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On the Caucasus terrain influence on the spatial and temporary evolution of the vortexes and displacement of the pollution clouds in the atmosphere

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Abstract

Numerical modeling and studies of the wind fields over the South-East Europe, Asia Minor, Middle East and Caucasus terrain is carried out. Traveling synoptic scale vortex wave generation and subsequent evolution of orographic vortices are discovered. The local structures of β-mesoscale wind field in vicinity of the east shoreline of the Black Sea and the central part of the South Caucasus are investigated.

It is also numerically investigated the distribution of the pollution emitted in the atmosphere from a hypothetical sources located both in internal points of the South Caucasus and its border areas. The main trajectories of movement of the maximal concentration zone of the clouds of pollution clouds are shown.

1. Introduction

At present many hydrometeorologists are actively studying mesoscale atmospheric processes above the complex terrains. The problem being complex, in itself, becomes more complicated because its solution is closely related to other important problems of dynamical meteorology [1, 2].

The essential contribution to the solution of this problem was brought by scientists of scientific school G. I. Marchuk, firstly in the Computer Center of Siberian Branch of Academy of Science USSR [3-15], and later in other scientific research institutes of the post soviet republics [16 - 21]. Distinctive feature of researches of this school is a use of modern highly effective numerical methods for the decision of the nonlinear equations of hydrothermodynamics of atmosphere and methods of parameterization of the subgrid scale of physical processes.

The Caucasus has very complex relief. Here two high mountain ridges mass – the Main Caucasus and Minor Caucasus ridges are surrounded by three seas – the Black, Azov and Caspian Seas, the high mountain ridges of Anatoly Peninsula and Iran. The existing network of natural supervision cannot describe in full all palette of large- and mesoscale features of spatial and temporary change of the hydrometeorological fields in this region. Therefore numerical modeling of development of atmospheric processes is effective way for research of the mechanism of interaction of the atmosphere and complex relief above this territory. For the last decades, a significant consideration is given as well to the problems of dynamics of land-locked seas: the Mediterranean, the Black and Caspian seas [16-20]. Therefore, the study of role of mountain ridges located in neighbourhood of Caucasus in formation of the vortexes fields above and the trajectory of pollution substance in this complex terrain area is a great theoretical and applied importance.

For investigation above-mentioned problems we use the regional model of development of the mesoscale atmospheric processes in vicinity of Caucasus elaborated at the Nodia Institute of Geophysics [19]. This model is also used for investigation of the trajectory of pollution clouds in the area of Caucasus.

2. Simulation Results

2.1. Generation of α-meso-scale vortices

In this part of the article we discuss the results of the numerical experiments carried out by using the model [19] for investigation of the influence of the Caucasus relief on spatial and temporary evolution of the moving synoptic scale vortex. It was considered the enlarged territory that involves the part of south-east Europe, Asia Minor and South-west Asia, North-east Africa, Near East and waters of the Black, Azov, Caspian and Mediterranean seas (Fig. 1 a). The Caucasus is located in the centre of this area. The background large-scale idealized anticyclonic and cyclonic waves flow this region with velocity 10 m/s directed to the east (Fig. 1 b).

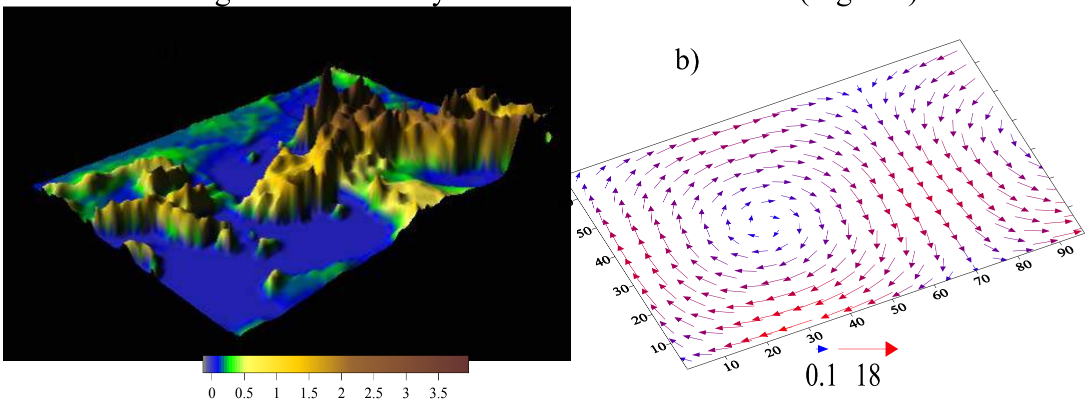

Fig. 1. The height of relief (km) of the modeling area – (a) and the background synoptic scale wind field (m/s) – (b).

In first, for estimation of the influence of roughness of the Earth surface, we model the evolution of the synoptic scale vortex wave in case of flat orography. The modeling shows that the large scale wave varies in shape and size during its traveling to the east, at the same time the separate α - mesoscale (500 - 1000 km) vortex of wind velocity (Fig. 2) generates and disappears. Life period of existing of these vortices is about 24-36 hours. Vortices are obtained not only at the surface of the Earth but also in the middle and upper troposphere. This indicates that there is an energy transfer from the large-scale vortex to the mesoscale vortices. The considered process takes place only in case of baroclinic atmosphere and is absent in barotropic one.

