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# Numerical investigation of the air possible pollution in case of large hypothetical accidents in some industrial territories of the Caucasus

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*Abstract*

*The distribution of anthropogenic passive and radioactive pollutions emitted in the atmosphere in the industrial centers of the Caucasus are investigated by means of a regional model of development of atmospheric processes in the Caucasian Region and the equation of substance displacements. The distribution of pollution is simulated in cases for the four basis synoptic situations, when the south, east, west and south-east background large scale winds blow.*

*It is shown, that the relief of the Caucasus significantly influences the trajectory of the pollution displacements. The north-west oriented Main Caucasian Range resists air motion to the north, constrains the pollution substance in the boundary layer to flow around the Main Caucasian Range from the west or east sides. The Likhi Range resists the distribution of the pollution emitted in atmosphere in the vicinity of t. Poti and causes its displacement to the south. It is obtained that 48 hours are mainly necessary for the pollution cloud to overflow the South Caucasus and distribute over the territory of the North Caucasus.*

*The radioactive pollute can fall out mainly in the central, southeast and northwest parts of the South Caucasus. The zone of the radioactive deposition is extended along the background wind and deformed by the influence of the relief. The maximal length of the zone of a significant deposition of radioactive substance equals approximately 750 km in case of the background south-east wind and 350 km in other cases. The maximum width of this zone approximately equals 150 km.*

## 1. Introduction

The South Caucasus is the region that has a high hazard-index of the environmental pollution. There, on a small territory of the Earth the some industrial centers, gas and oil-producing regions are located. The oil and gas are transfer by railway and pipelines between the main Caucasus and Minor Caucasus Ranges. The railways also used to transfer many other hazardous substances from Europe to the Middle Asia via Georgian seaports Batumi and Poti, and Azerbaijan seaport Baku.

The Armenian Nuclear Power Plant (ANPP) is one of such hazardous objects, also. It lies in Metsamor 20 km from the capital of Armenia Yerevan on a one of the Earth's most earthquake-prone terrain. The accidents of the Chernobyl, Fukushima and other power plants show that the nuclear reactors carry the great potential hazards for population and environment especially when plants are located in the seismic hazardous regions [1, 3]. ANPP, as a very dangerous object, was closed after earthquake in Armenia in 1988 but was reopened in 1995. ANPP has one of just a few remaining Soviet nuclear power reactors that were built without the primary containment structures. Consequently, the hazard of the radioactive pollution of the environment in the Caucasus becomes highly probable event. The neighbouring countries, Turkey and Azerbaijan, protest the operation renewal of ANPP, and Azerbaijan has called on the UN Security Council to suspend the operation of the nuclear power plant in Metsamor [4-6].

The pollution substances emitted in the atmosphere of the Caucasus can be distributed over the large territory of the region and cause the significant negative influence of health of population and ecological state of an environment. Therefore, an investigation of the distribution of pollution emitted in the atmosphere of Caucasus in result of an accident has significant practical importance. Some questions of this problem were considered in [7].

In the present article we continue an approach made in [7]. Using the regional model of evolution of the atmospheric processes in Caucasus region [8] and equation of distribution of substance in the atmosphere we will simulate and investigate the dispersion of the passive and non-passive pollution substances in the atmosphere of the Caucasus Region.

## 2. Formulation of the Problem

The equation of the substance transport in the atmosphere is

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+(\tilde{w} \quad \frac{W_{sed}}{h})\frac{\partial C}{\partial \zeta}=\mu\Delta C+\frac{\partial}{\partial \zeta}\nu\frac{\partial C}{\partial \zeta} \quad +\alpha C\ , \qquad (1)$$

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; $\delta$ is height of the relief; H (t, x y) is the height of the tropopause; $h = H - \delta$; u, v and $\tilde{w}$ are the wind velocity components along the axes x, y, and $\zeta$ , respectively; C is the concentration of substance; the index $\alpha = \ln 2 / T_{rad}$ is the decay constant; $T_{dec}$ is a decay period; $W_{sed}$ is an aerosol deposition velocity. μ and $\nu$ are the horizontal and vertical turbulent diffusion coefficients, respectively. u, v, $\tilde{w}$, μ and $\nu$ are known functions of temporary and spatial coordinates; $W_{sed}$ determined by Stockes formula, $T_{dec}$ is known parameter.

