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Spatial Distribution of the Local Meteorological Fields and Dust Concentration in Kakheti Atmosphere in Case of the Northern Background Wind

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ABSTRACT

Spatial distribution of meteorological fields and dust concentrations in case of northern background winds is studied by means of the model of mesoscale atmospheric processes evolution at the territory of Kakheti and numerical integration of transfer-diffusion of passive admixtures.

It is shown that the Kakheti terrain has significant impact on formation of meteorological fields in boundary layer. The impact of terrain is substantially weaker in free atmosphere. Influence of regional terrain on background flow causes formation of horizontal and vertical swirls and waves directed along the background flow. There is a wave not only in atmospheric boundary layer, but also in free atmosphere. Vertical vortexes are formed on windward and leeward sides of the Greater and Lesser Caucasus Mountains, some of them are in the vicinity of ranges. Sizes of formed vortexes are depended on ridge width and height or on gorge depth.

Pictures of dust spatial distribution are obtained. Dust dispersion areas in cities are determined. Dust dispersion kinematics is studied. It is obtained, that in 2-100 m atmospheric layer dust dispersion mainly occurs through turbulent diffusion. In layer from 100 meters to 1 km height the processes of diffusive and advective transfer are equal, while above 1 km advective transfer of dust is primary.

Key words: *numerical modeling, local circulation, meteorological field, air pollution, equation of mass transfer*

1. Introduction

In this article the numerical investigations of the local meteorological fields and the spatial distribution of the dust concentration obtained by the numerical model of the β-mesoscale atmospheric processes in the Kakheti Region made in [1, 2, 3] are continued.

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.

Climate conditions corresponding for June are taken. Meteorological situation corresponds with northern 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.

The distributions of the anthropogenic dust emitted in the atmosphere from Tbilisi and Rustavi cities and 19 little towns of Kakheti and 3 towns of Azerbaijan are numerically modeled. The data of National Environment Agency [4] are taken as the initial and boundary values of the monthly average concentrations at the height of 2 m in atmosphere at the territories of Tbilisi and Rustavi, while for territories of other cities, where observations over dust pollution were not conducted, an initial concentration values are calculated according to given methodology [5]. The initial concentration of dust at the points of the network that don’t belong to cities is considered equal to zero. The diameter of dust particle is assumed to be equal to 10 μm.

2. Results of modeling. On Fig. 1-12 are shown patterns of spatial and time distribution of meteorological fields at midnight (t = 0 h) obtained through calculation.

On Fig. 1 is shown wind velocity vector and module at the height of z = 10m – a), b) and z = 100 m – c), d), respectively. It is seen that terrain impact on northern background winds in surface layer of the atmosphere has caused significant change in velocity field at the territory located between the Greater Caucasus Mountains and Trialeti range. Northern wind occurs only on northern slopes of the Greater Caucasus Mountains and part of Trialeti range, which is situated in south-eastern part of modeling area. At the rest of territory north-western, western and south-western weak winds are obtained. Formation of clearly separated air convergence band along the southern slope of the Greater Caucasus Mountains should be noted. This band follows Alazani River valley. At the mentioned territory wind velocity is not big. At the height

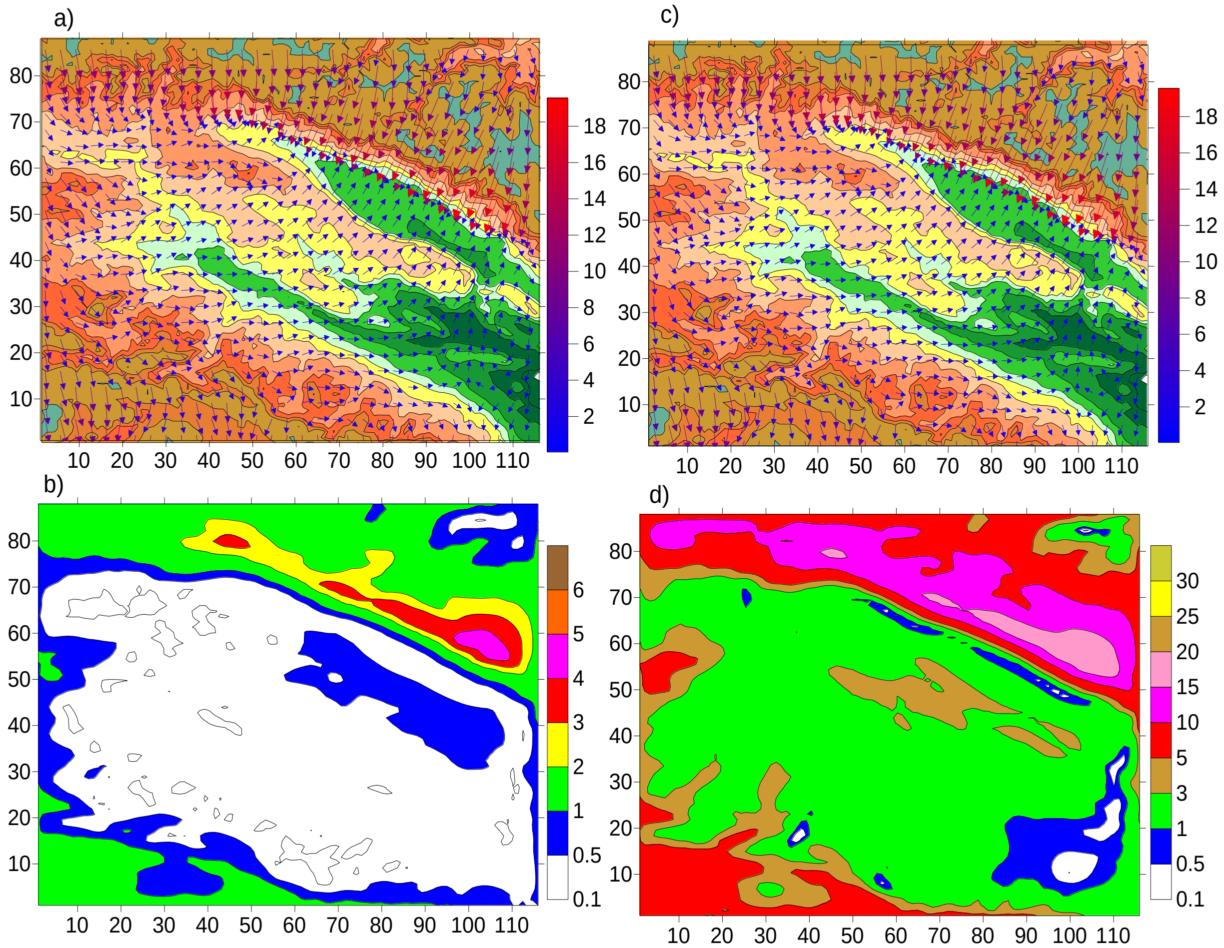

Fig. 1. Wind velocity and sped at height z =10m – a), b) and z =100m – c), d), from earth surface, respectively, when t = 0h.

of 10 meters windless conditions take place basically. At 2 and 100 m height from the earth surface (Fig. 1 ,c) and d) spatial distributions of wind velocity are similar to each other. Change in wind direction and magnitude in surface layer is analogous to changes peculiar to boundary planetary zone. At 100 m height from earth surface windless conditions are obtained only at small territories near Shiraki valley and Eldar lowland.