The results obtained when an influence of the real relief are taken into account are shown in the Fig. 3. As follows from the Figure 3a, complex relief significantly varies the general picture of large-scale movement of the air in the lower troposphere. Along with a dynamic baroclinic effect a kinematic effect of the relief lay on the motion of air. The mesoscale wave perturbation occurs at in the vicinity of the Carpathians as a result of the influence of orography. A zone of wind speed divergence is obtained in the Caucasus and northern Iran. The mesoscale cyclonic vortices generate in the vicinity of the eastern Black Sea and Mesopotamia. Strong north-west, north, northeast and east winds are obtained over the Caspian Sea, hilly areas of Iran and the Anatolian peninsula. A cyclonic circulation of wind was obtained over the relatively small territory to the east of the Caspian Sea. In general it is evident that the relief of the western and central parts of the region strengthens anticyclonic vorticity of the background movement of air. Figure 3b shows that as the background vortex propagates to the east, the surface flow varies significantly to the instant of time t=24 hours. Over the western region the anticyclonic vortex splits into medium-scale anticyclonic and cyclonic vortices with the centers in the vicinity of the Carpathians and the Crimea, respectively. Over the eastern part of the Mediterranean Sea wind was divided into two oppositely directed flows. Two counter- current flow of air in the vicinity of Mesopotamia converge and form a strong southeast wind, which reaches the South Caucasus.

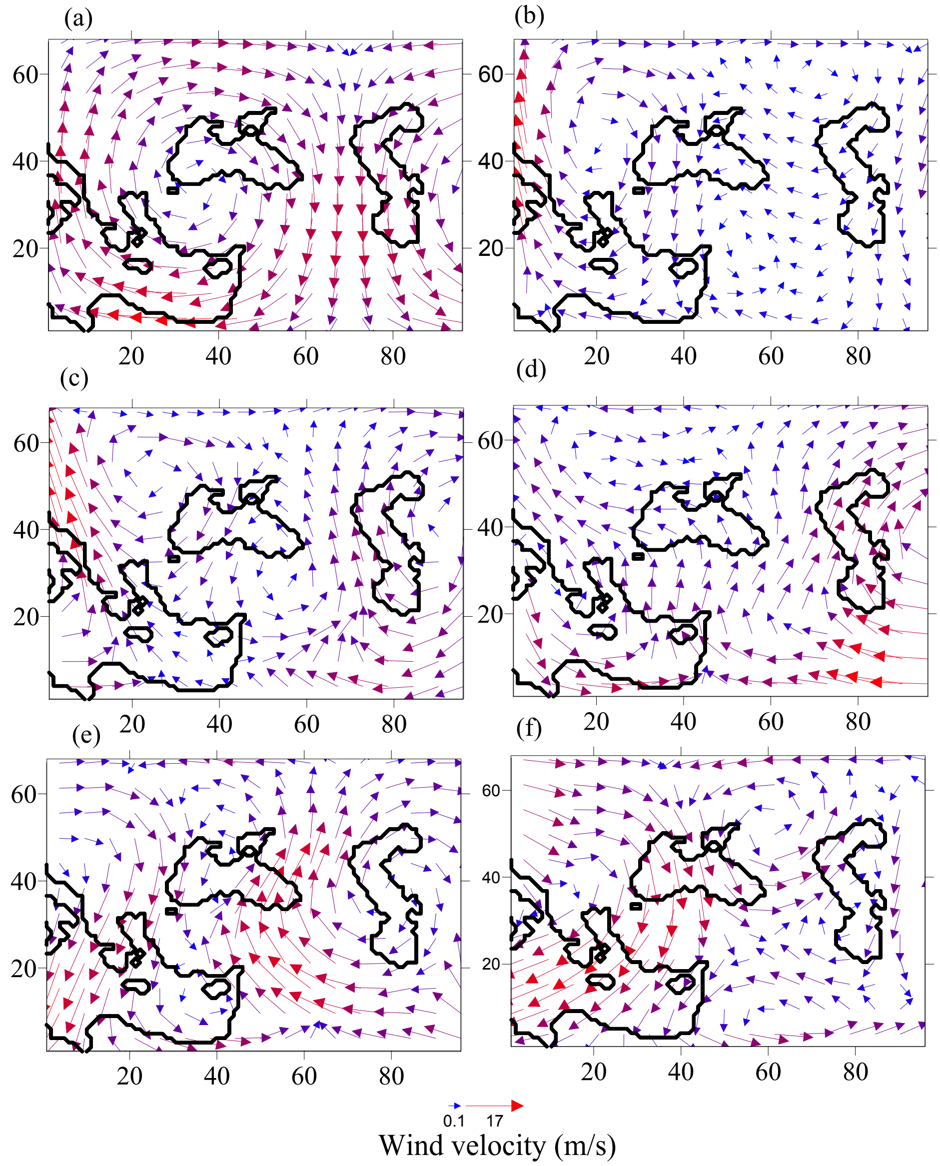

Fig. 2. The surface wind fields in the baroclyne approximation for a flat relief calculated at $t = 0$ *h* (a), 24 *h* (b), 48 *h* (c), 72 *h* (d), 96 *h* (e), and 120 h (f), respectively. Horizontal and vertical grids steps are equal 40 km.

During the time interval of hours anticyclonic vortex in the vicinity of the Carpathians gradually defuses (Fig. 3(c), (d)). In the vicinity of the Anatolian peninsula, the Caucasus and the Caspian Sea there are anticyclonic and cyclonic wind vortices. A cyclonic air movement over the Mediterranean Sea becomes stronger. After t = 96 hours the process of propagation of large-scale wave vortex recurs with some quantitative differences of the meteorological fields. In general, the obtained wind fields at the level of the atmospheric surface layer qualitatively reproduce the fields that were constructed via the analysis of synoptic maps at the passage of large-scale pressure formations [22] over the Caucasus. The differences of the wind speeds and temperatures were calculated for the quantitative estimation of the relief influence effect, obtained taking into account the influence of orography irregularities and without taking it into account at the moment t = 24 hours. It was found that the influence of relief on the surface layer is manifested in reduction of large-scale cyclonic and anticyclonic vorticities. The wind speed in some parts of separate territory can vary by the value of the order of background wind speed, and the temperature-up to 10°C. Thus, we can assume that the roughness of orography in the lower troposphere facilitates a development of mesoscale vertical turbulence followed by smoothing of the wind speed fields and temperature.

