ISSN 1512-1127

# საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

*ტომი 21 , № 2*

# JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

***Physics of Solid Earth, Atmosphere, Ocean and Space Plasma***

***Vol. 21, № 2***

**Tbilisi**

**2018**

ISSN 1512-1127

# საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

*ტომი 21 , № 2*

# JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma*

*Vol. 21, № 2*

**Tbilisi**
**2018**

## საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

### მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

### მთავარი რედაქტორი: თ. ჭელიძე



### ჟურნალის შინაარსი:

ჟურნალი მოიცავს მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკის ყველა მიმართულებას. ჟურნალში ქვეყნდება: კვლევითი წერილები, მიმოხილვები, მოკლე ინფორმაციები, დისკუსიები, წიგნების მიმოხილვები, განცხადებები, კონფერენციების მოხსენებები.

## JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

### *Physics of Solid Earth, Atmosphere, Ocean and Space Plasma*

### Editor-in-chief: T. Chelidze



### Scope of the Journal:

The Journal is devoted to all branches of the Physics of Solid Earth, Atmosphere, Ocean and Space Plasma. Types of contributions are: research papers, reviews, short communications, discussions, book reviews, announcements, conference reports.

## ЖУРНАЛ ГРУЗИНСКОГО ГЕОФИЗИЧЕСКОГО ОБЩЕСТВА

### Физика Твердой Земли, Атмосферы, Океана и Космической Плазмы

### Главный редактор: Т. Челидзе



### Содержание журнала:

Журнал Грузинского геофизического общества охватывает все направления физики твердой Земли, Атмосферы, Океана и Космической Плазмы. В журнале публикуются научные статьи, обзоры, краткие информации, дискуссии, обозрения книг, объявления, доклады конференций.

**მისამართი:**

საქართველო, 0160, თბილისი, ალექსიძის ქ. 1, მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტი
ტელ.: 233-28-67; ფაქსი; (995 32 2332867); ელ. ფოსტა: tamaz.chelidze@gmail.com; avtandilamiranashvili@gmail.com;
geophysics.journal@tsu.ge

**გამოქვეყნების განრიგი და ხელმოწერა:**

გამოიცემა წელიწადში ორჯერ. მყარი ვერსიის წლიური ხელმოწერის ფასია: უცხოელი ხელმომწერისათვის - 30 დოლარი, საქართველოში - 10 ლარი. ხელმოწერის მოთხოვნა უნდა გაიგზავნოს რედაქციის მისამართით. შესაძლებელია უფასო ონლაინ წვდომა:
http://openjournals.gela.org.ge/index.php/GGS

ჟურნალი ინდექსირებულა Google Scholar-ში:
https://scholar.google.com/citations?hl=en&user=pdG-bMAAAAAJ

**Address:**

M. Nodia Institute of Geophysics, 1 Alexidze Str., 0160 Tbilisi, Georgia
Tel.: 233-28-67; Fax: (99532) 2332867; e-mail: tamaz.chelidze@gmail.com; avtandilamiranashvili@gmail.com;
geophysics.journal@tsu.ge

**Publication schedule and subscription information:**

The journal is issued twice a year. The subscription price for print version is 30 $ in year.
Subscription orders should be sent to editor's address. Free online access is possible:
http://openjournals.gela.org.ge/index.php/GGS

The journal is indexed in the Google Scholar:
https://scholar.google.com/citations?hl=en&user=pdG-bMAAAAAJ

**Адрес:**

Грузия, 0171, Тбилиси, ул. Алексидзе, 1. Институт геофизики им. М. З. Нодиа
Тел: 233-28-67; 294-35-91; Fax: (99532)2332867; e-mail: tamaz.chelidze@gmail.com; avtandilamiranashvili@gmail.com;
geophysics.journal@tsu.ge

