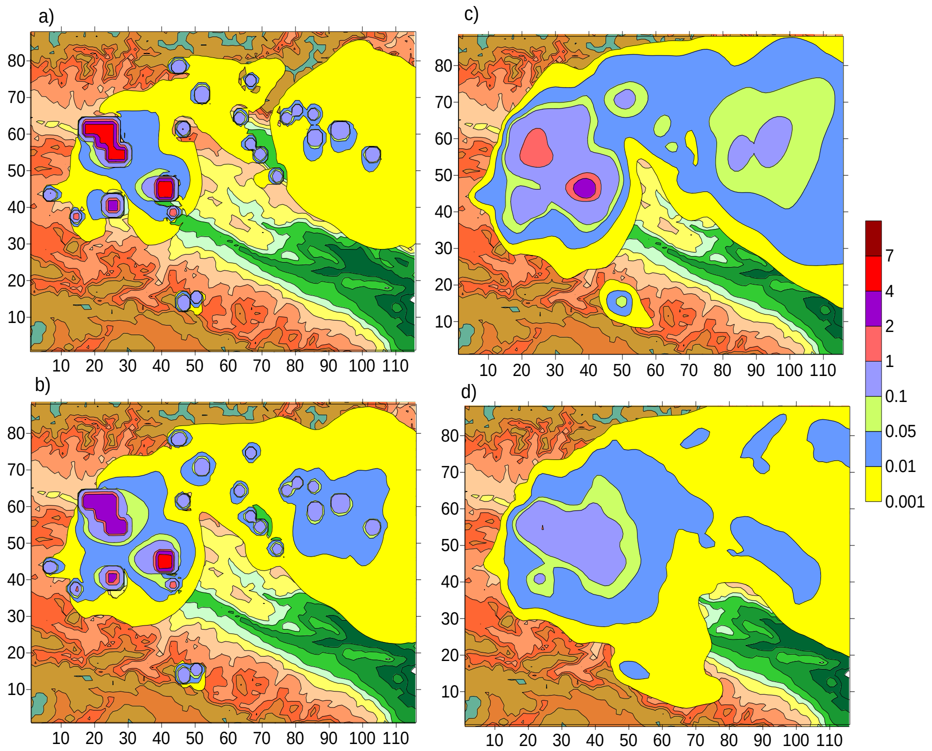

Fig. 2. Dust concentration in atmosphere at the height of z = 2 – a), 10 – b), 100 – c) and 600 - d) meters, when t = 12 hour.

In case of Rustavi the similar reduction takes place at 2-10 km distance. With increase of height the area of dust dispersal significantly increases. At a height of 100 meters the dust-loaded (dust-filled) area forms two basic and one relatively small cloud above Tbilisi, Rustavi, the Georgian part of the Greater Caucasus and above Aghstafa and Kazakh. With the increase of distance from atmospheric surface layer the dust concentration reduces and becomes insignificant at a height of 2 kilometers.

At 12 noon when concentration in atmospheric surface layers of cities reaches its maximum the dustiness zone significantly enlarges. At a height of both 2 and 10 meters, as well as at higher levels the dust of atmospheric surface layer is dispersed (concentrated) in the northern part of region (Fig. 2), where it creates the uniform cloud of shaped form, in which the concentration changes from 5 MAC to 0,001 MAC. Size of the area, where C > 0,01 MAC is minimal at a height of z = 2 m, increases with distance from earth surface and reaches maximum value in 100m ≤ z ≤ 600m layer. In atmospheric surface layer the dust as a united cloud, is dispersed in south-east direction and is located above central part of region (Fig. 3). The value of concentration decreases in upper part of boundary layer. Above 2 km the value of dust concentration is less than 0,001 MAC.

