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საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

სერია ა. დედამიწის ფიზიკა

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Issue A. Physics of Solid Earth

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Development of Strong Motion Network in Georgia

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ABSTRACT

In frame of Shota Rustaveli National Science Foundation project "Accelerometer and Very Low Frequency electromagnetic waves receivers network implementation in Georgia: basis for specifying seismic hazard" project, 6 strong motion recorders were installed on territory of Georgia. This is the beginning of restoration of old accelerometric network, which stopped working in 2006. We are studying soil properties for each station, using active and passive methods and ground resonance frequencies, with HVSR method. Accelerometric database is being created.

Key Words: seismic hazard, accelerometric network.

Introduction

The South Caucasus, particularly Georgia is highly vulnerable to various natural hazards, the most dangerous and devastating of which is seismicity [1]. Observed seismicity in Georgia is characterized as moderate. Maximum observed magnitude of earthquakes is Racha earthquake of 1991, Ms = 7. The moderate and strong earthquake reflect regional tectonics that is largely determined by position of Caucasus between still converging Eurasian and Africa-Arabian tectonic plates. Risk resulting from seismic hazard is closely related to sustainable development of the country. Assessment of seismic hazard is vital for the region. Probabilistic assessment of seismic hazard involves calculation of expected value of ground shaking for a specified probability of exceedance within a specified time period (e.g., peak ground acceleration that has a 10-perecent probability of being exceeded within the next 50 years). So, during the study of seismic hazard, it is important to have accurate earthquake information, which includes: earthquake epicentre location, depth, time and magnitude for seismic sources and good strong motion recordings for building new or selecting existing ground motion prediction equation (GMPE). GMPEs provide means of predicting ground shaking at any location based on earthquake magnitude, fault mechanism, source to site distance, etc. The territory of Georgia includes up to 40 broadband seismometer stations, which can be used for earthquake parameters and source physics study, but using their data by derivative velocity for seismic hazard assessment will introduce additional error. seismometer measures the velocity of the ground during earthquake shaking. Most velocity sensors are high precision, sensitive instruments designed to record motions from distant earthquakes rather than the strong shaking that occurs near earthquakes. Accelerometers are much less sensitive than seismometers, but have a much greater range, detecting ±2g or more of ground acceleration (things start flying off the ground at 1g, when gravity is overcome). By comparison a seismometer will clip at full scale if you tap it too hard with your finger (http://www.src.com.au/strong-motion-accelerographs/).

Strong Motion Network for territory Georgia

Digital accelerograph network in the Caucasus area was operated by National Survey for Seismic Protection of the Republic of Armenia, the Georgian Academy of Sciences and the Swiss Seismological

Service granted by the Swiss Disaster Relief. The initial network, which started operation in 1990 was gradually extending. The network consisted of 12 digital free-field stations, 16 analog strong-motion stations, 6 digital strong-motion instruments for aftershock studies and 2 structural monitoring related arrays. This network operated till 2006, so its data is limited. During EMME (Earthquake Model for Middle East Region) project (2010-2013), strong motion data from this network was analyzed and out of about 450 recording only 88 were used, because most earthquakes were of small magnitude or recording quality was too low [2].

Taking all these into consideration, creating a new strong motion network that covered the whole territory of Georgia was vital. (work presented here was done in the frame of Shota Rustaveli National Science Foundation project "Accelerometer and Very Low Frequency electromagnetic waves receivers network implementation in Georgia: basis for specifying seismic hazard"), 6 strong motion instrumentations have already been installed and more are planned next few years. The locations of stations have been chosen with several priorities. Security of the instrumentation being the first. The network was planned to be evenly distributed in the area. The locations and coordinates of installed and planned stations are shown on Fig 1.

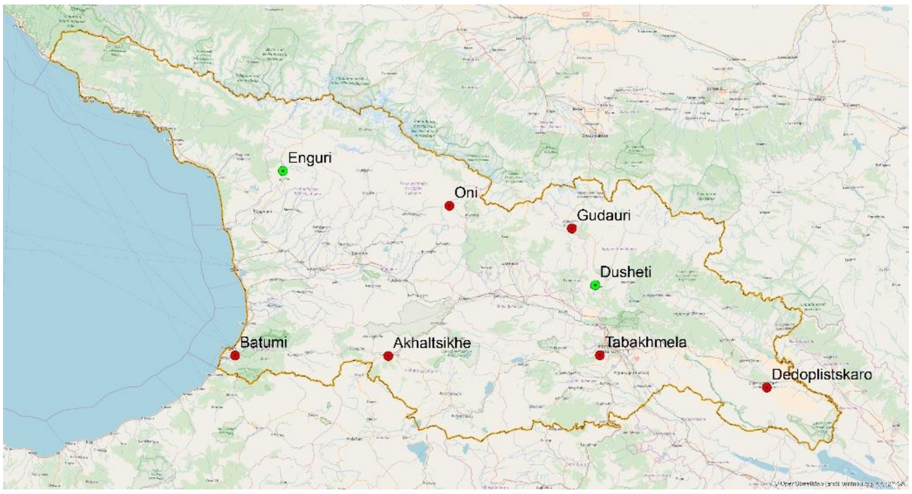


Fig. 1. Network map, red circles – installed, green – planned.

The local sight effects play important role in earthquake recordings. Different sight conditions can give amplification factors in different frequency ranges. Site characterization is necessary for strong motion. For large networks in Japan boreholes of 30 meters are made to study soil properties in detail. But such studies are costly, so for our network we studied shear-wave propagation velocity average for 30 meters (Vs_{30}) using seismic profiles. Horizontal to vertical spectral ratios (HVSR) of ambient seismic noise was used to estimate the thickness of sediment over bedrock, based on empirically-derived, power-curve relationships between sediment thickness and primary resonant frequency of shear-waves [3,4].

For this purpose, Seistronix RAS-24 and Tromino 3G are used. For resonance frequency Horizontal and Vertical Spectral Ratio (HVSR) method was used.

All stations have Kinemetrics Basalt 4X data recorders, with 3+1 channels, 24-bit Delta Sigma converter per channel, selectable sample rates and different supported file formats. An external GPS antenna is used for timing, with accuracy <1 microsecond. Internal Linux system and +1 channel gives user flexibility to use different types of external devices for communication and complex studies.

Tri-axial EpiSensor ES-T is used for ground motion detection. With Dynamic range: 155 dB+; Bandwidth: DC to 200 Hz; selectable full-scale range at: ± 0.25g, ± 0.5g, ± 1g, ± 2g or ± 4g; and extreme operating temperatures: -20° to 70°C.

In order to protect instrumentation from external influences and because of low budget old metal safes were used. To protect instrumentation from abrupt changes in temperature heat insulators were necessary. This provided us with sufficient safety from both weather conditions and theft. Reinforced concrete basement was designed for sensor, the depth of which was chosen considering local weather and soil freezing depths for noise reduction. Fig. 2 shows general block scheme for each station.

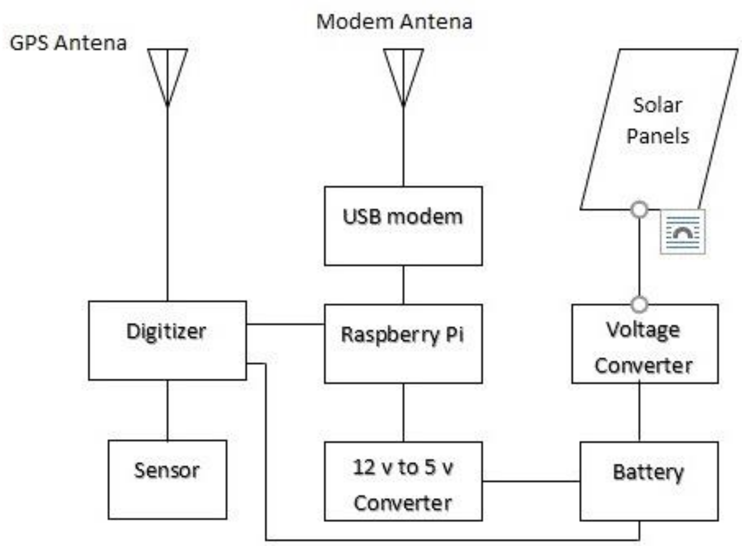


Fig. 2. Block diagram of stations

As none of the station except, Tabakhmela have AC power, solar panels were necessary. Wattage of solar panels were chosen taking weather conditions into consideration. Step down voltage converter with high efficiency can operate up to 80 Volt and give output of Maximum 10 A. 3G/SDMA modem is used for internet connection and Raspberry Pi with VPN technology for data transfer and remote access. Data is collected and stored on server using SSH protocol. Server is located at Tabakhmela, as it is the only location that has AC power and wired internet access.

Data processing of Georgian strong-motion database:

For data analysis different software is used: SMA (Strong Motion Analyst) and USDP (Utility Software for Data Processing). Main steps in data processing for both software are following:

1. Mean removal: Remove the entire mean for accelerograms without a pre-event buffer or Use the pre-event mean for removing it from the accelerogram whenever pre-event buffer is available

2. Baseline correction using the procedure proposed in [5] (procedure that opts to minimize residual displacements) for accelerograms with pre-event segments.

3. Filtering - Acausal

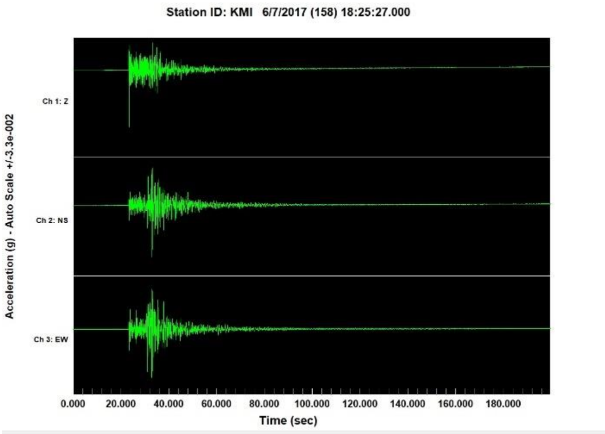
The major difference in causal and acausal filtering are the phase changes in the filtered time series. Causal filters result in phase distortion in the processed data whereas acausal filter does not introduce any phase change (phaseless) to the filtered data. The acausal, phaseless filtering is simply achieved in the time domain by passing the filter response along the record from start to finish and then reversing the order and passing it from the end of the record to the beginning. Acausal filtering requires leading and trailing zeros at the beginning and end of the aceelerogram, respectively to accommodate filter transients; acausal filtering leads to more stable processed data both in terms of time series and spectral calculations [6].

We have chosen Acausal filter. We use the default roll-off slope, that is 8 in USDP. The low and high-cut filter were determined through the guidance of f^2 and $1/f^2$ gradients that can be moved along the FAS plot by clicking on the relevant button. In the figure 38 is represented the pick the limited point in low – frequency.

As we know high frequency decay at rates $1/ f^2$, that means spectral amplitudes decrease with increasing frequency. But at some points noise produces an increase in spectral amplitudes. This point is limited point for high frequency

For data analysis different software is used: SMA (Strong Motion Analyst) and USDP (Utility Software for Data Processing) example of the earthquake recording and its processing is given below. data shown below is a recording of earthquake near Dedophlistskaro station, on 07 June, 2017 18:25:41, at coordinates: 41.4056/45.7956, which is about 27 Km from station. The magnitude was M_L=5.

Figs 3 and 4 show raw data from all three channels, and pre-processed data for Z direction, analysis in this case was done using SMA software.



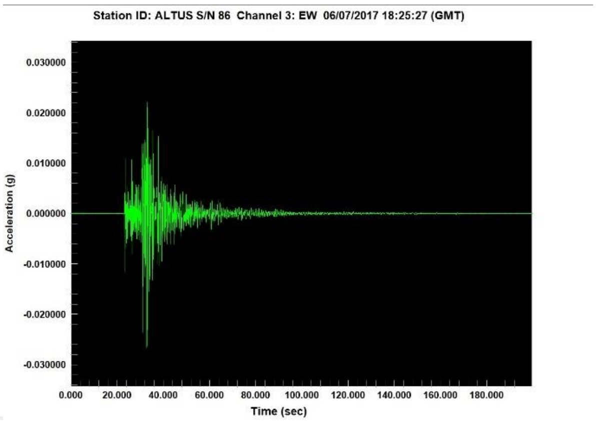
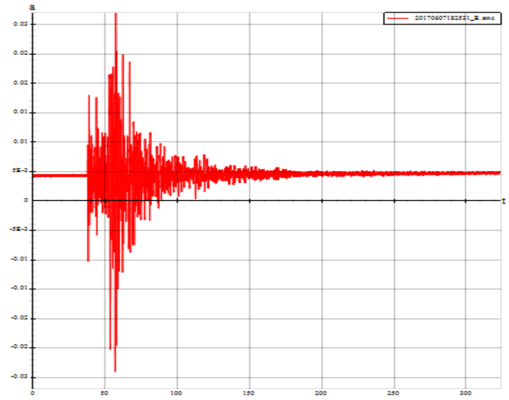


Fig. 3 and 4 – SMA raw data for all three channels and pre-processed data for Z channel.

Data processing by USDP software showing all the steps is shown below on Figs 5- 12. step 1.



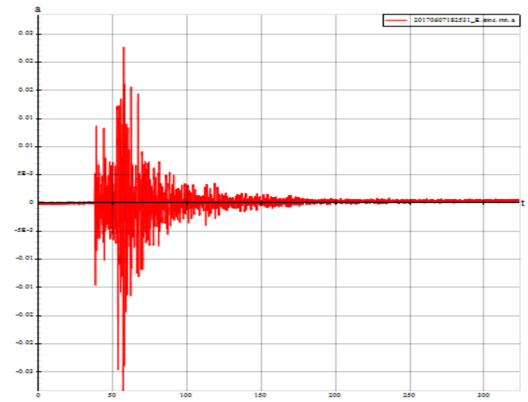
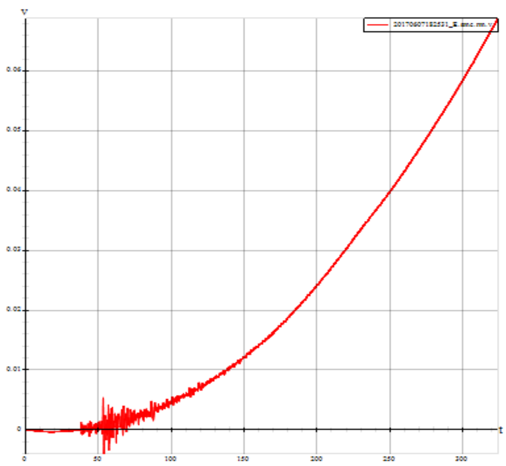


Fig. 5 - Uncorrected records of maximum horizontal components of earthquake (07.06.2017)

Fig. 6 - The mean of entire pre-events is 36 sec



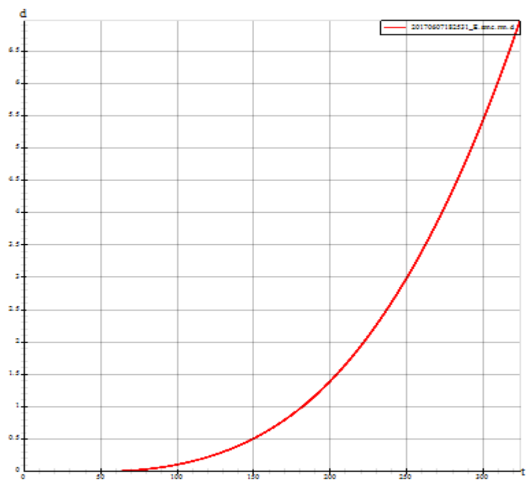


Fig. 7. Velocity time series

Fig. 8. Displacement time series

In practice the low-cut filtering is used to reduce the long period noise rather than baseline corrections with filtering. Totally there is not significant differences in results obtained by filtering and baseline corrections with filtering. We skipped baseline correction and used only filters.

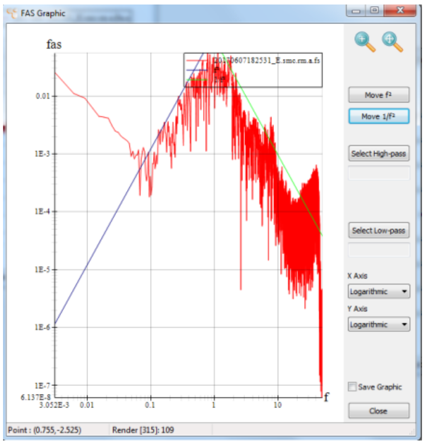


Fig. 9. Example of low and high-cut filter.

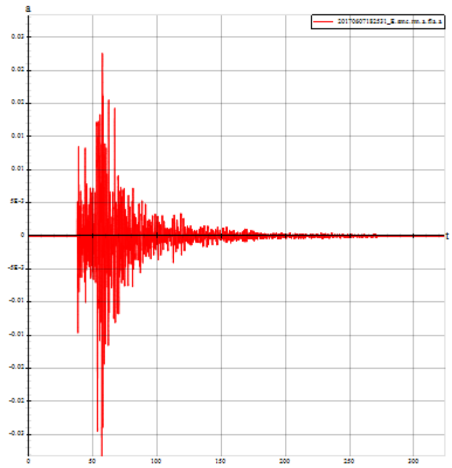


Fig. 10. Corrected records of acceleration time series

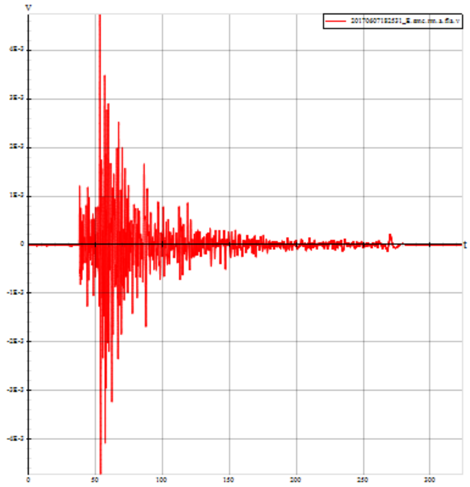


Fig. 11. Corrected records Velocity time series

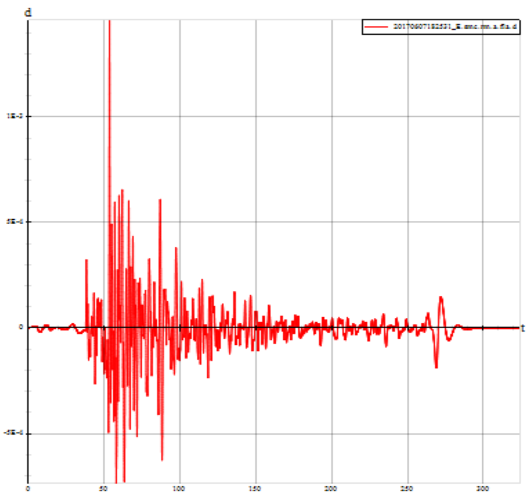


Fig. 12. Corrected records displacement time series

Conclusions

Because Georgia is located in seismically active region, accurate assessment of probabilistic seismic hazard and risk are extremely important. In the past seismic hazard study has shown that for Georgia there is no sufficient strong motion data. Taking this into consideration renewal of old strong motion network has begun. Today 6 stations are installed and operate. Two additional locations have already been chosen for more stations and are planned to be installed next year.

Finally, country-based metadata will be criated. In a reliable metadata, information must be same for same for each event: date and time, magnitude, epicenter coordinates, depth, focal mechanism; and each station must have its data on: initial waveform, processed waveform, description of processing procedure, PGA (Peak Ground Acceleration) and SA (Spectral Acceleration) value, site information, source to site distances.

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Развитие сети сильных движений в Грузии

Н.К. Кавадзе, К.Д. Кавадзе, Н.С. Церетели, А.Б. Гвенцадзе, З.Р.Гоголадзе

Резюме

В рамках проекта Национального научного фонда Шота Руставели «Внедрение сети акселерометров и низкочастотных электромагнитных волн в Грузии: основа для определения сейсмической опасности», 6 акселерометров были установлены на территории Грузии. Это начало восстановления старой акселерометрической сети, которая перестала работать в 2006 году. Мы изучаем свойства почвы для каждой станции с использованием активных и пассивных методов и резонансных частот грунта с использованием метода HVSR. Создается акселерометрическая база данных.

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Variation of Geophysical Parameters During Preparation of Seismic Events

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ABSTRACT

The article contain information about several hydrodynamic and geomagnetic anomalies were observed during March 2017 - December 2017 on the multiparametric monitoring network of M. Nodia institute of Geophysics. Data were analyzed by the special program which gives possibility to exclude the influence of geological factors by the common value of tidal variations. Was analyzed reaction of parameters to the earthquake preparation process.

Key Words: hydrodynamic and geomagnetic anomalies, seismic event precursors.

Introduction

Georgia is very vulnerable to various natural disasters, including earthquakes [1]. Significant number of works on the registration of earthquakes and the detection of their possible precursors is here carried out (electromagnetic and acquisition emissions, atmospheric electric parameter, soil radon, ULF electromagnetic variations, etc.) [2-10]. Multiparametric data (water level, atmosphere pressure, temperature, geomagnetic field etc.) were recorded with a minute frequency, in the deep boreholes located on the territory of Georgia. Observations were carried out using the special equipment providing measurement of deformation up to 10^{-8} degrees [11-12]. In order to exclude the influence of geological factors, the data from various stations were rated against the common value of tidal variations [13-14]. Variation and reaction of parameters to the earthquake preparation process [15-19] were analyzed.

Data analysis

Therefore, were analyzing the value of stress field by hydrodynamical parameters [20-21] and geomagnetic field variations during preparation of several earthquake processes on the territory of Caucasus were calculated and analyzed:

Earthquake in Tsalka area -24.03.2017 Mag-3.7

The earthquake of 24 March 2017 (Mag- 3.7, Tsalka), anomalies was observed on the Marneuli borehole, as well as at Dusheti Geomagnetic Observatory and Oni magnetic station.

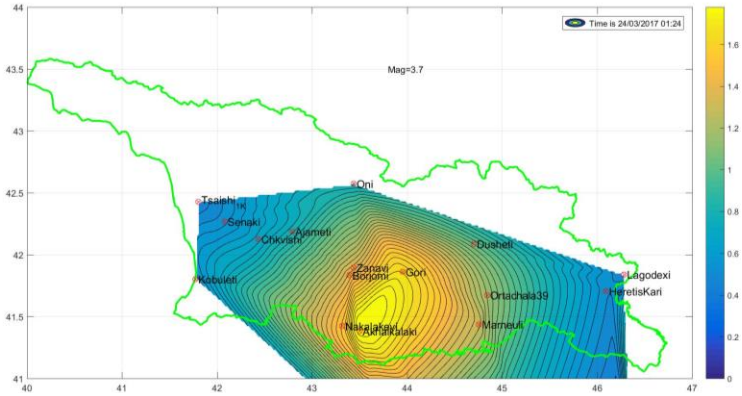
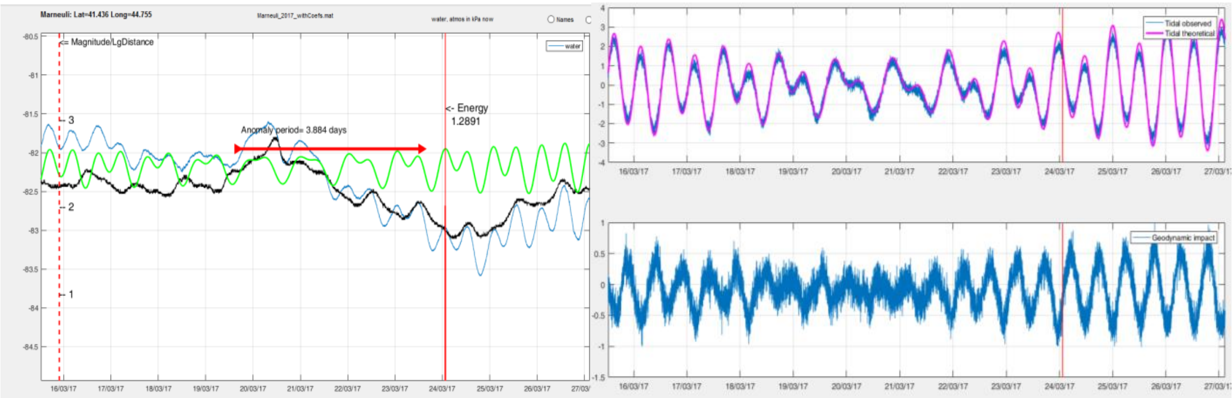


Fig.1 Stress map on the moment of 24 March 2017 earthquake, Mag-3.7.

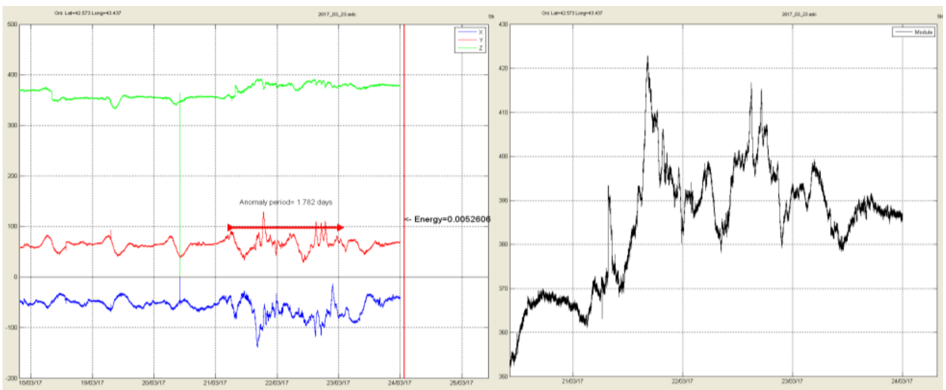
Anomaly was revealed on Marneuli station before 24 March 2017 earthquake, 4 days earlier. At the same time water level falling can be seen on the graph (Fig.2). Earthquake happened in 68 km far from the station.



a b

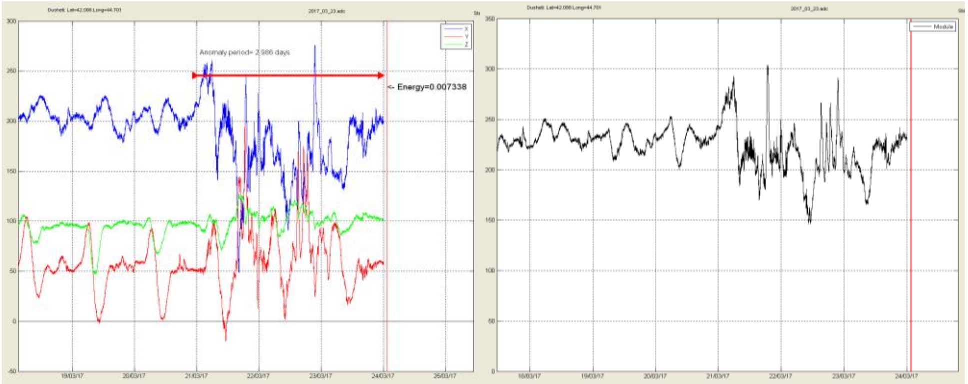
Fig.2. a - Water level, atmospheric pressure and tidal variations at the Marneuli borehole. Vertical line marks an earthquake. On abscis axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

At the Oni station, like the one at Dusheti Geomagnetic Observatory, anomaly was observed 3 day earlier before event.



a b

Fig.3. a-Variation of x,y,z components of the magnetic field at the Oni Station. b- Variation of the module value.



a b

Fig.4. a-Variation of x,y,z components of the magnetic field at the Dusheti Geomagnetic Observatory. b-Variation of the module value.

Earthquake in Kvareli area-15.04.2017, Mag-3.6.

Before the earthquake of 15 April 2017 (Mag- 3.6, Kvareli), anomalies were observed on the Naqalaqevi, Gori, Marneuli stations, as well as at Dusheti Geomagnetic Observatory.