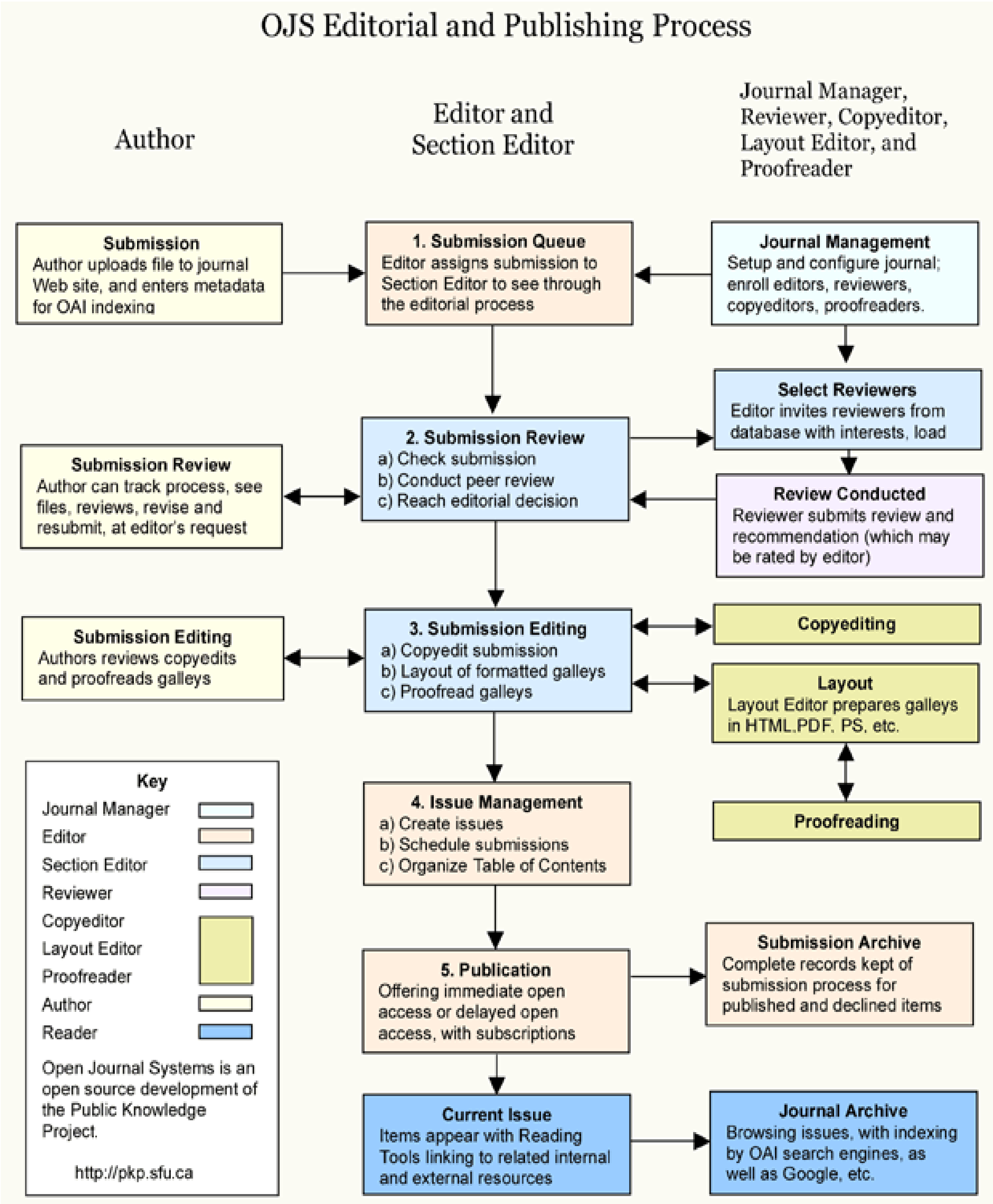
**Порядок издания и условия подписки:**

Журнал издается дважды в год. Годовая подписная цена для печатной версии - 30 долларов США. Заявка о подписке высылается в адрес редакции. Имеется бесплатный онлайн доступ
http://openjournals.gela.org.ge/index.php/GGS

Журнал индексирован в Google Scholar:
https://scholar.google.com/citations?hl=en&user=pdG-bMAAAAAJ

**This journal uses Open Journal Systems 2.4.8.3, which is open source journal management and publishing software developed, supported, and freely distributed by the Public Knowledge Project under the GNU General Public License.**