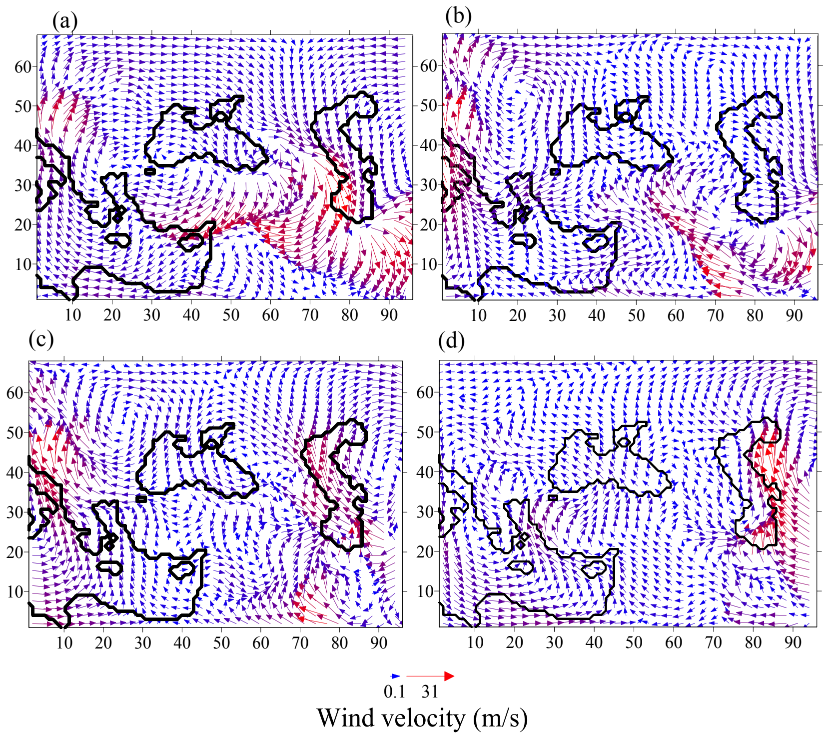

Fig. 3. The surface wind at $t = 0$ *h* (a), 24 *h* (b), 48 *h* (c), and 72 (d) *h*. Horizontal and vertical grids steps are equal 40 km.

2.2. β-mesoscale fields of the wind speed

Figure 4 shows spatial distributions of the wind field obtained at modeling of β-mesoscale circulation in the vicinity of city Batumi. From the figure it follows that the calculated field of wind speed in the lower and middle troposphere differs significantly from the background wind both by direction and magnitude. Northern, north-west and west winds were obtained at the surface layer (z = 50 m). A closed mesoscale vortex is generated at the level z = 1000 m above the Black Sea. At the height of 2000 meters this vortex travels to the south-west. The wind direction varies gradually in the middle and upper troposphere. The wind direction approaches the back-ground direction with removal from the Earth's surface. The analysis of the calculated wind field shows that the influence of relief is significant in the lower atmospheric layer having thickness 3-4 km. Here the relief can substantially vary the direction and magnitude of the wind speed. The influence of tropopause dominates at the levels of the upper troposphere, where the wave disturbance lies on the background wind field.

The local mesoscale vortex may be also formed above the mountain areas but in the upper levels of atmosphere. The main characteristic property for such territory is generation of mesoscale waves with length about 5-10 km which distribute in the direction of main flow of air (Fig. 5).

3. The possible trajectory of pollution clouds emitted from hypothetical sources in the atmosphere of the Caucasus

The series of numerical experiments were made for investigation of a trajectory of passive pollutant substance displacement in the Caucasus region on the base of model [19] and equation of diffusion of passive pollutant substance in the atmosphere. For this goal the hypothetical sources of the pollutions was located on the various points of this region. The location of such possible sources of pollution in vicinity of the port town Poti is shown in the Fig. 6. The passive pollutant substance