The initial and boundary conditions for (1) are following:

$$C = C_0 \text{ if } 0 \le t \le T \text{ and } x, y \text{ and } \in \Omega;$$
$$\partial C/\partial x = 0 \quad \text{if} \quad x = 0,\ X; \quad \partial C/\partial y = 0 \quad \text{if} \quad y = 0,\ Y; \qquad (2)$$
$$\nu \partial C/\partial \ = A|v_0|C \quad \textit{if} \quad \varsigma = 0; \quad \partial C/\partial \varsigma = 0 \text{ if } \zeta = 1.$$

Where $\Omega$ is the rectangular area where the emission of the pollutant substance takes place; $v_0 = (u^2(t,x,y,0) + v^2(t,x,y,0))^{1/2}$ is the wind velocity on the upper boundary of the surface layer $\zeta$ = 0, *X* and *Y* are the lateral boundaries of the area of solution along the axes x and y, respectively. The coefficient $\mu = 5 \times 10^3$ m$^2$/s; A= 0.001.

Equation (1) is numerically integrated using the implicit monotonic scheme [6]. The finite-difference-grid with horizontal and vertical steps equal to 10 km and 1/17, respectively, is used. The time step is 1 min. For the every time step the wind velocity components were calculated by the Regional Model of the atmospheric processes [8].

The equation (4) shows that any functions that equal to $C(t,x,y,\zeta) \times \text{const}$ obey also the equation (4). Therefore we will consider $C(t,x,y,\zeta)$ as unit value and then in order to obtain the real magnitude of concentration we must multiply the calculated field of C on a const .

The equations (1) is solved in the coordinate systems **(t, x, y,**$\zeta$**)** and *(t, x, y, z)*, respectively.The initial and boundary conditions, the values of background fields, and methods of parameterization of the separate meteorological processes are selected in accordance with specific objectives of modeling.

### 3. Analyses of results

Since we limit ourselves by the Caucasus Region, the calculations were performed for the winds that are most characteristic for this territory. For this purpose we consider the cases of the passive substance emission in the vicinity of t. Poti, Batumi and Baku, and emission of the radioactive nuclide $^{131}I$ in the vicinity of t. Metsamor (Fig.1). The calculations are performed for a period up of 48 h. The pollutant substances during first 6 h are emit in the atmosphere into rectangular prism area $\Omega$ (10 km$\times$10 km$\times$0.8km), in the vicinity the sources. The initial concentration $q_0 = 100$ arbitrary unit (a.u.). Such situation can take place in cases of accident on the oil tankers or the oil storages and in other processes of transfer of the air pollutants.

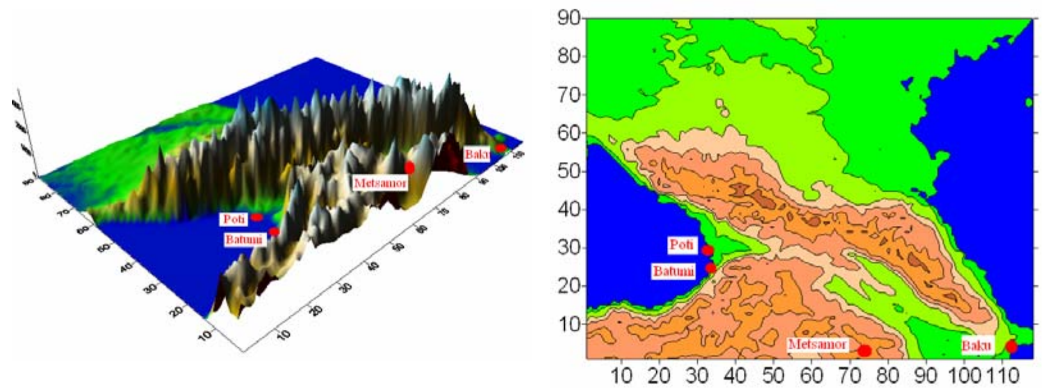


Fig. 1. The Caucasus Region relief and topography (heights in km) and the location of the ANPP (the red circle).

The temporary change of the spatial distributions of the pollutant substance emitted in the atmosphere in the vicinity of seaport t. Poti is shown in Fig. 2. This figure shows that the main part of the pollution cloud in the surface level $z \leq \delta$ is moved to the north-west direction and at t = 24 h is distributed over the north-east part of the Black Sea and west part of the Main Caucasus. The small part of the pollution substances is carried out to the east over the Colchis Lowland and passing over the Rikoti Pass is spread on the East Georgia over Kartli Plain. The maximal value of the concentration for 24 h interval of time in the boundary layer is decreased from its initial value 100 a.u. to 70 a.u. (z = 1 km).

For t = 48 h and 144 h the concentration of the pollution over the Georgian territory is significantly decreased (about $10^4$ times when t = 144h). On the surface level the maximal value of the concentration is in interval 0.16-0.18 a.u. and it is obtained in the north of the modeling area over the north- east part of the Caspian Sea. In other areas the concentration is less 0.01 a.u. The concentration decreases with a height and on the level z = 3 km, the concentration 0.01 a. u. is obtained only in a small area over the north-east part of the Main Caucasus Range.