**(http://openjournals.gela.org.ge/index.php?journal=GGS&page=about&op=aboutThisPublishingSystem)**



*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 5 - 11*

# Evaluation of Seismic Hazard for Georgia and Seismic Risk for City Mtskheta with Modern Aproaches

**Nino S. Tsereteli, Otar Sh . Varazanashvili, Zurab R. Gogoladze, Vakhtang G. Arabidze, Davit T. Svanadze, Manana P. Kupradze, Irine B. Khvedelidze**

*M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University*

***ABSTRACT***

In this paper we are presented brief overview of the project "Evaluation of seismic hazard for Georgia and seismic risk for city Mtskheta with modern aproaches". Seismic hazard and risk assessment is very importance in Southern Caucasus (SC) and particularly in Georgia. The goal of society is to create urban environment that is protected from destructive earthquakes and minimize the expected losses. However, complete elimination of expected losses is unreal. One of the reasons for it is deficiency of knowledge about real seismic hazard and vulnerability of urban areas and infrastructure. In this regard, the general purpose of this project was to provide a reliable seismic hazard assessment at the national level and risk assessment for strategically important objects (cities, critical facility, lifelines, cultural heritage and others) of Georgia. In our case Historic city Mtskheta was chosen as strategic objects. Historic city Mtskheta is located in eastern Georgia, and is the administrative centre of the region of Mtskheta-Tianeti and Mtskheta Municipality. Mtskheta is a city museum and in 1994 was listed as a UNESCO World Heritage Site. Mtskheta is characterized by increasing urbanization, population density and infrastructure. Also taking into account the current reality of high vulnerability, the results of this project allowed us to evaluate recommendations for a new strategy of urban planning of the city, by proposing specific mitigation actions in district with high seismic risk, as well as adequate protection of infrastructures in case of earthquake.

***Key words***: seismic hazard, seismic risk, earthquake

## Research goals

The one of main goal of the project includes a new assessment of the seismic hazard at the national level; evaluation of local seismic hazard for the city of Mtskheta; assessment of its seismic risk and analysis of mitigation action of the risk.

Seismic hazard analysis involves the quantitative estimation of ground shaking hazards at a particular area that are expressed in term of peak ground acceleration (PGA), spectral acceleration (SA) and macroseismic Intensity I. Seismic hazard analysis consists of four main steps: i. Definition of a reliable seismic earthquake catalogue extended back in time as much as possible; ii. development seismic sources model at national level; iii. selection of ground motion prediction attenuation models for the relevant ground shacking parameters; iv. Integrate (1)-(3) into probabilistic calculation of seismic hazard curves with uncertainties.

Seismic sources (SS) and methodology of probabilistic seismic hazard assessment of the region were developed in EMME project [1,2]. Catalogue were developed up to 2006 year for the region of Middle East [3]. Unification of catalogues towards of Mw and Ms were done according correlation equations proposed by Zare el al [3]. Following these work Catalogue of earthquakes were updated up to 2017 for Georgia and surrounding regions. In modern methods of seismic hazard assessment the use of active faoults as one of SS is recomended, which in turn requires accurate knowledge of the 3-dimensional geometry of the active faults and slip rates along them. Another type of SS is area seismic sources (ASS). In this work we have taken active foults sources from work [1] and developed new areas sources.

Each zone was defined with the parameters: the geometry, the magnitude-frequency relation parameters as slop of curve $b_{GR}$ and seismic activity - $a_{GR}$, maximum magnitude Mmax, depth distribution and tectonic characteristics.

Due to the lack of records for strong earthquakes at short epicentral distances, four (global and regional) models of prediction equation were used [4,5,6,7]. On the basis of obtained seismic sources probabilistic seismic hazard maps were calculated in terms of peak ground acceleration (PGA) and spectral accelerations (SA) at 0.2, 1, 2, 4 sec for 10% probability and 2% probability in 50 years using attenuation relationships [4,5,6,7] correspondingly for Rock $Vs_{30}$=801m/sc using EZ-FRISK. Results are presented in Fig. 1,2.