In the free atmosphere a wind keeps the direction of background wind (Fig. 2). Surface distribution of wind velocity module changes with height increase. At 3 km height wind velocity in the central part of region is less than velocity obtained in northern and southern parts. On the contrary, at 6 km height wind velocity along the Greater Caucasus Mountains is less than velocities of winds existing above lowland and plain territories.

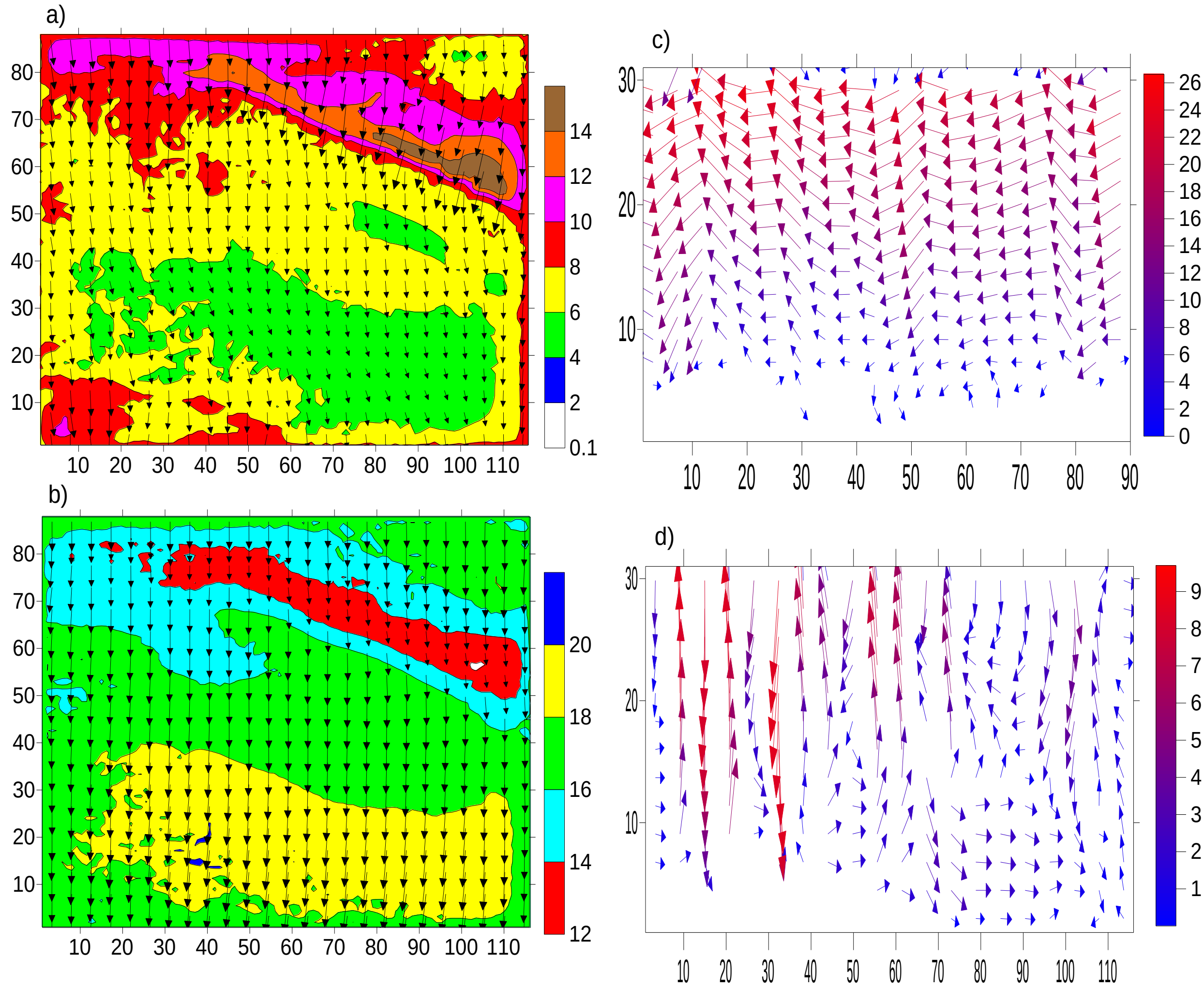

Fig. 2. Wind velocity and sped at height z = 3 km – a) and 6 km – b). The latitudinal projection of wind velocity on XOZ plane when Y = 20 – c), and longitudinal projection of wind sped on YOZ plane when X = 20 – d), when t = 0h.

For orography flow-around phenomenon is characteristic the formation of wave and vortex motions both in boundary layer and in free atmosphere (Fig. 2, c) d), Fig. 3 – Fig. 6). Vertical *vortexes* are more clearly expressed in the surface layers of atmosphere than waves in free atmosphere. Anticyclonic *vortexes* are obtained in planes directed along the background flows (meridian planes). They are formed not only at lowland territories, but also on hill-sides of ridges and highlands with sufficient length. Horizontal scales of swirls are depended on sizes of orography non-uniformities. In boundary layers of atmosphere vortex structures in planes perpendicular to background flows (along the parallel) are not clearly expressed. Flow direction above lowland and plain territories doesn't change with distance from earth surface.

In the surface layer of atmosphere the basic distinguishing feature of temperature field is its increase with distance from earth surface. In Alazani valley and in the vicinity of Iori plateau air temperature at 100 m height is roughly 4°C higher than atmosphere temperature at 2 m height. As to the soil, its temperature is equal or slightly lesser than temperature obtained at 2 m height.