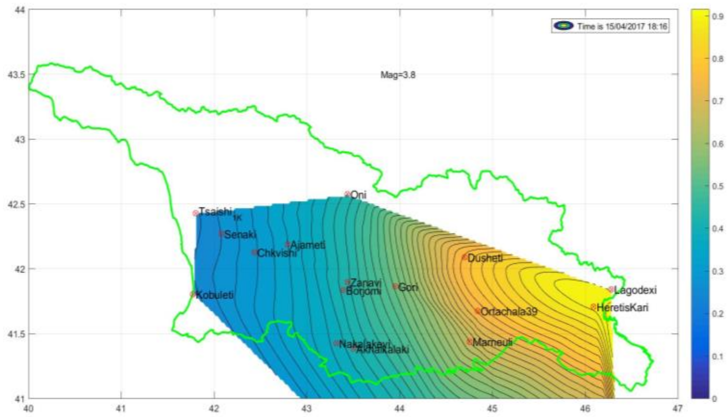
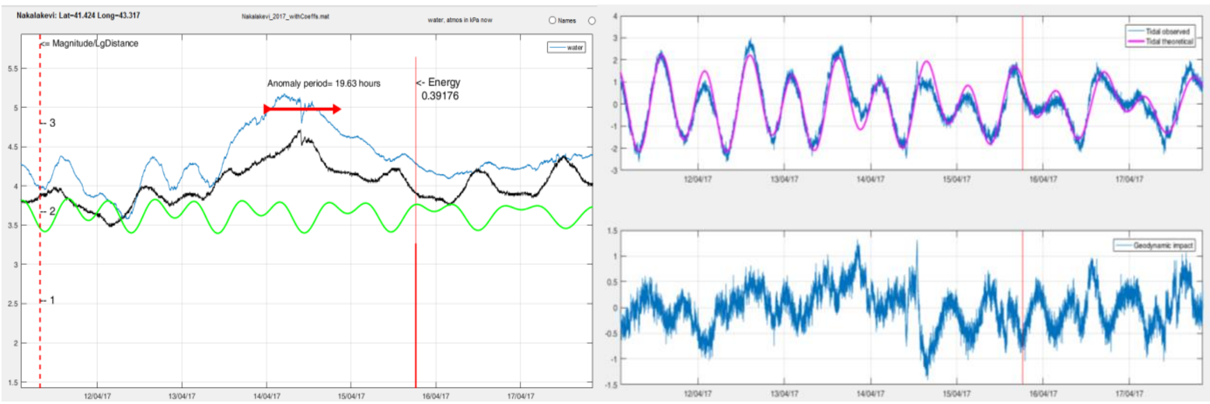


Fig.5 Stress map on the moment of 15 April 2017 earthquake, Mag-3.6.

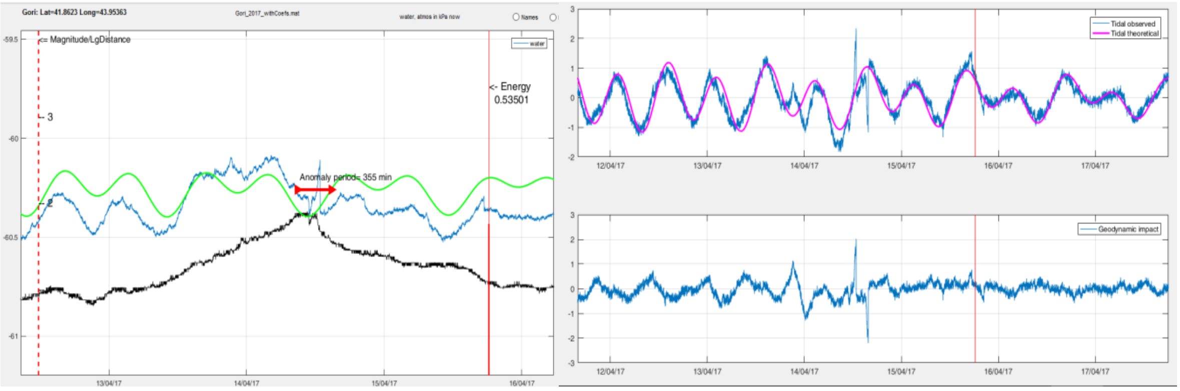
Anomaly was observed in Naqalaqevi borehole 1 day earlier before event of 15 April 2017. The Earthquake occurred in 210 km far from a station.



a b

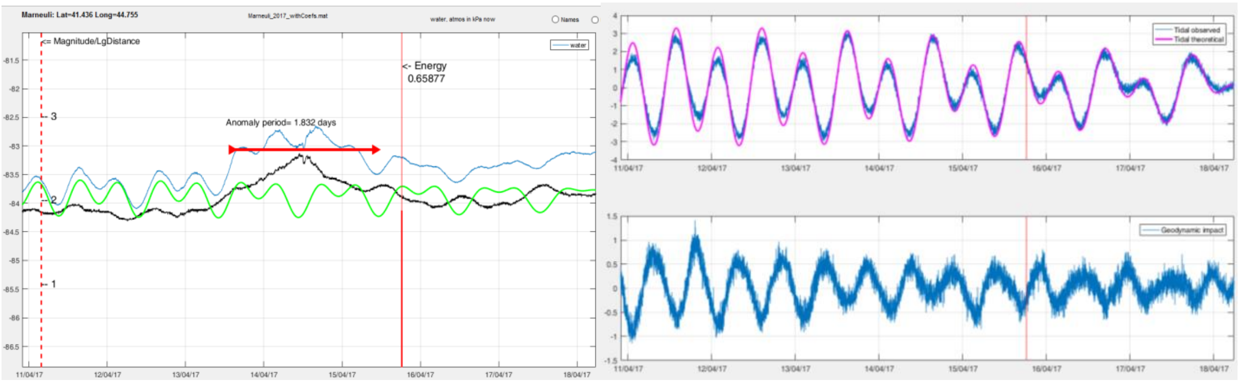
Fig.6. a - Water level, atmospheric pressure and tidal variations at the Naqalaqevi borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

As wall as Naqalaqev's station, at the Gori borehole anomaly of behavior of water level is revealed 1 days earlier before earthquake, 145 km from station.



a b

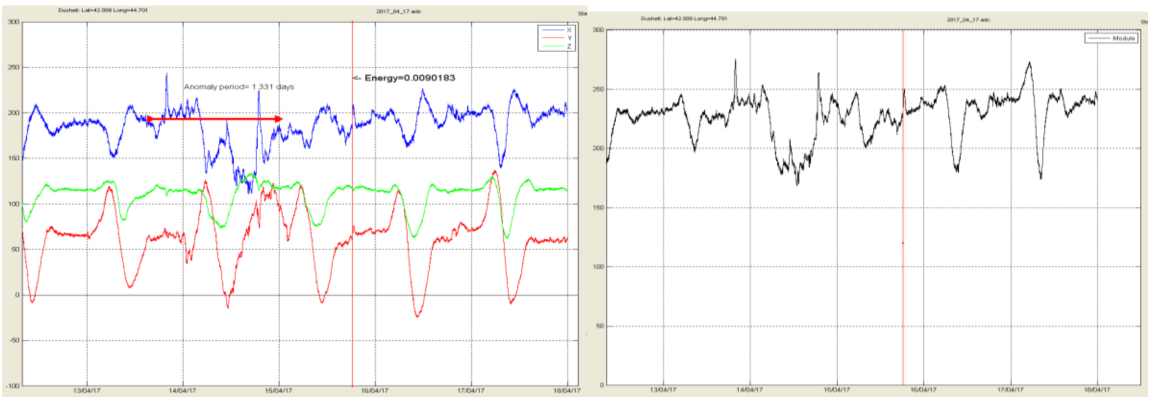
Fig.7. a - Water level, atmospheric pressure and tidal variations at the Gori borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.



a b

Fig.8. a-Water level, atmospheric pressure and tidal variations at the Marneuli borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

At Marneuli station anomaly behavior was 1 day earlier before the earthquake. Earthquake epicenter was located in 107 km far from the station.



a b

Fig.9. a-Variation of x,y,z components of the magnetic field at the Dusheti Geomagnetic Observatory. b-Variation of the module value.

Anomaly was observed at Dusheti Geomagnetic Observatory, 2 days earlier before the earthquake 15 April. The anomaly continued for 1 day. The earthquake occurred in 80 km far from the Dusheti.

Earthquake in Dmanisi area-09_05_2017, Mag-3.6.

The earthquake of 09 May 2017 (Mag- 3.6, Tsalka), anomalies was observed at the Kobuleti, Naqalaqevi, Oni, Gori and Marneuli boreholes.

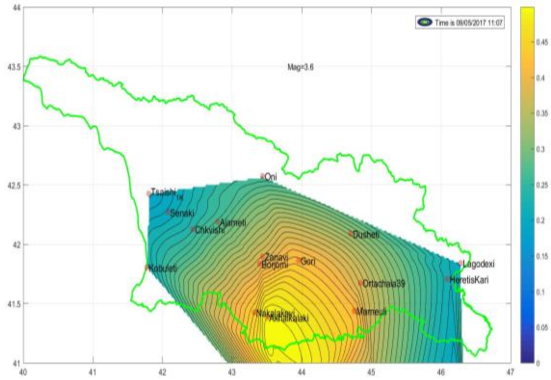
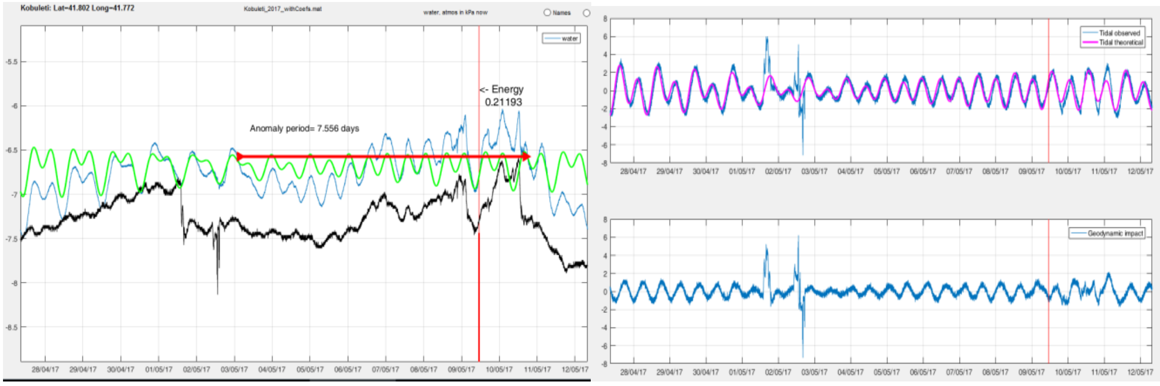


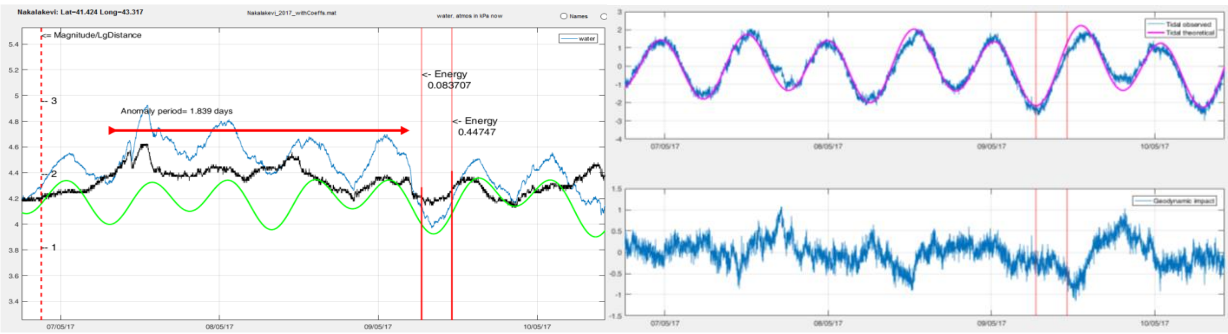
Fig.10 Stress map on the moment of 09 May 2017 earthquake, Mag-3,6.



a b

Fig.11. a - Water level, atmospheric pressure and tidal variations at the Kobuleti borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

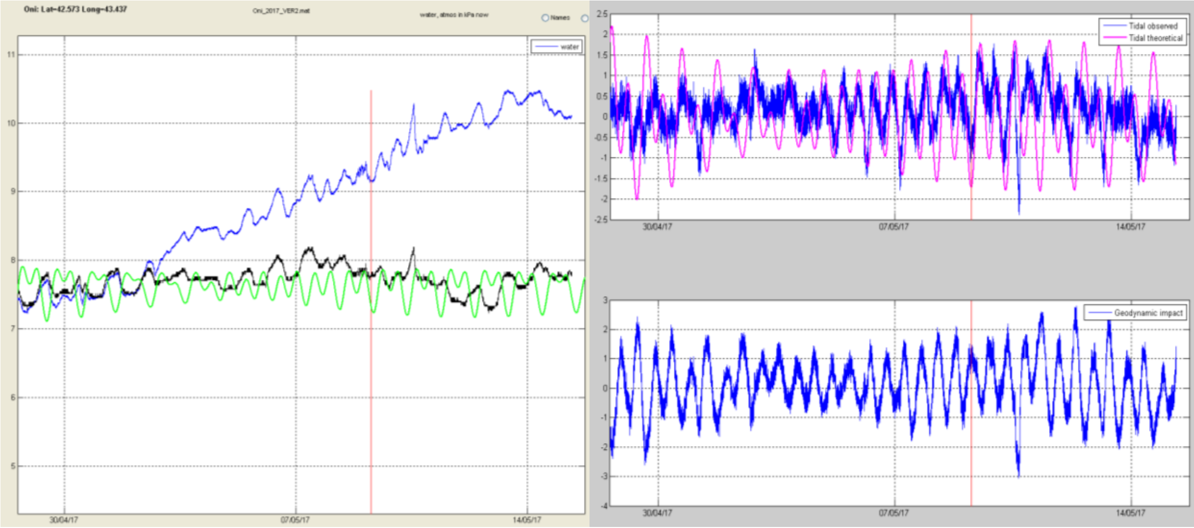
In Kobuleti, which is 193 km away from the epicenter, we observed an anomaly that continued for 7 days.



a b

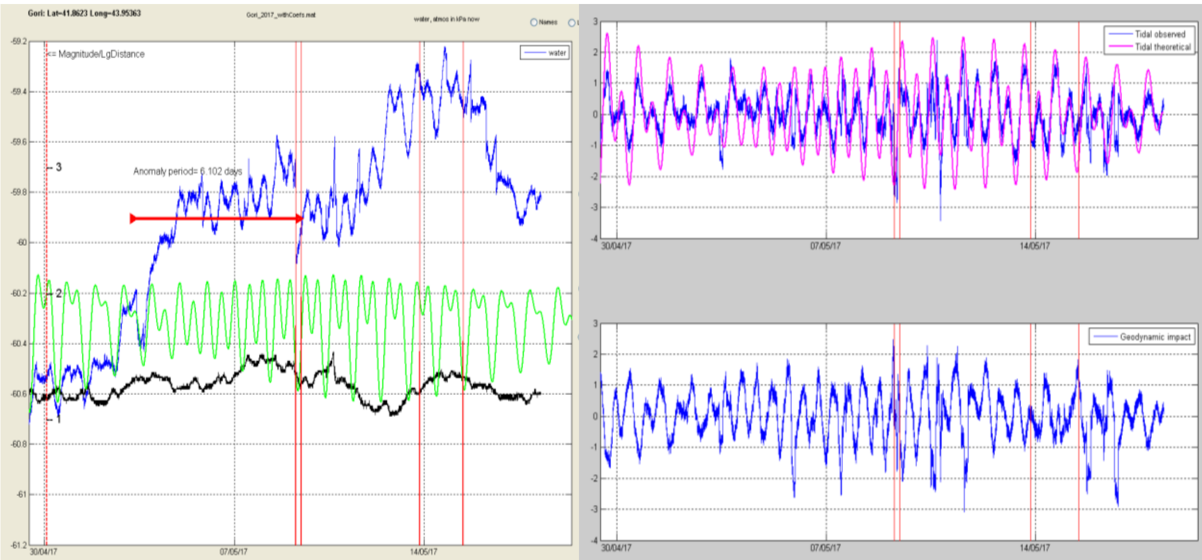
Fig.12. a - Water level, atmospheric pressure and tidal variations at the Naqalaqevi borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

At Naqalaqevi station anomaly was observed 2 days before of the earthquake. The duration of the anomalous period is fixed on figure. Naqalaqevi station is 58 km far away from the epicenter.



a b

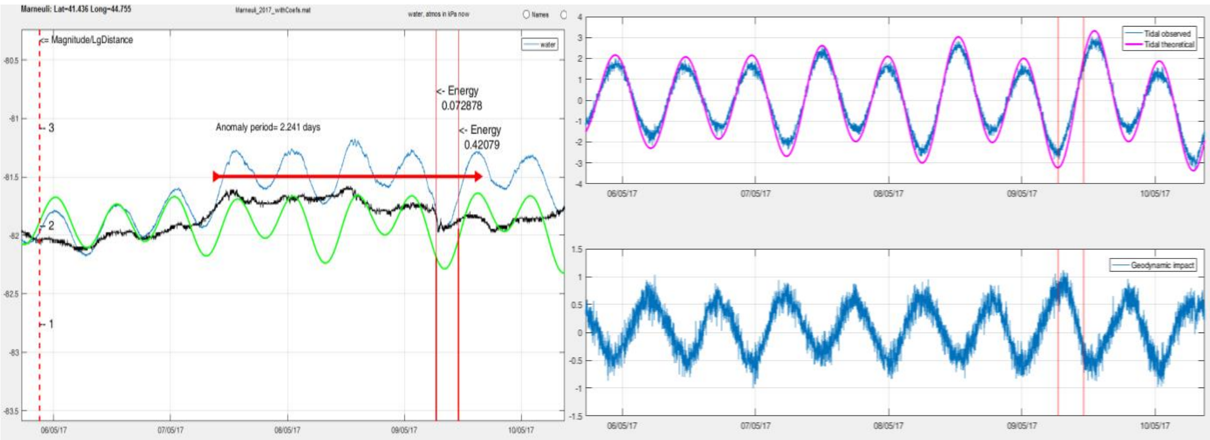
Fig.13. a - Water level, atmospheric pressure and tidal variations at the Oni borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.



a b

Fig.14. a - Water level, atmospheric pressure and tidal variations at the Gori borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

Increasing of water level at the Gori and Oni station can be seen on the graph (Fig.13 Fig.14). Anomaly can be seen before 5 days earlier of earthquake and continued after the event.



a b

Fig.15. a - Water level, atmospheric pressure and tidal variations at the Marneuli borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

At Marneuli borehole, which is 67 km away from the epicenter, the anomaly was observed 2 days prior to the earthquake. The duration of the anomalous period is shown on figure

Earthquake in Dedofliswyaro area-17_07_2017, Mag-4.1.

The earthquake of 17 July 2017 (Mag- 4.1, Dedoflitskaro), anomalies was observed on the Naqalaqevi borehole, as well as at Dusheti Geomagnetic Observatory and Oni station.

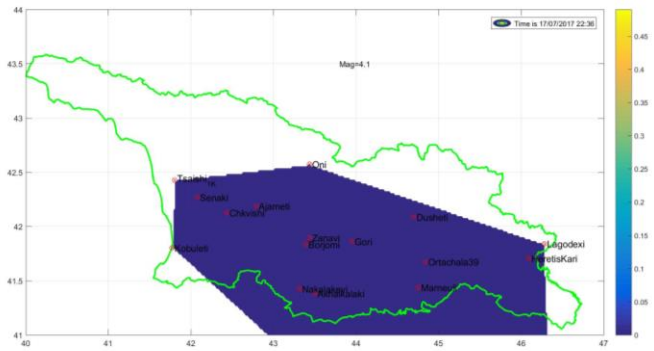
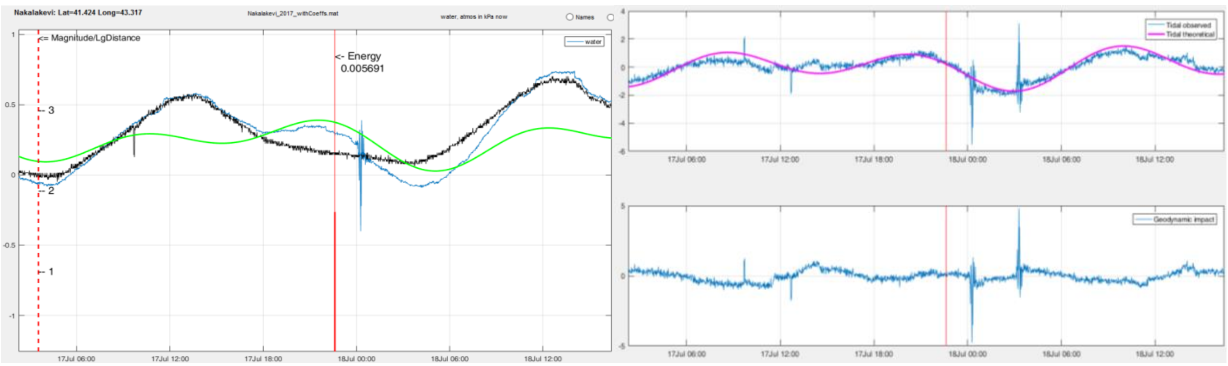


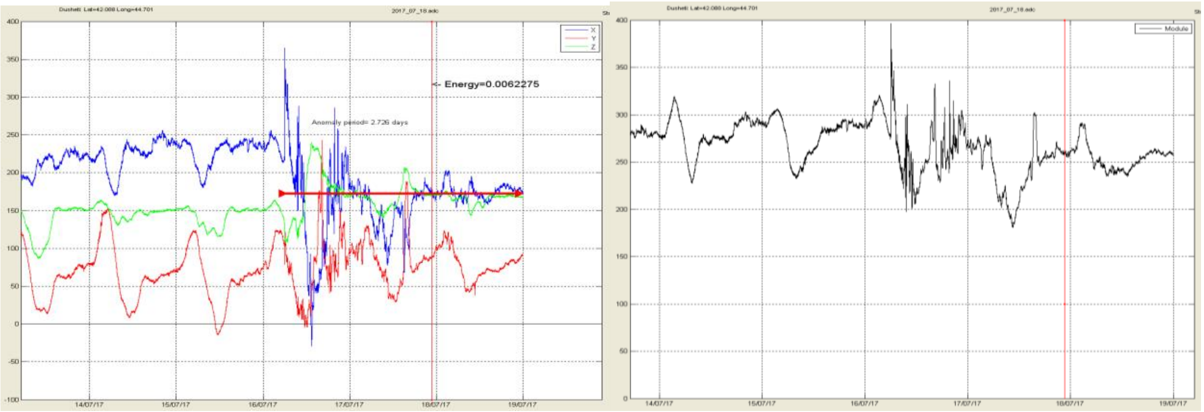
Fig.16 Stress map on the moment of 17 July 2017 earthquake, Mag-4,1.



a b

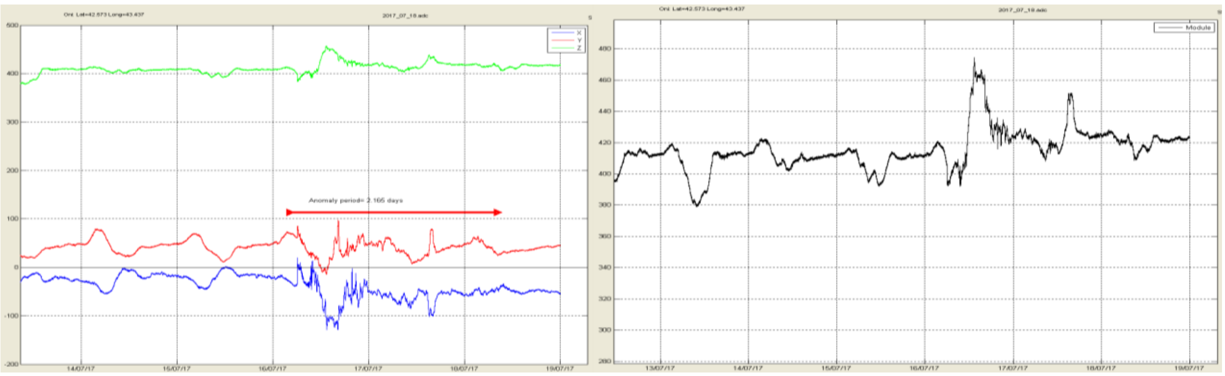
Fig.17. a - Water level, atmospheric pressure and tidal variations at the Naqalaqevi borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

Anomaly can be seen at Naqalaqevi station, before earthquake. The Epicenter of the 17 July earthquake occurred 232 km away from Naqalaqevi station. It is noteworthy that the earthquake of 20 July 2017 (Mag- 4,5 Azerbaijan) happened after this anomaly.



a a

Fig.18. a-Variation of x,y,z components of the magnetic field at the Dusheti Geomagnetic Observatory. b-Variation of the module value.



a b

Fig.19. a-Variation of x,y,z components of the magnetic field at the Oni Station. b- Variation of the module value.

About three days of anomalies are observed in the variations of magnetic field's components and its modules at Dusheti Geomagnetic Observatory and Oni station.

Earthquake in Tkvarcheli area-14_09_2017, Mag-3.4.

The earthquake of 14 September 2017 (Mag- 3.4, Tkvarcheli), anomalies was observed on the Naqalaqevi and Gori boreholes, as well as at Dusheti Geomagnetic Observatory.