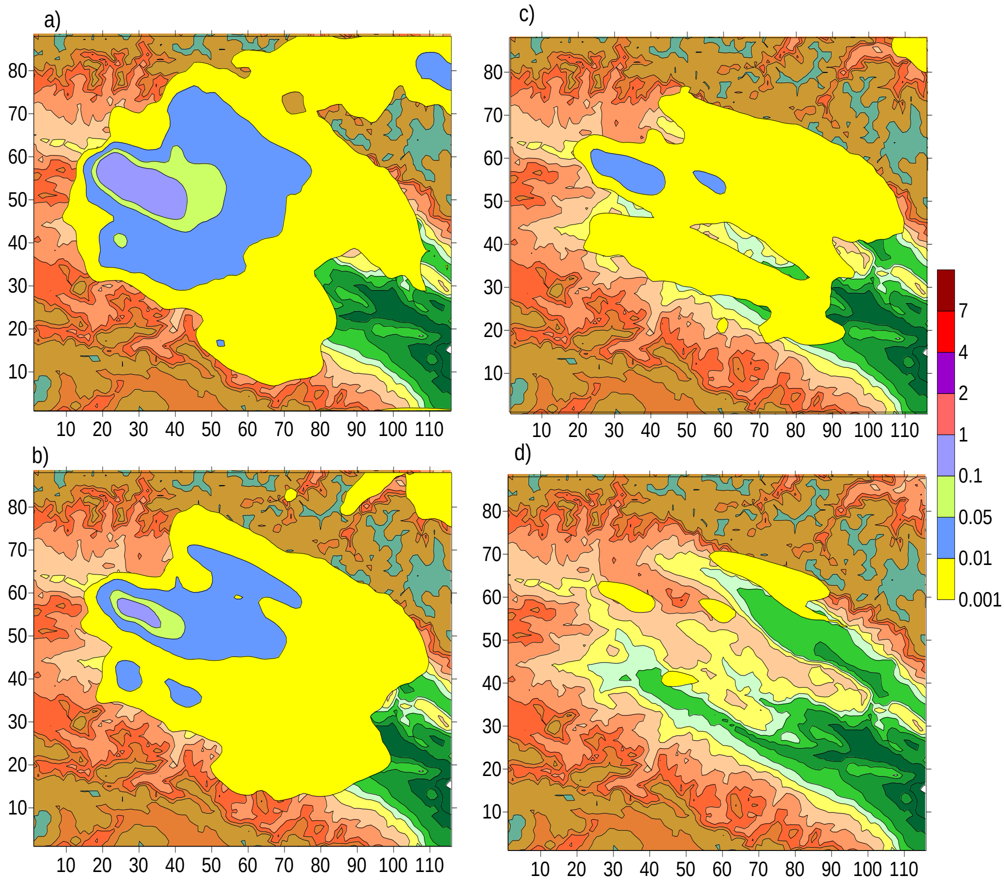

Fig. 3. Dust concentration in atmosphere at the height of z = 1 km – a), 1.5 km – b), 2 km – c) and 3 km - d) meters, when t = 12 hour.

On Fig. 4 and Fig. 5 are shown the dust concentrations in atmospheric surface sub-layer and boundary layer, when t = 21 hr. For this moment of time at urban territories at a height of 2 m the dust concentration is maximal and starts to decrease in time. When comparing Fig. 4 and Fig. 5 with Fig. 2 and Fig. 3 one can see the changes taken place during 9 hours. Namely, the area with c > 0,01 MAC is reduced in atmospheric surface sub-layer and is enlarged in 100m ≤ z ≤ 600m layer. Differences between concentration distributions above 600 m are insignificant. Obtained result is caused by daily variations of thermal, dynamic and turbulent field. Their daily variations are big in atmospheric surface sub-layer, gradually decrease in boundary layer and are getting small in free atmosphere.