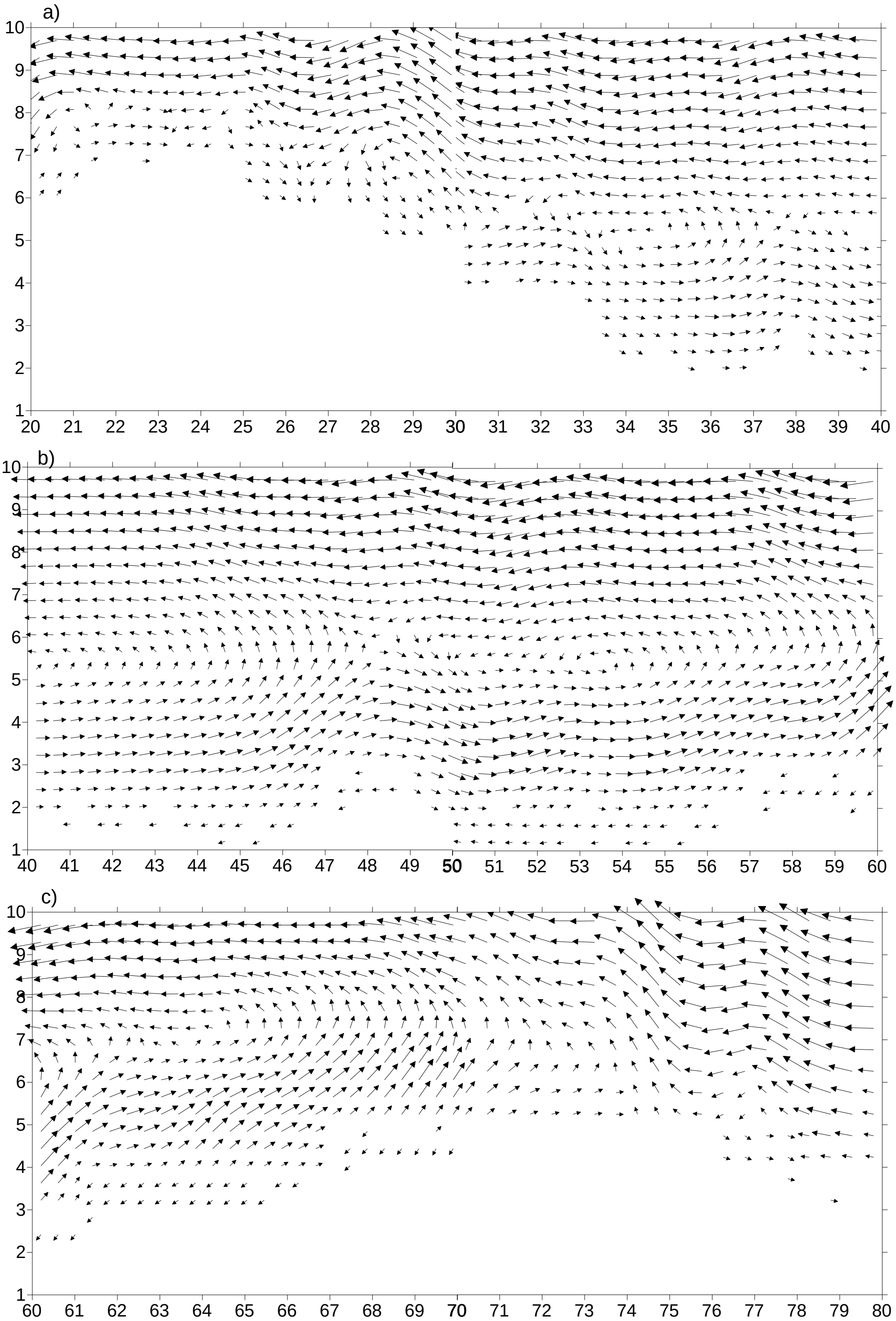

Fig. 3. Longitudinal projection of wind sped on YOZ plane when $z \leq 3$, x = 30, $20 \leq y \leq 40$ – a), $40 \leq y \leq 60$ – b), $60 \leq y \leq 80$ – c) and t = 0h.

Temperature gradient in atmospheric boundary layer and in free atmosphere is mainly directed westward (Fig. 7). In the free atmosphere temperature field is represented by meridionally oriented zones, which are deformed by advective and turbulent heat transfers. Deformation is complicated and its explanation needs additional research (Fig. 8).

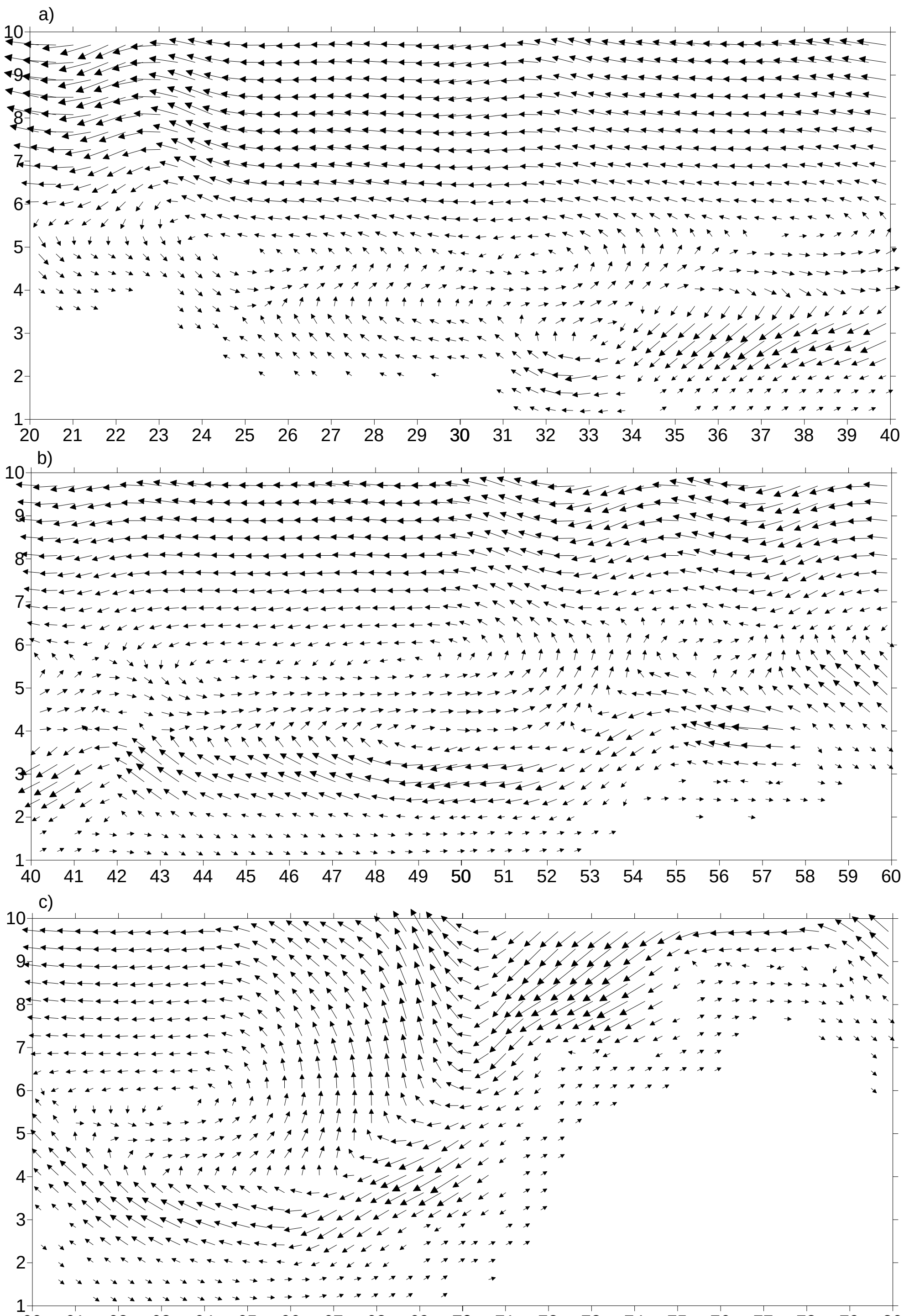

Fig. 4. Longitudinal projection of wind sped on YOZ plane when $z \le 3$, $x = 60$, $20 \le y \le 40$ – a), $40 \le y \le 60$ – b), $60 \le y \le 80$ – c) and $t = 0h$.