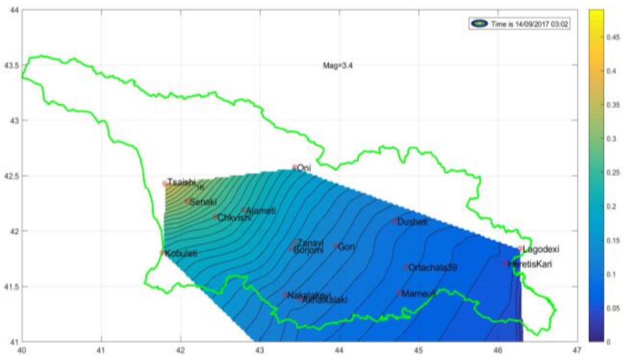
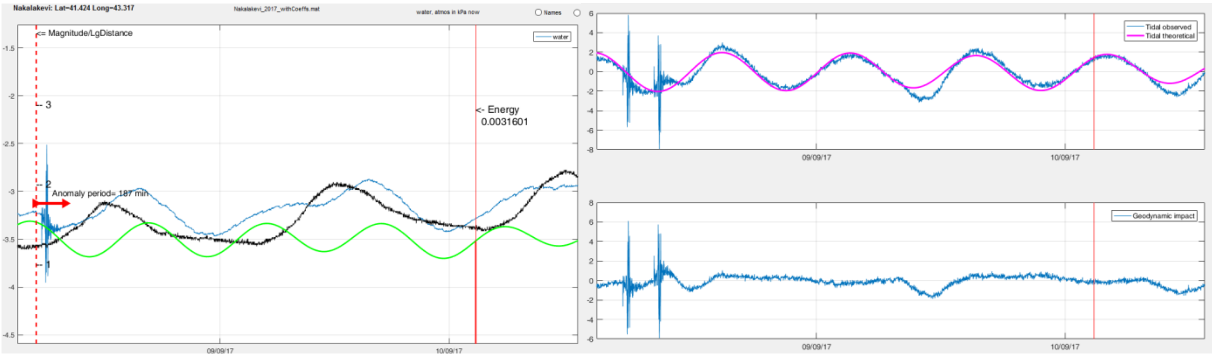


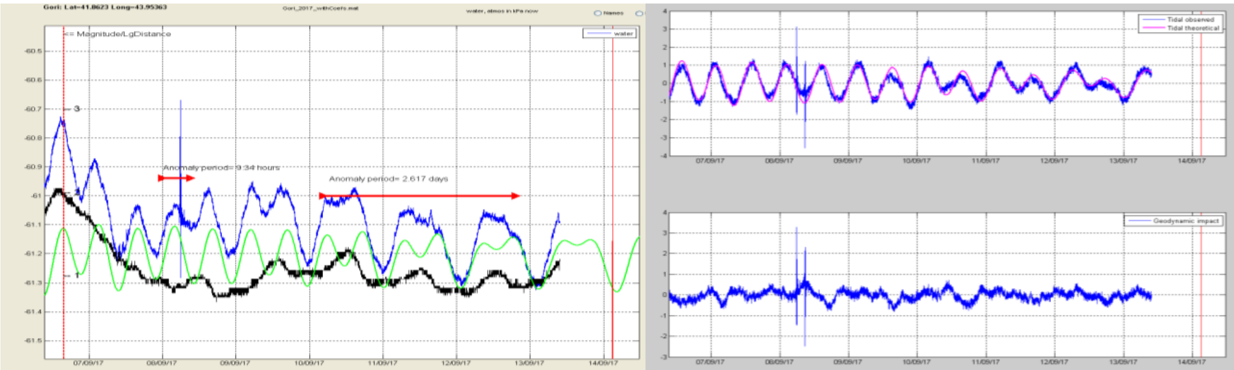
Fig.20 Stress map on the moment of 14 September 2017 earthquake, Mag-3,4.



a b

Fig.21. a - Water level, atmospheric pressure and tidal variations at the Naqalaqevi borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

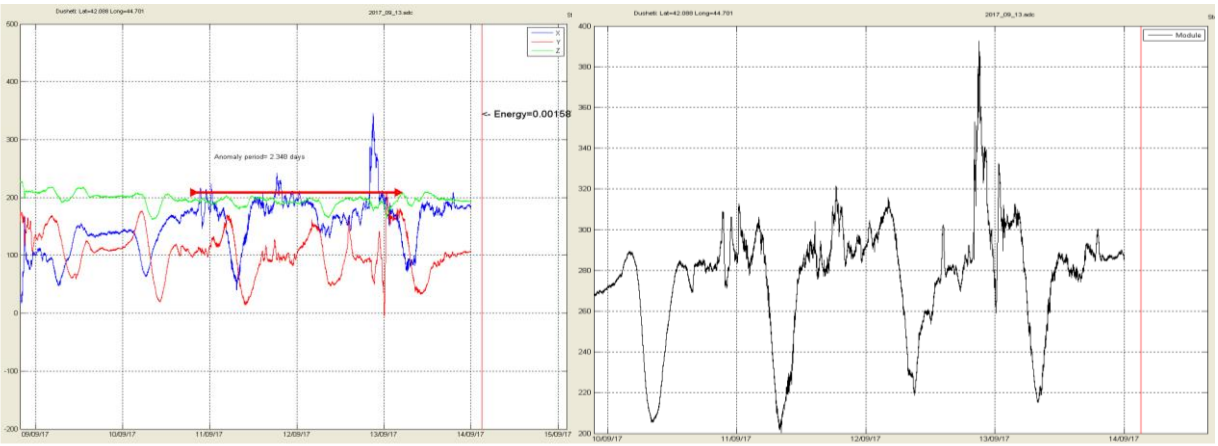
As we can see the graph, the anomaly at Naqalaqevi borehole is observed 6 days prior to the 14 September earthquake.



a b

Fig.22. a - Water level, atmospheric pressure and tidal variations at the Gori borehole. Vertical line marks an earthquake. On abscise axis time is in hours. b- Speed factor of variations water level and earth tidal and the difference between them.

At Gori station the anomaly was observed a week prior to the earthquake. Gori borehole is located 254 km away from the epicenter.



a b

Fig.23. a-Variation of x,y,z components of the magnetic field at the Dusheti Geomagnetic Observatory.

b- Variation of the module value.

A 2-day anomaly that is observed before 14 September 2017 earthquake is shown on the Dusheti magnetic data plot.

Conclusions

Variations in hydrodynamic and geomagnetic parameters are caused by the earth stress. During normal period it change according tidal variation and has “background” value. Before seismic event character of variation changed above “background” value, as indicator of tectonic activity. During the observed time period were fixed earthquakes with Magnitude 3-5, between 200-500 km from the station, occurred on the territory of Caucasus. Character of “anomalies” depended on energy of earthquakes. Period of “anomalies” varied between 2-5 days.

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გეოფიზიკური პარამეტრების ვარიაციები სეისმური მოვლენების მომზადების პროცესში

გ. მელიქაძე, თ. ჯიმშელაძე, გ. კობზევი, ა. ჭანკვეტაძე

რეზიუმე

სტატია გადმოგვცემს ინფორმაციას სხვადასხვა ჰიდროდინამიკურ და გეომაგნიტურ ანომალიებზე, რომლებიც დაფიქსირებულია 2017 წლის მარტიდან დეკემბრამდე, მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტის მულტიპარამეტრიკულ ქსელზე. მონაცემები მუშავდებოდა სპეციალური პროგრამის მეშვეობით, რათა გამორიცხულიყო გეოლოგიური ფაქტორების გავლენა სხვადასხვა სადგურების მონაცემები კალიბრებოდა მიმოქცევითი ვარიაციებით. გაანალიზდა პარამეტერბის ვარიაციები და რეაქციები მიწისძვრის მომზადების პროცესზე.

Вариации геофизических параметров в период подготовки землетрясений

Г.И. Меликадзе, Т. Дж. Джимшеладзе, Г.Н. Кобзев, А. Ш. Чанкветадзе

Резюме

Статья содержит информацию о гидродинамических и геомагнитных аномалиях в период с марта по декабрь 2017 года по данным наблюдений мультипараметрическом мониторинговой сети Института геофизики им. М. Нодиа. Данные проанализированы с помощью специальной программы. С целью исключения влияния геологических факторов, данные с различных станций были откалиброваны с помощью значений приливных вариаций. Осуществлен анализ вариаций и реакции параметра на процесс подготовки землетрясения.

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On the Geometric Formalism of Thermodynamics: In the ContextofLiquid Bubble-Boiling and Matter Glassy State

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ABSTRACT

Modelling of fluids vertical convection in nature by means of our original bubble-boiling method (BBM) allowed us to investigate behavior of the thermodynamic parameters of solutions during the whole process of heating (result of joint action of the processes of temperature conductivity, thermals and vapour bubbles mixing convective motion). There were obtained the universal dependence between the of bubble-boiling temperature and density of the solutions and existence of linear lows between points of discontinuities: T_{dc}, t_{dc}, S_{dc}, and ρ_{dc} which we can write, for q = const., as: $(dT/ d\rho)_{dc}$ = const., $(d\rho/ dt)_{dc}$ = const., and $(dS/ dT)_{dc}$ = const. This method allowed us to show experimentally a similarity between the temperature-time (T, t)-diagrams of some matters water solutions and Tammann's glassy state-diagrams. We try to find accordance between well-known Euler's theorem on right polyhedrons and Gibbs thermodynamic rule about heterogeneous systems. Perhaps, using Gibbs-Tammann method for description of multicomponent system (n = 4, 5 , …), may obtain tetrahedron, octahedron and others. Then, for precise establishment of the moments of the liquids the micro- and macro-scale bubble-boiling regimes beginning, we analyzed our experimental (T, t)-, (dT/dt, T)-, and (d^2 T/dt^2, T)-curves, which showed the existence of the acute maximums near temperatures T = 40 ^{0}C and T = 80 ^{0}C, respectively. Naturally, the same picture shows the temperature dependence of following even derivative of T with respect to t. Thus, this method of processing of T(t)-experimental data allowed us to avoid use of complex high-speed filming technique. Obtained analogy between thermodynamic diagrams of the glassy state of matter and the bubble boiling of liquids is caused by the fluidity of the glass as liquid (that is, "glass is liquid" (Tammann); undoubtedly, this is the best example of the phenomenon supporting well-known Frenkel's kinetic theory of liquids). More over one can assume that the idea of the kinetic theory was "prompted" to Frenkel by Tammann's glassy state, as probably form of Gibbs rule was "prompted" to him by Euler theorem about polyhedrons.

Key words: thermodynamic state, homogeneous, heterogeneous, spherulite, glassy state, bubble-boiling method, Gibbs' rule, Tammann's diagrams, Euler's theorem, polyhedrons.

1. Introduction

Some years ago the authors suggested new fluids bubble boiling method for modeling (BBM) of vertical convection processes having place in the geospheres. Then they were developed in our recent articles for artificial solutions and analyzed by means of T (t), ΔS (T), and T (ρ) experimental curves for definition of admixture of the mass content density of solutions or natural waters. There were obtained optimal values of the liquid volume, the heating intensity, and temperature measurement frequency. BBM-method allows us for short time to determine main thermodynamic parameters, to avoid the technical difficulties of preparation, and carry out measuring, especially near the points of the second kind of discontinuity in the temperature interval 40 ^{0}C – 80 ^{0}C between the micro- and macro-bubble boiling regimes[7-12].For more precise determination of the second kind of discontinuity of the temperature of heating liquids in time except of time dependence of the classical entropy ($dS = dQ/T$ ^{0}K, t) there were constructed time dependence of pseudo-entropy ($d\Sigma = dQ'/T$ ^{0}C, t),where instead of Kelvin's degree ^{0}Kof temperature was used Celsius, ^{0}C, one. By this way it was discover the point of discontinuity at T near 40 ^{0}C which was not seen in case of the curve ($dS = dQ/T$ ^{0}K, t). Therefore then it was recommended to use pseudo-entropy ($d\Sigma = dQ'/T$ ^{0}C, t) at (40^{0}C <T< 50^{0}C).Below it is considered: (a) similarity between experimental (T, t)-curves of any matter water solutions and according diagrams of the matter glassy state; (b) the peculiarities of mentioned (T, t)-

curves at the points of discontinuities (40 ^{0}C and 80 ^{0}C) by means of applying the calculus method to the points of contrary flexure (liquid micro- and macroscale bubble-boiling regimes beginning, respectively) on the curves (dT/dt, T).It is also discussed accordance between well-known Euler's theorem about polyhedrons, Gibbs thermodynamic low and Tammann-Frenkel view on the similarity of solid and liquid bodies structure.

2. Thermodynamics of Gibbs-Tammann and Euler's polyhedron [1-3, 6]

2.1. Geometrical formalism of thermodynamics

As necessary, the classic sciences consider ideal model of their objects of investigation: themathematics – right geometric figures, mineralogy– crystalpolyhedron, physics and chemistry – ideal gases and liquids, geophysics– crystals, which play paramount role, in particular, on close examination of pieces of volcanic glass and the Earth's interior generally. Therefore, study of a thermodynamics of the matter phase transformation in nature and in a laboratory usually is provided on the basis of correlation between a form of crystal and its configuration energy. In this connection it is interesting to pay attention to the well-known expressions – thermodynamic rule of Gibbs [1], and geometric formula of Euler [6].

On the one hand, when a chemical homogeneous substance is appeared in two or three aggregate states simultaneously under invariable pressure and temperature, then they are in equilibrium with each other and submitted to the following Gibbs rule of phases:

$$F = N + 2 - R, \quad (1)$$

Where F is a degree of freedom, N is a number of matters, and R is a number of phases.

On the other hand, Euler's formula for relation between the geometric characteristics of a polyhedronis following:

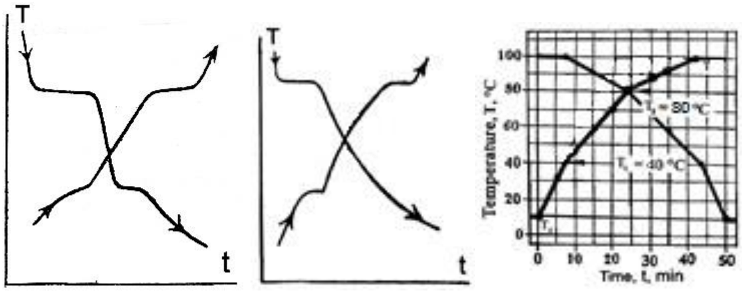
$$F = E + 2 - V, \quad (2)$$

where F is a number of faces, E is a number of edges, and V is a number of vertexes.

In formal comparison of these expressions it is arisen an instant a neo us impression that they are similar not only outwardly. They also reflect dependence between them: between thermodynamic parameters of the system and its inner structure, exactly – crystal structure or in case of Euler's geometric formula –the polyhedron. Both of them characterize the stable state of the systems.

As is well known, a "transition of non-isotropic state into other one is impossible, as a transition of isotropic state into non-isotropic one is impossible". In view of this property of crystals, I think that it is possible to find among of many-component systems corresponding sample one. Analysis shoes that such object is the four-component (n = 4) system. For $n \leq 3$Tammann uses plane geometry, for $n \geq 4$ his thermodynamic diagram is projected in space geometry, in particular, in the form of tetrahedron (n = 4). More detail this question will be discuss below.

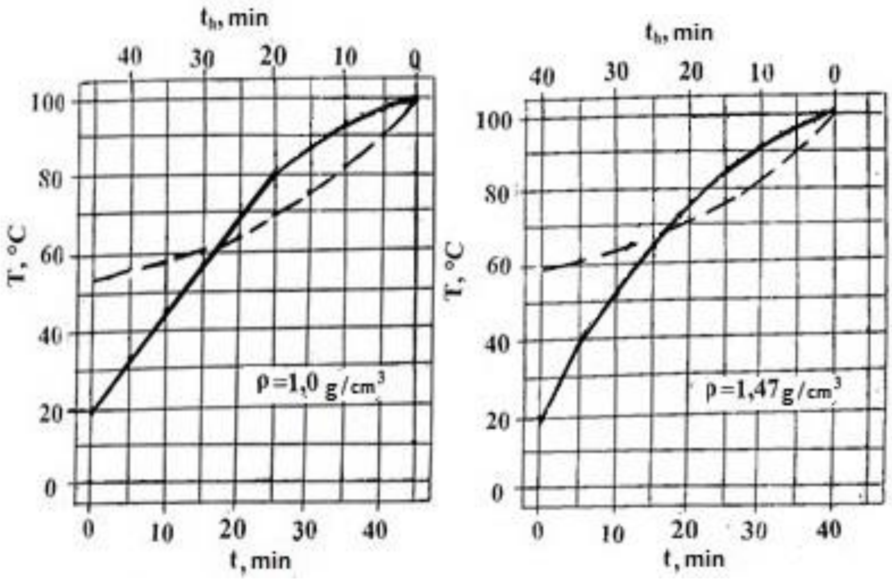
2.2. The stable and unstable stations of melting and bubble boiling thermodynamic systems



(a) (b) (c)

Fig. 1. Temperature-time (T, t)-diagrams of heating and cooling of some matters:(a), (b) –Tammann's qualitative curves are (T, t)-diagrams of according processes [3]; (c)– (T, t)-experimental curves of saturated solution for any matters (using [11,12]).

Analyze of Fig. 1 shows that at the points of phase-transformations crystal-liquid and vise-versa (Fig. 1a, b) the angle of refraction is larger than at the change of micro- and macro-bubble boiling at heating and cooling (Fig. 1c), respectively. It is necessary to note, that the brunch of the cooling curve in Fig. 1c, is the dashed curve in Fig. 2b. Full time of cooling is 184 min (not 40 min as in the diagram of Fig. 1c), then real curve in the last case would have view as the cooling curves in diagrams of Fig. 1a, b, respectively. Above mentioned similarity of the diagrams allow us to speak about the short-range ordering considered thermodynamic systems. This moment is confirmed by investigations [2] according which "molecules are more active in a glass than in a crystal: in crystal lattice molecules are more ordered, and in a gl**ass** they are settled down chaotically." Thus, in that case the glass is supersaturated liquid. It is interesting other citation: three isotropic states: gaseous, liquid and solid (glassy) can transform from one state into another one without division on two phases (persistently). Quite otherwise the things are in case of crystal – non isotropic phase – generation from a vapour, liquid or glass [2]. That is, above mentioned likeness of diagrams allows us to speak about of short-range order in the considered substances. From the point of view both of physics and mathematics, the order-disorder phenomena and superlattice alloys demand special consideration, firstly proofed by Tammann experimentally which further were developed in [13-17] and others.



(a) (b)

Fig. 2. The hysteresis curves of: (a) – pure water (ρ = 1 g/cm^3) and (b) – sugar solution in a water (ρ = 1.47 g/cm^3) when the intensity of heating q = 2W/cm^2; the solid lines correspond to the heating process of liquids (time scale is below), and dashed lines – to the cooling of them (time scale – above). Time of cooling of pure water was equal to 136 min, in case of the sugar solution – 184 min.

Fig. 2 shows the results of detail measuring during heating from initial temperature T_0 = 20 ^{0}C to the intensive bubble boiling temperature T_3 = 100^{0}C and then reverse motion of both curves (H_2O and $C_{12}H_{22}O_{11}$ solution of maximal density, ρ= 1.47g·cm^{-3}). There are two points of crossing curves at temperature T_3 = 100^{0}C and lower at $T_2 \approx$ 62^{0}C. In case of clear wate**r,** H_2O, time of heating from 20^{0}C to 100^{0}C equals to 45 min; coordinates of the second kind discontinuity are following T_1(80^{0}C, 25 min); coordinates of point of boiling areT_3(100^{0}C, 45 min). In case of sugar, $C_{12}H_{22}O_{11}$, time of heating from 20^{0}C to 100^{0}C equals to 40 min; coordinates of the second kind discontinuity are following T_2 (40^{0}C, 5 min); coordinates of point of boiling are – T_3 (100^{0}C, 40 min).

Unlike the water solution of NaCl (with maximal density ρ = 1.2 g cm^{-3}, and temperature of boiling $T_3 \approx$ 108^{0}C), in case of sugar water solution ($C_{12}P_{22}O_{11}$), a rise of boiling temperature doesn't occur, and its boiling temperature was equal toT_3 = 100^{0}C. In case of sugar water solution of maximal density (ρ = 1.47 g·cm^{-3}), the hysteresis square between solid line an dashed one, directed in the opposite direction (of low cooling process of the solution from the point of boiling T_3 =100^{0}C) before their crossing with each other equals to, respectively: (a) for clear water (ρ = 1.0 g·cm^{-3}) the hysteresis square$\Delta D_h(H_2O)$≈ 3.5 sq. un. coordinates of this point are following: T_h ≈ 62^{0}C, and corresponding time of cooling, t_h= 28 min; for sugar solution of maximal density ρ = 1.47 g·cm^{-3}, $\Delta D_h(C_{12}P_{22}O_{11})$ ≈ 2 un. sq.; coordinates of this point are following: T_h= 68^{0}C, and corresponding time of cooling, t_h= 23 min; ratio between hysteresis squares of sugar and clear water equals to≈ 4:7. Time of cooling of pure water was equal to 136 min = 2 h 16 min, and in case of the sugar water solution was equal to 184 min = 3 h 04 min. (Fig. 2).

Fig. 3 represents results of the experimental investigation of temperature change in time of saturation solution of any organic or nonorganic matters in a beaker of water (as usually, in our early experiments [7-12]). Analysis of the (dT/dt, t)-curveoftheliquidtemperaturegrowthrateshowsthepointsofdiscontinuities (tangent dashed lines: 1, 2, 3, 4, 5) and the point of inflection between points 3 and 4 atT = 40 ^{0}C (on the T(t)-curve showed to the right of arrow). As this was to be expected, there the curve of (d^2 T/dt^2, t) has extremum at the point between the micro- and macro-scale bubble boiling regimes of liquids [11, 12]. The availability of the point of inflection (T_w) was shown by Tammann [2] for dependence of the second order differential of the glasses physical properties on the temperature curves. The point T_w is in the temperature interval of softening of the glass (T_f , T_g),where T_f is the temperature of the glass transformation into liquid under slow heating; T_g is the temperature at which the body is become fragile under cooling, but not at once [2].

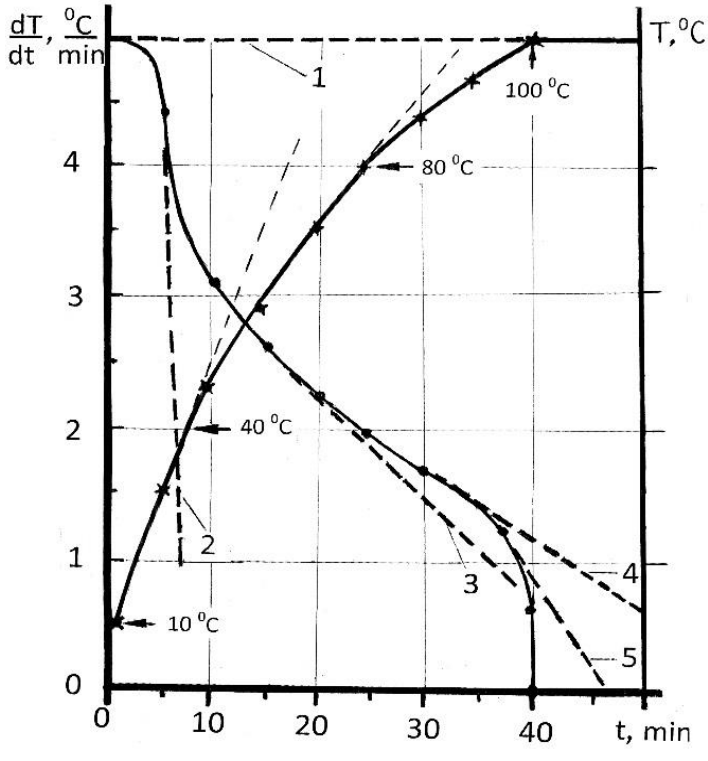


Fig.3. (dT/dt, t)-curve shows the rate of liquid temperature growth against the time, T (the curve joins points: ●); and (T, t)-curve shows the liquid temperature against the time, t (the curve joins points: **x**).

For making more precise of the moments of the liquids bubble-boiling micro- and macro-scale regimes appearances, respectively at T = 40 ^{0}C and T = 80 ^{0}C, we also constructed the curve (d^2T/dt^2, T) (Fig. 4.). Here we see as both points of contrary flexure at the values of temperature T = 40 ^{0}C and T = 80 ^{0}C (the curve (dT/dt, T)) are illustrated by means of two acute maximums (!) of the curve (d^2T/dt^2, T)). As this was to be expected, the availability of these maximums near 40 ^{0}C and T = 80 ^{0}C was not accident.

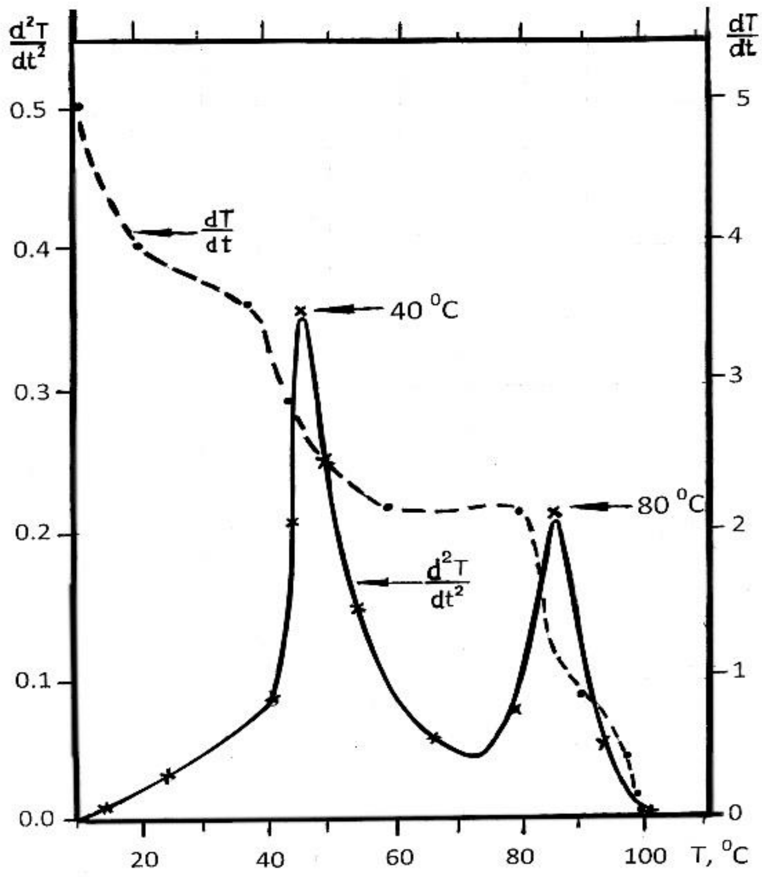


Fig. 4. (dT/dt, T)-curve shows the rate of the liquid temperature growth against the temperature, T, (the curve joins points: ●); and (d^2T/dt^2, T)-curve shows the liquid temperature growth acceleration against the temperature (the curve joins points: **x**).

As it is seen, the experimental curves of Fig. 3 and Fig. 4 are in a good accordance with each other and with Fig. 1a, b give additional new information about similarity of considered here heating and bubble-boiling process of liquids and peculiarities of glassy state-crystallization processes (Fig. 1c) [2, 3].

3. Analysis and discussion.

3.1. Analyze of Fig. 1 shows that at наthe points of phase-transformations crystal-liquid and vise-versa (Fig. 1a, b) the angle of refraction is larger than at the change of micro- and macro-bubble boiling at heating and cooling (Fig. 1c), respectively. Difference between (T, t)-crystal heating-cooling diagrams (Fig. 1a, b) and according curves of any matter saturated solution (Fig. 1c) takes place as crystal’s heat conduction is larger than the liquid’s one. Though the results of different processes are discussed here (process of glass formation on the one hand and the bubble boiling on the other hand), it would be interesting to compare the spherulites and the vapour bubbles concentration with micro- and macro-scale spectrums of water pulverization and with air bubbles formation in the liquid phase during freezing of the super-cooled water (or ice melting) in front of the moving front of the solid phase.

According results are represented below in Fig. 4. For making more precise of the moments of the liquids bubble-boiling micro- and macro-scale regimes appearances it was used (d^2T/dt^2, T)-function, which (and every even derivative of T with respect to t) has an acute maximum. For example, the curve (d^4T/dt^4, T) is narrower and lower than the curve of (d^2T/dt^2, T): near 40 ^{0}Capproximately ten times and near80 ^{0}C twenty times, respectively. Therefore, one may conclude that precise measuring of temperature T(t) is enough for exact definition of the bubble-boiling micro- and macro-scale regimes beginnings moments (without of high-speed filming technique).

As we see, the experimental curves of Fig. 3 and Fig. 4 are in a good accordance with each other and with Fig. 1a, b) [2, 3]. They give new additional information about similarity of considered here heating and bubble-boiling process of liquids and peculiarities of glassy state-crystallization processes (Fig. 1c). Obtained analogy between thermodynamic diagrams of the glassy state of matter and the bubble boiling of liquids is caused by the fluidity of the glass as liquid ("glass is liquid" (Tammann); undoubtedly, this is the best example of the phenomenon supporting well-known Frenkel's kinetic theory of liquids).More over one can assume that the idea of the kinetic theory was "prompted" to Frenkel by Tammann's glassy state, as probably form of Gibbs rule was "prompted" to him by Euler theorem about polyhedrons.

4. Conclusion

Modelling of fluids vertical convection in nature by means of our bubble-boiling method allowed us experimentally to investigate the thermodynamic parameters of solutions and their behavior during the whole process of heating. For more definition of the point of temperature discontinuity (T_{dc}) was introduced pseudo-entropy function ($\Sigma = Q/t^0C$), where temperature was measured in Celsius degrees. It is suggested to use pseudo-entropy parameter, Σ, in above mentioned cases. Then it was shown experimentally the likeness between the temperature-time (T, t)-diagrams of any matters water solutions and according crystal's glassy state ones. We try also to find accordance between well-known Euler geometry and Gibbs thermodynamic equations. As a transition of non-isotropic state into other one is impossible, as a transition of isotropic state into non-isotropic one is impossible. In view of this property of crystals, I think that it is possible to find among of many-component systems the corresponding sample. Analysis shows that such object is the four-component system, which will give us to use Tammann's thermodynamic tetrahedron for example. For making more precise of the moments of the liquids bubble-boiling micro- and macro-scale regimes appearances, respectively at T = 40 ^{0}C and T = $_{80}{}^0$C, we also constructed the graph (d^2T/dt^2, T) in Fig. 4. Here we see as the points of contrary flexure at the value of temperature T = 40 ^{0}C and T = 80 ^{0}C (the curve (dT/dt, T)) are illustrated by means of the presence of two acute maximums on the curve (d^2T/dt^2, T). As this was to be expected, the availability of these maximums near temperature 40 ^{0}C and 80 ^{0}C was not accident. It is interesting also to note that according maximums on the curve (d^4T/dt^4, T) are narrower and lower than maximums of the curve (d^2T/dt^2, T). We can conclude that an accurate measuring, for example, of the temperature, T(t), is quite enough for exact definition of the micro- and macro-scale bubble-boiling regimes beginning moments without using, for example, of high-speed filming technique. Analogy between thermodynamic diagrams both of the glassy state of minerals and the bubble boiling of liquids is caused by the fluidity of the glass as liquid, that is, "glass is liquid" (Tammann); this is the best example of the phenomenon supporting Frenkel's kinetic theory of liquids). Obtained results quite naturally are in the channel of Euler-Gibbs-Tammann-Frenkelclassic works.