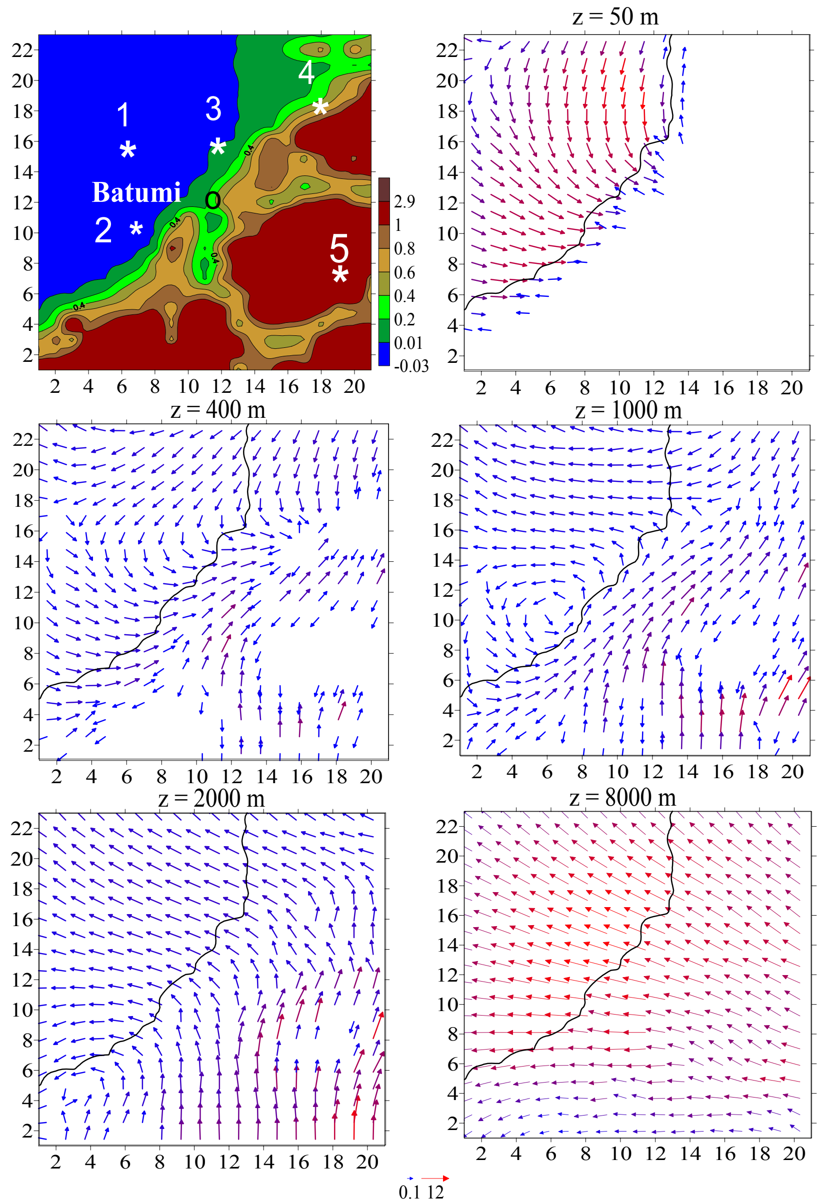

Fig. 4. The topography and wind fields at altitudes z = 50 m, 400 m, 1000 m,2000 m, and 8000 m, respectively. Horizontal and vertical grids steps are equal 5 km.

during 6 h is continuously emitted in the atmosphere in the rectangular area Ω (10 km×10 km×0.8 km). The initial concentration in the area of source is equal 100 arbitrary unit (a.u.). Such situation can be take place in cases of accident on the oil tankers or the oil storages and in the other processes of transfer of the air pollutants.

The meteorological situation corresponds to the flow of the Caucasus by the weak stationary background west wind. The background wind velocity on the surface level z = 40 m is equal to 0.1 m/s and it is permanently increasing with height. On the level z = 12 km the background wind becomes equal to 20m/s. The effect of the relief on the stationary background flow provides the quasi-stationary air motion (Fig. 6b). The wind velocity field on the low layer is similar to anticyclone one. It gradually changes on the upper levels and in vicinity of the tropopause it becomes like the background western wind. The temporary change of the spatial distributions of the

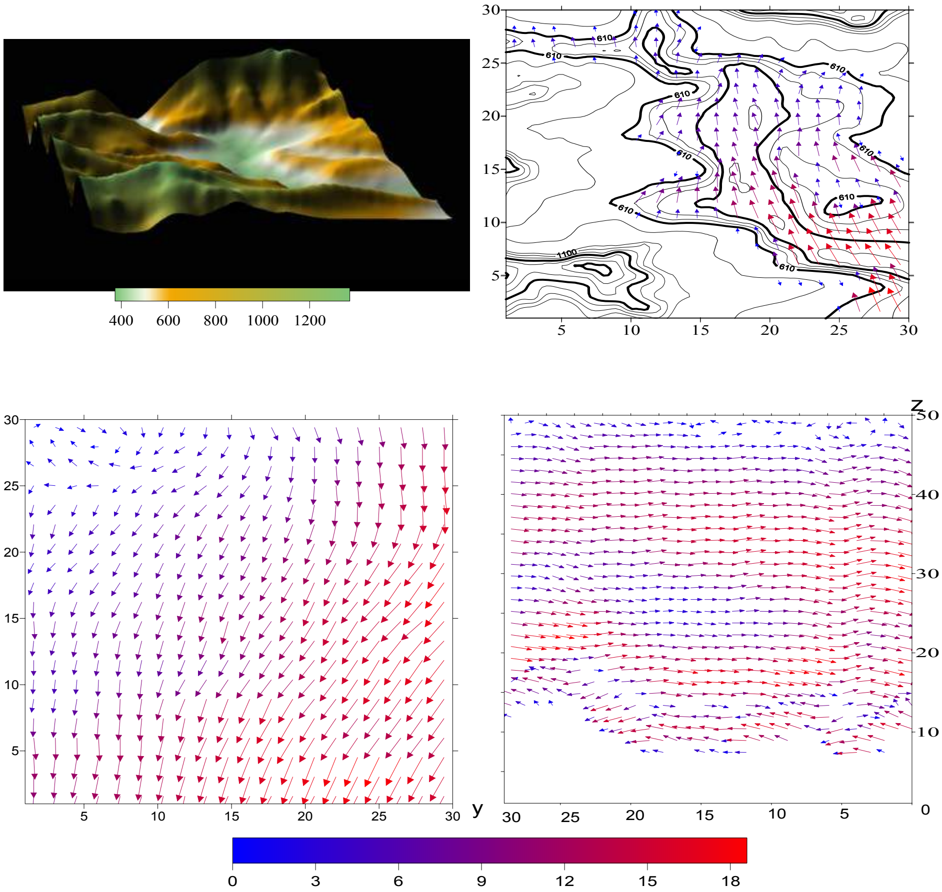

Fig. 5. The topography – (a), the wind fields at the levels z = 450m – (b), 6000m – (c) and the cross section on Y0Z surface when X = 25 in vicinity of Tbilisi city.

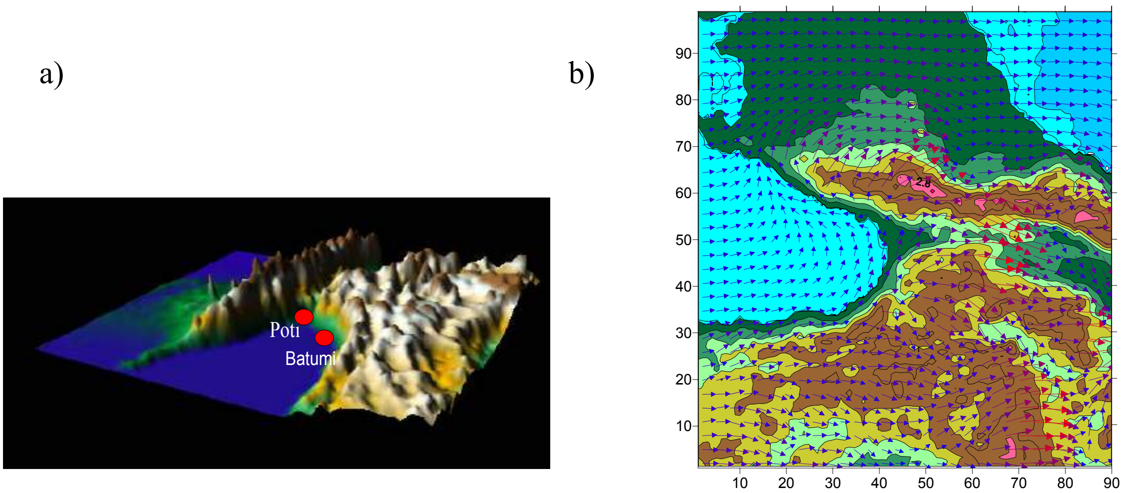

Fig. 6. The spatial picture of the Caucasus relief – (a) and the distribution of the wind field on the level of the surface layer of the atmosphere in case of the weak background western wind – (b).The red circles point to the location of the pollution sources (Poti and Batumi cities).