When the background northern wind blows (Fig. 3.) the spatial distribution of the pollution substance is significantly different than it is obtained in case of the western wind. The orography of the Main Caucasus and Likhi Ranges resists the pollution cloud movement to the north and east, and constrains the pollution distribution from north to south. During all 48 h the pollution clouds are located over the west part of Georgia, northern Turkey and Armenia.

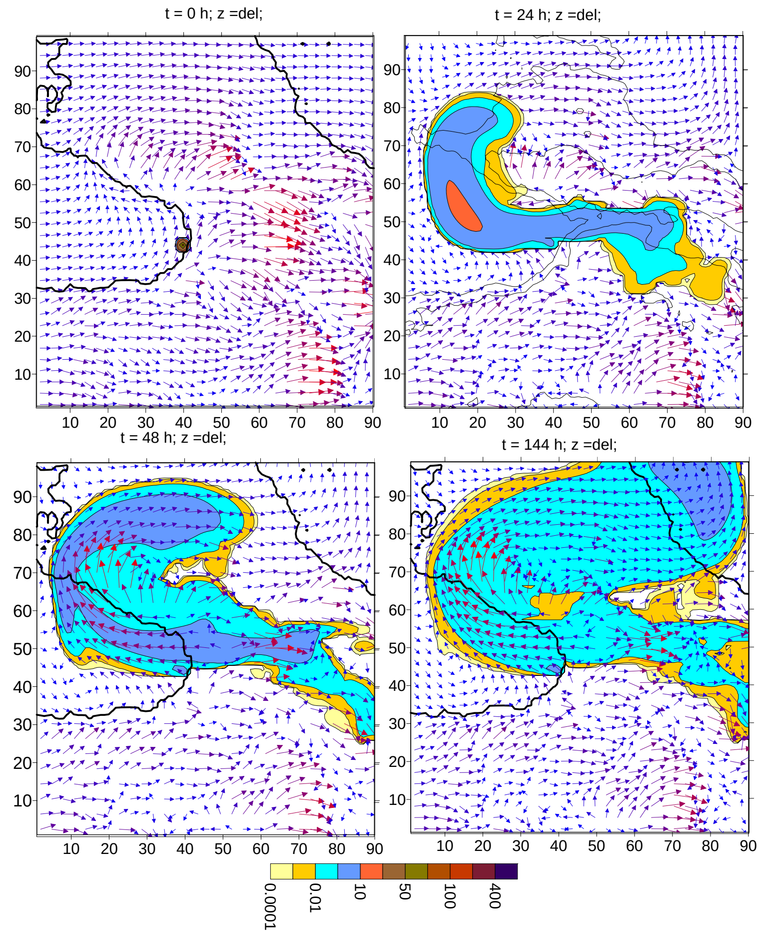


Fig. 2. The spatial distribution of the concentration C(a.u.) of the passive pollution substance emitted in the vicinity of t. Poti in t = 0, 6, 24 and 48 h on the levels $z = \delta(x, y)$ and 2 km in case of the background western wind.

If the emission takes place in the vicinity of t. Batumi the pollution cloud during first five-six hours moves to the north along the east shore of the Black Sea and after the process of the pollution the diffusion continues as it was described in case of emission in the vicinity of t. Poti. In Fig. 4 and 5 the spatial distributions of passive pollution substance emitted in the vicinity of t. Baku in cases of the eastern and south-eastern winds are shown. By these figures we can conclude that the pollution emitted in atmosphere in the vicinity of t. Baku distributes in the South Caucasus atmosphere when the eastern wind blows. The pollution cloud during first 6 h is located in the vicinity of the Absheron Peninsula into area heaving 300 km length and 150 km width. Then the pollution cloud moves along the northern incline of the Minor Caucasus Range over the Mugami and Shirvani Lowlands, and occupies almost all territory of the Armenia and Azerbaijan. When t = 48 h, the pollution is distributed over of the South Caucasus from the Caspian Sea to the Black Sea.

The pollution cloud when the south-east background wind takes place, the displacement is over the territory of the North Caucasus (Fig. 5). At t = 24 h the pollution cloud is distributed over the Dagestan and Chechen Autonomy Republics, and reaches the south-west part of the Stavropol Krai. Then the pollution moves to the north-west and at t = 48 it is distributed over the territory of the Stavropol Krai. The zone of a maximal concentration is in the centre of the pollution cloud and its magnitude varies in interval 0.1a.u.– 10 a.u.