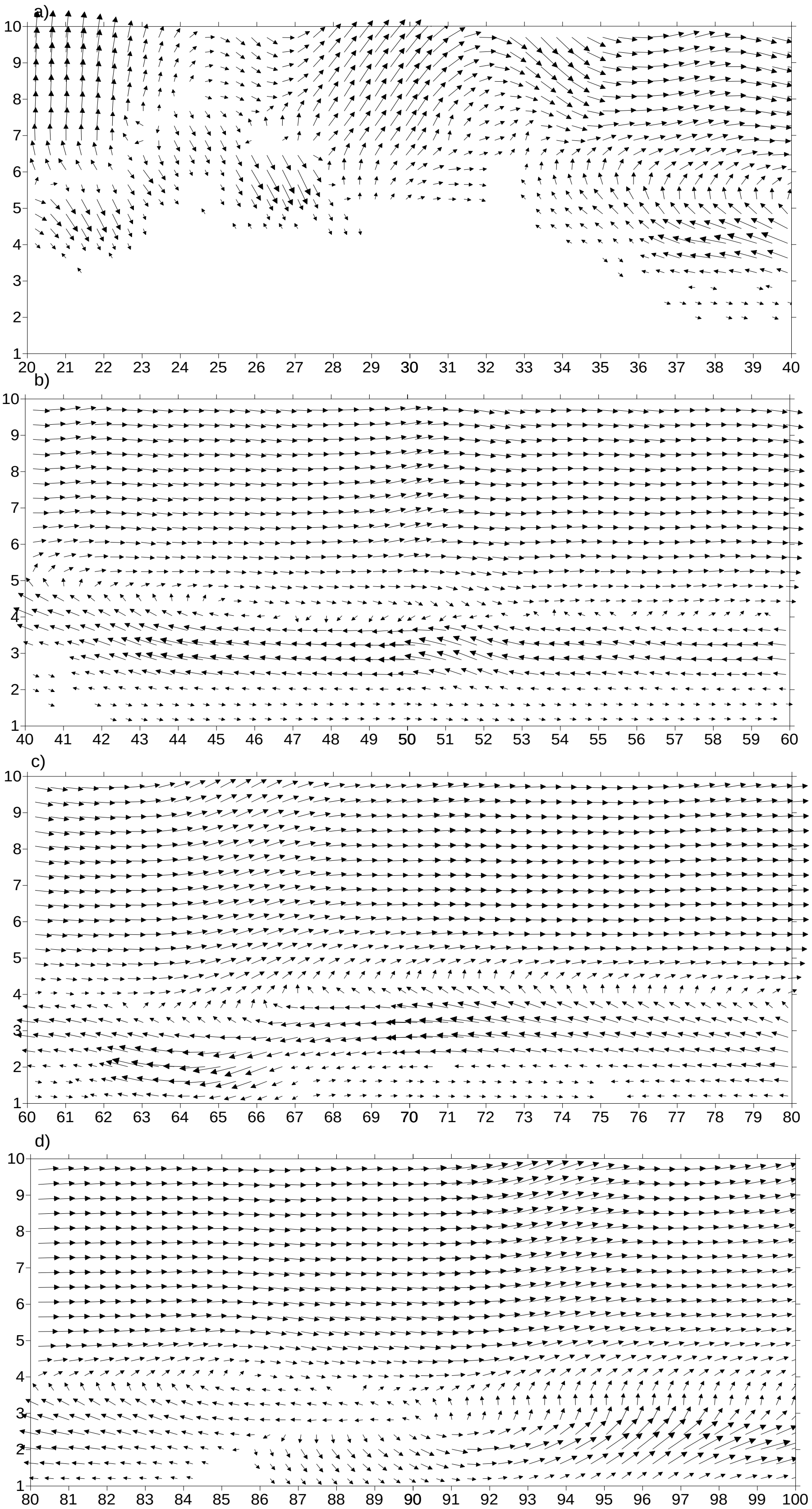

Fig. 5. Latitudinal projection of wind sped on XOZ plane when $z \leq 3$, $y = 30$, $20 \leq x \leq 40$ – a), $40 \leq x \leq 60$ – b), $60 \leq x \leq 80$ – c) and $t = 0$h.