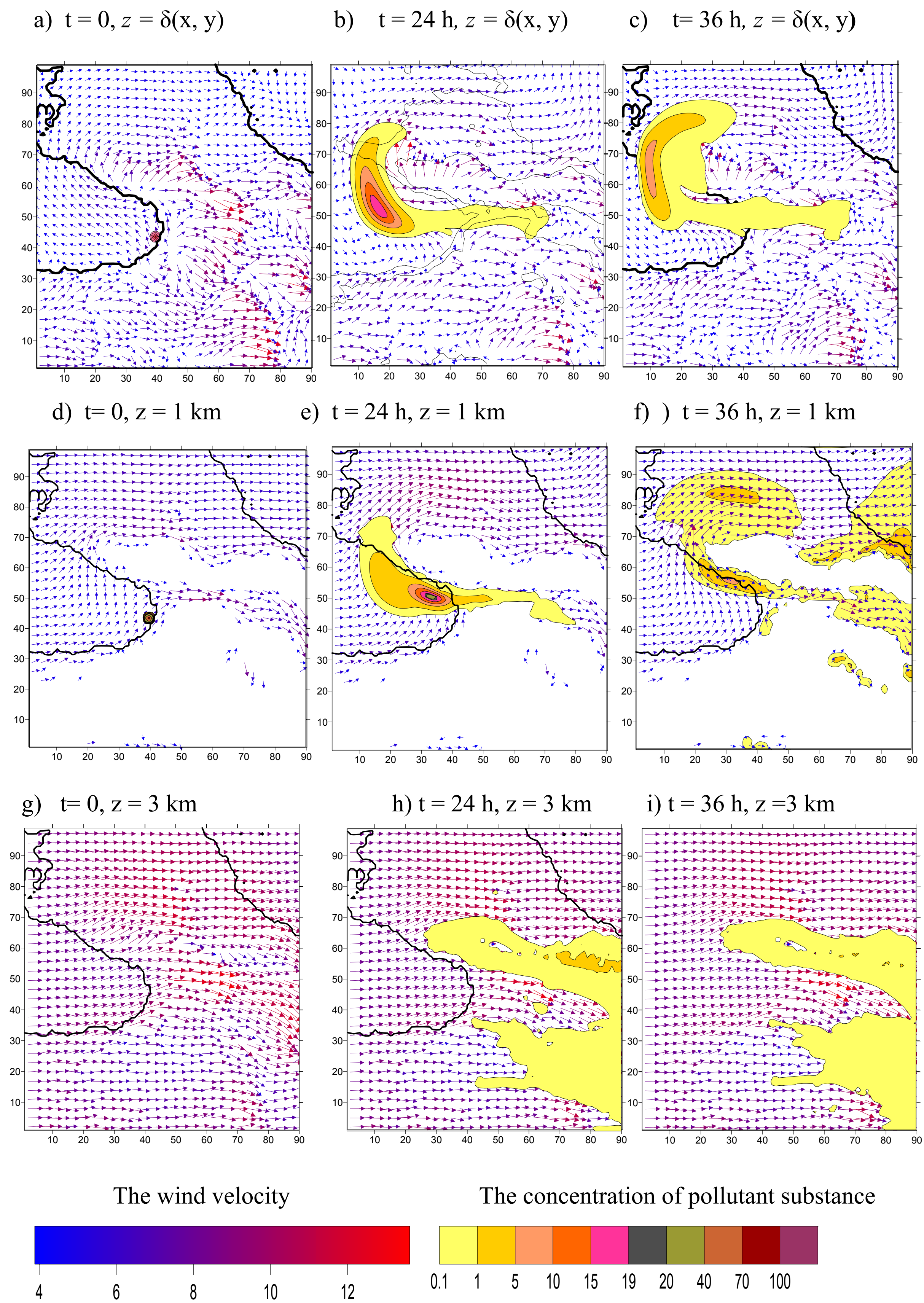

Fig. 7. The distribution of the concentration pollution substances q and the wind velocity vectors at t = 0, 24 and 36 h on the surface level of the atmosphere z = δ(x,y).