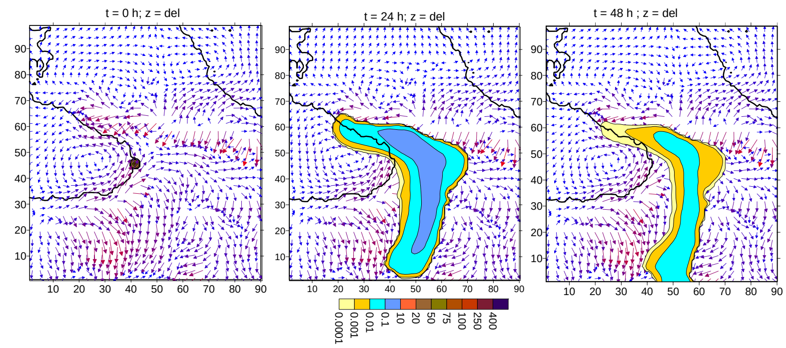


Fig. 3. The spatial distribution of the concentration C(a.u.) of the passive pollution substance emitted in the vicinity of t. Poti in t = 0, 24 and 48 h on the atmosphere surface level $z = \delta(x, y)$ in case of the background northern wind.

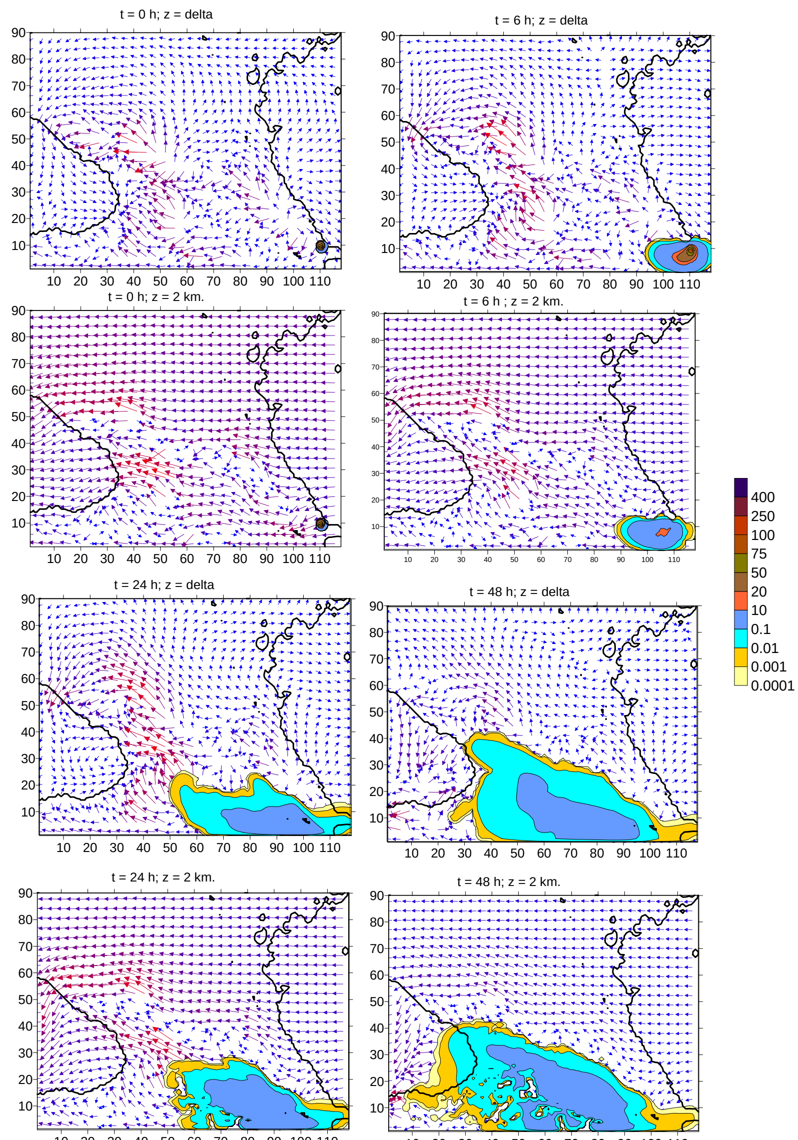


Fig. 4. The spatial distribution of the concentration C(a.u.) of the passive pollution substance emitted in the vicinity of t. Baki t = 0, 6, 24 and 48 h on the atmosphere surface level $z = \delta(x, y)$ and z = 0 in case of the background eastern wind.