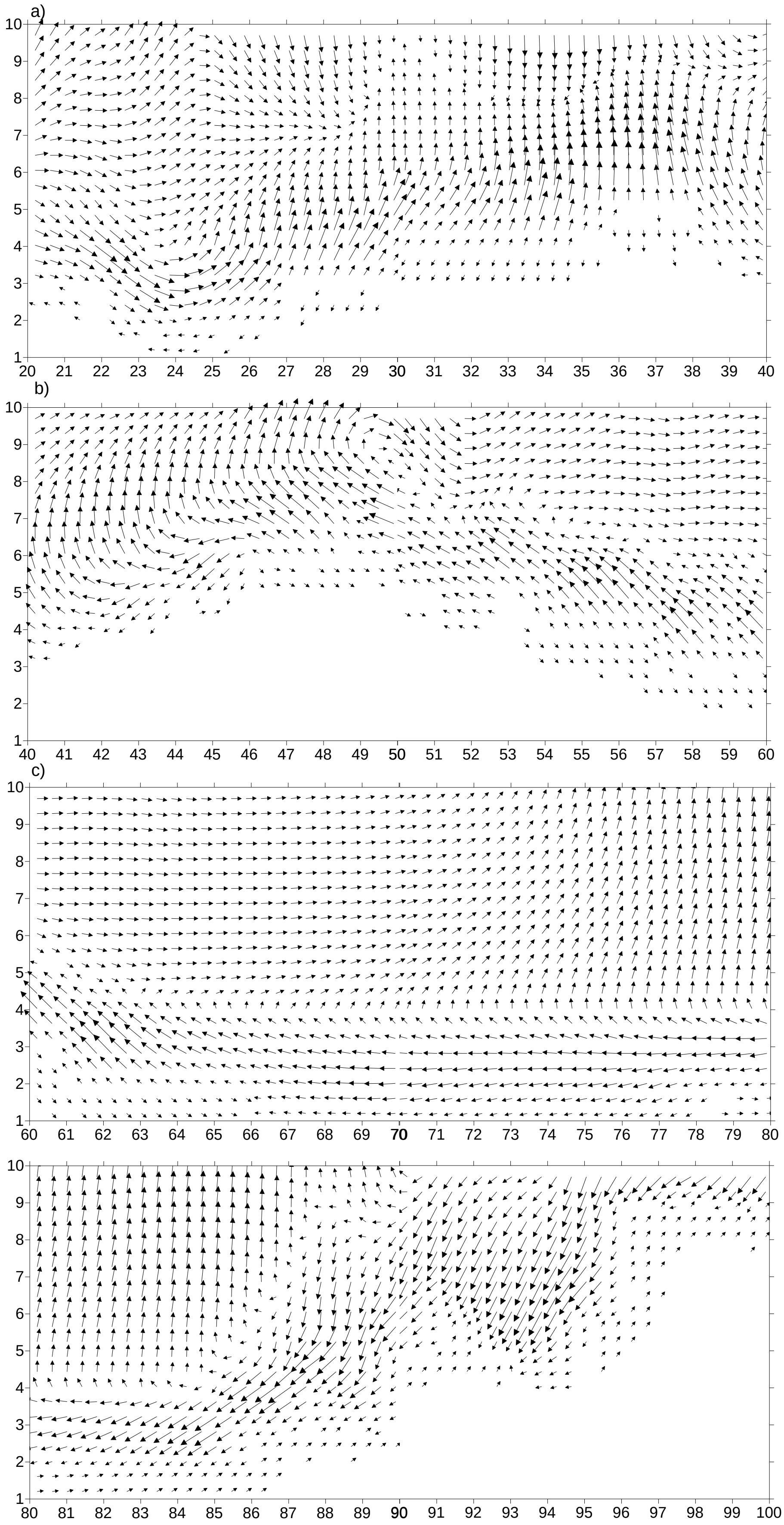

Fig.6. Latitudinal projection of wind sped on XOZ plane when $z \le 3$, y = 60, $20 \le x \le 40$ – a), $40 \le x \le 60$ – b), $60 \le x \le 80$ – c) and t = 0h.

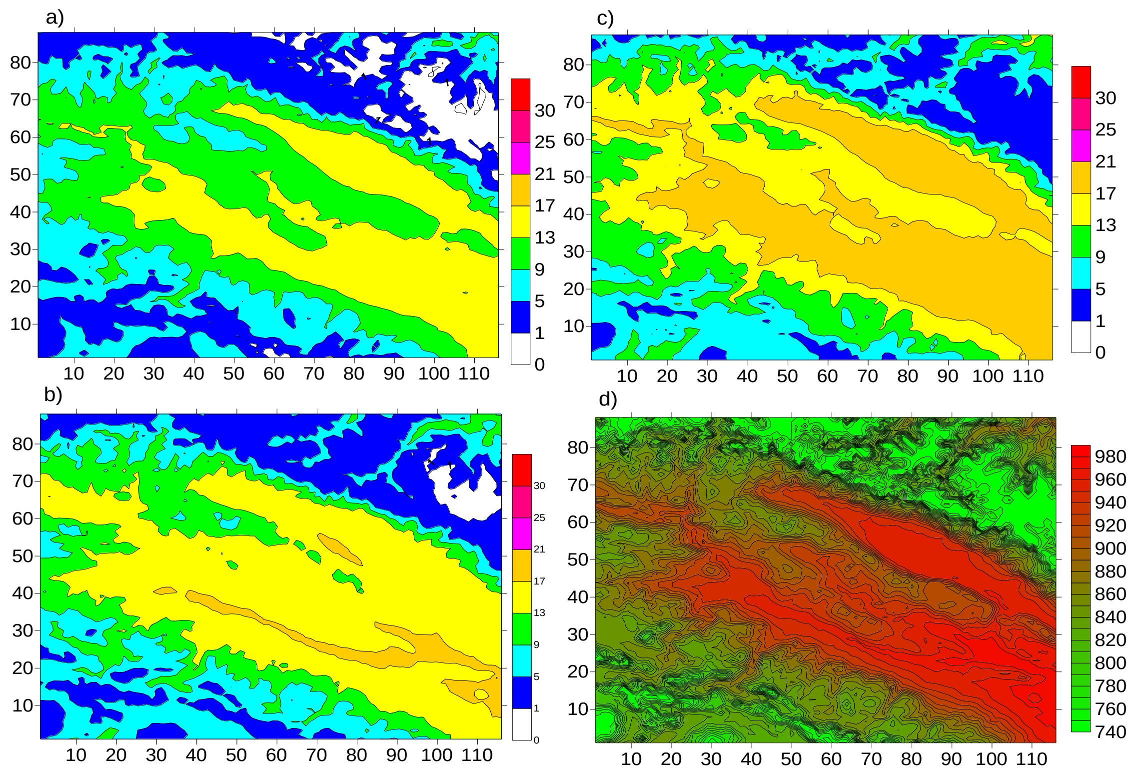

Fig. 7. Temperature (^{o}C) on the earth surface – a), at height from earth surface z = 2m– b), 100m - c) and surface pressure (mb), when t =0h.

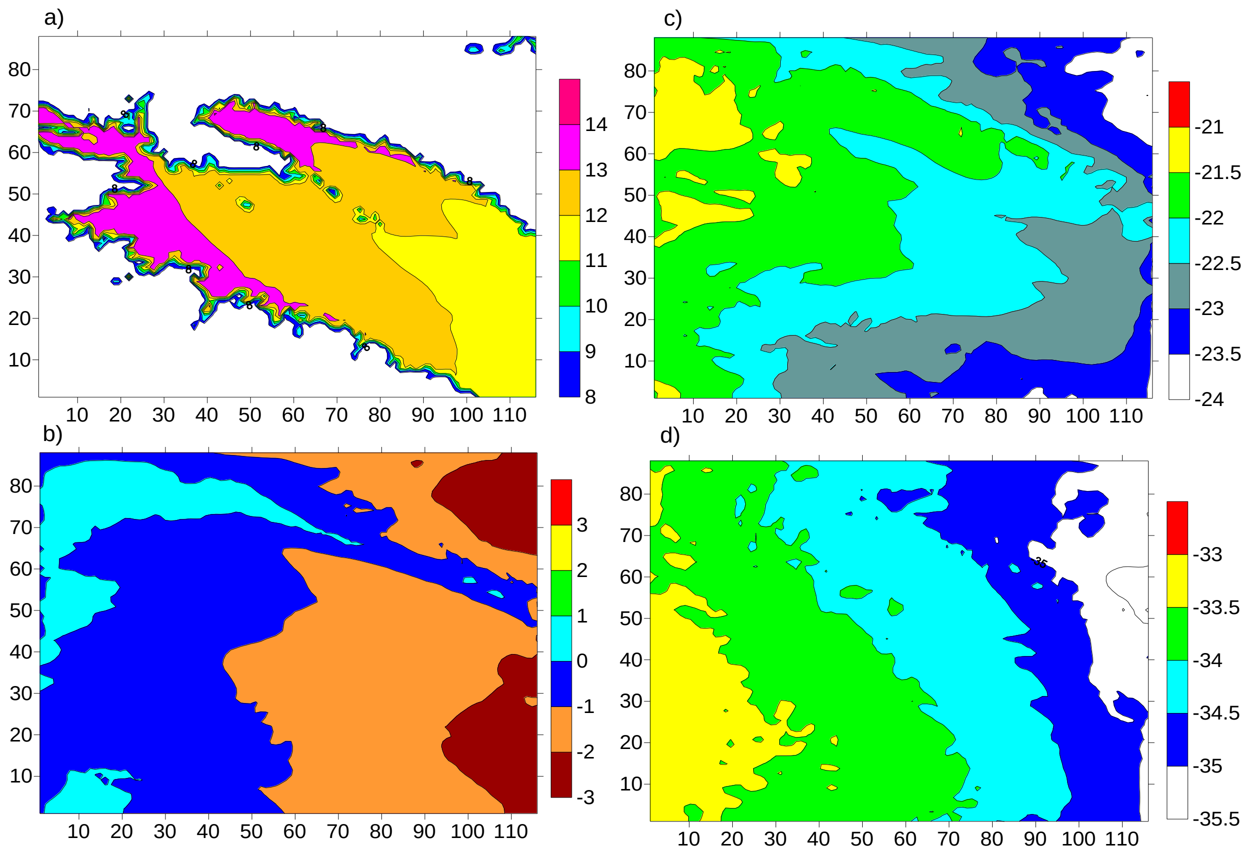

Fig. 8. Temperature (^{o}C) on at heights z = 1, 3, 6. 8km when t =0h.