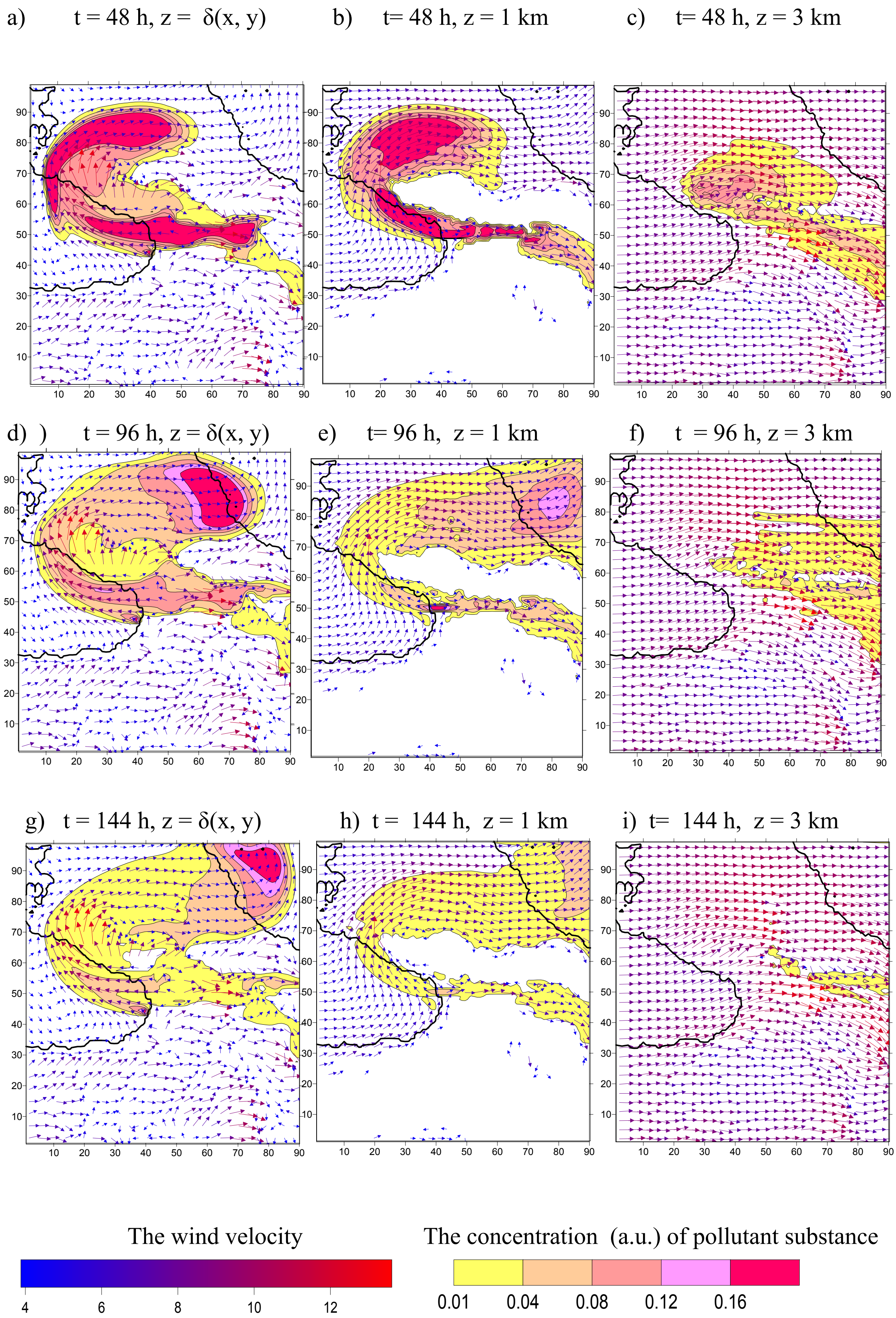

Fig. 8. The spatial distribution of the wind field vectors and the concentration of pollutant substance q in t =72 and 120 h on the surface level z = δ(x, y) and the levels z = 1 and 3km.

pollutant substance is shown in Fig. 7. This figure shows that the main part of the pollution cloud in the lower levels $z \leq 2$ km 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 = 144 h the pollution over the Georgian territory is significantly decreased (about 5×10^4 times). On the surface level the maximal value of the concentration is equal 0.16-0.18 a.u. and this value is obtained in the north of the modeling area over the north east part of the Caspian Sea. In the other areas the concentration is les than 0.01 a. u. The concentration decreases with a height and the on thee level z = 3 km the concentration approximately equal to 0.01 a. u. is obtained only in the small area over the north-east part of the Main Caucasus.

If emission of the pollutant substances takes place in vicinity of Batumi city, then moves during first five-six hours to the north near the east-north shore of the Black Sea. The diffusion processes are continued as it was described above.