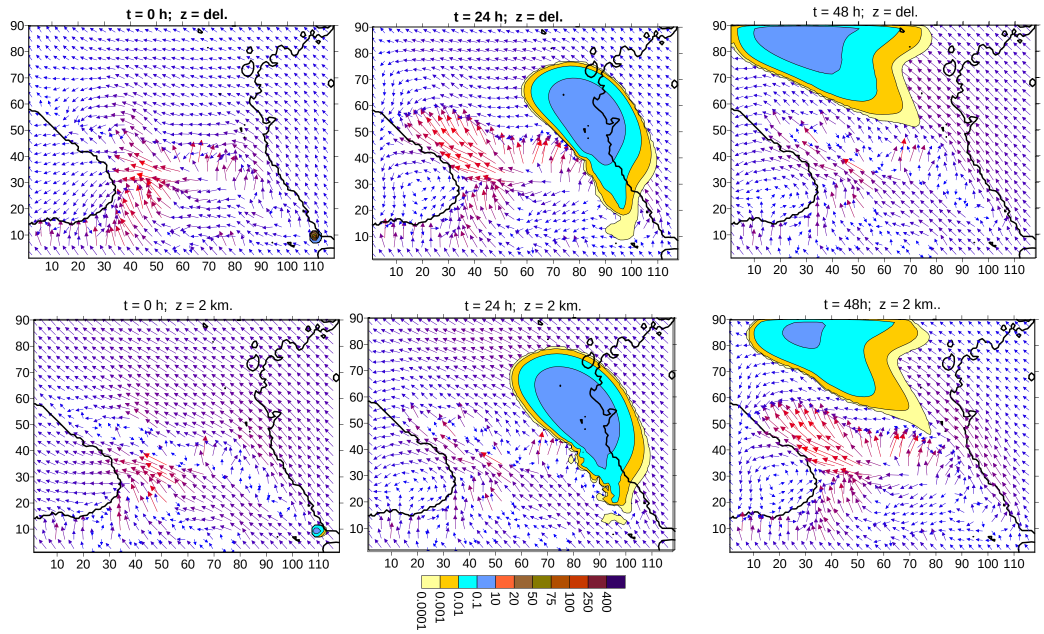

Fig. 5. The spatial distribution of the concentration C(a.u.) of the passive pollution substance emitted in the vicinity of t. Baku in t = 0, 24 and 48 h on the atmosphere surface level z $=\delta(x,y)$ and 2 km in case of the background north wind.

The possible pollutions of the Caucasus Region in case of hypothetical emission $I^{131}$ from the Armenian Power Plant were also simulated. Were considered emissions of the iodine particles with a radius equal 10 $\mu m$. A corresponding fall-out velocity of the particles calculated by Stokes formula is equal to $W_{sed}$ = 1cm/s [9], the decay period $T_{rad}$ =8.02 day.

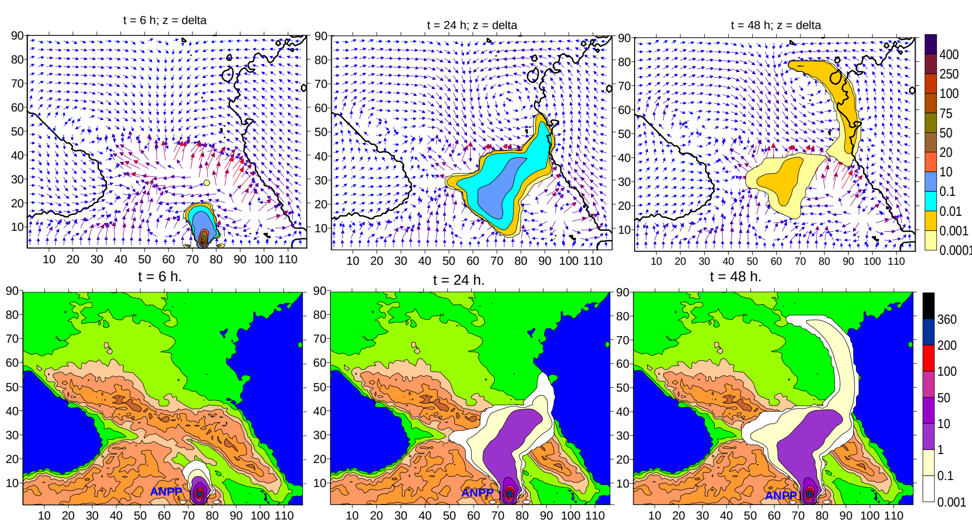

Fig. 6. The spatial distribution of the concentration in the atmosphere surface layer (upper row) and surface density of the sediment on the earth (lower row) of the radioactive pollution $I^{131}$ (a.u./m$^2$) at t = 0, 24 and 48 in case of the background southern wind.