APPENDIX

The points of the second kind discontinuities (dc)on the experimental (T, t)-curves

Here it is represented the original universal experimental curve (T_{dc}, ρ_{dc}) obtained by us for water solutions of NaCl, $C_{12}H_{22}O_{11}$and other matters (Fig. 5). The extremums of the curve (d^2T/dt^2, T) on Fig. 4 accordance to these points (T_{dc}).

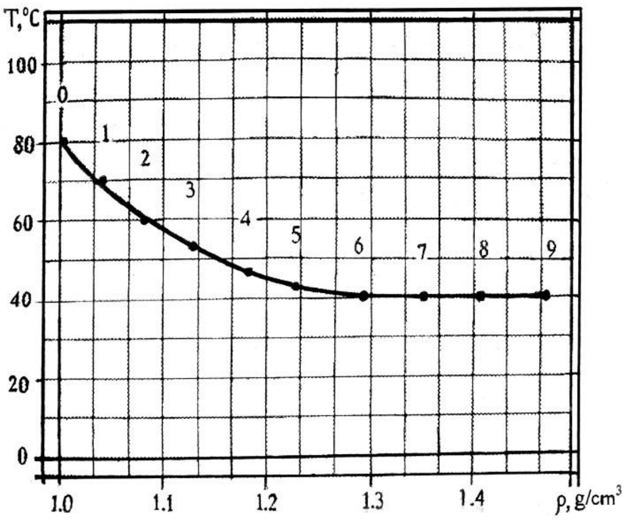


Fig. 5. The universal experimental curve of dependence of the temperature, T, of the second kind of discontinuity in time, to the concentration, ρ, of any matter water solution. (0) ρ = 1. 0 g/cm^3, (1) ρ = 1. 04 g/cm^3(2) ρ = 1.08 g/cm^3, (3) ρ= 1. 13 g/cm^3, (4)ρ = 1. 18 g/cm^3,(5) ρ = 1.23 g/cm^3,(6) ρ = 1.29 g/cm^3. (7) ρ = 1.35 g/cm^3, (8) ρ = 1.41 g/cm^3, (9) ρ = 1.47 g/cm^3.The intensity of heating of solution q = 47 J/s

Fig. 6 shows the original universal experimental curve (t_{dc}, ρ_{dc})-time-density dependence obtained by us both for the water solutions represented on Fig. 5 (●) and the natural waters of Georgia by means of the bubble-boiling points (**x**).

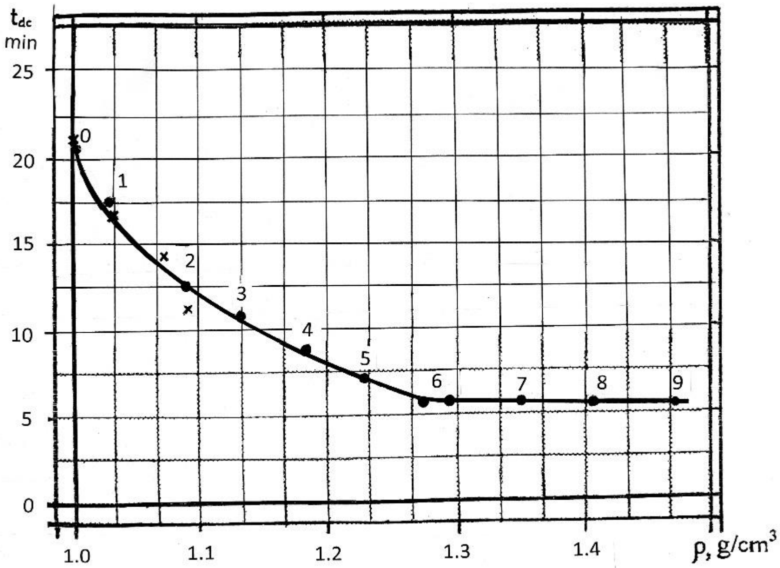


Fig. 6. The universal experimental curve of dependence of the temperature, T, of the second kind of discontinuity in time, to the concentration, ρ, of any matter water solution. The dark circle points (●) correspond to above mentioned artificial solutions with densities: (0) ρ = 1. 0 g/cm^3, (1) ρρ = 1. 04 g/cm^3, (2) ρ = 1.08 g/cm^3,(3) ρ = 1. 13 g/cm^3, (4) ρ = 1. 18 g/cm^3,(5) ρ = 1.23 g/cm^3, (6) ρ =1.27 and 1.29 g/cm^3, (7) ρ = 1.35 g/cm^3, (8) ρ = 1.41 g/cm^3, (9) ρ = 1.47 g/cm^3. The points (**x**)correspond to natural waters of Georgia with densities: (0) ρ = 1.0 g/cm^3(t. Tsalka), (1) ρ = 1. 02 g/cm^3(Black Sea, near t. Anaklia), (2) ρ = 1.07 g/cm^3(sulfuric waters of Lisi Lake),(3) ρ= 1. 08 g/cm^3 (sulfuric waters of the old Tbilisi bathe house). (4) The intensity of heating of solution q = 47 J/s.

The curves of Fig. 5 and Fig. 6 having similar behavior show high influence of the density of the solution on the beginning of its bubble-boiling regime during the process of heating. Therefore, between T_{dc} and t_{dc} exists linear low (result of joint action of the processes of temperature conductivity, thermals and vapour bubbles mixing convective motion). Therefore, for q = const. we can write that $(dT/ d\rho)_{dc}$ = const., $(d\rho/ dt)_{dc}$ = const., and $(dS/ dT)_{dc}$ = const.

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თერმოდინამიკისგეომეტრიული ფორმალიზმი:სითხისბუშტოვანი დუღილის და მინისებრი მდგომარეობის კონტექსტში

ა. გველესიანი

რეზიუმე

გეოსფეროში მიმდინარე ვერტიკალურიკონვექციის მოდელირებისათვის ინსტიტუტის თერმობაროკამერის ბაზაზე შემუშავებულ იქნა სითხის ბუშტოვანი დუღილის მეთოდი(ბდმ), რომელმაც შესაძლებლობა მოგვცა შეგვესწავლა თერმოდინამიკური სისტემების (ბუნებრივიწყლების, წყლის ხელოვნური ხსნარების) პარამეტრების ყოფაქცევა გათბობის პროცესში თერმიკული-მიკრო და -მაკრო-ბუშტოვანი რეჟიმების გავლით ინტენსიურ დუღილამდე მიყვანისას. აგებულ და გაანალიზებულ იქნა(T, t)-, (dT/dt, T)- და $(d^2 T/dt^2, T)$-ექსპერიმენტული მრუდები, სადაც T სინჯის ტემპერატურაა, t-დრო (შემოთავაზებულ ადრე ფსევდო-ენტროპიის Σ = Q/T, სადაც გათბობის საწყის, თერმიკების რეჟიმში ტემპერატურა იზომებოდაცელსიუსის გრადუსებში, ^0C).მიკრო-და-მაკრო-ბუშტოვანი რეჟიმების ზუსტი მომენტების დადგენისათვის აგებულ იქნა (dT/dt, T)- და $(d^2 T/dt^2, T)$-მრუდები. ანალიზმა გვიჩვენა (T, t)-მრუდებზე (შეჯერებულიხსნარის40 ^0C დასუფთა წყლის 80 ^0Cწერტილებში) ადგილი ჰქონდა მეორე გვარის წყვეტას. ეს გარემოება თავს იჩენს გადახრის წერტილების სახით (dT/dt, T)-მრუდებზე, ხოლო $(d^2 T/dt^2, T)$- მრუდებზე –ორიმკვეთრი ექსტრემუმის სახით (ექსტრემუმები აღინიშნა აგრეთვე $(d^4 T/dt^4, T)$-მრუდზე).ამით საბოლოოდ დამტკიცდა შემოთავაზებული ბუშტოვანი დუღილის მეთოდის სიზუსტე და უპირატესობა შრომატევად რთულ ჩქაროსნულ კინოგადაღების ტექნიკის გამოყენებასთან შედარებით. ნაჩვენებია აგრეთვე წყლის ხსნარებისათვის აქ მიღებული (T, t)-მრუდებისმსგავსება ტამმანნის ნივთიერების მინისებრი მდგომარეობის დიაგრამებთან. ოილერისმრავალწახნაგების თეორემის და ჯიბზსის თერმოდინამიკური წესის შორის მსგავსების გამო (რაც ფორმით და შინაარსით ინტეგრირებულია ბუნებრივ თუ ხელოვნურ კრისტალში)გამოთქმულია მოსაზრება, რომმრავალკომპონენტიანი სისტემისათვის ჯიბზს-ტამმანნის მეთოდის მეშვეობითშესაძლებელიათერმოდინამიკური დიაგრამების გამოსახვა მრავალწახნაგების (ტეტრაედრის, კუბის, ოქტაედრის, ...)სახით. აღსანიშნავია, რომ ამ გზით თვით ტამმანნმა ოთხკომპონენტიანი სისტემისათვის მიიღოტეტრაედრი.და ბოლოს, უნდა ითქვას, რომკრისტალებისმინისებრი მდგომარეობის და სითხის ბუშტოფანი დუღილის დიაგრამებს შორის ზემოთ აღნიშნული მსგავსება არაა შემთხვევითი და აიხსნება ორივე სისტემისძირითადი მახასიათებელითვისებით – დინებადობით(“მინა სითხეა“ (ტამმანნი).მაშასადამე, სითხის ბუშტოვანი დუღილის მეთოდის დიაგრამები ტამმანნის დიაგრამებთან ერთობლიობაში ბრწყინვალედეთანხმება ფრენკელის სითხის კინეტიკური თეორიის ძირითადკრიტერიუმს“მყარი სხეულის და სითხის სტრუქტურული მსგავსების” შესახებ.მეტიც, შეგვიძლია ვივარაუდოთ, რომ ფრენკელსსითხის კინეტიკური თეორიის იდეა“უკარნახა“ ტამმანნის შრომამ კრისტალის მინისებრი მდგომარეობის შესახებ, როგორც შესაძლოა ოილერის ფორმულამ მრავალწახნაგის შესახებ უნებლიედ ერთგვარი “ნატურის” როლი შეასრულა ჯიბზსის ფორმულისათვის ქიმიურად-ერთგვაროვანი ნივთიერების ფაზების წონასწორობის შესახებ.

Геометрический формализм термодинамики: в контексте пузырькового кипения жидкости и стеклообразного состояния вещества

А.И. Гвелесиани

Резюме

Моделирование вертикальной конвекции в естественных условиях оригинальным методом пузырькового кипения (ППМ) жидкости, разработанным автором, позволило экспериментально исследовать поведение термодинамической системы (образцов природных вод и искусственных водных растворов) в течение процесса их нагрева до интенсивного крупнопузырькового кипения. Для точного установления моментов наступления микро-имакро-масштабного режимов пузырькового кипения жидкости были построены и проанализированы экспериментальные кривые зависимостей: (T, t) – температура-время, (dT/dt, T) – скорость нарастаниятемпературы- температура, (d^2T/dt^2, T) - ускорение нарастания температуры-температура. Построение двух последних кривых было обусловлено наличием разрывов непрерывности второго рода в (T, t)- кривых (без привлечения энтропии (S) и введённой нами “псевдоэнтропии” (Σ), где температура бралась в ^{0}C). Для точного установления моментов наступления микро- имакро-масштабного режимов пузырькового кипения жидкости были построены кривые зависимости скорости (dT/dt, T) и ускорения (d^2T/dt^2, T) нарастания температуры от температуры, T. В результате при 40 ^{0}C и 80 ^{0}C точки перегиба кривой (dT/dt, T) проявились, как и следовало ожидать, в виде ярко выраженных максимумов на кривой (d^2T/dt^2, T). Максимумы ж екривых (d^4T/dt^4, T) выражены значительно слабее). Таким образом, для точного установления моментов начала микро-имакро-масштабного режимов пузырькового кипения жидкости вполне достаточно внимательно фиксировать во времени рост температуры исследуемой жидкости, не прибегая к помощи трудоёмкой скоростной киносъёмки. Показано подобие между построенными диаграммами (T, t) для жидких растворов и соответствующими диаграммами стеклообразного состояния вещества Таммана. Делается попытка установить связь между геометрической формулой Эйлера и термодинамической формулой Гиббса. Тамманн пришёл к тетраэдру, рассматривая четырёхкомпонентную систему (n = 4). По-видимому, для многокомпонентых систем (n = 4, 5 , ...) методом, условно называя его методом Эйлера-Гиббса-Таммана можно будет придти к кубу, октаэдру и пр. многогранникам, соответственно (тема следующей работы). Замеченная аналогия между термодинамическими диаграммами стеклообразного состояния кристаллов и пузырькового кипения жидкостей обусловлена тем, что стекло также текуче, как и жидкость, т.е. “стекло есть жидкость” (Тамманн) (пример, ярко подтверждающий кинетическую теорию жидкости Френкеля). Можно предполагать, что идея кинетической теории жидкости была “подсказана” Френкелю таммановским стеклообразным состоянием кристалла, как возможно эйлеровская формула о многогранниках послужила своего рода “натурой” для термодинамической формулы Гиббса о равновесном состоянии фаз химически-однородного вещества.

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Application of MODIS Data for Vegetation Cover Analysis in Georgia

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ABSTRACT

The MODIS Surface reflectance Daily L2G Global 250m, 500 and 1km data were used for analysis of vegetation cover of Georgia. NDVI and EVI daily values were calculated on the basis for 2008-2016 period. Mean decadal and monthly maps of NDVI and EVI were compiled with an object of future analysis of vegetation change dynamics.

Keywords: MODIS Surface reflectance, vegetation cover

Introduction

Vegetation indices are widely applied to monitor terrestrial landscapes via satellite sensors. These parameters proved to be highly successful in assessing of vegetation condition, foliage, cover, processes like primary productivity, evapotranspiration. [1-3]. Vegetation indices may be easily cross-calibrated, across different sensor systems, providing continuity of long-term monitoring of climate related land processes. The global records of Normalized Differential Vegetation Index NDVI, derifed from NOAA Advanced Very High Resolution Radiometer (AVHRR) data cover period since 1981. The Moderate Resolution Imaging Spectrometer (MODIS) on the Terra satellite provides nearly daily coverage of Earth surface since 2001 with 250 m pixel resolution and are cross-calibrated with AVHRR data. This data made great contribution in global climate, ecosystem, and agricultural studies [3].

Calculation of vegetation indices

The most used vegetation index, NDVI, is calculated as:

$$NDVI = (NIR – Red)/ (NIR – Red)$$

where NIR are Red are reflectance values of Red and Near Infrared light detected at sensors. As a ratio, NDVI has the advantage to minimize band-correlated noise, influence attributed to cloud shadows, sun and view angles, topography, atmospheric attenuation. Rationing also reduces, to a certain extent, instrument and calibration related errors. Main disadvantage is related with asymptotic behavior, which lead to insensitivities to vegetation variations in certain conditions. The Enhanced Vegetation Index (EVI) is determined as:

$$EVI = G (NIR – Red)/ (NIR+C_1Red – C_2Blue + L)$$

where NIR, Red and Blue are atmpsheric corrected surface reflections, L is the canopy background adjustment for nonlinear differential NIR and Red radiant transfer through canopy, C_1 and C_2 are coefficients of aerosol resistance term, G is a gain, scalling factor. For Modis EVI algorithm adopted values of coefficients are $L = 1$, $C_1 = 6$, $C_2 = 7.5$ and $G = 2.5$ [4]

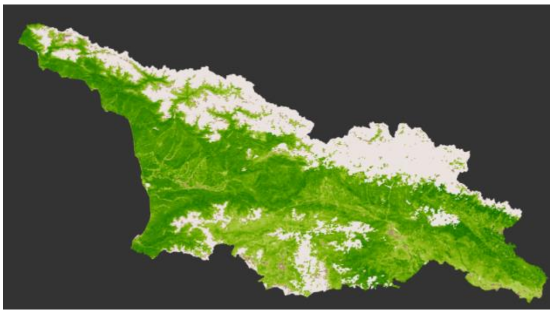
EVI gives errors over the bright objects, clouds, snow and ice due to saturation of blue band. To address this issue, standard EVI was replaced with modified 2-band EVI, calculated as:

$$EVI = 2.5 (NIR – Red)/ (NIR+2.4 Red + L);$$

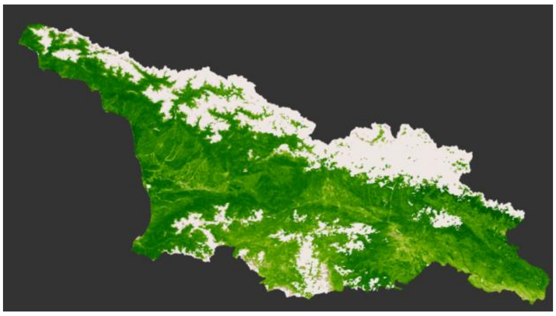
In the present work The MODIS Surface reflectance Daily L2G Global 250m, 500 (MOD09GQ) and 1km (MOD09GA) data were applied for analysis of vegetation cover of Georgia. MOD09GQ product provides MODIS band 1,2 daily surface reflectance at 250 m resolution. MOD09GQ product ought to be used in conjunction with MOD09GA, where important quality information is stored. MOD09GA provides MODIS sensor band 1-7 daily surface reflectance at 500 m resolution and 1 km observation and geolocation statistics [5]. MOD09GA also contains cloud information, necessary for NDVI and EVI cloud masking procedures.

Fig. 1 presents samples of EVI and NDVI indices of 3 decades and monthly NDVI, EVI for May 2016. Calculation of decadal EVI and NDVI gives possibility to compose monthly mean values of vegetation indices both for any particular year and for whole 2008-2016 period. Fig. 2 and 3 present EVI and NDVI mean values for 2008-2016 period. Fig. 4 shows samples of EVI NDVI color legends.

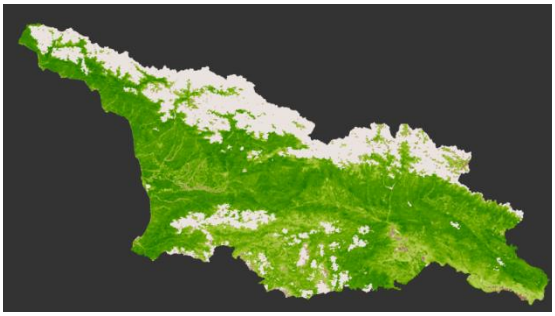
In the nearest future vegetation analysis of 2000-2007 is planned. It gives us possibility to cover whole MODIS dataset from 2000 till present days. As it was mentioned earlier, there is about 35 year NDVI global dataset from NOAA-AVHRR and in conjugation with MODIS data it provides a long term data record for use in operational monitoring studies, vegetation cover changes analysis and etc.



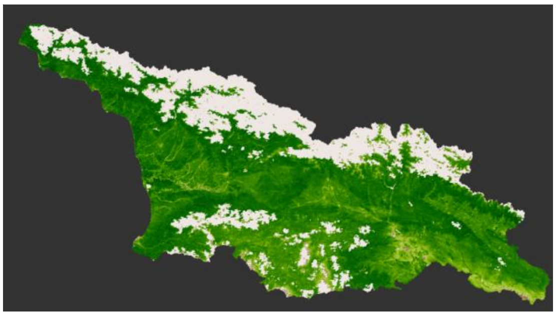
EVI, I decadem of May, 2016



NDVI, I decade of May, 2016

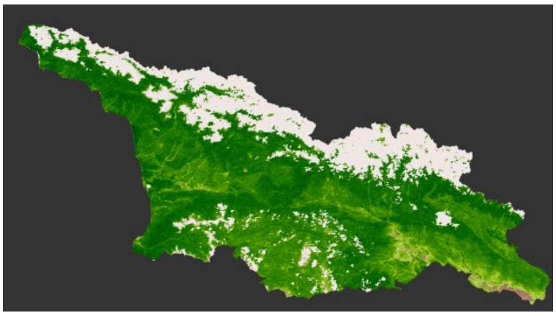


EVI, I decade of May, 2016

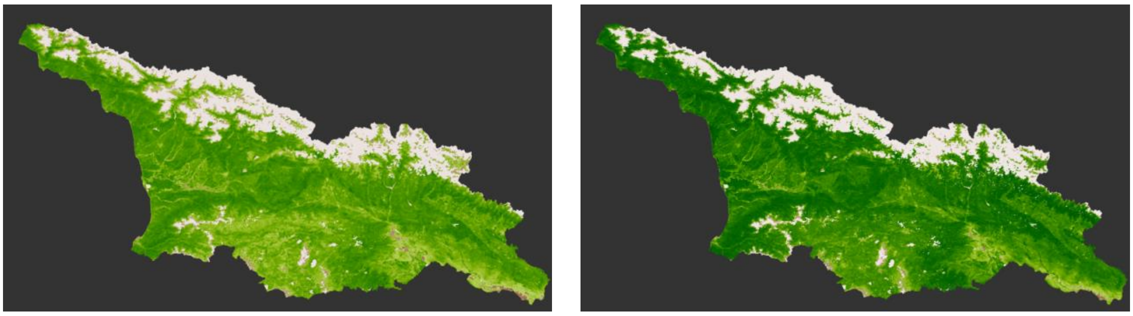


NDVI, II decade of May, 2016

EVI, II decade of May, 2016

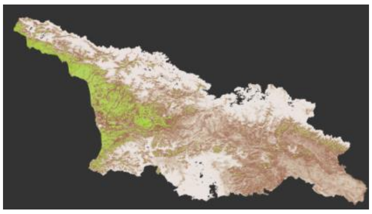
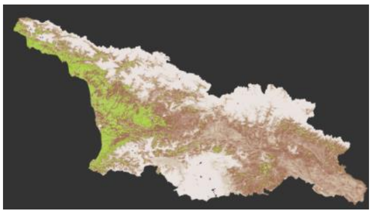
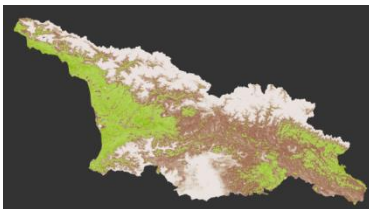


NDVI, III decade of May, 2016

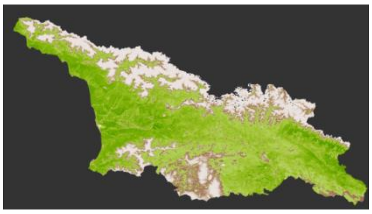
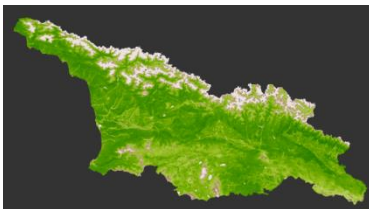


EVI, III decade of May, 2016 NDVI, May, 2016

Fig. 1. EVI and NDVI maps for May, 2016

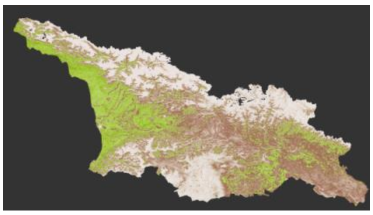
January February March

April May June

July August September

October November December

Fig.2. Monthly mean EVI for 2008-2016 period.

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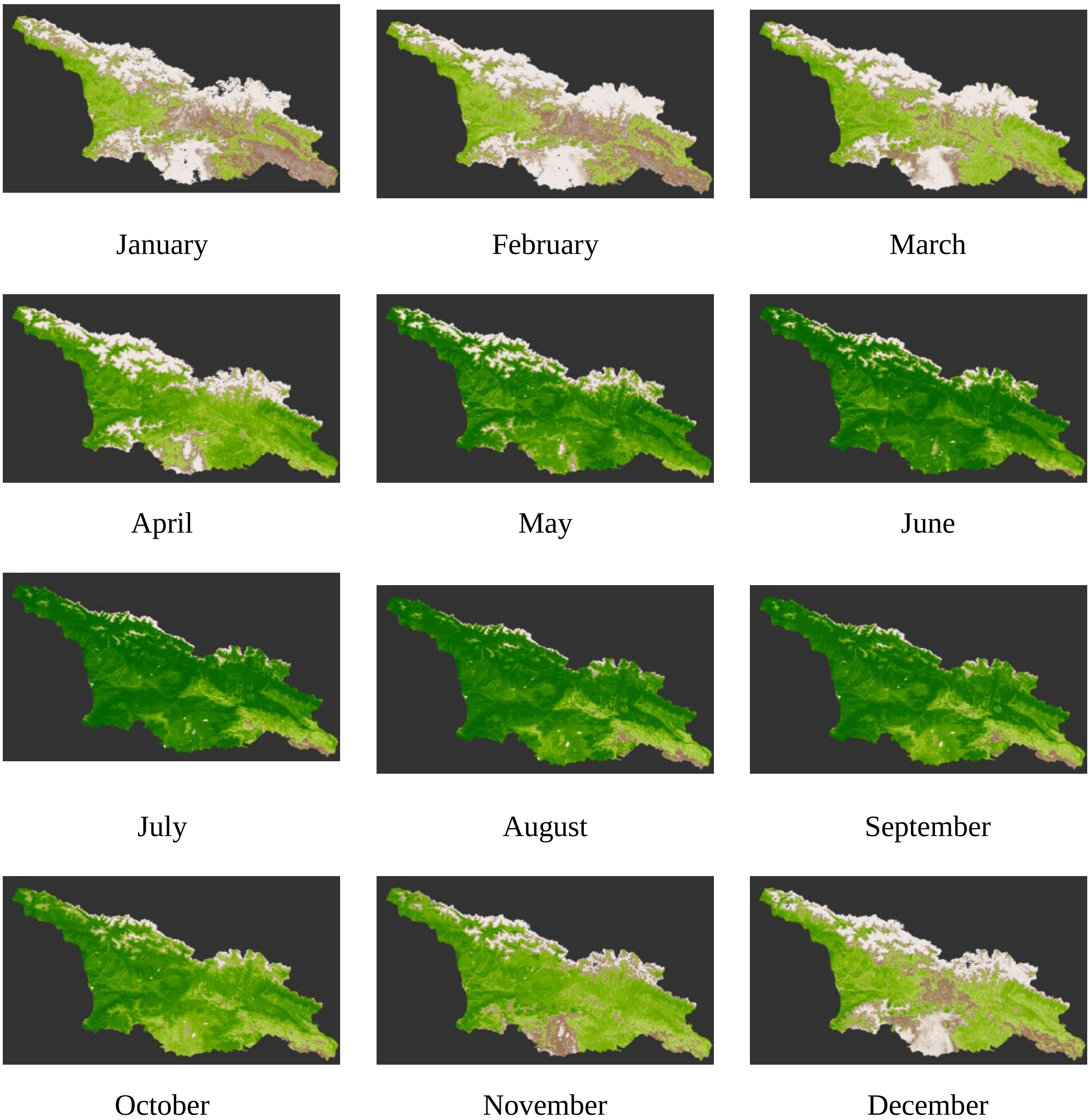
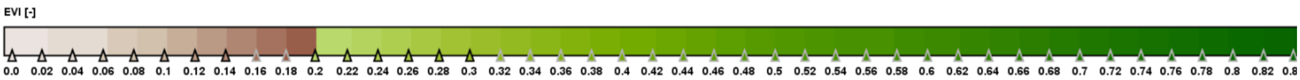
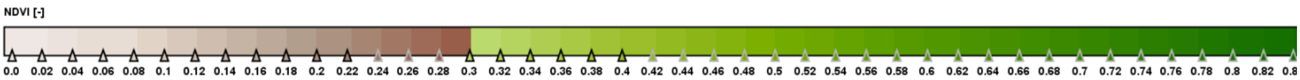


Fig. 3. Monthly mean EVI for 2008-2016 period.



a. EVI Color Legend



b. NDVI Color Legend

Fig 4. Color legends of EVI and NDVI

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საქართველოს მცენარეული საფარის შესწავლა MODIS სენსორის მონაცემების საშუალებით

გ. თვაური, ტ. ჯინჯოლია, კ. ქორიძე

რეზიუმე

საქართველოს მცენარეული საფარის ანალიზის მიზნით გამოყენებული იქნა MODIS სენსორის ზედაპირის არეკვლადობის 250 მ, 500 მ და 1000 სივრცითი გარჩევადობის მონაცემები. მათ საფუძველზე გამოთვლილია მცენარეული საფარის მდგომარეობის შესაფასებელი NDVI და EVI ინდექსები 2008-2016 წლების თითოეული დღისთვის, შედგენილია NDVI და EVI ინდექსების სივრცითი განაწილების დეკადური და საშუალო თვიური რუკები, რაც მომავალში მცენარეული საფარის ცვალებადობის დინამიკის შესწავლის შესაძლებლობას იძლევა.