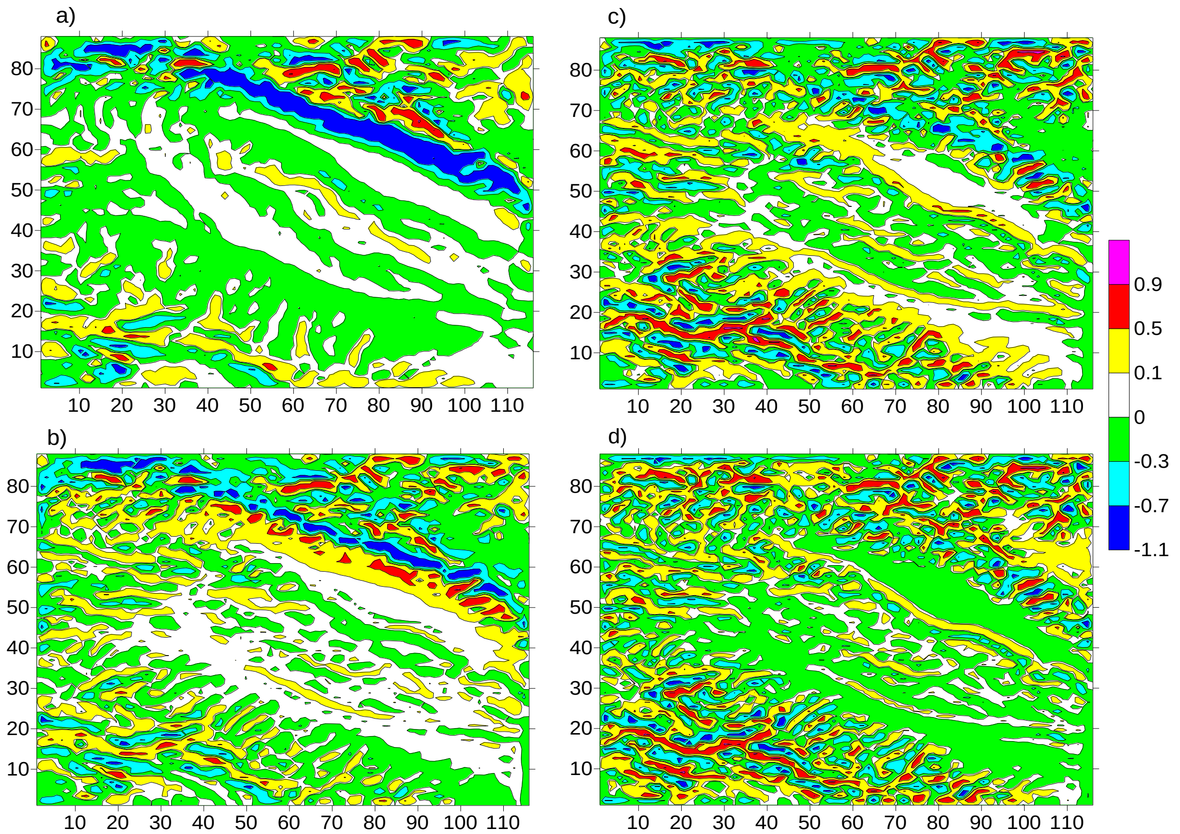

Fig. 9. Vertical velocity field (m/sec) at at height from earth surface z= 100 m – a), 3 km – b), 6 km – c) and 8 km – d) when t = 0h.

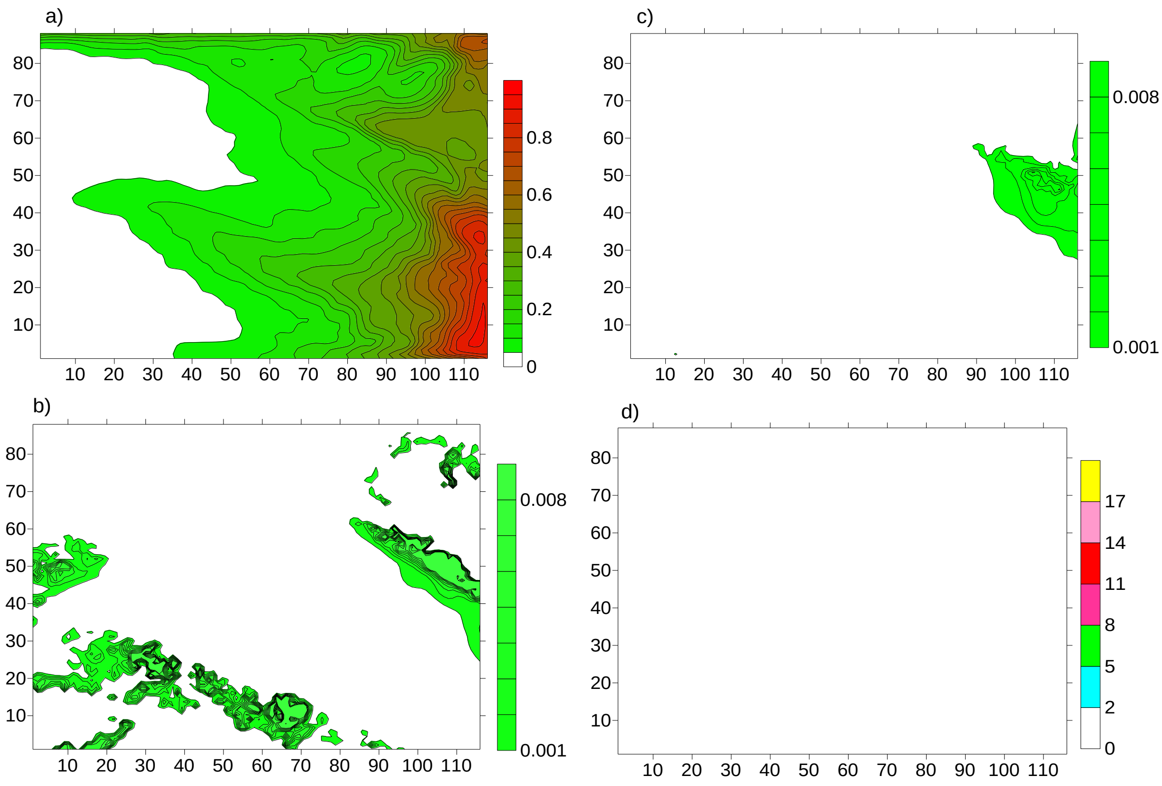

Fig. 10. The mass content of water steam (g/kg) at height z= 3km –a),   mass content of water (g/kg) at z= 2km – b), 3 km – c), and precipitate – d), when t=0h.