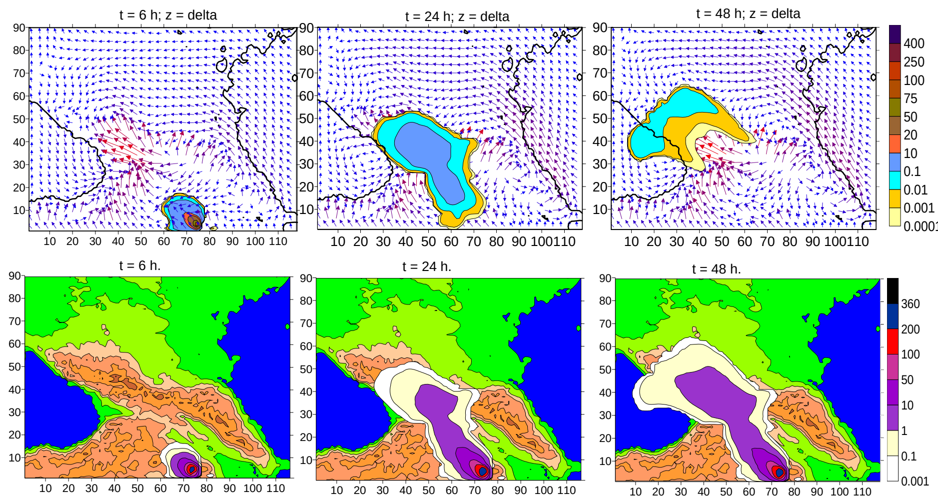


Fig. 7. The spatial distribution of the concentration in the atmosphere surface layer (upper row) and surface density of the sediment on the earth (lower row) of the radioactive pollution $I^{131}$ (a.u./$m^2$) at t = 0, 24 and 48 in case of the background south-east wind.

Figs. 6 and 7 show the distribution of the concentration of $I^{131}$ and the wind fields obtained in case of the background south wind on the surface level $z = = \delta(x, y)$ and surface density of the sediment radioactive pollution at the moment of the time t = 6, 24 and 48 h, respectively. In Fig. 6 we can note that during 6 h the radioactive emission forms the radioactive cloud over ANPP that by wind and atmosphere turbulence is stretched to the north along the direction of the background wind. The radioactive cloud is located into ellipsoid columns area with maximum horizontal sizes 100 km and 170 km along x and y coordinates, respectively. By calculation it is also obtained that the vertical width of the radioactive cloud approximately equals 9 km. The magnitude of the concentration is equal to 100 a. u. into the emission plume in the 4 km layer and exponentially decreases on the periphery of this area.

After six hours the radioactive cloud increases step-by-step in size because of the movement along the wind and atmospheric turbulence. Simultaneously the concentration of the pollutant substance decreases in result of the processes of dispersion, deposition, and radioactive-decay. The radioactive cloud in the surface layer at t = 24 h is obtained over the central part of the South Caucasus mainly up of the territory of the north part of the Armenia and the east part of Georgia. Over this surface layer the size of the polluted atmosphere volume gradually increases up to 6 km. The zone of the higher concentration is displaced from the South Caucasus to the North Caucasus (from the East Georgia to the Stavropol Kray). The magnitude of maximal concentration during the 24 hours is decreased down to 0.48 a. u.

During two days (Fig. 6) the radioactive cloud mainly moves over territory of the North Caucasus and localizes over the Stavropol Kray. In the South Caucasus the radioactive cloud is obtained over a small territory of the central part of Georgia. The concentration there is small and is varying between 0.001a.u. - 0.006 a.u. The maximal value of concentration in the plume of pollution caused by the processes of dispersion, deposition, and radioactive-decay is decreased about 2000 times from 100 a. u. to 0.05a.u. The spatial distribution of the radioactive deposition on the earth surface is shown in Fig. 6, also. As it is shown here, the main part of the radioactive dust falls on the territory of Armenia and Georgia into the stripe of 100 km in width and about 400 km in length. The radioactive ingredient up to 12 h falls out only on the territory of the South Caucasus. After this time the process of fallout begins also on the territory of the North Caucasus. After 20 h from the beginning of emission the radioactive fallout happens mainly on the territory of the North Caucasus and at t = 48 h the surface density of $^{131}I$ on the territory of the north slope of the Main Caucasus Range reaches 10 a.u. on 1 $m^2$. The radioactive deposition on the territory of the South Caucasus ends after 30 h.