Изучение растительного покрова Грузии с помощю данных сенсора MODIS

Г.А. Тваури, Т.Д. Джинджолия, К.Дж. Коридзе

Резюме

Для анализа растительного покрова Грузии были использованы данные отражаемой способности земной поверхности сенсора MODIS с пространственным разрешением 250 м, 500 м и 1000 м. Были определены ежедневные значения вегетационных индексов NDVI и EVI для периода 2008-2016 гг. На их основе были составлены среднедекадные и среднемесячные карты распределения NDVI и EVI индексов для территории Грузии, что в будущем даст возможность изучения динамики изменения растительного покрова.

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Numerical Simulation of Dust Distribution Over the Complex Terrain Region of Georgia

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ABSTRACT

Kinetics of dust propagation in Kakheti region is numerically studied. It is determined that in 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. Maximum values of dust concentration are obtained in 100 m surface air layer. Spatial dust distribution region increases and concentration decreases along with height increase. Urban influence zone is determined.

Key words: Atmospheric air pollution, urban dust propagation, numerical simulation.

Introduction

Studies of environmental pollution have important role for solution of ecological problems and implementation of practical environmental protection measures. One of the basic directions of studies is creation of mathematical models of substance propagation in continuous medium and their numerical integration. Semiempirical theory is noteworhty from this viewpoint [1,2]. On the basis of this theory were processed guideline documents [3], which are widely used in post-Soviet space when assessing the level of air local pollution by enterprises.

In the works [4-8] non-stationary three-dimensional models of transfer-diffusion of substances in the atmosphere and methods of their numerical integration are elaborated. Models describe the processes of propagation, dynamics and kinetics of small admixtures and solid aerosols in the atmosphere.

Elaborated numerical methods became widely used for solution of many practical ecological problems. Among them should be noted the study of atmospheric pollution by aerosols' propagation as a result of forest fires [9, 10] by harmful agents and solid aerosols [11-13] released from enterprises located in regions with complex terrain [14-17], urban territories [18] with the use of numerical simulation and method of experimental observations.

There are ecological problems in separate regions of Georgia, too. From this viewpoint Kakheti should be noted. Kakheti is near-border region with complex terrain and 11,3 sq. km area located in the eastern part of Georgia. It is the main agricultural region of Georgia and is known for production of many export products, including high-quality brand wines. Kakheti region borders basic industrial centers of Georgia – Tbilisi, Rustavi, Marneuli etc. Propagation of agents discharged in the atmospheric air in settlements and along highways causes pollution of neighbour territories and has an impact on population health and quality of manufactured production.

There are no routine observations over atmospheric pollution at the territory Kakheti. No numerical or online models of research purposes that would enable us to determine expected concentrations of dust and other air polluting agents in the atmosphere are elaborated for Kakheti territory.

In the presented work numerical model of dust propagation at Kakheti territory is elaborated using regional model of atmospheric process studies in Caucasis region [19], methods of meteorological field parametrization in surface layer of atmosphere [20] and equations of transfer-diffusion of small admixtures in continuous medium. Peculiarities of dust propagation at Kakheti territory for four basic meteorological situations typical for this region are studied.

Formulation of the Problem

The area 236×180 km^2 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 are placed Shirvan steppes. Orography height varies from 70 m to 3 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 - δ ; $H(t, x, y)$- 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

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

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 surface layer of atmosphere and in free atmosphere are defined by means of regional models [19, 20].

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 [21] 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, concentration values are calculated according to given methodology [22]. 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.

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 [4]. The rectangular numerical grid with $118 \times 90 \times 31$ points and the horizontal step equal to 2 km and the vertical step equal to 1/31 were used. In surface layer 17 vertical grid points with grid steps from 2 to 15 m are taken. Time step is 10 sec. The numerical integration is continued more than 3 days.

Results of modeling

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

As is seen from the Figure 1, dust concentrations at a height of 2 and 10 m are 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 point of pollution the value of concentration is roughly 10 times, while at 20-30 km distance – 10^2-10^3 times less than concentrations at the territories of 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. Influence area is different for different directions and is depended on orography. Horizontal dust transfer mainly occurs along the gorges, both in case of Tbilisi, Rustavi and other cities.

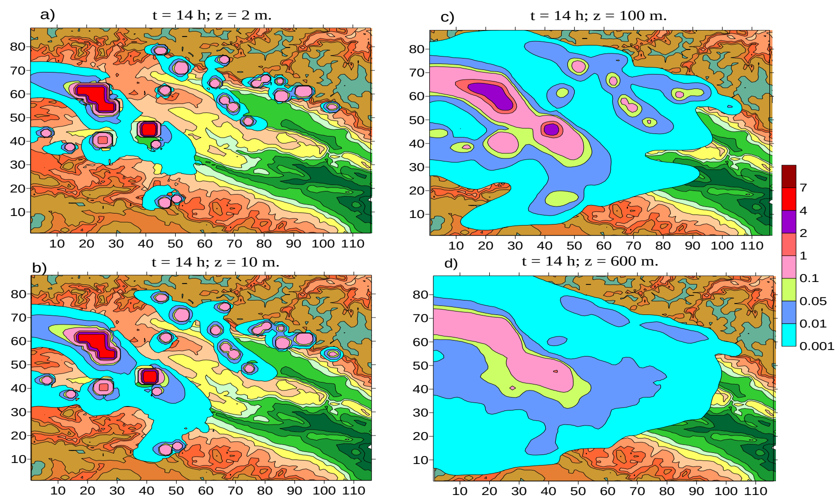

Fig. 1. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background eastern winds, when t = 14 hours.

Processes of vertical, horizontal turbulent diffusions, advective and convective transfers become intensive in the area at a height of 10-600 m from earth surface. As a result the dust propagates at large territory, mostly in western direction.

Along with height increase takes place decrease in maximum concentrations (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 wind the kinematics of propagation of received dust pollution is qualitatively similar to the described above. Basic difference is the form of dust pollution cloud (Fig. 2). 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. The dust cloud takes a single ellipse-like form for z > 100 m.

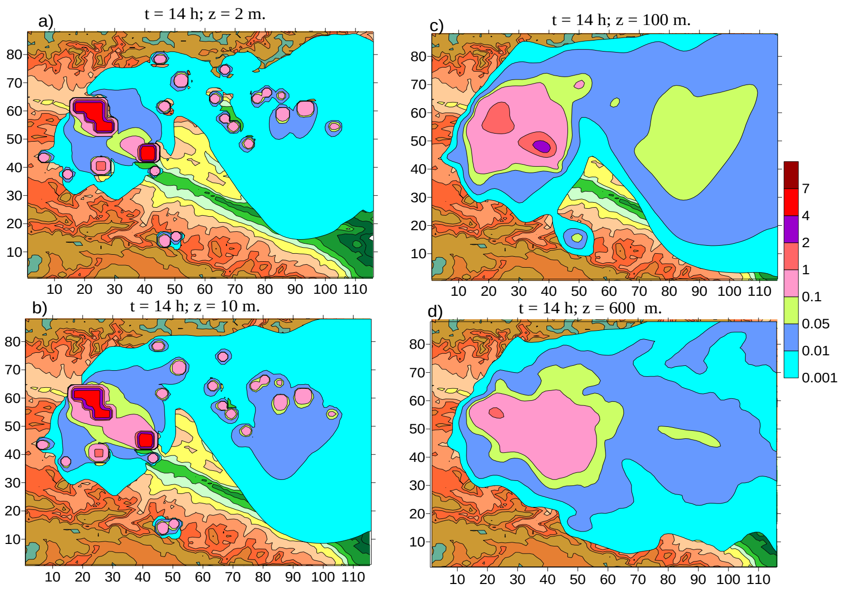

Fig. 2. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background western winds, when t = 14 hours.

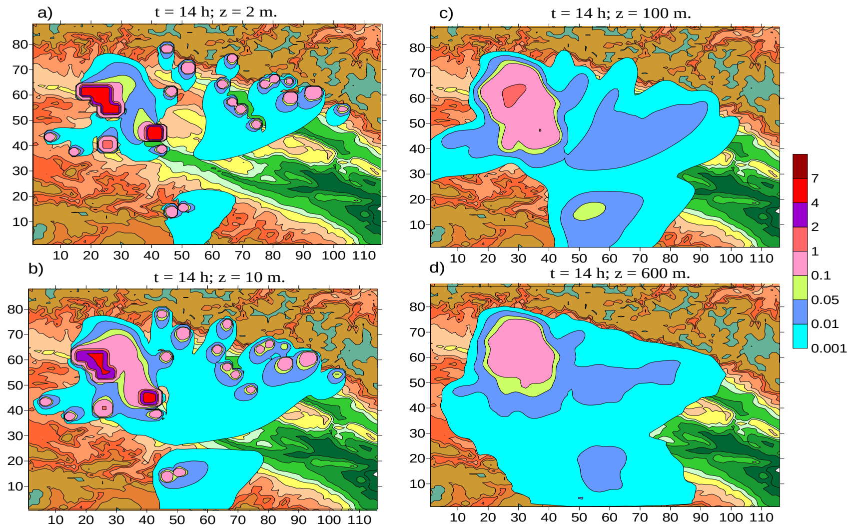

Fig. 3. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background northern winds, when t = 14 hours.

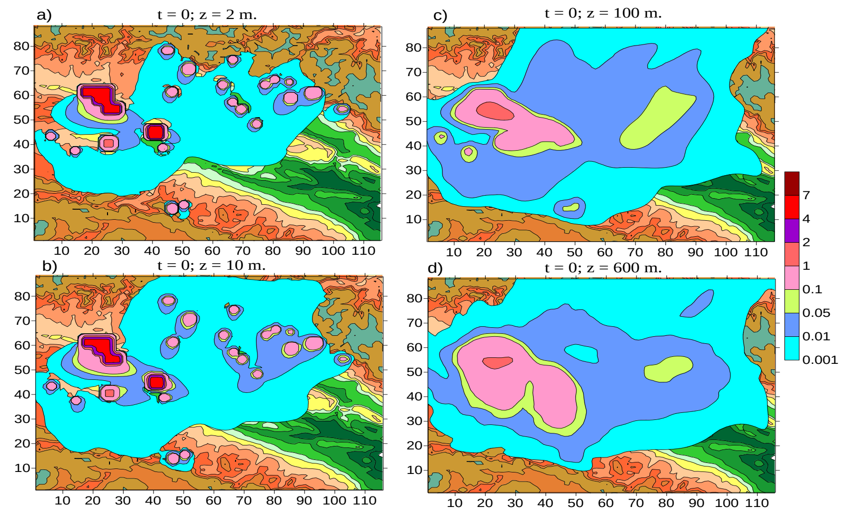

Fig. 4. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background southern winds, when t = 14 hours.

In case of background northern winds (Fig. 3) 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 third is the zone of Shida Kakheti cities (Fig. 3, a, b). In first and second zones advective transfer of dust occurs in north-eastern direction, while in the third zone – in 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 concentration value is within 0,001- 0,05MAC. 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 region.

During background southern winds, local circulation system of air current originated by orography creates complicated picture of dust propagation (Fig. 4). 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 in north-eastern direction. Increased air turbulization related to rapid change of velocity causes dust propagation throughout 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 increase in height from 0,01 to 0,001 MAC, when z = 1 and z = 3 km, respectively.

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 territory of Kakheti

Discussion

Dust propagation at the territory of Kakheti in case of four basic meteorological situation and non-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 are obtained dust concentration pictures, which qualitatively coincide with 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.

The complex terrain, displacement of the sources of urban pollution and the wind fields, formed by interaction of background wind and orography, promotes dust existence in the central part of the region between two main ridges – the Main Caucasus and Small Caucasus Mountains.

By means of obtained results one can determine the following values of background concentration: 0,05MAC can be taken as 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 is expedient to further develop a model through use of different parametrization methods of surface sub-layer of atmosphere.

There are no ongoing natural observations over air pollution at the territory of Kakheti, and therefore is impossible to determine quantitative accuracy of obtained results. Aiming the determination of modeling accuracy it is planned to carry out experimental measurements and compare them with modeling results.

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საქართველოს რთული რელიეფის ტერიტორიაზე მტვრის გავრცელების რიცხვითი მოდელირება

ა. სურმავა, ლ. გვერდწითელი, ნ. გიგაური, ლ. ინწკირველი

რეზიუმე

რიცხობრივად შესწავლილია მტვრის გავრცელების კინემატიკა კახეთის რეგიონში. მიღებულია, რომ ატმოსფეროს მიწისპირა 100 მ ფენაში მტვრის გავრცელების პროცესში უპირატესი მნიშვნელობა გააჩნია ტურბულენტური დიფუზიის პროცესს. 100 მ-დან 1 კმ-დე დიფუზიური და ადვექციური გადატანის პროცესები ტოლფასია, ხოლო 1კმ-ის ზევით უპირატესობა ენიჭება მტვრის ადვექციურ გადატანას. 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.

Численное исследование распространения пыли над сложным рельефом Грузии

А. А. Сурмава, Л.В. Гвердцители, Н. Г. Гигаури, Л. Н. Инцкирвели

Резюме

Численно исследована кинетика распространения пыли в Кахетском регионе. Установлено, что основным механизмом распространения пыли в приземном слое атмосферы толщиной 100 м является процесс турбулентной диффузии. В слое 100 м - 1км турбулентная диффузия и горизонтальная адвекция имеют одинаковые значения, а выше 1 км - преобладает процесс горизонтальной адвекции. Показано, что пыль, поступающая в атмосферу из городов, в основном концентрирована в приземном 100 м слое атмосферы. С удалением от поверхности земли увеличивается область распространения пыли и уменьшается её концентрация. Определены зоны влияния городов в загрязнении окружающей территорий.

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Comparative Analysis of the Distribution of Number of Days with Hail Per Annum on the Territory of Kakheti According to the Data of the Meteorological Stations and State Insurance Service of Georgia

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ABSTRACT

The results of the comparative analysis of distribution on the territory of Kakheti of the number days with the hail per year according to the data of Hydrometeorological Department (8 stations - Akhmeta, Gurjaani, Dedoplistskaro, Telavi, Lagodekhi, Sagarejo, Signagi, Kvareli; the registration of all days with the hail) and the State Insurance Service of Georgia (123 locations, the registration of the days with hail fall, which led to the damage of agricultural crops) are represented. Period of the study: 1982, 1984-1989 for State Insurance Service data and 49-94 year(including 2016) for data of Hydrometeorological Department of Georgia. In particular it is obtained that for the points Akhmeta, Gurjaani, Sagarejo, Signagi and Kvareli on the meteorological stations the larger number of days with the hail was recorded, than by the State Insurance Service in the same territories. For the points Dedoplistskaro, Telavi and Lagodekhi this difference is insignificant. The detailed analysis of distribution on the territory of Kakheti of the number of days with hail according to the data of both indicated organizations also is carried out.

Key Words: Hail climatology, statistical analysis.

Introduction

Georgia is small mountain country with 15 climatic zones, on which territory from time to time proceed geophysical catastrophes of different types (earthquakes, landslides, mudflows, avalanches, mountain collapses, strong wind, rain, snow, hail, fogs, thunder-storms, extreme air temperatures, droughts, floods, sea storms, etc.) [1-5]. With the this on the changeability of repetition and intensity of the majority of the types of dangerous hydrometeorological phenomena (Including hail processes) essential influence render the processes of urbanization [1,6,7], climate change [8-11], aerosol and gas pollution of the atmosphere [6,7,12-15].

Concerning hail damages, Georgia is one of the hail-dangerous countries of world [1,3,16-19]. Therefore, to the problem of hail in this country are dedicated numerous works, that covers the wide spectrum of studies, beginning from the hail climatology [20-30] and long-term variations of hail processes [31-38], ending with the methods and the results of action on the hail processes [39-42].

Material and methods

The data about the number of days with hail per year of the Hydrometeorological Department of Georgia (8 stations - Akhmeta, Gurjaani, Dedoplistskaro, Telavi, Lagodekhi, Sagarejo, Signagi, Kvareli; the registration of all days with the hail) and State Insurance Service of Georgia (123 locations, the registration of the days with hail fall, which led to the damage of agricultural crops) are used. Period of the study: 1982, 1984-1989 for State Insurance Service (below – SIS) data and 1982, 1984-1989, 49-94 year for data of Hydrometeorological Department of Georgia (below – HD).

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [43]. The following designations will be used below: Min – minimal values, Max - maximal values, Range - variational scope, St Dev - standard deviation, σ_m – standard error, R - coefficient of linear correlation, R^2 – coefficient of determination, α - the level of significance.

Results and discussion

Results in the Table 1 and Figures 1-11 are presented.

Table 1

The statistical characteristics of number of days with hail per year in Kakheti

	Kakheti	Akhmeta	Gurjaani	Dedoplistskaro	Telavi	Lagodekhi	Sagarejo	Signagi	Kvareli
	I. Municipality - 1982, 1984-1989, Data of State Insurance Service of Georgia								
Mean	0.64	0.55	0.83	0.52	1.07	0.34	0.46	0.43	0.57
Min	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Max	2.57	1.14	1.43	1.00	2.57	1.29	0.86	0.86	1.00
St Dev	0.45	0.34	0.39	0.25	0.65	0.30	0.20	0.20	0.26
σ_m	0.04	0.10	0.09	0.07	0.15	0.08	0.05	0.06	0.08
Count	123	12	21	14	21	15	16	13	11
	Kakheti	Akhmeta	Gurjaani	Dedoplistskaro	Telavi	Lagodekhi	Sagarejo	Signagi	Kvareli
	II. Data of Meteorological Station - 1982, 1984-1989								
Mean	1.30	1.57	2.29	0.71	1.29	0.29	1.29	1.43	1.57
Min	0.29	0	0	0	0	0	0	0	0
Max	2.29	4	5	2	4	1	3	3	3
St Dev	0.60	1.27	1.70	0.76	1.38	0.49	1.11	0.98	0.98
σ_m	0.23	0.52	0.70	0.31	0.56	0.20	0.45	0.40	0.40
Count	8	7	7	7	7	7	7	7	7
α, Differ. (II-I)	0.005	0.05	0.05	Not sign	Not sign	Not sign	0.05	0.015	0.015
	III. Data of Meteorological Station - All Years								
Mean	1.78	1.66	2.14	1.31	2.17	1.14	2.03	2.13	1.64
Min	1.14	0	0	0	0	0	0	0	0
Max	2.17	8	7	4	7	5	5	6	8
St Dev	0.40	1.37	1.61	0.96	1.49	1.28	1.32	1.44	1.36
σ_m	0.15	0.15	0.17	0.14	0.16	0.15	0.14	0.18	0.16
Count	8	83	86	49	83	77	94	64	76
α, Differ. (III-II)	0.05	Not sign	Not sign	0.05	0.07	0.005	0.07	0.07	Not sign

In the Table 1 the statistical characteristics of number of days with hail per year in Kakheti according to the data of Hydrometeorological Department of Georgia and State Insurance Service are presented. In the figures 1-4 distribution on the territory of Kakheti of the average number of days with hail per year are presented: for 123 locations (Fig. 1, Data of SIS), average for 8 municipalities (Fig. 2, Data of SIS), average for 8 meteorological stations of the municipal centers of Kakheti (Fig. 3 - 1982, 1984-1989; Fig 4 – all years, Data of HD).

As follows from Fig. 1 and Table 1 the number of days with hail per year in 123 locations of Kakheti according to the data of SIS changes from 0.14 to 2.57 with average value – 0.64. The maximum repeatability of the number of days with hail per year falls on the range 0.14 - 0.5 (47.2%), the minimum - on the range >2.0-2.6 (1.6%), (Fig. 2).

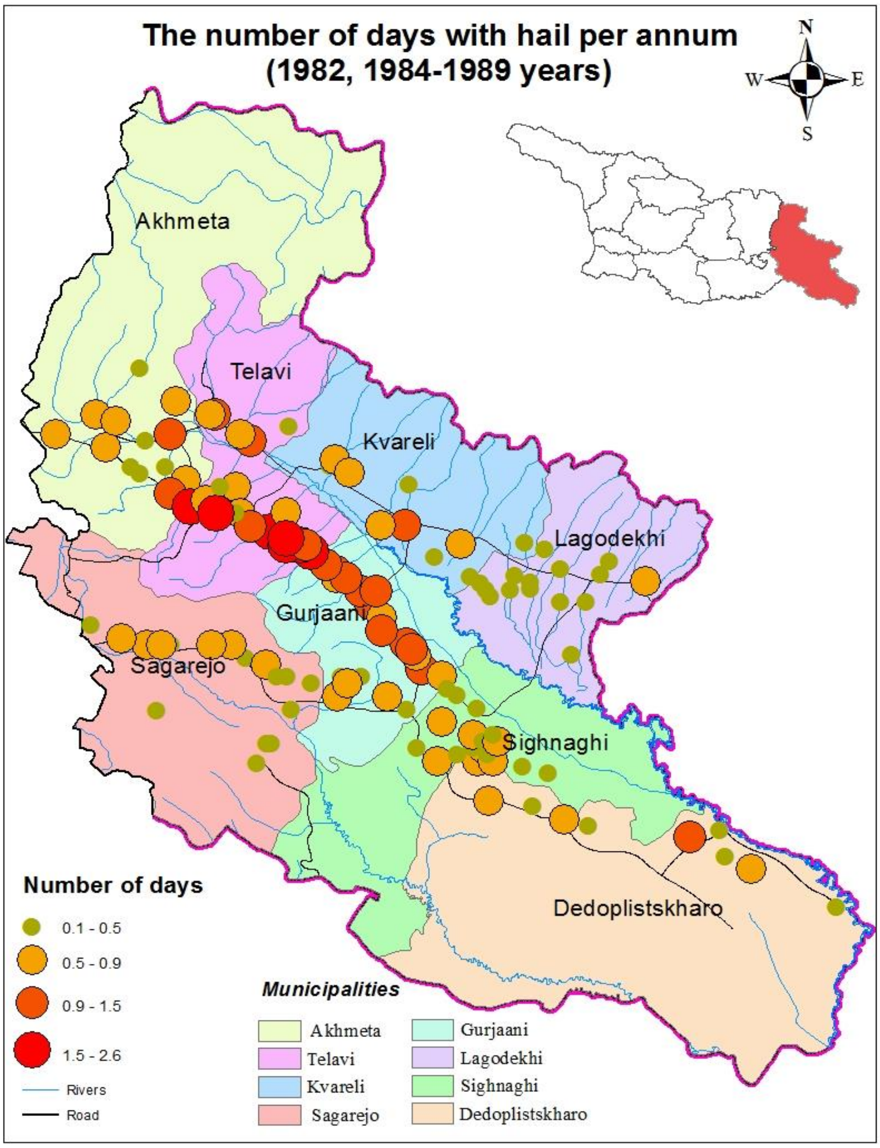

Fig. 1. The average number of days with hail per year in 123 locations of Kakheti in 1982, 1984-1989 (Data of SIS).

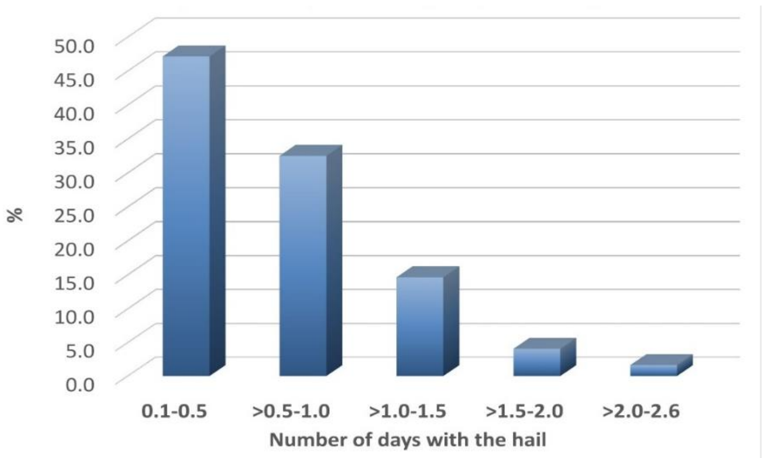

Fig. 2. Repetition of the average number of days with the hail in the separate locality of Kakheti (Data of SIS).

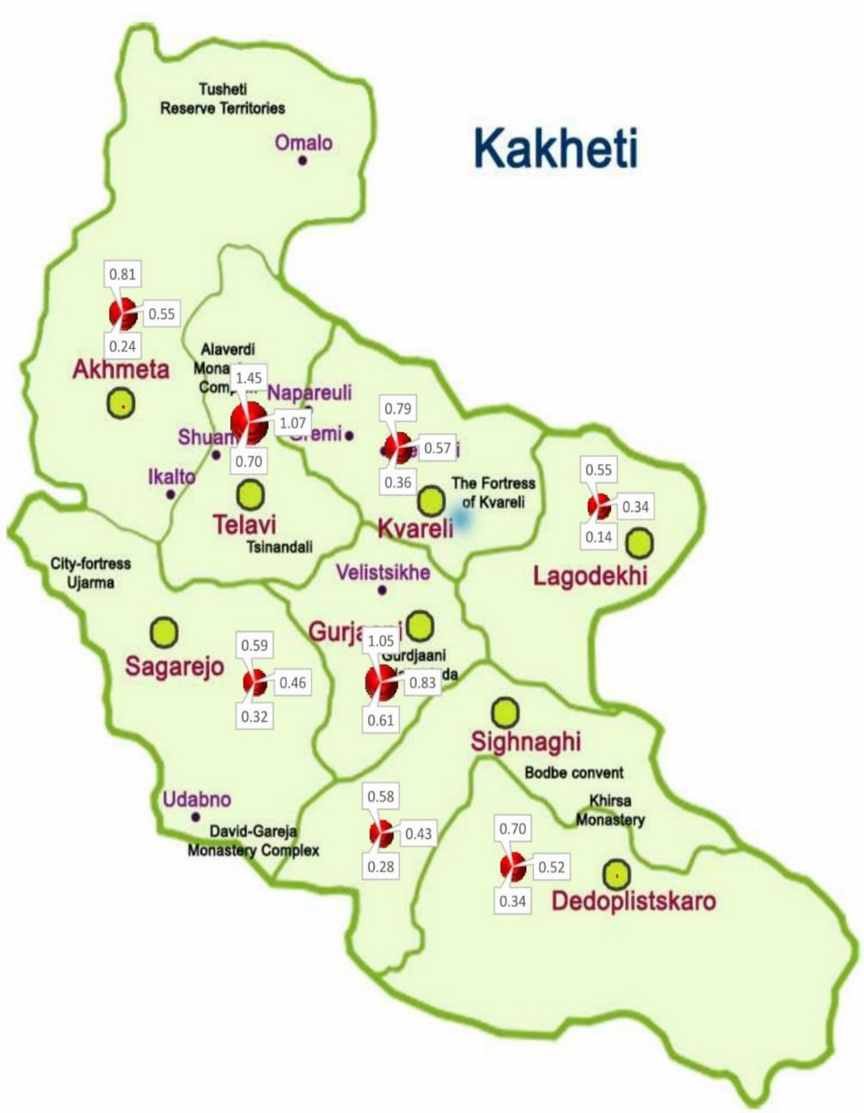

Fig. 2. The average number of days with hail per year (right) and 99% the upper and lower levels of confidence interval on the territories of 8 municipalities of Kakheti in 1982, 1984-1989 (Data of SIS).