The value of surface pressure changes from 1000 mb in the vicinity of Mingachevir reservoir to 740 mb in the neighborhood of main peaks of Caucasus Mountains.

On Fig. 9 is shown distribution of isolines vertical of velocity. As is seen from figures, in the central part of the region – Iori plateau, Alazani valley and in the vicinity of Jeiran valley the field of vertical velocity has band structure, in which the value of downward motion velocity changes within 0 – -1m/sec, while the value of upward vertically motion velocity doesn't exceed 0,1 m/sec.

At the 3 km and more height vertical distribution of velocity is typical for region. It consists of small-size cells of upward and downward motions, location of which corresponds with disposition of separate small-size ridges.

Massive content of water steam, cloud water and precipitations fallen obtained by calculations are shown on Fig. 10. As is seen from figure, the cloud is formed in two areas, but water content in them is so small that despite great magnitudes of vertical velocities, water content is not sufficient for rain.

Dust distribution in surface and boundary layers of atmosphere obtained by calculation is shown on Fig. 11 and 12. It is seen from figures that in the neighborhood of Tbilisi, Rustavi, Marneuli and Bolnisi cities dust distributions at 2 and 10 m height are virtually the same and their concentrations insufficiently differ from each other. The mentioned distribution in the vicinity of pollution sources is caused by windless condition and meteorological situation close to windless one. At 100 m height the dust emitted from different sources experiences

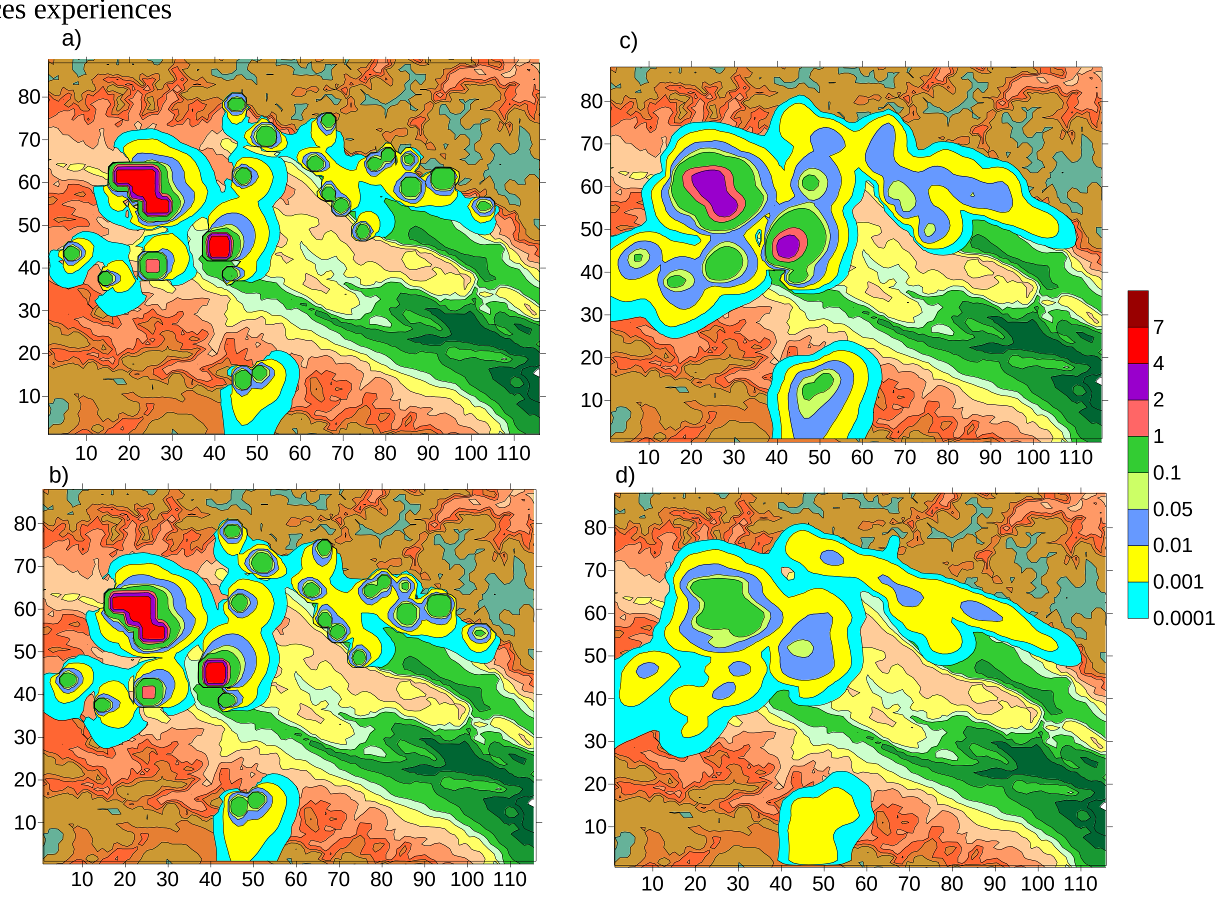

Fig. 10. Dust concentration at heights z = 2, 10, 100 and 600 m when t = 0h.