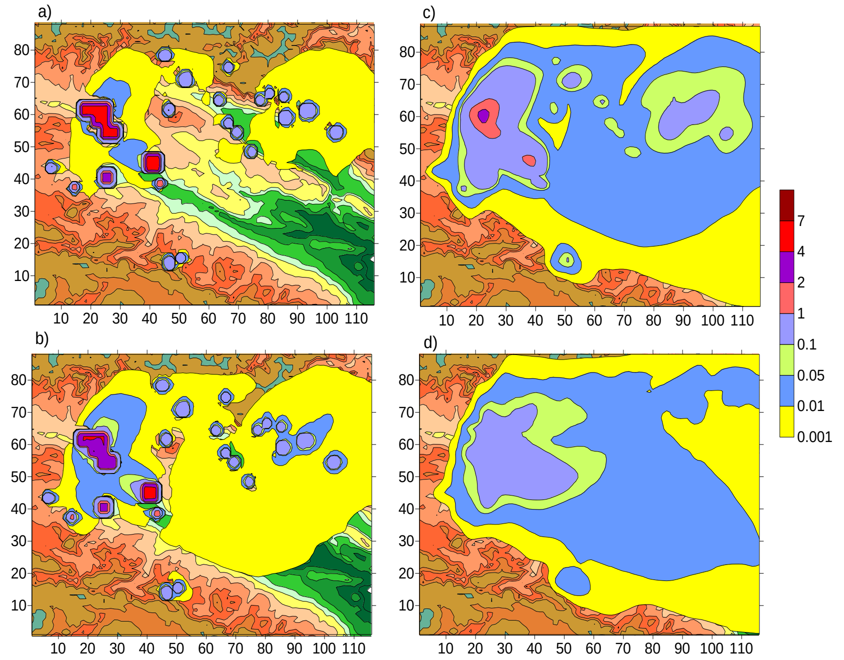

Fig. 4. Dust concentration in atmosphere at the height of z = 2 – a), 10 – b), 100 – c) and 600 - d) meters, when t = 21 hour.

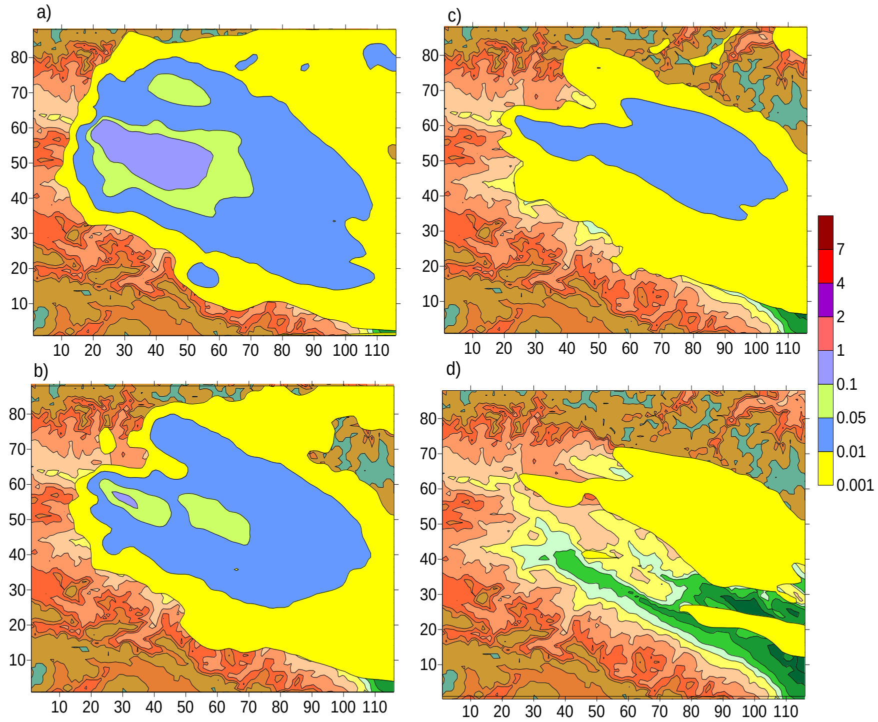

Fig. 5. Dust concentration in atmosphere at the height of z = 1 km – a), 1.5 km – b), 2 km – c) and 3 km - d) meters, when t = 12 hour.

On Fig. 6 and Fig. 7 is shown spatial distribution of dust concentration, when t = 24 hr. As is seen, concentrations in atmospheric surface sub-layer are significantly reduced directly on urban territories and are less decreased at their adjacent areas. Concentration change is also small in upper part of atmospheric surface layer. Mentioned effect shows us the inertness of spatial distribution of pollution.

Analysis of calculation results, which were carried out for second day (24hr $\leq t \leq$ 48hr) showed that quasi-periodical change of dust concentration takes place in time and it changes a bit in the space.