According to the data of SIS (Table 1, Fig.2) the maximum average value of number of days with hail per year on the territory of Telavi municipality is observed - 0.70 ≤ 1.07 ≤ 1.45, the minimum - on the territory of Lagodekhi municipality - 0.14 ≤ 0.34 ≤0.55. For other municipalities the average value of number of days with hail per year are: Signagi - 0.28 ≤ 0.43 ≤0.58, Sagarejo - 0.32 ≤ 0.46≤ 0.59, Dedoplistskaro - 0.34 ≤ 0.52 ≤0.70, Akhmeta - 0.24 ≤0.55 ≤0.81, Kvareli - 0.36 ≤ 0.57≤ 0.79, Gurjaani - 0.61 ≤ 0.83 ≤1.05 (Table 1, Fig.2).

The number of days with hail per year at 8 meteorological stations of the municipal centers of Kakheti in 1982, 1984-1989 (Data of HD) changes from 0.29 to 2.29 with average value – 1.30. The maximum average value of number of days with hail per year on the Gurjaani meteorologycal station is observed - 0.49 ≤ 2.29 ≤4.08, the minimum - on the meteorologycal station of Lagodekhi - 0.00 ≤ 0.29 ≤0.80. For other meteorological stations the average value of number of days with hail per year are: Dedoplistskaro - 0.00 ≤ 0.71 ≤1.51, Telavi and Sagarejo - 0.00 ≤ 1.29≤ 2.74 and 0.11 ≤1.29 ≤2.46 respectively, Signagi - 0.40 ≤ 1.43≤ 2.46, Akhmeta and Kvareli - 0.23 ≤ 1.57 ≤ 2.91 and 0.54 ≤ 1.57 ≤ 2.60 respectively (Table 1, Fig.3).

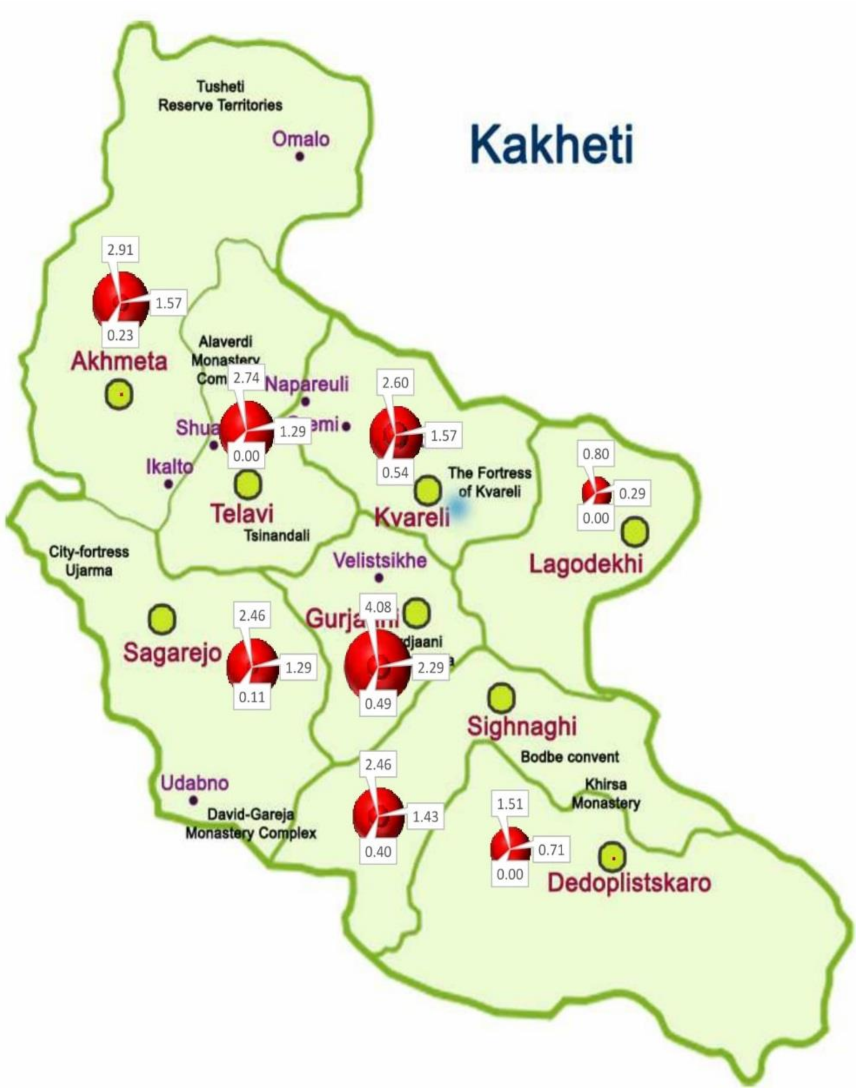

Fig. 3. The average number of days with hail per year (right) and 99% upper and lower levels of confidence interval at 8 meteorological stations of the municipal centers of Kakheti in 1982, 1984-1989 (Data of HD).

As follows from Table 1 and Fig.4 the number of days with hail per year at 8 meteorological stations of the municipal centers of Kakheti according to all observation data of HD changes from 1.14 to 2.17 with average value – 1.78. The maximum average value of number of days with hail per year on the meteorologycal station of Telavi is observed - $1.74 \le 2.17 \le 2.59$, the minimum - on the meteorologycal station of Lagodekhi - $0.76 \le 1.14 \le 1.52$. For other meteorological stations the average value of number of days with hail per year are: Dedoplistskaro - $0.95 \le 1.31 \le 1.66$, Kvareli -$1.24 \le 1.64 \le 2.05$, Akhmeta - $1.27 \le 1.66 \le 2.05$, Sagarejo - $1.68 \le 2.03 \le 2.38$, Signagi - $1.66 \le 2.13 \le 2.59$, Gurjaani - $1.69 \le 2.14 \le 2.59$.

The comparison of the average number of days with the hail per year according to the data of SIS and HD into 1982, 1984-1989 shows the following. As a whole, for the territory of Kakheti the number of days with the hail per year according to the data of HD is higher than according to the data of SIS. On the meteorological stations Akhmeta, Gurjaani, Sagarejo, Signagi and Kvareli the larger number of days with the hail, than by the State Insurance Service on the average on the territories of the same municipalities was recorded. At the meteorological stations Dedoplistskaro, Telavi and Lagodekhi and the territories of similar municipalities on the average the identical number bottom with the hail was recorded (Table 1).

The comparison of the average number of days with the hail per year according to the data of SIS into 1982, 1984-1989 and HD on all years of observations shows that on all meteorological stations the larger number of days with the hail, than on the average on the territories of the corresponding municipalities was recorded (Table 1).

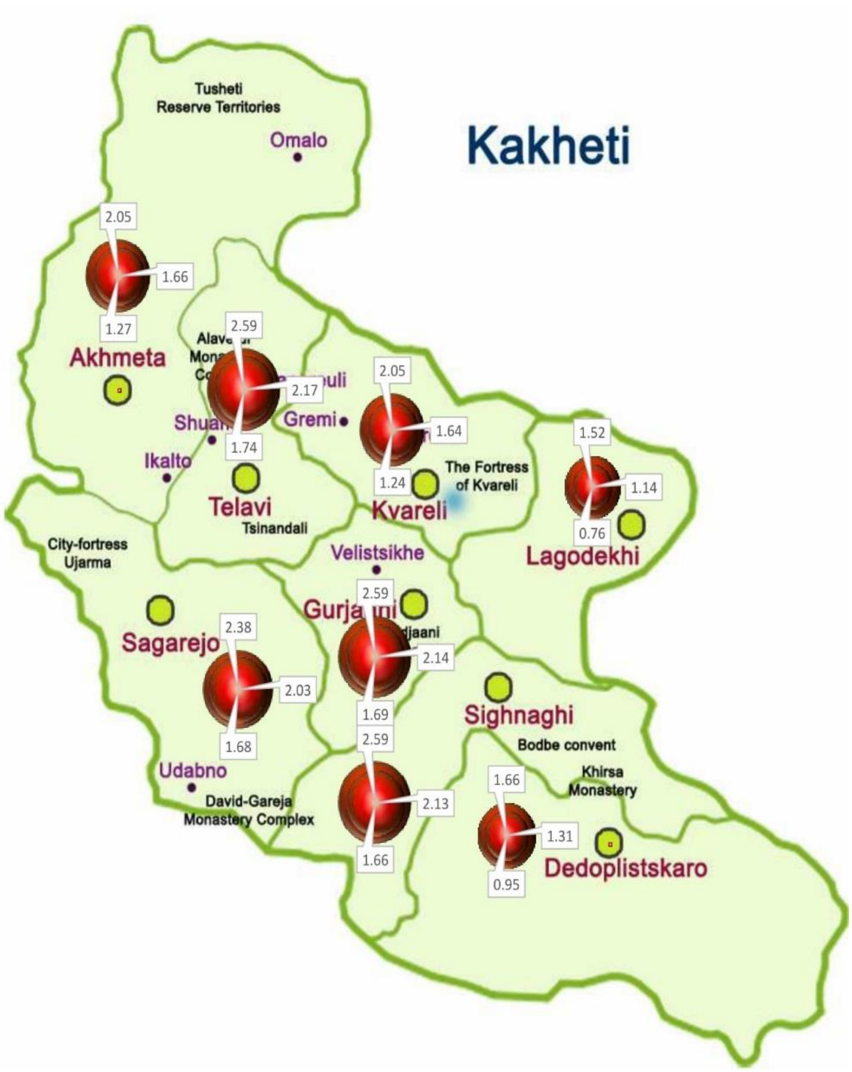

Fig. 4. The average number of days with hail per year (right) and 99% upper and lower levels of confidence interval at 8 meteorological stations of the municipal centers of Kakheti for all years of observation (Data of HD).

The comparison of the average number of days with the hail per year according to the data of HD into 1982, 1984-1989 and for all years of observations shows that on the average for the territory of Kakheti and meteorological stations Dedoplistskaro, Telavi, Lagodekhi, Sagarejo and Signagi the number of days with the hail, averaged in all years, are higher than averaged in 7 years. For the meteorological stations Akhmeta, Gurjaani and Kvareli this difference is insignificant (Table 1).

In the Fig. 5 data about correlation between number of days with hail per year on the meteorological stations and their average value in 8 municipalities of Kakheti in 1982, 1984-1989 is presented. Correlation between the indicated parameters is moderate (R = 0.48, α = 0.23).

In the Fig. 6 data about correlation between number of days with hail per year on the meteorological stations (all data of HD) and their average value in 8 municipalities of Kakheti in 1982, 1984-1989 according of data of SIS is presented. Correlation between the indicated parameters is noticeable (R = 0.57, α = 0.15).

Correlation between number of days with hail per year on the meteorological stations in Kakheti according to all data and data of 1982, 1984-1989 of HD (Fig. 7) is strong (R = 0.74, α = 0.025).

As a whole the linear correlation between number of days with hail per year and altitude in Kakheti for 123 locations is significant, but is very weak (R = 0.14, α = 0.1). A certain tendency of an increase in the number of days with the hail with an increase in altitude of locality is noticeable (Fig. 8).

However, with the averaging of data of 123 locations for different altitude ranges the clearer picture of the dependence of the number of days with the hail from the height of locality is observed (Fig. 9). As follows from Fig. 9 dependence between the averaged values of the number of days with the hail per year and the height of locality is very strong and has the form of the third power polynomial (R^2 = 0.996, α = 0.001). Approximately to the height of 550 m above sea level an increase in the number of days with the hail bringing damage to agricultural crops is observed, then - decrease.

From Fig. 10 follows, that correlation between number of days with hail per year on the meteorologycal stations and altitude in Kakheti according to data of HD is very weak (R = 0.14 and 0.22, α is insignificant).

Concerning the correlation between number of days with hail per year and mean altitude of hail-damaged area of 8 municipalities in Kakheti in 1982, 1984-1989 according to data of SIS (Fig. 11), that here dependence is noticeable (R^2 = 0.3585, α = 0.12). As in the preceding case (Fig. 9), in this case the dependence of the number of days with the hail from the height of locality also takes the form of the third power polynomial (Fig. 11).

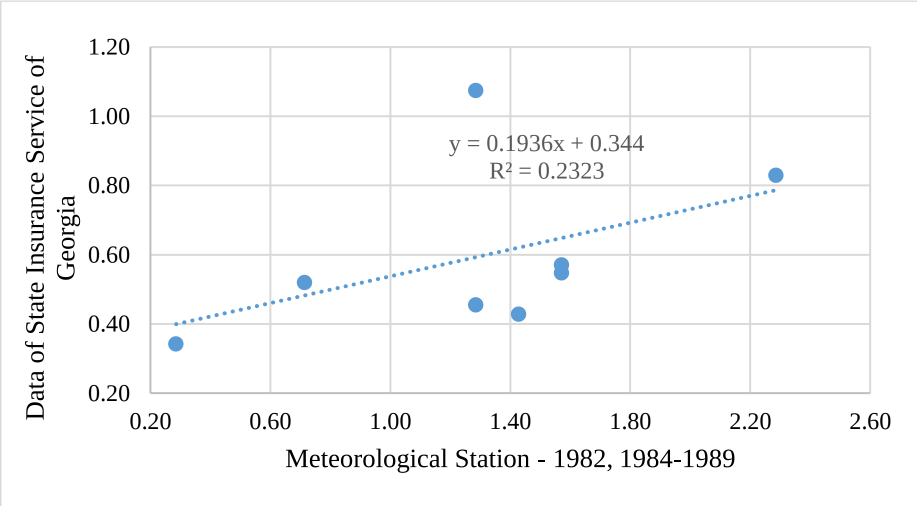

Fig. 5. Linear correlation between number of days with hail per year on the meteorological stations (Data of HD) and their average value in 8 municipalities of Kakheti in 1982, 1984-1989 (Data of SIS).

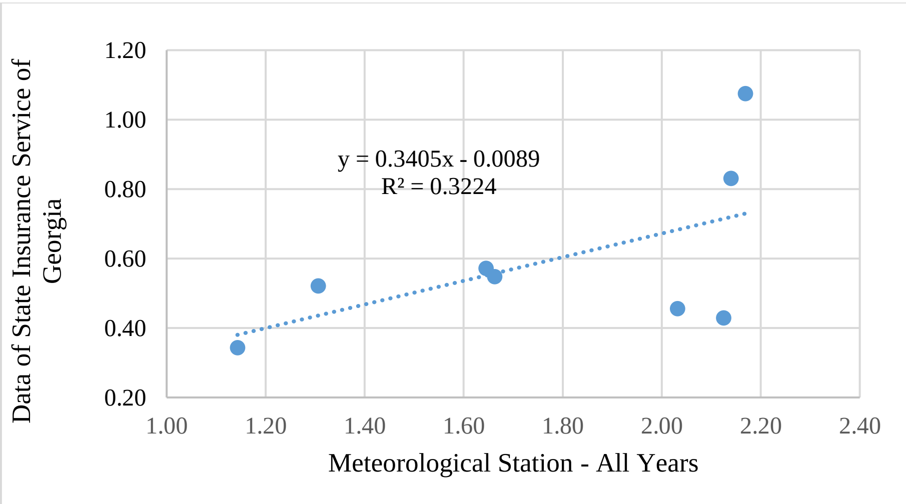

Fig. 6. Linear correlation between number of days with hail per year on the meteorological stations (all data of HD) and their average value in 8 municipalities of Kakheti in 1982, 1984-1989 according of data of SIS.

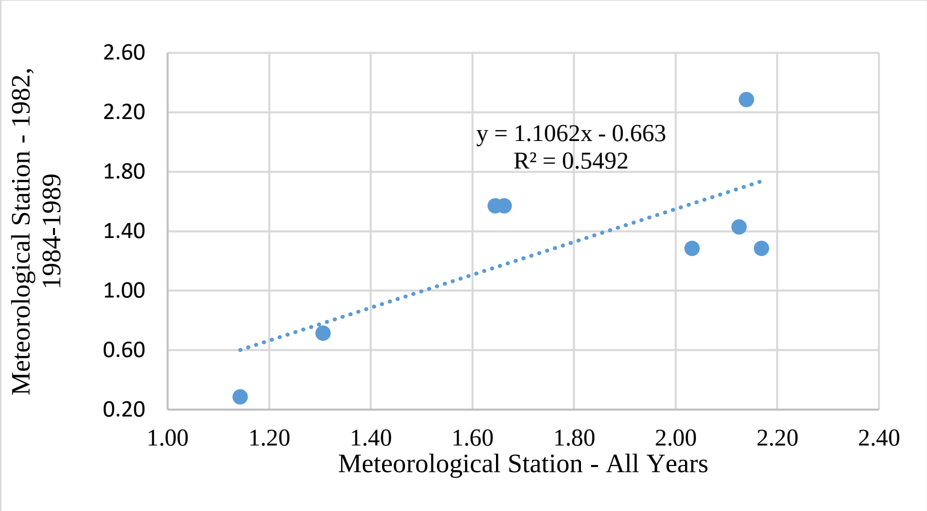

Fig. 7. Linear correlation between number of days with hail per year on the meteorological stations in Kakheti: all data and data of 1982, 1984-1989 of HD.

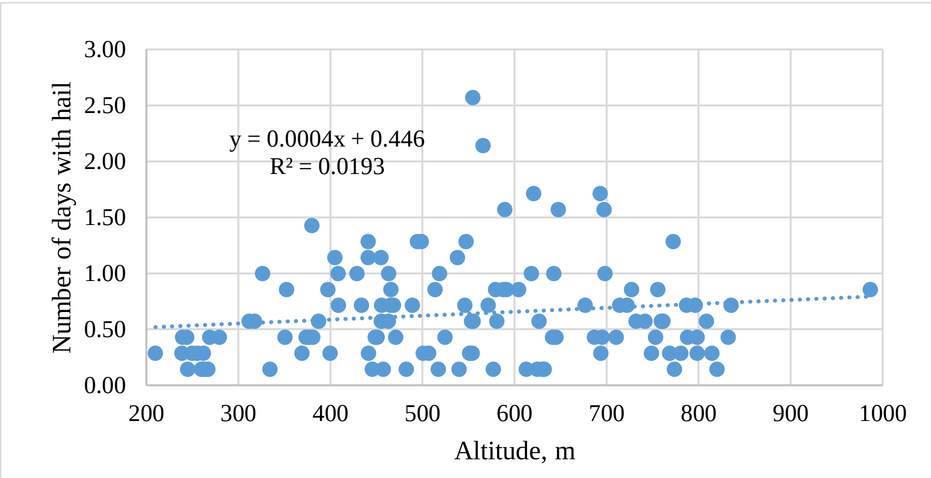

Fig. 8. Linear correlation between number of days with hail per year and altitude in Kakheti for 123 locations in 1982, 1984-1989 (Data of SIS).

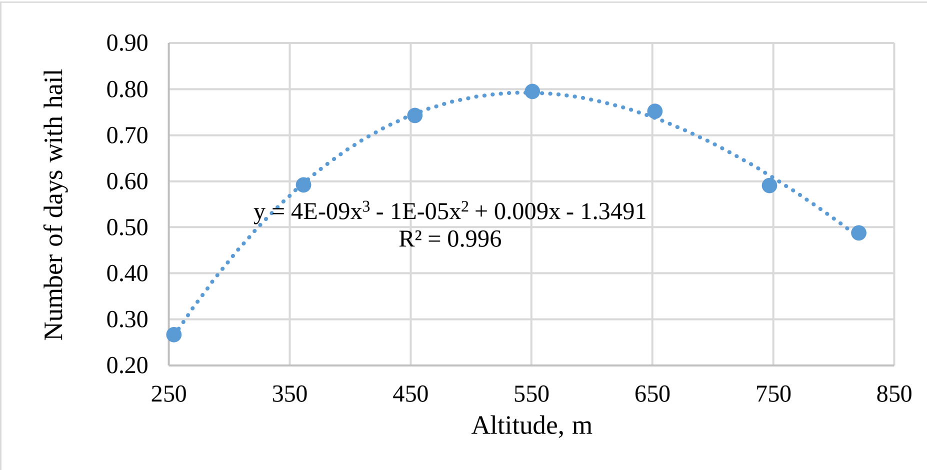

Fig. 9. Dependence of the average number of days with hail per year on the mean height of the terrain in Kakheti for 123 locations in 1982, 1984-1989 (Data of SIS).

Averaging is carried out in a range of heights: 210-280 m – 15 points, 312-400 m – 14 points, 405-500 m -25 points, 501-591 m – 23 points,605-698 m - 19 points, 711-774 m – 15 points, 787 – 987 m – 12 points,

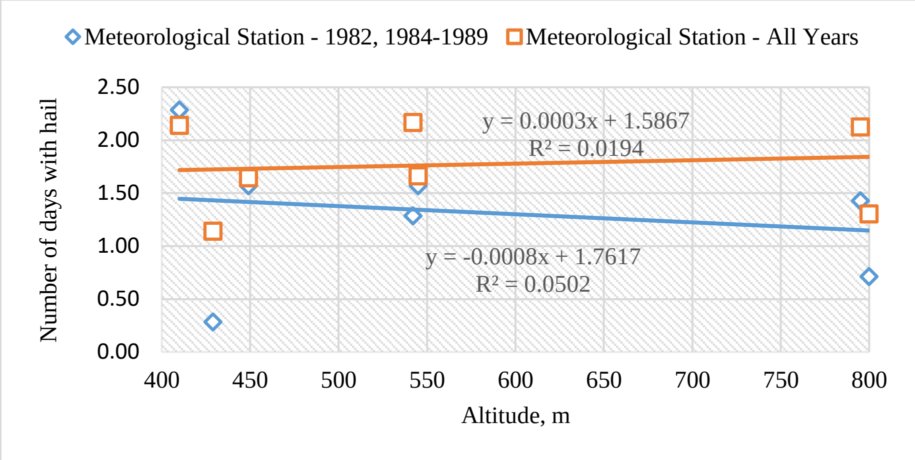

Fig. 10. Linear correlation between number of days with hail per year on the meteorologycal stations and altitude in Kakheti (Data of HD).

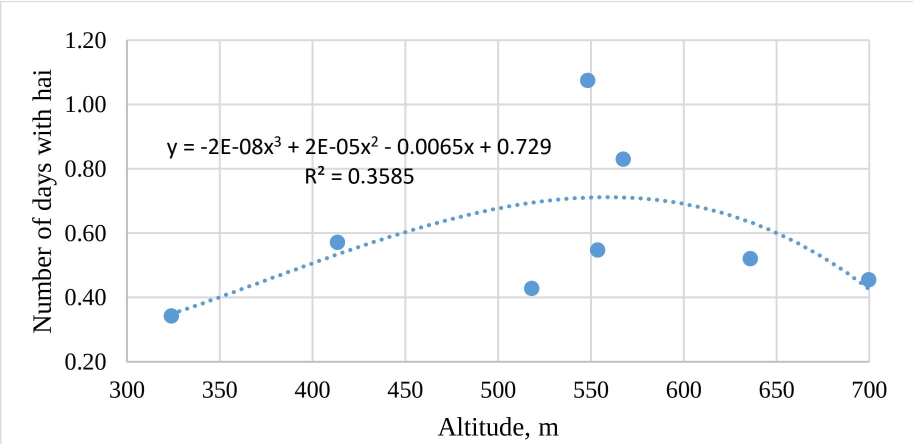

Fig. 11. Correlation between number of days with hail per year and mean altitude of hail-damaged area of 8 municipalities in Kakheti in 1982, 1984-1989 (Data of SIS).

Conclusion

According to the data of State Insurance Service of Georgia (SIS) for 123 locations of the territory Kakheti, in comparison with the data of the Hydrometeorological Department of Georgia (HD) for the 8 meteorological stations, the understated number of days with the hail per year was recorded (approximately two times less in comparison with data for 1982, 1984-1989 and almost three times less in the comparison with data for all years of observations at the meteorological stations - from 49 to 94 years).

The linear correlation between the average number of days with hail per year in 8 municipalities of Kakheti (1982, 1984-1989, data of SIS) and on the corresponding meteorological stations of municipalities centers of Kakheti (data of HD) are moderate (1982, 1984-1989, data of SIS and HD) and noticeable (1982, 1984-1989 data of SIS and all data of HD).

In the range of heights from 410 to 802 m the average number of days with the hail per year according to the data of 8 meteorological stations does not depend on height. The vertical distribution of averaged number of days with the hail per year according to the data of 123 locations of Kakheti (data of SIS, the range of mean altitudes from 254 to 821 m) takes the form of the third power polynomial.

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კახეთის ტერიტორიაზე წელიწადში სეტყვიანი დღეების განაწილების შედარებითი ანალიზი მეტეოროლოგიური სადგურების და საქართველოს სახელმწიფო სადაზღვევო სამსახურის მონაცემების მიხედვით

ა.ამირანაშვილი, თ.ბლიაძე, ნ.ჯამრიშვილი,
თ.ხუროძე ,
მ.ფიფია, ხ.თავიდაშვილი

რეზიუმე

წარმოდგენილია კახეთის ტერიტორიაზე წელიწადში სეტყვიანი დღეების განაწილების შედარებითი ანალიზის შედეგები ჰიდრომეტეოროლოგიური დეპარტამენტის (8 სადგური - ახმეტა, გურჯაანი, დედოფლისწყარო, თელავი, ლაგოდეხი, საგარეჯო, სიღნაღი, ყვარელი; ყველა სეტყვიანი დღეების დაფიქსირება) და საქართველოს სახელმწიფო სადაზღვევო სამსახურის (123 პუნქტი, დაფიქსირებულია ის სეტყვიანი დღეები, როდესაც სასოფლო-სამეურნეო კულტურები

დაზიანდა). კვლევის პერიოდი: 1982 და 1984-1989 წლები სახელმწიფო სადაზღვევო სამსახურის მონაცემებით და 49 – 94 წელი (2016 წ. ჩათვლით) საქართველოს ჰიდრომეტეოროლოგიური დეპარტამენტის მონაცემებით. მიღებულია კერძოდ, რომ პუნქტებისთვის ახმეტა, გურჯაანი, საგარეჯო, სიღნაღი და ყვარელი დაფიქსირებულია მეტი სეტყვიანი დღეები, ვიდრე სახელმწიფო სადაზღვევო სამსახურმა დააფიქსირა იმავე ტერიტორიაზე. პუნქტებისთვის დედოფლისწყარო, თელავი, ლაგოდეხი ეს სხვაობა არ არის ნიშნადი. ჩატარებულია აგრეთვე კახეთის ტერიტორიაზე წელიწადში სეტყვიანი დღეების განაწილების დეტალური ანალიზი ორივე ხსენებული ორგანიზაციის მონაცემების მიხედვით.

Сравнительный анализ распределения количества дней с градом в год на территории Кахетии по данным метеорологических станций и службы государственного страхования Грузии

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Резюме

Представлены результаты сравнительного анализа распределения на территории Кахетии числа дней с градом по данным гидрометеорологического департамента (8 станций - Ахмета, Гурджаани, Дедоплисцкаро, Телави, Лагодехи, Сагареджо, Сигнаги, Кварели; регистрация всех дней с градом) и службы государственного страхования Грузии (123 пункта, регистрация дней с градобитиями, приведших к повреждению сельскохозяйственных культур). Период исследования: 1982, 1984-1989 годы по данным Службы государственного страхования и 49-94 года (включая 2016 год) по данным Гидрометеорологического департамента Грузии. В частности получено, что для пунктов Ахмета, Гурджаани, Сагареджо, Сигнаги и Кварели на метеорологических станциях регистрировалось большее число дней с градом, чем службой государственного страхования на тех же территориях. Для пунктов Дедоплисцкаро, Телави и Лагодехи эта разница незначимая. Проведен также детальный анализ распределения на территории Кахетии числа дней с градом по данным обеих указанных организаций.