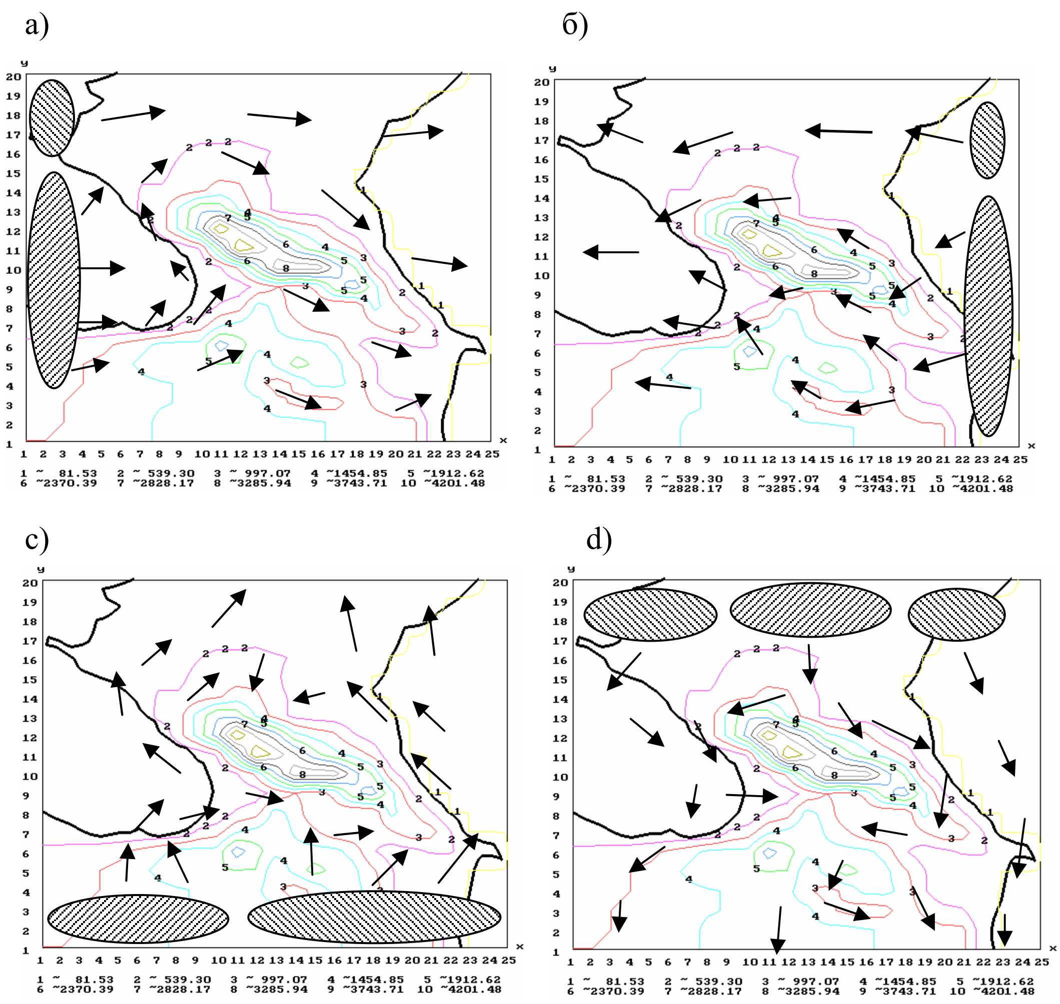

Fig. 9. The possible directions of motion (arrows) of the zone maximal concentration of the pollution clouds in the surface area of the atmosphere in case of the background west – (a), east – (b), south – (c) and north – (d) winds. The isolines (1-10) show the height of the relief (m), the dashed ellipsoids show the area of initial location of pollution clouds and thick lines show the shoreline of the Back, Azov, and Caspian seas.

A lot of numerical experiments made in case of various locations of the sources of pollution and background wind fields allow us to construct the scheme of possible displacements of pollutant clouds in the Caucasian Region (Fig. 9). Fig. 9 shows that the trajectory of displacement of pollution cloud significantly depends on its initial location and the direction of the background wind. The pollution predominantly moves along the flank of mountain ridge and tries to flow around an obstacle. The Likhi Ridge plays an important role in the process of distribution of pollutant substance in cases of the background east and west winds. This ridge prevents to distribution of pollution of the atmosphere from the western part of Georgia on east part and vice versa. Therefore, only a small amount of pollutant substances can displace over the Rikoti Pass and distribute along the gorge situated between Main and Minor Caucasian ridges.

In whole, the numerical experiments show that the South Caucasus does not promote to distribute the pollution emitted in the atmosphere near the Caucasus (dashed ellipsoids in Fig. 9) over its territory in the surface layer. In the middle troposphere the influence of relief on the distribution of pollution is insignificant. There the pollution clouds are transferred by the background motion.

4. Conclusions

Numerical investigation of the large-scale wind fields at the junction of three continents has been carried out for the first time: over the complex territories of the South- east Europe, Asia Minor and Southwest Asia, Caucasus, Middle East and the water areas of the Black, Caspian and Mediterranean seas. By the example of a traveling synoptic-scale (~6000 km) vortex wave generation and subsequent evolution of orographic vortices of the order of 1000 km are considered.

The mesoscale structures of hydrodynamic fields in the eastern coastal part of the Black Sea and in the mountain area of the centre of Caucasus are modeled. On the mesoscale area (~100 km) of the generated medium- scale vortex flow in the vicinity of the western Black Sea coast, hydrodynamic structure of the wind wave (~ with length 5-10 km) in the mountain area are studied by the nested grids method. It is shown that the local relief, atmospheric hydrothermodynamics and air-proof tropopause facilitate the generation of β-mesoscale vortex in the vicinity of the atmospheric boundary layer and tropopause and β- mesoscale waves in the middle troposphere.

Calculations showed the features of large- and mesoscale terrains influence on generation of the wind fields and vortex turbulence:

Large and high mountain ranges of the Caucasus, Minor and Southwest Asia facilitate formation of medium-scale zones of wind speed divergence and vortex structures;

The main favorable territories for the generation of orographic vortices are the neighborhoods of the Carpathian Mountains and the Black, Caspian and Mediterranean seas;

The orographic vortices are generated in the lower troposphere and their sizes can vary from a few hundred kilometers to 1 thousand kilometers and higher;

Atmosphere tends to a smoother distribution of the large-scale meteorological fields due to the orographic vortices;

Separate β-mesoscale vortices can generate against the background of the α-mesoscale vortices in the atmospheric boundary layer in the vicinity of the sea land at the low values of the vertical wind speed gradients;

The orography of the Caucasian region significantly influences on the distribution of a pollution substance in the low troposphere. The directions of spreading of pollution substances depend on both a values of the backgdround wind speed and the height and shape of the relief. The influence of the orography on trajectory of pollution clouds in the middle troposphere is week. In the middle troposphere these trajectories are mainly determined by the background flow.

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References

[1] Volkert H. The International Conferences on Alpine Meteorology: Characteristics and trends from a 57-year-series of scientific communication. Meteorol. Atmos. Phys. 2009, V. 103, pp. 5– 12.