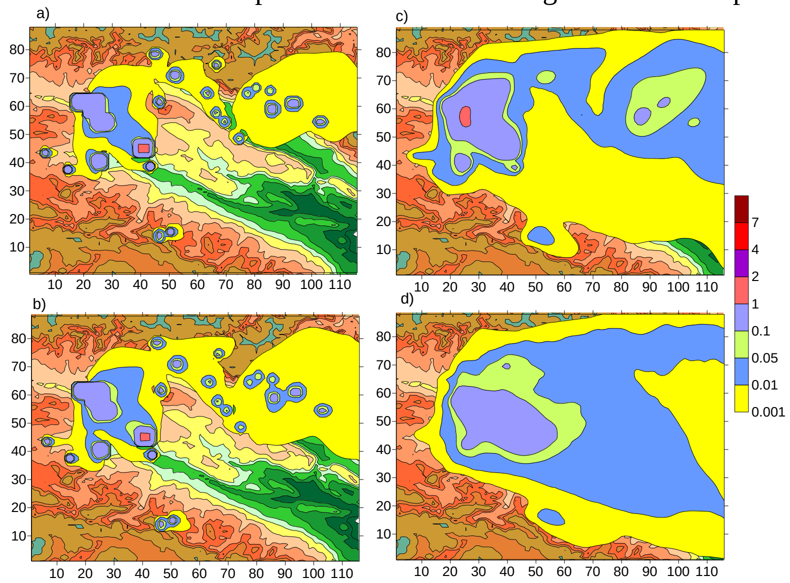

Fig. 6. Dust concentration in atmosphere at the height of z = 2 – a), 10 – b), 100 – c) and 600 - d) meters, when t = 24 hour.

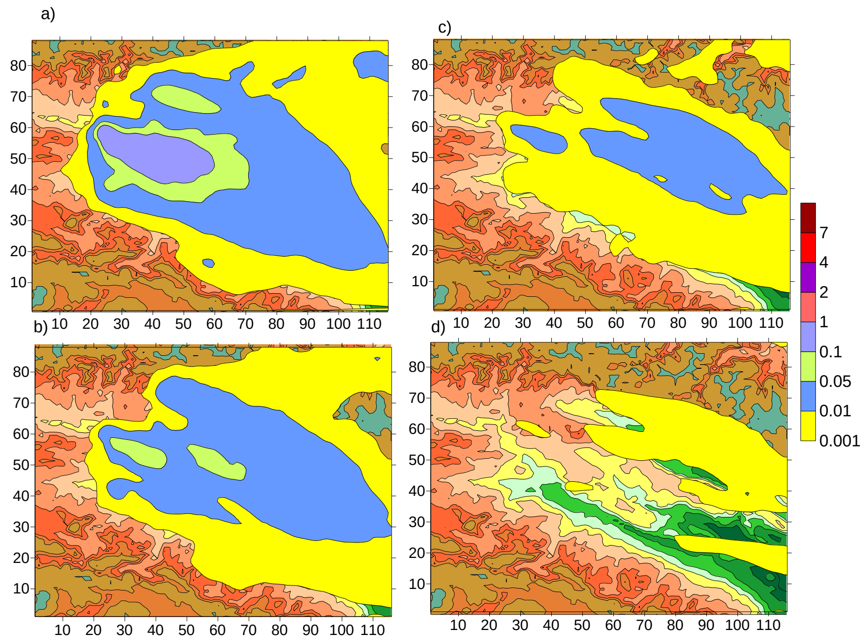

Fig. 7. Dust concentration in atmosphere at the height of z = 1 km – a), 1.5 km – b), 2 km – c) and 3 km - d) meters, when t = 24 hour.

Dust mass is concentrated in the central part of Kakheti region and covers major part of region's territory. But, the concentration c ≥ 0,01 MAC is obtained only at the territories of contaminated cities of Tbilisi, Rustavi and other small atmosphere-polluting cities, as well as roughly at the territory of 300-400 sq. km around them.

4. Conclusions. Conducted numerical modeling showed that quasi-periodical dust distribution is formed at the territory of Kakheti under conditions of stationary western winds and non-stationary dusting of cities. Kinematic analysis of dust dispersal process showed that in 100 m atmospheric surface layer the basic mechanism of dust dispersal is represented by vertical and horizontal turbulent diffusions. The share of advective transfer and turbulent diffusion in the boundary layer of the atmosphere is approximately equal, while in the free atmosphere advective transfer is dominant.

There were determined the areas, where dust concentration varies in a range of C ≥ 0,01 MAC. This area in case of Tbilisi and Rustavi is located within a circle of 20-30 km radius and 10 km radius from city boundaries, respectively. In case of small cities the zone with C ≥ 0,01 MAC is located within circle of 2-4 km radius. Concentration values are near 0,001 MAC at greater distances from cities.