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Monthly and Ten-Day Average Values of Freezing Level in the Atmosphere Above Kakheti Territory (Georgia) from April to October

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ABSTRACT

Results of the analysis of the data about height of zero isotherm in the atmosphere above the territory of Kakheti (Telavi) from April through October 2012-2016 are presented. At present in Georgia the aerological sounding of the atmosphere is not conducted. Therefore, in the work the resources of the worldwide network aerological observation http://ready.arl.noaa.gov/READYcmet.php are used, according to which data the extrapolation of the vertical distribution of meteorological elements for any location of world is possible. In particular, the repetition of height of zero isotherm according to daily data for 04, 10, 16 and 22 hours on the Tbilisi time for each month is studied; it is obtained that monthly average values of the zero isotherm change from 2603 m during April to 4439 m during August, and ten-day average - from 2415 m in the first decade of April to 4615 m in the second decade of August.

***Key Words*:** aerological sounding of the atmosphere, freezing level.

Introduction

The thickness of the supercooled part of the convective clouds is one of the most important conditions for formation and development of hail processes in them. Besides this, the data about the levels of negative temperatures in the clouds are necessary for the meteorological forecast of showers, thunderstorms and hail, determination of different characteristics of convective clouds from the data of radar measurements, optimum zones of sowing in them by the ice-forming reagent with the operations on the active actions for the purpose of the interruption of hail, the regulation of precipitations, etc. [1-4].

In the past century in the Soviet period of time the aerological sounding of the atmosphere in Tbilisi, Sukhumi, Batumi [5-7], and in the years of the work of anti-hail service in Kakheti in the village of Ruispiri of the Telavi municipality was carried out [8-11]. The aerological sounding of the atmosphere is not conducted after 1991 in Georgia.

At present, in connection with the restoration of anti-hail works in Kakheti [12-15], arose the need of obtaining the operational information about the vertical distribution of the meteorological parameters in this region of the Georgia, which was necessary both for conducting active actions to the hail-dangerous and hail clouds [4,15] and for operational provisions of contemporary radar on recording of the parameters of hail clouds (probability of hailstorm, the size of hail, etc.) [16-21]. For obtaining this information the resources of service of the worldwide network of the aerological observations of http://ready.arl.noaa.gov/READYcmet.php are used, according to data of which is possible the extrapolation of the vertical distribution of meteorological elements for by any point of world.

It should be noted that the indicated resource has 10-years data file. Therefore, besides the use of operational information, is a possibility of studying the influence of climate variation in Georgia [22-25] on a variation in the vertical profiles of a meteorological element in free-air conditions at present. Similar works in Georgia are begun in 2015 year [26,27]. Let us note also, that the operational and averaged long-term data about the level of the zero isotherm, it is planned to use for evaluating the sizes of hail stones on the earth's surface taking into account their sizes in the clouds according to the data of radar measurements and the height of locality with the use of known methodology [1-3, 28-31]. This will make it possible to build the detailed operational and model maps of the distribution of potential damage from the hail of agricultural crops, to conduct the estimation of the physical effectiveness of action on the hail processes, to improve the procedure of anti-hail works and so forth [4,32].

This work is the continuation of the studies [26,27,33] initiated. Below some results of the analysis of the statistical structure of height of zero isotherm in the atmosphere above the territory of Kakheti from April through October 2012-2016 are represented. The selection of the indicated season of year is caused by the need of using the results of a study in the work of anti-hail service in Kakheti.

Material and methods

For investigating the thermal regime in the free atmosphere above the territory of Kakheti as in [26,27,33] the resources of http://ready.arl.noaa.gov/READYcmet.php were used.

Height of zero isotherm H(0°C) was determined from the formula:

$$H(0°C)=(T1 \cdot H2-T2 \cdot H1)/(T1-T2)$$

where, T1 and T2 are the temperature of air at the levels H1 and H2 respectively. With this T1 must be > 0°C, and T2 < 0°C.

In the work the statistical analysis of hourly (04, 10, 16 and 22 hours on the Tbilisi time) heights of zero isotherm from April through October 2012-2016 is carried out. The total quantity of data composes 4280. As the informational unit the values of height of zero isotherm, average in the twenty-four hours are used, averaged in five years.

The analysis of data with the use of the standard statistical analysis methods is carried out [34]. The following designations will be used below: Min – minimal values, Max - maximal values, Range - variational scope, St Dev - standard deviation, σ_m – standard error, Cv (%) - coefficient of variation, 95%(+/-) - 95% of confidence interval.

The statistical data about the decade average and monthly average values of the height of zero isotherm above the investigated region are represented below.

Results and discussion

Results in Fig. 1-2 and Table 1-4 are represented.

Fig. 1 presents the data about the repetition of heights of zero isotherm for the separate months of the season of anti-hail works. As follows from this figure the greatest repetition of the hour values of the level of the zero isotherm it falls to the following altitude ranges - April: >2.6-3.0 km (26.3 % of the cases), May: >3.0-3.4 km (33.7 % of the cases), June: >3.8-4.2 km (38.3 % of the cases), July: >4.2-4.6 km (38.1 % of the cases), August: >4.6-5.0 km (38.5 % of the cases), September: >3.8-4.2 km (33.3 % of the cases), October: >2.6-3.0 km (18.1 % of the cases).

Tables 1-4 statistical characteristics of the average monthly and decade (ten-day) average values of heights of zero isotherm (m) above the territory of Kakheti from April through October depict.

April (Table 1). Average monthly value of H(0°C) = 2603 m, the range of change: 1902 - 3215 m.
1 ten-day periods. Average monthly value of H(0°C) = 2415 m, the range of change: 1902 - 2989 m.
2 ten-day periods. Average monthly value of H(0°C) = 2627 m, the range of change: 2487 - 2893 m.
3 ten-day periods. Average monthly value of H(0°C) = 2767 m, the range of change: 2251 - 3215 m.

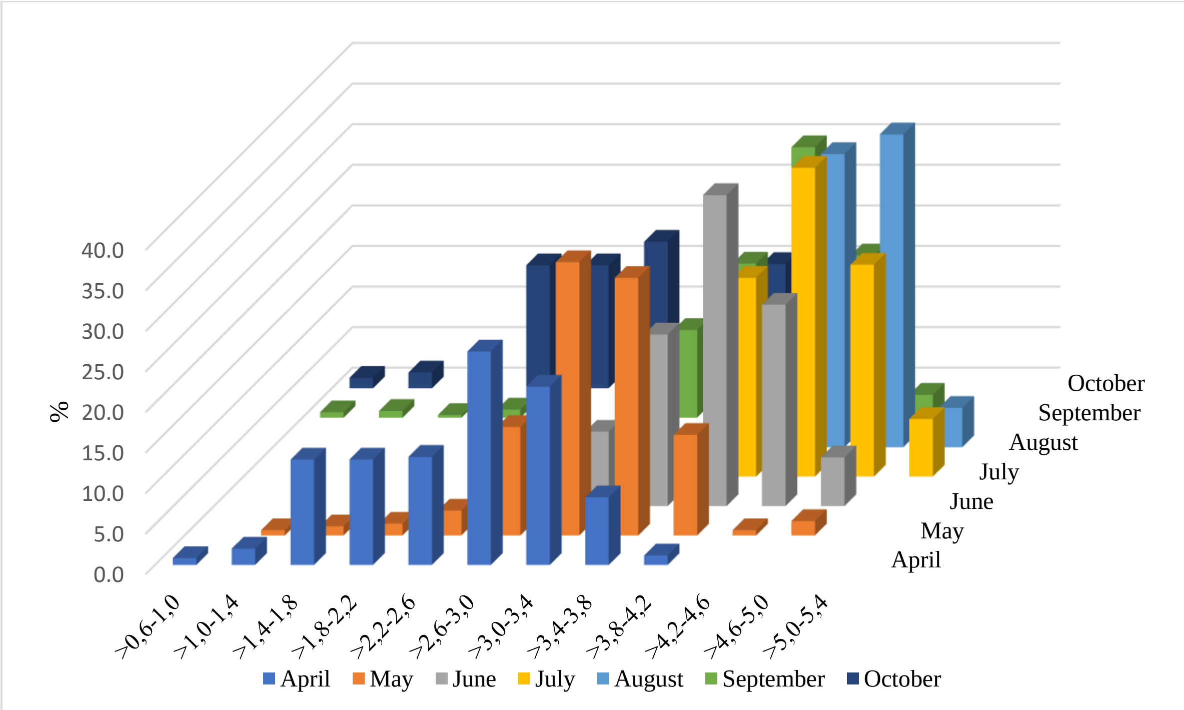

Fig. 1. Repetition of height of zero isotherm (km) above the territory of Kakheti in April- October of 2012-2016 according to the data for 04, 10, 16 and 22 hours on the Tbilisi time.

Table 1

Statistical characteristics of the average monthly and decade average values of heights of zero isotherm (m) above the territory of Kakheti during April and May

Month	April				May			
Parameter	Month	1 Decade	2 Decade	3 Decade	Month	1 Decade	2 Decade	3 Decade
Mean	2603	2415	2627	2767	3340	3260	3205	3534
Min	1902	1902	2487	2251	2976	2976	3018	3110
Max	3215	2989	2893	3215	3762	3555	3351	3762
Range	1313	1086	407	964	786	579	333	651
Median	2608	2344	2573	2812	3313	3219	3249	3570
St Dev	347	409	131	366	220	200	130	167
σ_m	64	136	44	122	40	67	43	53
Cv (%)	13.3	16.9	5.0	13.2	6.6	6.1	4.0	4.7
95%(+/-)	126	267	86	239	79	131	85	103

May (Table 1). Average monthly value of H(0°C) = 3340 m, the range of change: 2976 – 3762 m.
1 ten-day periods. Average monthly value of H(0°C) = 3260 m, the range of change: 2976 – 3555 m.
2 ten-day periods. Average monthly value of H(0°C) = 3205 m, the range of change: 3018 – 3351 m.
3 ten-day periods. Average monthly value of H(0°C) = 3534 m, the range of change: 3110 – 3762 m.

Table 2

Statistical characteristics of the average monthly and decade average values of heights of zero isotherm (m) above the territory of Kakheti during June and July

Month	June				July			
Parameter	Month	1 Decade	2 Decade	3 Decade	Month	1 Decade	2 Decade	3 Decade
Mean	3978	3763	3990	4181	4432	4330	4524	4442
Min	3642	3642	3736	4020	4231	4248	4331	4231
Max	4294	3878	4294	4290	4658	4408	4658	4614
Range	652	237	558	271	427	160	327	383
Median	3985	3767	3985	4192	4397	4323	4553	4431
St Dev	212	75	183	91	133	51	129	128
σ_m	39	25	61	30	24	17	43	41
Cv (%)	5.3	2.0	4.6	2.2	3.0	1.2	2.9	2.9
95%(+/-)	77	49	120	60	48	34	85	80

June (Table 2). Average monthly value of H(0°C) = 3978 m, the range of change: 3642 – 4294 m.
1 ten-day periods. Average monthly value of H(0°C) = 3763 m, the range of change: 3642 - 3878 m.
2 ten-day periods. Average monthly value of H(0°C) = 3990 m, the range of change: 3736 - 4294 m.
3 ten-day periods. Average monthly value of H(0°C) = 4181 m, the range of change: 4020 – 4290 m.

July (Table 2). Average monthly value of H(0°C) = 4432 m, the range of change: 4231 - 4658 m.
1 ten-day periods. Average monthly value of H(0°C) = 4330 m, the range of change: 4248 – 4408 m.
2 ten-day periods. Average monthly value of H(0°C) = 4524 m, the range of change: 4331 – 4658 m.
3 ten-day periods. Average monthly value of H(0°C) = 4442 m, the range of change: 4231 - 4614 m.

Table 3

Statistical characteristics of the average monthly and decade average values of heights of zero isotherm (m) above the territory of Kakheti during August and September

Month	August				September			
Parameter	Month	1 Decade	2 Decade	3 Decade	Month	1 Decade	2 Decade	3 Decade
Mean	4439	4505	4615	4220	3721	3764	3946	3452
Min	3974	4385	4477	3974	3103	3591	3756	3103
Max	4763	4574	4763	4456	4100	3984	4100	4008
Range	788	189	286	482	997	392	344	904
Median	4494	4526	4616	4174	3818	3817	3929	3362
St Dev	209	62	98	176	282	142	116	291
σ_m	38	21	33	56	52	47	39	97
Cv (%)	4.7	1.4	2.1	4.2	7.6	3.8	2.9	8.4
95%(+/-)	75	41	64	109	103	93	76	190

August (Table 3). Average monthly value of H(0°C) = 4439 m, the range of change: 3974 - 4763 m.
1 ten-day periods. Average monthly value of H(0°C) = 4505 m, the range of change: 4385 - 4574 m.
2 ten-day periods. Average monthly value of H(0°C) = 4615 m, the range of change: 4477 - 4763 m.
3 ten-day periods. Average monthly value of H(0°C) = 4220 m, the range of change: 3974 - 4456 m.

September (Table 3). Average monthly value of H(0°C) = 3721 m, the range of change: 3103 - 4100 m.
1 ten-day periods. Average monthly value of H(0°C) = 3764 m, the range of change: 3591 - 3984 m.

2 ten-day periods.   Average monthly value of H(0°C) = 3946 m, the range of change: 3756 – 4100 m.
3 ten-day periods.   Average monthly value of H(0°C) = 3452 m, the range of change: 3103 – 4008 m.

Table 4

Statistical characteristics of the average monthly and decade average values of heights of zero isotherm (m) above the territory of Kakheti during October

Month	October			
Parameter	Month	1 Decade	2 Decade	3 Decade
Mean	2842	3133	2905	2520
Min	2145	2629	2145	2165
Max	3777	3777	3466	3054
Range	1632	1148	1321	889
Median	2870	3045	2924	2459
St Dev	432	377	413	276
σ_m	79	126	138	87
Cv (%)	15.2	12.0	14.2	10.9
95%(+/-)	155	246	270	171

October (Table 4). Average monthly value of H(0°C) = 2842 m, the range of change: 2145 - 3777 m.
1 ten-day periods.   Average monthly value of H(0°C) = 3133 m, the range of change: 2629 - 3777 m.
2 ten-day periods.   Average monthly value of H(0°C) = 2905 m, the range of change: 2145 - 3466 m.
3 ten-day periods.   Average monthly value of H(0°C) = 2520 m, the range of change: 2165 – 3054 m.

The greatest average monthly value of H(0°C) during August (4439 m) is observed, smallest - during April (2603 m). Average value of H(0°C) from April through October equal to 3622 m. Greatest decade average value of H(0°C) to the second ten-day period of August (4615 m) is observed, smallest - in the first ten-day period of April (2415 m). The greatest intra-monthly amplitude of values of H(0°C) during October (1632 m) is observed, smallest - during July (427 m). The greatest intra-decade amplitude of values of H(0°C) in the second decade of October (1321 m) is observed, smallest - in the first decade of July (160 m).

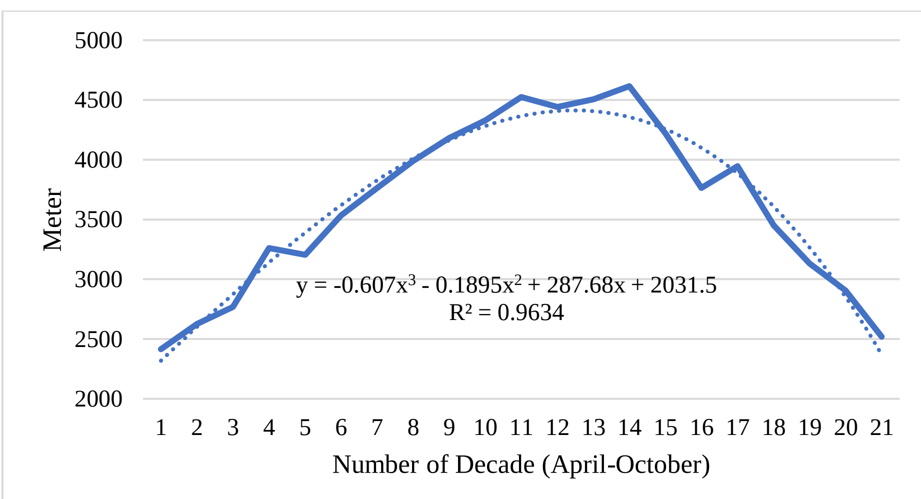

Fig. 2. The time dependence of the decade average values of the level of the zero isotherm above the territory of Kakheti from April through October

As follows from Fig. 2 the time dependence of decade average values of H(0°C) above the territory of Kakheti from April through October it takes the form of the third power polynomial.

Conclusion

In the near future it is provided the continuation of the initiated studies on the study of the influence of climate change in Eastern Georgia [22-25] to the contemporary variations of height of zero isotherm in the atmosphere (preliminary results into [26,27] are obtained), and also the study of the statistical structure of values of H(0°C) in the days with the hail processes at present and its comparison with the analogous works, in the past century carried out [9].

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ატმოსფეროში ნულოვანი იზოთერმის სიმაღლის საშუალოთვიური და დეკადური მნიშვნელობები კახეთის ტერიტორიაზე (საქართველო) აპრილიდან ოქტომბრის ჩათვლით

ნ.ჯამრიშვილი

რეზიუმე

წარმოდგენილია ნულოვანი იზოთერმის სიმაღლის მონაცემების ანალიზის შედეგები კახეთის ტეროიტორიაზე 2012-2016 წლების აპრილიდან ოქტომბრის ჩათვლით. ამჟამად საქართველოში ატმოსფეროს აეროლოგიური ზონდირება არ ტარდება. ამიტომ ნაშრომში გამოყენებულია მსოფლიო აეროლოგიური დაკვირვებათა ქსელის რესურსები http://ready.arl.noaa.gov/READYcmet.php, ამ მონაცემებით შესაძლებელია მეტეოროლოგიური ელემენტების ვერტიკალური განაწილების ექსტრეპოლაცია მსოფლიოს ნებისმიერ წერტილისათვის. კერძოდ, შესწავლილია ნულოვანი იზოთერმის სიმაღლის ყოველდღიური მონაცემების განმეორებადობა 04, 10, 16 და 22 საათებისთვის ყოველი თვის განმავლობაში თბილისის დროით. მიღებულია, რომ ნულოვანი იზოთერმის საშუალოთვიური მნიშვნელობები იცვლება 2603 მ-დან აპრილში 4439 მ-მდე აგვისტოში, ხოლო საშუალოდეკადური მნიშვნელობები 2415 მ-დან აპრილის პირველ დეკადაში 4615 მ-მდე აგვისტოს მეორე დაკადაში.

Среднемесячные и декадные значения уровня нулевой изотермы в атмосфере над территорией Кахетии (Грузия) с апреля по октябрь месяцы

Н. К. Джамришвили

Резюме

Приводятся результаты анализа данных о высоте нулевой изотермы в атмосфере над территорией Кахетии с апреля по октябрь месяцы 2012-2016 гг. В настоящее время в Грузии аэрологическое зондирование атмосферы не проводится. Поэтому в работе использованы ресурсы мировой сети аэрологических наблюдений http://ready.arl.noaa.gov/READYcmet.php, по данным которой возможна экстраполяция вертикального распределения метеорологических элементов для любой точкой Мира. В частности, изучена повторяемость высоты нулевой изотермы по ежедневным данным за 04, 10, 16 и 22 час. по Тбилисскому времени для каждого месяца; получено, что среднемесячные значений нулевой изотермы меняются от 2603 м в апреле до 4439 м в августе, а среднедекадные – от 2415 м в первой декаде апреля до 4615 м во второй декаде августа.

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The Statistical Characteristics of Hourly Values of the Height of Isotherm -6°C in the Atmosphere Above Kakheti Territory (Georgia) from April to October

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ABSTRACT

The detailed statistical analysis of daily data for 04,10, 16 and 22 hours on the Tbilisi time about the height of isotherm -6°C in the atmosphere above the territory of Kakheti (Telavi) from April through October 2012-2016 is represented, information about which is necessary while planning and performing of work on the weather modification. In the work the resources of the worldwide network aerological observation http://ready.arl.noaa.gov/READYcmet.php are used, according to which data the extrapolation of the vertical distribution of meteorological elements for any location of world is possible.

Key Words: aerological sounding of atmosphere, weather modification.

Introduction

The Kakheti region of Georgia is one of the hail-dangerous regions of world [1-3], in connection with this in the period from 1967 through 1989 here was conducted production work on the fight with the hail [1-4]. In parallel were conducted scientific studies of weather modification (regulation of the thunderstorm activity of clouds, the gain of precipitation, etc. [2,5]. In 2015 year of work on modification the weathers (first of all - fight with the hail) in this region of the Georgia were restored [6,7].

In connection with this arose the need of obtaining the operational information about the vertical distribution in free atmosphere above the territory of Kakheti of the meteorological parameters (including of the air temperature). Since in Georgia the aerological sounding of the atmosphere was conducted only up to 1991 [8-11], for obtaining this information were used the recource of service of the worldwide network of the aerological observations of http://ready.arl.noaa.gov/READYcmet.php, according to data of which the extrapolation of the vertical distribution of meteorological elements for by any point of world was possible .

In recent years with the use of these data is begun the work on the analysis of the vertical distribution of the air temperature in free atmosphere above the territory of Kakheti, the study of variations in height of zero isotherm [12-14]. Special importance have the operational and averaged data about the height of the isotherm -6°C, information about which is extremely important while planning and performing of work on the weater modification, the selection of places for the arrangement of the points of action on the clouds, the determination of the necessary quantity of anti-hail rockets into season, etc. [15-21].

The results of the statistical analysis of data for 04, 10, 16 and 22 hours on the Tbilisi time about the height of isotherm -6°C in the atmosphere above the territory of Kakheti (Telavi) from April through October 2012-2016 are represented below.

Material and methods

For investigating the thermal regime in the free atmosphere above the territory of Kakheti as in [12-14] the resources of http://ready.arl.noaa.gov/READYcmet.php were used.

Height of isotherm (H-6°C) was determined from the formula:

$$(H\text{-}6°C)=(T1 \cdot H2-T2 \cdot H1)/(T1-T2)$$

where, T1 and T2 are the temperature of air at the levels H1 and H2 respectively. With this T1 must be > -6°C, and T2 <-6°C.

Work gives the statistical data about the hourly, daily and monthly average values of the height of the isotherm -6°C for the season of anti-hail works (April- October), information about which is extremely important while planning and performing of work on the weather modification. The total quantity of data composes 4280.

Analysis of data with the use of the standard statistical analysis methods is carried out [22]. The following designations will be used below: Min – minimal values, Max - maximal values, Range - variational scope, St Dev - standard deviation, σ_m – standard error, Cv (%) - coefficient of variation, 95%(+/-) - 95% of confidence interval, height of isotherm -6°C - H(-6°C).

Results and discussion

The results of work in tables 1-8 are represented.

Table 1

Statistical characteristics of values of H(-6°C) above the territory of Kakheti in April- October 2012-2016 (meter)

Parameter	April	May	Jun	July	August	September	October
Mean	3602	4285	4896	5393	5355	4686	3978
Min	1648	1854	3679	4095	3381	1572	1666
Max	4775	5737	5843	6363	6149	5778	5262
Range	3127	3883	2163	2268	2769	4205	3597
St Dev	589	483	380	360	428	650	632
σ_m	24	19	16	14	17	27	25
Cv (%)	16	11	8	7	8	14	16
Count	600	620	600	620	620	600	620
95%(+/-)	47	38	30	28	34	52	50

As follows from Table 1, the average values of H (-6 ° C) vary from 3602 m (range: 1648 - 4775 m) in April to 5393 m (range: 4095 - 6363 m) in July.

Table 2

Repetition of the heights of isotherm -6°C above the territory of Kakheti in April- October 2012-2016 according to the data for 04, 10, 16 and 22 hours on the Tbilisi time (km)

Month	>1.4-1.8	>1.8-2.2	>2.2-2.6	>2.6-3.0	>3.0-3.4	>3.4-3.8	>3.8-4.2	>4.2-4.6	>4.6-5.0	>5.0-5.4	>5.4-5.8	>5.8-6.2	>6.2-6.6
4	0.7	1.2	4.8	10.0	14.8	25.2	29.8	11.5	2.0				
5		0.5	0.6	0.6	2.4	5.8	26.3	42.7	17.7	1.5	1.8		
6						0.5	2.5	22.3	31.5	34.7	8.3	0.2	
4							0.6	1.6	7.7	44.0	32.6	12.7	0.6
8						1.5	1.9	2.1	8.5	31.5	45.5	9.0	
9	0.8	0.7	0.2	0.3	1.7	5.2	9.5	14.2	33.5	26.8	7.2		
10	0.3	1.0	0.6	4.5	11.3	20.5	21.8	23.9	13.7	2.4			

Table 2 presents data on the repeatability of the height of isotherm -6 °C for individual months of the anti-hail season. As follows from this table, the highest repeatability of values of H (-6 °C) falls on the following altitude ranges: April: > 3.8-4.2 km (29.8% of cases), May: > 4.2-4.6 km (42.7% of cases), June: > 4.6-5.0 km (31.5% of cases), July: > 5.0-5.4 km (44.0% of cases), in August: > 5.4-5.8 km (45.5% of cases), September: > 4.6-5.0 km (33.5% of cases), October: > 4.2-4.6 km (23.9% of cases).

Tables 3 - 6 show the results of a statistical analysis of the characteristics of height of isotherm -6 ° C in separate observation periods (04, 10, 16 and 22 hours in Tbilisi time) for individual months from April to October.

Table 3

Statistical characteristics of values of H(-6°C) above territory of Kakheti in April- May within the various periods of observations (meter)

Month	April					May				
Hour	04	10	16	22	04-22	04	10	16	22	04-22
Mean	3550	3546	3662	3650	3602	4250	4260	4297	4333	4285
Min	1648	1691	2253	1886	1999	2395	2817	1854	2625	2548
Max	4742	4753	4768	4775	4690	5665	5670	5695	5737	5674
Range	3094	3062	2515	2889	2691	3270	2854	3842	3111	3125
St Dev	607	630	561	551	569	509	448	524	446	445
σ_m	50	52	46	45	47	41	36	42	36	36
Cv (%)	17	18	15	15	16	12	11	12	10	10
Count	150	150	150	150	150	155	155	155	155	155
95%(+/-)	97	101	90	89	91	80	71	83	70	70

In April (Table 3), the average value of the height of isotherm -6 °C varies from 3546 m to 10 h. up to 3662 m at 16 h., the minimum value of values of H (-6 °C) varies from 1648 m to 04 h. up to 2253 m at 16 h., the maximum - from 4,742 m at 04 h. up to 4775 m at 22 h.

In May (Table 3), the average value of the height of isotherm -6 °C varies from 4250 m to 04 h. up to 4333 m at 22 h., the minimum value of H (-6 °C) varies from 1854 m at 16 h. up to 2817 m at 10 h., the maximum - from 5665 m at 04 h. up to 5737 m at 22 h.

Table 4

Statistical characteristics of values of H(-6°C) above territory of Kakheti in June - July within the various periods of observations (meter)

Month	June					July				
Hour	04	10	16	22	04-22	04	10	16	22	04-22
Mean	4841	4858	4945	4941	4896	5347	5350	5442	5434	5393
Min	3679	3697	3990	4121	3967	4160	4095	4212	4128	4188
Max	5689	5732	5843	5778	5737	6306	6335	6363	6258	6291
Range	2009	2035	1852	1658	1770	2146	2240	2151	2129	2103
St Dev	379	380	372	383	365	356	364	361	350	342
σ_m	31	31	31	31	30	29	29	29	28	28
Cv (%)	8	8	8	8	7	7	7	7	6	6
Count	150	150	150	150	150	155	155	155	155	155
95%(+/-)	61	61	60	61	59	56	58	57	55	54

In June (Table 4), the average value of the height of isotherm -6°C varies from 4841 m at 04 h. up to 4945 m at 16 h., the minimum value of H (-6°C) varies from 3679 m at 04 h. up to 4121 m at 22 h., the maximum - from 5689 m to 04 h. to 5843 m at 16 h.