The results of the numerical modeling of the radioactive diffusion when the background south-east wind blows, are show in Fig.7. The calculation shows that the radioactive pollution moves to the north firstly on the territory of Armenia and then over the central and north-west parts of the Caucasus Region. At t = 24 h the main part of atmosphere over Georgia is polluted by radioactive ingredient. Further, the radioactive cloud falls over the Main Caucasus Range, splits in two parts and at t = 48 h we obtain two zones of the radioactive pollution. One of these zones is located over the Black Sea and another over the north slope of the Main Caucasus Range. The radioactive deposition obtained at t =0, 24 h and 48 h are also shown in Fig. 7. We see that in 48 h the radioactive fallout mainly happens on the territory of the north part of Armenia, the south, central, and north-west parts of Georgia. The small amounts of the radioactivity are also deposited on the territories of Turkey and Russian. The maximal magnitude of he surface density at t = 48 h is equal to 360 a.u./$m^2$ and is obtained in the vicinity of the source of emission.

## 4. Discussion

In the article the possible pollution of the atmosphere of the South Caucasus is numerically simulated. It considers the four main cases when the pollution is distributed from four, most hazardous in sense of accident, industrial territories. As the regional air circulation significantly depends of the large scale background wind we have limited our simulation by cases of regional transport of pollution into the South Caucasus. We consider the cases when the background wind in the surface layer of the atmosphere is $\vec{v} \leq 5$ m/s.

The numerical modeling shows that the regional orography significantly deforms the trajectory of the pollution cloud. In case of the background western wind the pollution emitted in the atmosphere in the vicinity of t. Poti can by distributed in the surface layer of atmosphere both to east and to north-west. The pollution emitted in the atmosphere in the vicinity of t. Baku can cause a pollution of the South Caucasus atmosphere only in one case – when it blows the background eastern wind. When the background south- east wind blows the pollution distributes in the North Caucasus and it does not cause a pollution of the South Caucasus Atmosphere.

The simulation shows the radioactive emission from ANPP pollutes the atmosphere of the South Caucasus in two cases when the east and south-east winds take place. The radioactive pollution falls out mainly on the central, southeast, and northwest parts of the South Caucasus. The zone of radioactive deposition is extended along the background wind and deformed by influence of the relief. In case of the background southeast wind the maximal length of the zone of significant deposition of radioactive substance approximately equals 750 km, and 350 km in other cases. The maximal width of this zone equals approximately 150 km. The concentration of deposited radioactive element in the zone of radioactive fall-out decreases from 360 a.u./$m^2$ down to 1 a.u./$m^2$.

For the reason of the absence of the observation data it isn't possible to estimate a quantitative reality of the obtained results. But, having compared the trajectory and shape of the radioactive cloud (Fig. 8.) obtained in this article and in other works [10, 11], it may be concluded that the obtained results properly describe the main features of the radioactive dispersion process in the Caucasus. Therefore, the model and results obtained here can be considered as first approximation for the further investigation and practical use. In addition, in our opinion, the spatial grid step 10 km is rather large for adequate description of studied process over complex terrain of Caucasus. We intended simulating the diffusion processes of radioactive pollution with the horizontal step approximately equal to 1-5 km in the atmosphere of the Caucasus.

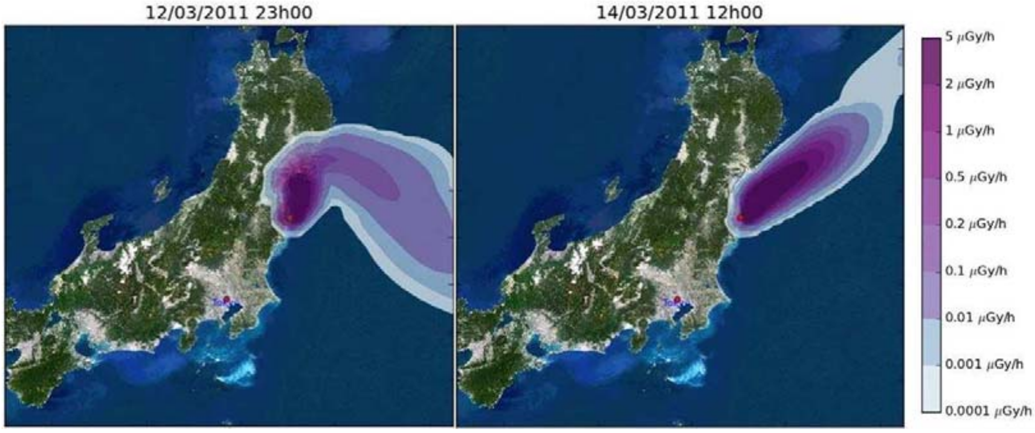


Fig. 8. Atmospheric dispersion of radionuclides from the Fukushima-Daichii Nuclear Power Plant [10].