When considering various practical ecological problems, we often need to know background concentrations at the adjacent territory of cities. Today, the urban background concentrations or even 0 are taken as background concentrations for these territories that is not completely reasonable. Studies conducted in this article give us an opportunity to determine the values of background concentrations at the adjacent territories of cities. In particular, in the zones 20 km, 10 km and 2-4 km width, adjacent to Tbilisi, Rustavi and small cities, respectively, 0,03 of daily MAC should be taken as background concentration, and 0,01 MAC – beyond these zones.

Conducted modeling is the first ever theoretical study of air purity at adjacent territories of Georgian cities. Obtained results showed that for territories with compound relief forms is expedient to conduct calculations with less than 2 km horizontal step (spacing). It is necessary to carry out experimental observations of air pollution and to compare theoretically calculated concentrations with values obtained via field observations.

References

[1] Marchuk G. I. Matematicheskoye modelirovaniye v probleme okruzhayushchey sredy. L., Gidrometeoizdat, 1982, 320 s., (in Russian).

[2] Berlyand M.Ye. Sovremennyye problemy atmosfernoy diffuzii i zagryazneniya atmosfery. L., Gidrometeoizdat, 1975, 448 s., (in Russian).

[3] Kordzadze A. A., Surmava A. A., Demetrashvili D. I., Kukhalashvili V. G. Izvestia, Atmospheric and Oceanic Physics. 43, 6, 2007, pp. 722-730.

[4] Kazakov A. L., Lazriyev G. L. O parametrizatsii prizemnogo sloya atmosfery i deyatel'nogo sloya pochvy. Izvestia AN SSSR. Fizika atmosfery i okeana, 1978, t. 14, №3. s. 257-265, (in Russian).

[5] Ed. Georgian National Environmental Agency. Short review of Georgian environment pollution. www.nea.gov.ge (in Ceorgian).

[6] RD 52.04.186-89. Rukovodstvo po kontrolyu zagryazneniya atmosfery. M.,1991, 693 s., (in Russian).

კახეთის ატმოსფეროში მტვერის კონცენტრაციის სივრცული განაწილება დაბინძურების არასტაციონალური წყაროების შემთხვევაში

ა. სურმავა, ნ. გიგაური

რეზიუმე

კავკასიაში ატმოსფერული პროცესების განვითარების რეგიონალური მოდელის გამოყენებით და პასიური მინარევის გადატანა - დიფუზიის განტოლების რიცხვითი ინტეგრირებით მიღებულია ატმოსფეროში გაფრქვეული მტვრის განაწილების სურათები

მიწის ზედაპირიდან სხვადასხვა დონეზე. ნაჩვენებია, რომ ქალაქებიდან ატმოსფეროში გაბნეული მტვერი ძირითადად კონცენტრირებულია ატმოსფეროს მიწისპირა 100მ ფენაში. სიმაღლის ზრდასთან ერთად იზრდება მტვრის სივრცული გავრცელების არე და მცირდება კონცენტრაცია. განსაზღვრულია ქალაქების გავლენის ზონები. ქ. თბილისის გავლენის ზონა 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 გავრცელება უპირატესად ტურბულენტური დიფუზიით ხდება. 100 მ-დან 1 კმ-დე ფენაში დიფუზიური და ადვექციური გადატანის პროცესები ტოლფასია, ხოლო 1 კმ-ის ზევით ძირითადია მტვრის ადვექციური გადატანა.

Пространственное распространение пыли в атмосфере в Кахети в случае нестационарных источников загрязнения

А. А. Сурмава, Н.Г. Гигаури

Резюме

С помощью региональной модели развития атмосферных процессов на Кавказе и уравнения переносса и диффузии примеси получены пространственные распределения пыли на разных высотах в атмосфере Кахети. Показано, что основая масса пыли сконцентрирована в приземном слое атмосферы толщиной около 100 м. С удалением от приземного слоя расширяется пространство распространения пыли и уменьшается его концентрация. Определены зоны влияния городов на запыленность окружающей среды. Для г. Тбилиси зона влияния простирается на 20-30 км, для г. Рустави -10 км, а для остальных малых городов - 2-4 км.
Изучена кинематика процесса распространения пыли. Получено, что в нижнем 2-100 м слое атмосферы турбулентная диффузия играет преобладающую роль в процессе распространения пыли. В слое от 100 м до 1 км влияния турбулентной диффузии и адвективного переноса одинаковые, а выше 1км адвективный перенос преобладает над турбулентной диффузией.