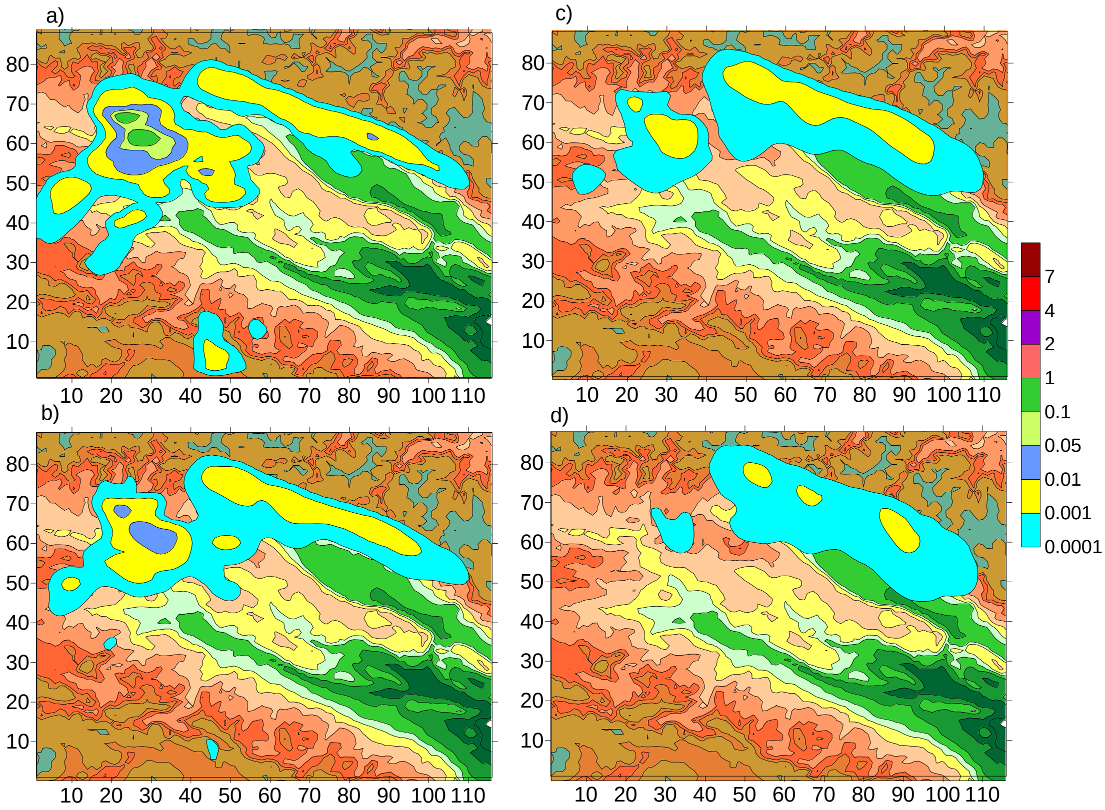

Fig.11.Dust concentration at heights z = 1, 1.5, 2 and 3km when t = 0h.

superposition as a result of horizontal diffusion and pollution area is like unite dust cloud with two clearly expressed centers in the outskirts of Tbilisi and Rustavi. In Sagarejo and Gardabani the dust is dispersed at very large distances that primarily is caused by the processes of advective transfer.

Conclusions

Thus, carried out numerical modeling has manifested the meteorological features, which are peculiar to Kakheti region in case of flow-around of its terrain by northern background winds at midnight (t = 0h). It is shown that terrain impact on background flow causes formation of vertical wind swirls. Horizontal size of swirls is depended on the width of terrain deepening, while vertical size – on the value of wind velocity in atmospheric boundary layer. Formed centers of local circulations are located like sublayers close to surface and also at a remote. Circulating swirls are mainly dominant in meridian plane and they have the direction of anticyclonic rotation. In swirls formed in planes directed along the parallels wind rotation direction is both cyclonic and anticyclonic.

Orographic internal gravitation waves are formed in atmospheric boundary layer and are spread in free atmosphere. Wave amplitudes are directly proportional to orographic resistance, height and wind velocity.

Formation of vertical motion bands with up to 1 m/sec velocity in atmospheric boundary layer is peculiar to flow-around process. These bands are narrow and in the form of several dozen kilometer length areas follow the southern slopes of the Greater Caucasus Mountains and north-eastern hillsides of Tsiv-Gombori range.

Separate multiple cells of vertical convection are formed above regional ridges both in atmospheric boundary layer and in lower and middle tropospheres.

Specific picture of temperature horizontal distribution is peculiar to this process. Temperature field in surface layer of atmosphere is determined by the form of sublayer surface, orography inclination to the horizon and its height. Temperature field in troposphere is represented by vertically oriented bands, which are deformed as a result of impact of thermodynamic heat transfer processes in the region.

Complicated hydrodynamics of the region has an impact on dust dispersion in atmosphere. Vertical diffusive dust transfer is dominant in surface layer of atmosphere, while in atmospheric boundary layer the important role belongs to advective dust transfer and horizontal diffusion. As a consequence, dust is dispersed at large areas in atmospheric boundary layer. Dust pollution zone with more than 0.1 MAC is limited between Tbilisi and Rustavi cities and small-size atmosphere part situated in the vicinity.

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ლოკალური მეტეოროლოგიური ველების და მტვრის კონცენტრაციის სივრცული განაწილება კახეთის ატმოსფეროში ფონური ჩრდილოეთის ქარის დროს

ნ. გიგაური, ა. სურმავა

რეზიუმე

კახეთის ტერიტორიაზე მეზომასშტაბის ატმოსფერული პროცესების ეოლუციის მოდელის და პასიური მინარევის გადატანა - დიფუზიის განტოლების რიცხვითი ინტეგრირების საშუალებით შესწავლილია მეტეოროლოგიური ველების და მტვრის კონცენტრაციის სივრცული განაწილება მსხვილ ჩრდილოეთის ფონური ქარის შემთხვევაში.

ნაჩვენებია, რომ კახეთის რელიეფი მნიშვნელოვან გავლენას ახდენს მეტეოროლოგიური ველების ფორმირებაზე ატმოსფეროს სასაზღვრო ფენაში. რელიეფის გავლენა თავისუფალ ატმოსფეროში მნიშვნელოვნად სუსტია. რეგიონის რელიეფის მოქმედება ფონურ დინებაზე ჰორიზონტალური, ვერტიკალური გრიგალებისა, და ფონური დინების გასწვრივ მიმართული ტალღების წარმოშობას იწვევს. ტალღა არსებობს როგორც ატმოსფეროს სასაზღვრო ფენაში, ასევე თავისუფალ ატმოსფეროში. ვერტკალური გრიგალები ფორმირებული არიან მთავარი მცირე კავკასიონის ქედების ქარპირა და ქარზურგა მხარეს, ზოგიერთი მცირე ქედების მიდამოებში. წარმოშობილი გრიგალის ზომები დამოკიდებულია ქედის სიგანეზე და სიმაღლეზე, ან ხეობის სიღრმეზე.

მიღებულია მტვრის სივრცული განაწილებების სურათები. განსაზღვრულია ქალაქების მტვრის გავრცელების არეები. შესწავლილია მტვრის გავრცელების კინეტიკა. 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 1კმ-ის ზევით ძირითადია მტვრის ადვექციური გადატანა.

Пространственное распространение метеорологических полей и концентрация пыли в атмосфере Кахети в случае фонового северного ветра

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Резюме

С помощью модели эволюции мезометеорологических атмосферных процессов и численного интегрирования уравнения переноса-диффузии примеси на территории Кахети исследованы пространственное распределение метеорологических полей и концентрация пыли в случае фонового северного ветра. Показано, что рельеф Кахети существенно влияет на формирование локальных метеорологических полей в атмосферном пограничном слое. В свободной атмосфере влияние значительно слабее. Воздействие рельефа на фоновое движение воздуха вызывает возникновение мезомасштабных горизонтальных и вертикальных вихрей и волны, направленной вдоль фонового движения воздуха. Волна существует как в пограничном слое, так и в свободной атмосфере. Вертикальные вихри формируются с наветренной и подветренной сторон орографического препятствия. Размеры возникших вихрей зависят от ширины и высоты или глубины горного хребта или ущелья, соответственно.

Получены картины пространственного распределения и определены зоны распространения городской пыли. Изучена кинетика процесса диффузии загрязнения воздуха. Получено, что в нижнем, 2-100 метровом 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 одинаковы, а выше 1км - адвективный перенос преобладает над турбулентной диффузией.