[2] International Conference on Alpine Meteorology, 4-8 June 2007, Chambéry, France. http://www.cnrm. meteo.fr/icam2007/ICAM2007.
[3] Marchuk G. I.. Numerical solutions of the problems of the atmosphere and ocean dynamics. Hydrometeoizdat, Leningrad, 1974, 302 p.
[4] Gutman L. N.. Introduction to the nonlinear theory of mesometeorological processes in the Atmosphere. Hydrometeoizdat, Leningrad. 1969, 296 p.
[5] Gutman L. N., M. I. Shaposhnikova, G. P. Lambert. To a question on influences of the Earth surface on the large-scale meteorological processes. Izvestia AN USSR, Atmospheric and Oceanic Physics. 1972, V. 8, No. 5, pp. 494-504.
[6] Sokhov T. About nonlinear orographical waves in the atmosphere. Izvestia AN USSR, Atmospheric and Oceanic Physics. 1970, V.6, No.5, pp.115-126.
[7] Perov V. V. Gutman L. N. Barotrophic model of the local forecast of a catabatic winds. Izvestia AN USSR, Atmospheric and Oceanic Physics. 1972, V.8. No.11, pp.1129-1142.
[8] Penenko V. V., Alojan A. E. Models and methods for tasks of preservation of the environment. Novosibirsk: Nauka. 1985, 256 p.
[9] Marchuk G. I., V. P. Dimnikov, V. B. Zalesnii, V. N. Likosov and V. Ya. Galin. The mathematical simulation of the general circulation of the atmosphere and ocean. Hydrometeoizdat, Leningrad, 1984, 320 p.
[10] Marchuk G. I. Mathematic modeling in the problems of environment. Moscow: Nauka. 1982, 320 P.
[11] Kazakov A. L., Lazriev G. L. About parameterization of the surface layer of the atmosphere and active layer of the soil. Izvestia AN USSR, Atmospheric and Oceanic Physics. 1978, v. 14, No 3. pp. 257- 265.
[12] Penenko V. V. Methods of numerical modeling of atmospheric processes. Leningrad: Hydrometeoizdat, 1981. 252 p.
[13] Volodin E. M, Likosov V. N. Parametrization of processes heat- and moisture exchange in system vegetation - ground for modelling the general common circulation of an atmosphere. 1. The description and calculations with use of the local given supervision.. Izvestia RAN , Atmospheric and Oceanic Physics. 1998, V. 34, pp.1129-1142.
[14] Lykossov V.N., Atmospheric and oceanic boundary layer physics, in: Wind stress over the ocean (Eds. I.S.F. Jones and Y. Toba). 2002. Cambridge University Press. pp. 54-81.
[15] Glazunov A.V., Lykossov V.N., Large-eddy simulation of interaction of ocean and atmospheric boundary layers, Russ. J. Numer. Anal. Math. Modeling. 2003, v. 18, pp. 279- 295.
[16] Kordzadze A., Surmava A. Mathematical model of middle-scale movements over the Caucasian region in free atmosphere. J. Georgian Geophys. Soc. 1998, v.3B, pp. 66-73.
[17] Miqashavidze B. A certain features of the account of influence of a relief in problems of weather forecast. Works of institute of Hydrometeorology. 1998, v. 101. pp. 38-45.
[18] Khvedelidze Z., Khvedelidze R. On the influence of the relief on the geopotential in the lover layers of the atmosphere. J. Georgian Geophys. Soc. 1996, v.1, pp. 51-58.
[19] Kordzadze A. A., Surmava A. A., Demetrashvili D. I., and Kukhalashvili V. G. Numerical investigation of the influence of the Caucasus relief on the distribution of hydrometeorological fields. Izvestia, Atmospheric and Oceanic Physics. 2007, v. 43, No. 6. pp. 722-730.
[20] Kordzadze A. A, Demetrashvili D. I. , and Surmava A. A. Numerical modeling of hydrophysical fields of the Black Sea under the condition of alternation of atmospheric circulation processes. Izvestia, Atmospheric and Oceanic Physics. 2008, v. 44, No. 2, pp. 227- 238.
[21] Kordzadze A.A., Surmava A.A., Demetrashvili D.I. Numerical modeling of a wind field in vicinities of east part of Black Sea and the western part of the Caspian Sea formed by influence of the Caucasian region the relief. Ecological safety of coastal and shelf zones and complex use of resources of a shelf. 2004, Issue10, pp. 257-264.

[22] Papinashvili K. I. Atmospheric processes in Transcaucasia and their relation with macro-circu lation processes above the territory of Eurasia. Hydrometeoizdat, Leningrad, 1963, 184 p.

О влиянии рельефа Кавказа на пространственно-временную эволюцию вихрей и перемещение облаков загрязнения в атмосфере

Александре А. Сурмава

Резюме

Проведено численное моделирование и изучение движения воздуха в окрестности Кавказа и окружающих его территорий Юго-восточной Эвропы, Малой Азии и Ближнего Востока. Исследованы перемещение вихря синоптического масштаба и последующая эволюция возникших орографических вихрей. Изучены локальные структуры β- мезмасштабного вихря в окрестности восточной береговой зоны Чёрного моря и волн в тропосфере центральной части южного Кавказа.

Численно исследованы распространение в атмосфере Кавказа пассивного загрязняющего вещества, выброшенного из гипотетических источников, находящихся как внутри, так и в приграничных территориях Южного Кавказа. Установлены основные траектории распространения зон максимальных концентраций.

კავკასიის რელიეფის გავლენის გამოკვლევა გრიგალების სივრცეში და დროში ევოლუციაზე და ატმოსფეროში დამაბინძურებელი ნივთიერების გავრცელების ტრაექტორიაზე

ალექსანდრე ა. სურმავა

რეზიუმე

რიცხობრივად მოდელირებული და შესწავლილია კავკასიისა და მისი მიმდებარე სამხრეთ – აღმოსავლეთ ევროპის, მცირე და შუა აზიის ტერიტორიებზე ატმოსფერული ჰაერის მოძრაობის კანონზომიერებანი. შესწავლილია სინოპტიკური მასშტაბის გრიგალური ტალღის გადაადგილებისას წარმოშობილი ოროგრაფიული α-მეზომასშტაბის გრიგალების და შავი ზღვის აღმოსავლეთ სანაპირო ზოლში წარმოშობილი β-მეზომასშტაბის გრიგალის ევოლუცია და სამხრეთ კავკასიის ცენტრალური ნაწილის მთაგორიან ტერიტორიაზე მიღებული ქარის სივრცული სტრუქტურა.

რიცხობრივად მოდელირებულია სამხრეთ კავკასიისა და მის სასაზღვრო არეში მდებარე ჰიპოთეტური წყაროებიდან ატმოსფეროში ამოფრქვეული პასიური დამაბინძურებელი ნივთიერების გავრცელება. დადგენილია დამაბინძურებელი ნივთიერების მაქსიმალური კონცენტრაციების ზონების გადაადგილების ტრაექტორიები.