In July (Table 4), the average value of the height of isotherm -6°C varies from 5347 m to 04 h. up to 5442 m at 16 h., the minimum value of H (-6°C) varies from 4095 m at 10 h. up to 4212 m at 16 h., the maximum - from 6258 m at 22 h. up to 6363 m at 16 h.

Table 5

Statistical characteristics of values of H(-6°C) above territory of Kakheti in August - September within the various periods of observations (meter)

Month	August					September				
Hour	04	10	16	22	04-22	04	10	16	22	04-22
Mean	5323	5322	5383	5391	5355	4664	4665	4711	4703	4686
Min	3543	3381	3496	3555	3494	1675	1572	1751	1761	1690
Max	6064	6124	6149	6047	6073	5662	5778	5670	5636	5679
Range	2521	2743	2654	2491	2579	3988	4205	3919	3875	3989
St Dev	409	430	447	424	417	652	659	645	649	643
σ_m	33	35	36	34	34	53	54	53	53	53
Cv (%)	8	8	8	8	8	14	14	14	14	14
Count	155	155	155	155	155	150	150	150	150	150
95%(+/-)	65	68	71	67	66	105	106	104	104	103

In August (Table 5), the average value of the height of isotherm -6°C varies from 5322 m to 10 h. up to 5391 m at 22 h., the minimum value of H (-6°C) varies from 3381 m at 10 h. up to 3555 m at 22 h., the maximum - from 6047 m to 22 h. up to 6149 m at 16 h.

In September (Table 5), the average value of the height of isotherm -6°C varies from 4664 m at 04 h. up to 4711 m at 16 h., the minimum value of H (-6°C) varies from 1572 m to 10 h. up to 1761 m at 22 h., the maximum - from 5636 m to 22 h. up to 5778 m at 10 h.

Table 6

Statistical characteristics of values of H(-6°C) above territory of Kakheti in October within the various periods of observations (meter)

Month	October				
Hour	04	10	16	22	04-22
Mean	3969	3949	4013	3981	3978
Min	1666	1687	1831	1877	1778
Max	5199	5249	5262	5252	5241
Range	3533	3562	3431	3375	3462
St Dev	613	659	629	628	613
σ_m	49	53	51	51	49
Cv (%)	15	17	16	16	15
95%(+/-)	97	104	99	99	97

In October (Table 6), the average value of the height of isotherm -6°C varies from 3494 m at 10 h. up to 4013 m at 16 h., the minimum value of H (-6°C) varies from 1666 m to 04 h. up to 1877 m at 22 h., the maximum - from 5199 m at 04 h. up to 5262 m at 16 h.

Table 7

Statistical characteristics of the daily amplitude of values of H(-6°C) above the territory of Kakheti in April-October 2012-2016 according to the data for 04, 10, 16 and 22 hours on the Tbilisi time (meter)

Параметр	April	May	June	July	August	September	October
Mean	312	275	215	235	192	226	318
Min	58	28	22	38	23	48	35
Max	1424	2539	1293	1019	1264	996	1324
Range	1366	2511	1271	981	1241	948	1288
St Dev	247	355	169	166	167	162	243
σ_m	20	29	14	13	13	13	20
Cv (%)	79	129	79	71	87	72	76
Count	150	155	150	155	155	150	155
95%(+/-)	40	56	27	26	26	26	38

As follows from Table 7, the average value of the daily amplitude of the values of H (-6°C) is: in April - 312 m (range: 58 - 1424 m), in May - 275 m (range: 28-2539 m), in June - 215 m (range: 22 - 1293 m), in July 235 m (range: 38 - 1019 m), in August - 192 m (range: 23 - 1264 m), in September - 226 m (range: 48 - 996 m), in October - 318 m (range: 35 - 1324 m).

Table 8

Repetition of the daily amplitude of values of H(-6°C) above the territory of Kakheti in April- October 2012-2016 according to the data for 04, 10, 16 and 22 hours on the Tbilisi time

Meter	0-100	>100-200	>200-300	>300-400	>400-500	>500-600	>600-700
H(-6 °C), %	18.0	36.0	19.1	11.9	4.9	3.9	2.1
Meter	>700-800	>800-900	>900-1000	>1000-1200	>1200-1500	>1500-2000	>2000-2500
H(-6 °C), %	1.4	0.56	0.75	0.47	0.65	0.19	0.19

Table 8 presents data on the frequency of the daily amplitude of the height of isotherm -6°C above the territory of Kakheti in April-October, according to all observational data. From this table it follows that the greatest repeatability of the daily amplitude of the height of the isotherm -6°C falls within the range >100-200 m (36.0% of cases). On a range of 0-400 m there are 85.0% of cases of observation. On a range > 1500-2500 m - 0.38% of cases of observations. Significant fluctuations in the daily amplitude of the height of the isotherm -6°C during the intrusion of atmospheric fronts are usually observed.

Conclusion

With the operational work on averting of hail damages it is expedient to use at least six hours observational data of the vertical distribution of the temperature of air in the troposphere in order not to miss the sharp of the oscillation of values of H(-6°C).

During the statistical processing of the large massif of the data about the values of H(-6°C) for the purpose of the establishment of general laws governing their intra-annual changeability, average monthly profiles of the temperature of air, etc. is sufficiently the presence of given in two periods observations (for example, into 04 and 16 hours).

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ატმოსფეროში -6°C იზოთერმის სიმაღლის საათობრივი მნიშვნელობების სტატისტიკური ანალიზი კახეთის ტერიტორიაზე (საქართველო) აპრილიდან ოქტომბრის ჩათვლით

ხ.თავიდაშვილი

რეზიუმე

ნაშრომში წარმოდგენილია, კახეთის ტერიტორიაზე (თელავი), ატმოსფეროში -6°C-იანი იზოთერმის სიმაღლის ყოველდღიური დეტალური სტატისტიკური ანალიზი, დაკვირვებათა 4 ვადისათვის (04, 10, 16 და 22 სთ, თბილისის დროით), აპრილიდან ოქტომბრის ჩათვლით, 2012-2016 წწ. მოცემული ინფორმაცია აუცილებელია ამინდის მოდიფიკაციისთვის საჭირო სამუშაოების დასაგეგმად. 2012-2016 წლების მონაცემები გამოყენებულია მსოფლიო აეროლოგიური ცენტრის ბაზიდან https://ready.arl.noaa.gov/READYcmet.php, არსებული ცენტრის მონაცემებით შესაძლებელია მეტეოროლოგიური ელემენტების ვერტიკალური განაწილების ექსტრაპოლაცია მსოფლიოს ყველა წერტილისთვის.

Статистические характеристики часовых значений высоты изотермы -6 ° С в атмосфере над территорией Кахетии (Грузия) с апреля по октябрь месяцы

Х. З. Тавидашвили

Резюме

Представлен детальный статистический анализ ежедневных данных за 04, 10, 16 и 22 час. по Тбилисскому времени о высоте изотермы -6°C в атмосфере над территорией Кахетии (Телави) с апреля по октябрь месяцы 2012-2016 гг., информация о которой необходима при планировании и проведении работ по модификации погоды. В работе использованы ресурсы мировой сети аэрологических наблюдений http://ready.arl.noaa.gov/READYcmet.php, по данным которой возможна экстраполяция вертикального распределения метеорологических элементов для любой точкой Мира.

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Properties and Advantages of Powdered Ice-Forming Reagents Based on Nanoscale Silica

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ABSTRACT

A series of powder ice-forming reagents based on the principle of Levilites was synthesized by gas-phase solvate-stimulated adsorption modification (GSSAM) of highly disperse nanoscale silica with silver iodide and phloroglucinol. Lab studies of the prepared materials showed that ice-forming activity per mass unit of AgI and phloroglucinol deposited onto a surface of silica nanoparticles according to the GSSAM technology corresponds to the values of native preparations. In this case, the best sample containing AgI is superior in the efficiency to known AD-1 reagent.

***Keywords*:** Ice-forming reagents, principle of Levilites, nanosilica, adsorption modification.

Introduction

Active influence on clouds and fogs carried out in order to (i) cause precipitation from the clouds; (ii) dispersal of fogs over the runway of airports; and (iii) suppress hail [1, 2].

The main way to influence clouds containing supercooled water droplets is to create ice crystals in them, which help accelerate the process of precipitation formation. Crystallizing and hygroscopic reagents, as well as coolants, are used for seeding clouds [3-7].

The physical basis for the use of crystallizing reagents is the ability of their aerosols to create ice crystals in supercooled clouds. Aerosols of many inorganic and organic substances possess this property, but aerosols of silver (AgI) and lead (PbI_2) iodides have the most effective crystallizing ability [8].

In practice, the problem of using ice-forming reagents is largely reduced to the issue of obtaining aerosols with the required structural parameters by using different dispersion methods.

For the dispersion of AgI, the following methods are mainly used: 1) explosions of AgI containing composition in pyrotechnic flares in rockets, 2) burning AgI containing solutions in a generator of particles attached to an airplane.

In the first case, the pyrotechnic compositions containing the active reagent (AgI) and iodination components (KI, NH_4I, NH_4IO_3, $C_7O_2H_5I$) are used to contribute increasing ice-forming efficiency of the composites. Typically, pyrotechnic compositions based on silver iodide and perchlorate or ammonium nitrate at AgI content of 2 to 40% are used. The formation of the ice-forming aerosol occurs due to high-temperature (from 700 to 1400 °C) sublimation of AgI, followed by the condensation of Ag and I ions on particles consisting of products of burning pyrotechnic composition. Therefore, such an aerosol is often called "thermocondensation aerosol".

The second method to prepare a thermocondensation aerosol is burning acetone solution of AgI. This method is used for aircraft seeding of layered clouds. To improve the solubility of silver iodide and to increase its ice-forming activity, iodides of ammonium and other elements are added to the solution.

The effectiveness of the crystallizing reagents is characterized by several parameters, the most important of which is the yield of active ice-forming nuclei per gram of composition. The yield of ice-forming nuclei using a thermocondensation aerosol depends on many factors: the AgI content, the activating components and their physicochemical properties; design features of the aerosol generator; dispersion conditions of the reagent, air humidity; speed of blowing of the generator, etc. [3].

These factors determine the dispersity of the formed aerosol that affect the structure and ice-forming activity. The increase in dispersity leads to an increase in the number of particles per mass unit of the reagent, but too small particles show ice-forming activity only at very low temperature. The formation of large particles leads to the production of an aerosol that is active in the required temperature range (from -5 to -10 °C), but the yield decreases per gram of composition. Therefore, the composition of the crystallizing reagents is specially selected that the formation of an ice-forming aerosol with core-shell particles composed of a core with the combustion products on a surface of which there are fragments of AgI. This ensures the production of sufficiently large particles with a minimum consumption of AgI contained on their surface.

The mentioned above methods for the dispersion of silver iodide are sufficiently effective, but they have a number of technological flaws, in particular, it needs to use dangerous combustible and explosive substances. The shortcomings of the pyrotechnic composition also include the high laboriousness of manufacturing charges and low energy characteristics. Anti-hail rockets containing pyrotechnic compounds have a small payload mass factor due to the lack of unitarity of loading, low efficiency and range.

An alternative to the use of pyrotechnic flares and burning of solutions can be the AgI dispersion method based on the principle of Levilites. It consists in spreading a thin layer of active substance at a surface of particles of a cheap inert highly disperse carrier. It is believed that the use of a highly disperse carrier can significantly increase the yield of ice-forming particles per mass unit of the active substance [9].

In the 80s of the last century, an amorphous, nonporous, highly disperse nanoscale silica (nanosilica) was used as an inert carrier [10]. One gram of such nanosilica with a specific surface area of 300 m^2/g and a bulk density of 50-60 g/dm^3 contains approximately 10^{18} primary particles with a diameter of 9-10 nm. On the surface of the nanoparticles there are free silanol groups ≡Si–OH, which are the main adsorption sites (in an amount of ~0.8 mmol/g) and sorbed water molecules (0.8-1.5 mmol/g or 1.5-2 wt.%) [11]. Due to the high adsorption potential, nanoparticles form such secondary structures as aggregates (50-1000 nm) and agglomerates (1-20 μm), which can disintegrate easily under external action (Fig. 1).

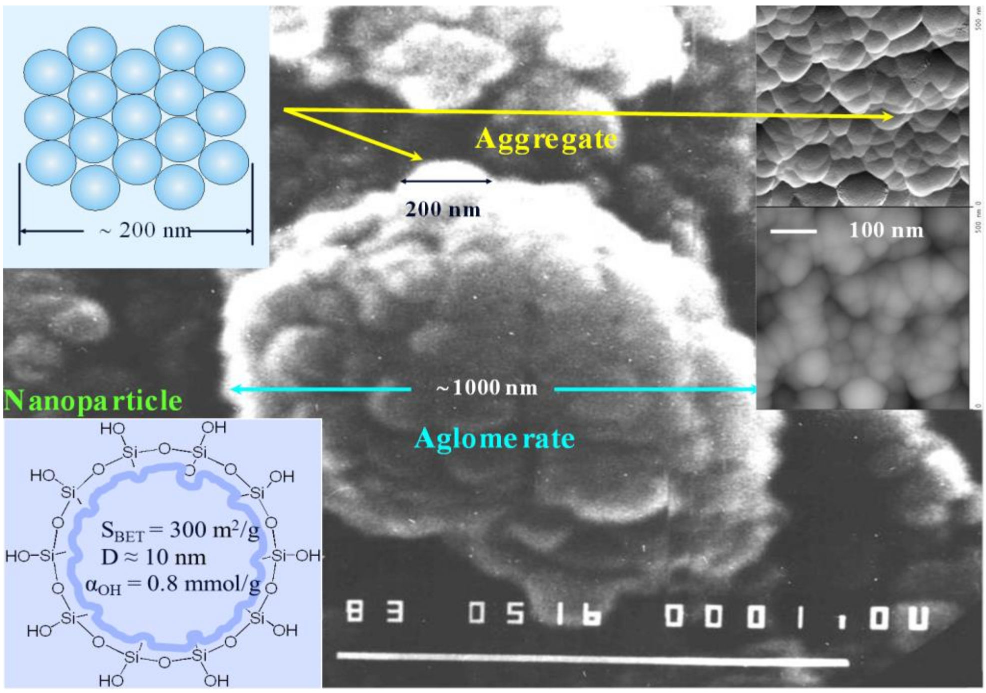


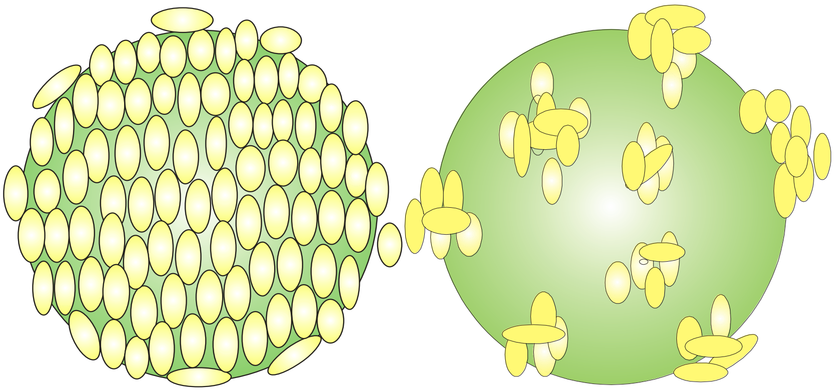
Fig.1. Scheme and microphotographs of nanosilica.

By adsorption modification with the use of vacuum technology, various inorganic and organic substances with ice-forming activity were grafted onto the surface of the nanoparticles. Surface clusters were formed both with pure AgI and additives of other iodides such as ammonium, potassium and calcium [12-14]. As an organic substance, phloroglucinol (1,3,5-trioxibenzene) was used. Two types of structures were created on the surface of nanoparticles: (I) a monomolecular adsorption layer, and (II) phloroglucinol molecules chemically bonded to the surface.

Studies of the ice-forming properties of the prepared reagents were carried out in a laboratory at UkrNIGMI. It was found that the yield of active particles depends on the nature and content of substances possessing ice-forming activity. For synthesized samples, it was varied from 10^{13} g^{-1} in the case of surface clusters with pure AgI to 10^{11} g^{-1} for a monolayer of phloroglucinol. By combination of content of precious metals, synthesis conditions, availability of raw materials, etc., reagents with additives of iodides of other metals could be considered as promising compositions. However, the combination of pulverized highly disperse silica and vacuum technology has made it impossible to convert such a laboratory method for preparation of a new type of crystallizing reagents into a real industrial technology.

Materials and methods

In recent years at the Chuiko Institute of Surface Chemistry of NAS of Ukraine in collaboration with colleagues from other countries, a method has developed for gas-phase solvate-stimulated adsorption modification (GSSAM) of nanosilica with inorganic salts and non-volatile organic compounds that is realized under normal conditions (room temperature and atmospheric pressure) [11, 15-17]. The use of the GSSAM method allows us to form submonolayer, monolayer or multilayer coatings on a surface of silica nanoparticles, as well as individual clusters with any nonvolatile organic compounds or inorganic salts (Fig. 2).



a) monolayer coating b) clusters

Fig. 2. Scheme of possible distribution of molecules at a surface of a silica nanoparticle.

The described synthetic capabilities of the GSSAM method allow us substantial simplification of the formation of a layer or clusters of ice-forming substances on a surface of nanoparticles. As a result, on the basis of the GSSAM method, the laboratory and then pilot technology for preparation of powdered ice-forming reagents based on nanosilica was created in at CISC.

Using a variety of GSSAM technologies including in situ reactions, samples based on nanosilica containing pure AgI and AgI with additions of other iodides, as well as samples containing phloroglucinol in the amount of 1 and 3 layers (Tables 1 and 2) were preparated.

Table 1

Samples of crystallizing reagents based on nanoscale silica with low bulk density

Sample number	Synthesis number	Composition	Bulk density, g/l	Ice crystals yield per 1 g of powder	
				t, °C	
1	M-333	AgI (≈ 10%), nanosilica	80	-12.0	$5.5 \cdot 10^{13}$
				-10.0	$4.46 \cdot 10^{13}$
				-9.0	$4.12 \cdot 10^{13}$
				-8.0	$1.53 \cdot 10^{13}$
				-5.5	$8.1 \cdot 10^{12}$
				-5.0	$6.0 \cdot 10^{12}$
				-4.0	$1.08 \cdot 10^{12}$
				-3.0	$9.66 \cdot 10^{11}$
2	M-335	AgI (≈ 10%), nanosilica	207	-10.0	$2.12 \cdot 10^{13}$
				-6.5	$4.3 \cdot 10^{12}$
				-5.5	$4.02 \cdot 10^{12}$
				-5.5	$3.9 \cdot 10^{12}$
				-5.0	$1.8 \cdot 10^{12}$
				-4.5	$4.84 \cdot 10^{11}$
				-2.4	$< 10^{9}$
3	M-336	AgI (≈ 10%), nanosilica	91	-12.0	$7.82 \cdot 10^{13}$
				-10.0	$5.94 \cdot 10^{13}$
				-10.0	$4.98 \cdot 10^{13}$
				-6.0	$3.6 \cdot 10^{12}$
				-5.5	$3.3 \cdot 10^{12}$
				-5.0	$2.5 \cdot 10^{12}$
				-4.5	$1.23 \cdot 10^{12}$
				-3.6	$3.74 \cdot 10^{11}$
4	M-332	phloroglucinol (≈ 9%), nanosilica	61	-11.0	$2.23 \cdot 10^{13}$
				-10.0	$2.01 \cdot 10^{13}$
				-6.0	$2.81 \cdot 10^{11}$
				-5.0	$1.80 \cdot 10^{11}$
5	M-334	phloroglucinol (≈ 23%), nanosilica	110	-11.0	$3.47 \cdot 10^{13}$
				-10.0	$3.38 \cdot 10^{13}$
				-5.0	$1.67 \cdot 10^{11}$

Table 2

Samples of crystallizing reagents based on nanoscale silica with high bulk density

Synthesis number	Composition		Bulk density, g/l	Note
	Active substance	content, %		
LN-211	AgI	10	377	
LN-212	AgI	10	413	
LN-213	Phloroglucinol	9	267	Monolayer
LN-214	Phloroglucinol	23	279	3 layers

Results and discussion

Studies of the ice-forming activity of the prepared reagents were carried out at CAO under the standard "Laboratory Method for Evaluating the Efficiency of Ice-Forming Reagents and Pyrotechnic Compositions in Laboratory Conditions" [18].

The yield of active particles per gram of preparation in a laboratory cloud chamber at temperatures of supercooled fog from -3 ºC to -12 °C, the moisture absorption capacity of the preparations, the size distribution and shape of the resulting particles were determined during testing.

The aerosol was obtained by spraying 10-20 mg of the reagent powder from a small glass using a syringe, followed by injection (insufflation) of the sample into a separate 800-liter aerosol chamber. After mixing and leveling the concentration with a fan, a sample of the obtained aerosol in optimum volume (from 20 to 150 cm^3 at different fog temperatures) was introduced into a supercooled fog into a cloud chamber (300 liters volume). The formed ice crystals were registered by the replica method.

Table 3 [19,20] gives generalized data on the yield of active particles for the investigated AgI-containing crystallizing reagents and pure silver iodide obtained using a two-stage CAO generator. For comparison, the average yields of active particles for the currently used pyrotechnic composition AD-1 containing 8% AgI are shown.

As can be seen from Table 3, the yield of active particles for reagents based on nanoscale silica is higher than that for pyrocomposition AD-1 with the advantage of nanoscale preparations being particularly high at a limit temperature of -3 °C.

Table 3

Temperature dependences of the yield of active particles on preparations based on silver iodide and pure AgI

Temperature, °C	AgI		Pyrotechnic composition AD-1
	Pure substance	On nanosilica surface	
-12	$(5÷7)·10^{14}$	$(5÷40)·10^{13}$	$(1÷2)·10^{13}$
-10	$(2÷4)·10^{14}$	$(2÷40)·10^{13}$	10^{13}
-8	$(2÷3)·10^{13}$	$(2÷20)·10^{13}$	$(5÷7)·10^{12}$
-6	$(2÷4)·10^{12}$	$(4÷40)·10^{12}$	$(2÷4)·10^{12}$
-5	$5·10^{11}$	$(2÷7)·10^{12}$	10^{12}
-4	limit of action	$(2÷20)·10^{11}$	$(5÷7)·10^{11}$
-3	–	$10^{11}÷10^{12}$	$(3÷6)·10^{10}$

Table 4 shows the temperature dependences of the yield of active particles for the most effective samples M-333 and LN-212 studied. For comparison, the efficiency values for the pyrotechnic composition of AD-1 tested at CAO in 2013 are given. At the temperature of supercooled fog of -10 °C, the yield of active particles for the most effective preparation LN-212 was $4·10^{14}$ per 1 g of composition, and at temperature of –3 ÷ –5°C it was $(1÷8)·10^{12}$.

Table 4

Comparison of the temperature dependences of the yield of active particles for the most effective preparations with AgI

Temperature, °C	M-333	LN-212	AD-1
-12	$5.50·10^{13}$	$5.0·10^{14}$	$1.27·10^{13}$
-10	$4.60·10^{13}$	$5.0·10^{14}$	$1.23·10^{13}$
-8	$1.53·10^{13}$	$3.50·10^{14}$	$7.84·10^{12}$
-6	$8.0·10^{12}$	$4.40·10^{13}$	$2.84·10^{12}$
-5	$6.0·10^{12}$	$8.0·10^{12}$	$1.0·10^{12}$
-4	$1.08·10^{12}$	$2.80·10^{12}$	$3.52·10^{11}$
-3	$9.66·10^{11}$	$\sim 10^{12}$	$6.0·10^{10}$

The tests showed that the ice-forming activity per mass unit of the AgI substance and phloroglucinol deposited on the surface of silica nanoparticles according to the GSSAM technology corresponds to the values of native preparations. In this case, the best sample containing AgI (Fig. 3) is superior in efficiency to the known AD-1 reagent.

Fig. 3. Photo of AgI/nanosilica powdery reagent (LN-212).

Conclusions

The results of the research have proved that the use of nanoscale highly disperse silica carrier and GSSAM technology of its modification with active ice-forming substances allows obtaining effective powder reagents for weather modification based on the principle of Levilites.

Such powder highly disperse nanoscale reagents have a number of advantages over the currently used pyrotechnic flares and burning of solutions:

- GSSAM technology allows creating a uniform layered coating or clusters on a surface of silica nanoparticles with practically any ice-forming substances such as organic, e.g., phloroglucinol, 1,5-dioxinaphthalene, copper acetylacetonate, and inorganic salts, e.g., metal iodides and chlorides and ammonium. Choosing the nature of the active substance, one could create both crystallizing and hygroscopic reagents.
- It is technically possible to combine several different active substances of different nature in an ice-forming preparation. This circumstance opens the possibility to create new reagents optimized by various parameters such as efficiency, price, availability of components, environmental friendliness, etc.
- When pyrotechnic flares and burning of solutions are used, the formation of highly disperse particles (nuclei of ice formation) takes place when a reagent is introduced into the zone of action. As noted, several factors influence this process that is difficult to predict. In our case, the reagent already contains the ice nuclei formed during the synthesis process. Their number and parameters, if necessary, can be estimated in advance.
- The process of introducing the reagent into the impact zone is greatly simplified. For this purpose it is sufficient to spray powder agent due to the air flow.

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ნანოზომის კაჟბადის ოქსიდის საფუძველზე დამზადებული ყინულწარმომქმნელი ფხვნილისებური რეაგენტების თვისებები და უპირატესობები

ე. ვორონინი, ლ. ნოსაჩი, ვ. გუნკო, ე. სოსნიკოვა,
ბ. დანელიანი, ბ. ხარმასი

რეზიუმე

მაღალდისპერსული ნანოზომის კაჟბადის ოქსიდის (SiO_2 (IV)) ვერცხლის იოდიდით და ფლოროგლუცინით აირფაზური სოლვატო-სტიმულირებული ადსორბციული მოდიფიცირების (ასსამ) გზით იქნა სინტეზირებული ლევილიტების პრინციპზე დაფუძვნებული რიგი ყინულწარმომქმნელი რეაგენტები ფხვნილის სახით. მიღებული რეაგენტების ლაბორატორულმა კვლევებმა გვაჩვენა, რომ (ასსამ) ტექნოლოგიით მაღალდისპერსული ნანოზომის კაჟბადის ოქსიდის ზედაპირზე დატანილი AgI და ფლოროგლუცინის ნივთიერების ყინულწარმომქმნელი აქტიურობა მასის ერთეულზე ნატიური პრეპარატების მნიშვნელობებს შეესაბამება. ამასთანავე AgI-ს შემცველი საუკეთესო ნიმუში თავის ეფექტურობით აღემატება ცნობილ АД-1 ტიპის რეაგენტს.

Свойства и преимущества порошковых льдообразующих реагентов на основе наноразмерного кремнезёма

Е.Ф. Воронин, Л.В. Носач, В.М. Гунько,
Е.В. Сосникова, Б.Г. Данелян, Б. Хармас

Резюме

Путём газофазного сольвато-стимулированного адсорбционного модифицирования (ГССАМ) высокодисперсного наноразмерного кремнезёма иодидом серебра и флороглюцином был синтезирован ряд порошковых льдообразующих реагентов, основаных на принципе левилитов. Лабораторные исследования полученных реагентов показали, что льдообразующая активность на единицу массы вещества AgI, и флороглюцина, нанесённых на поверхность наночастиц кремнезёма по ГССАМ-технологии, соответствует значениям нативных препаратов. При этом лучший из образцов, содержащий AgI, превосходит по эффективности известный реагент АД-1.

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CONTENTS

სარჩევი

საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

სერია ა. დედამიწის ფიზიკა

ჟურნალი იბეჭდება საქართველოს გეოფიზიკური საზოგადოების პრეზიდიუმის დადგენილების საფუძველზე

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