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# კავკასიის ინდუსტრიულ ცენტრებში ჰიპოთეტური მძლავრი ავარიების შემთხვევებში ჰაერის შესაძლო დაბინძურების რიცხვითი გამოკვლევა

ა.ა. კორძაძე, ა. ა. სურმავა, ვ. გ კუხალაშვილი


რეზიუმე

კავკასიაში ატმოსფერული პროცესების განვითარების რეგიონალური რიცხვითი მოდელისა, პასიური და რადიოაქტიური მინარევის გავრცელების განტოლების გამოყენებით შესწავლილია კავკასიის ატმოსფეროს შესაძლო დაბინძურება კავკასიის ინდუსტრიულ ცენტრებში დამაბინძურებელი ნივთიერებების ჰიპოთეტური ავარიული ამოფრქვევების შემთხვევებში. დაბინძურების გავრცელება შესწავლილია ოთხი ძირითადი სინოპტიკური სიტუაციის დროს, როდესაც ქრიან დასავლეთის, ჩრდილოეთის, აღმოსავლთის და სამხრეთის ფონური ქარები.

ნაჩვენებია, რომ კავკასიის რეგიონის რელიეფი ძლიერ მოქმედებს მინარევების გავრცელების ტრაექტორიაზე. ჩრდილო-დასავლეთით ორიენტირებული მთავარი კავკასიონის ქედი ეწინააღმდეგება რა ჰაერის მოძრაობას ჩრდილოეთის მიმართულებით აიძულებს დამაბინძურებელ ნივთიერებას ატმოსფეროს სასაზღვრო ფენაში გარსშემოედინოს ქედს ჩრდილო-დასავლეთისა და აღმოსავლეთის მხრებიდან და შემდგომ გავრცელდეს ჩრდილოეთ კავკასიაში. ლიხის ქედი, ეწინააღმდეგება რა ქ. ფოთში ამოფრქვეულ დამაბინძურებელ ნივთიერებას გავრცელდეს აღმოსავლეთით იწვევს დაბინძურების გავრცელებას სამხრეთით. ნაჩვენებია, რომ 48 საათია საჭირო იმისათვის, რომ დაბინძურების ღრუბელი გადაევლოს სამხრეთ კავკასიასა და გავრცელდეს ჩრდილოეთ კავკასიაში.

რადიოაქტიური ნუკლიდები შეიძლება დაილექოს სამხრეთ კავკასიის ცენტრალურ, სამხრეთ-აღმოსავლეთ და ჩრდილო-დასავ;ეთ ნაწილებში. რადიოაქტიური დანალექის ზონა არის გაჭიმული ფონური დინების გასწვრივ და დეფორმირებულია რელიეფის გავლენით. მნიშვნელოვანი რადიაციული დანლექის ზონის სიგრძე დაახლოებით 750 კმ-ს შეადგენს სამხრეთ-დასავლეთის ფონური ქარის შემთხვევაში და 350 კმ-ს სხვა შემთხვევებში. ამ ზონის მაქსიმალური სიგანე არ აღემატება 150 კმ-ს.


# Численное исследование возможного загрязнения воздуха в случаях гипотетических крупных аварий в индустриальных центрах Кавказа

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Резюме

С помощью региональной модели развития атмосферных процессов в Кавказском регионе, уравнений переноса пассивной и радиоактивной примесей исследовано возможное загрязнение атмосферного воздуха Кавказа в случаях гипотетических аварийных выбросов загрязняющих веществ в индустриальных центрах Кавказа.. Распространение загрязнения исследовано для четырёх основных синоптических ситуаций, когда имеются западный, северный, восточный и южный фоновые ветры.

Показано, что рельеф Кавказа в приземном слое атмосферы существенно влияет на траекторию распространения примесей. Ориенторованный на северо-запад Большой

кавказский хребет, препятствуя перемещению воздуха на север, заставляет основную часть загрязнения обтекать препятствие с северо-взападной или  с северо-восточной, стороны, и далее распространиться над територией Северного кавказа. Лихский хребет препятствуя распространению загрязнения, выброшенного в атмосферу на восток, заставляет его перемещаться на юг. Получено, что проблизительно 48 часов нужны облаку загрязнения для перетекания через Южный кавказский хребет и распространения над Северным кавказом.

Основная масса радиоактивных веществ могут выпасть над центральной, северо-западной и юго-восточной частями Южного кавказа. Зоны радиоактивного осаждения вытянуты вдоль фоновых ветров и частично деформированы под влиянием рельефа территории. Максимальная длина зоны значительного выпадения радиоактивных веществ приблизительно равна 750 км в случае фонового юго-восточного ветра и -  350 км для других направлений фоновых ветров.