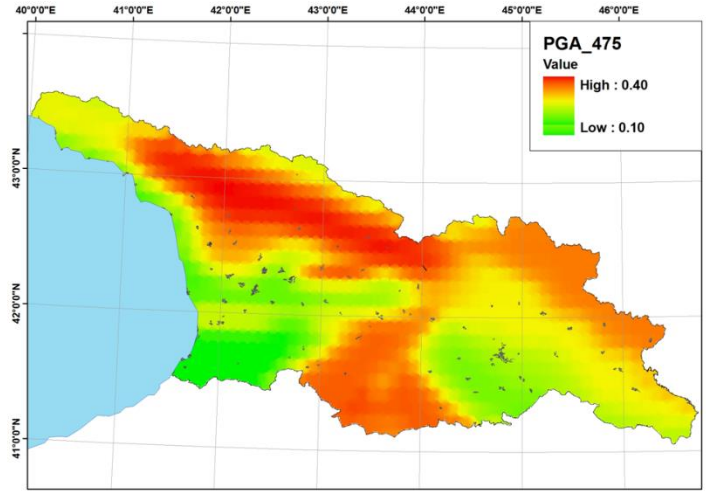



Fig. 1. Probabilistic seismic hazard maps for 10% probability in 50 years.

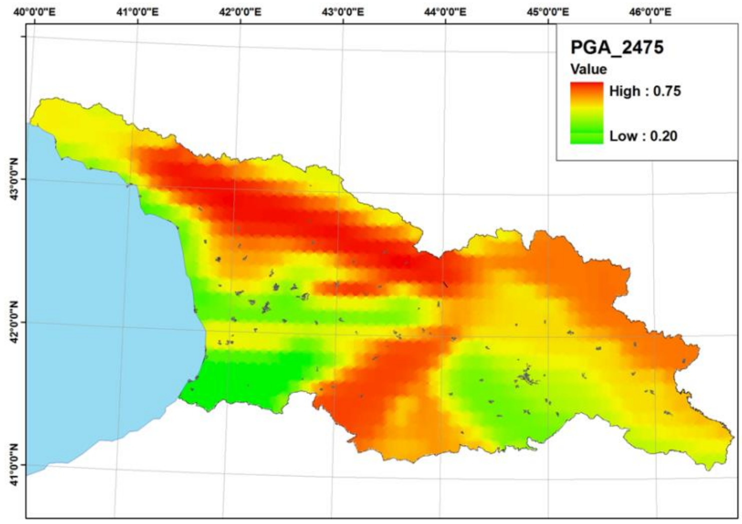



Fig. 2. Probabilistic seismic hazard maps for 2 % probability in 50 years
Estimated seismic hazard were used as input motion for local seismic hazard assessment for Mtskheta region.

## Local seismic hazard assessment

In Mtskheta areas, for the local seismic hazard assessment first all information of previously available geological, geotechnical, geophysical data were collected. These information were provided by City Hall of Mtskheta.

New on-sight fieldworks investigations were done to define the subsoil model, based on local lithological-geotechnical units, their stratigraphic and geometric relationships, and their typical physical-mechanical parameters. The site investigation of Mtskheta was carried by geophysical measurements that performed MASW and noise measurements processed with HVSR technique. HVSR method is widely used for the site investigation studies in the last two decades [8,9]. However the horizontal and vertical (H/V) spectral ratio of natural seismic noise first proposed by Nogoshi and Igarashi [10,11]) and this technique revised by Nakamura [12]. The analysis of H/V allows us to estimate S-wave resonance frequency $f_0$ *(Hz)* of the sedimentary cover and it's thickness of overlying bedrock. As a relation between the thickness $h$ and average S-wave velocity (Vs) of the sedimentary layer [13,14] by the equation :

$$f = \frac{Vs}{4h} \quad (1)$$

In order to evaluate S-wave velocity profile with depth we use Joint inversion of Raylegh wave dispersion curve and H/V curve. The inversion procedure was carried out by Montecarlo algorithm (MC), a multimodal Monte Carlo inversion based on a modified misfit function [15] that was proposed by Maraschini and Foti [16].

Figure 3 is presented investigating area. Red dots are were single station investigations were done and blue lines indicated place were MASW measurement were done.

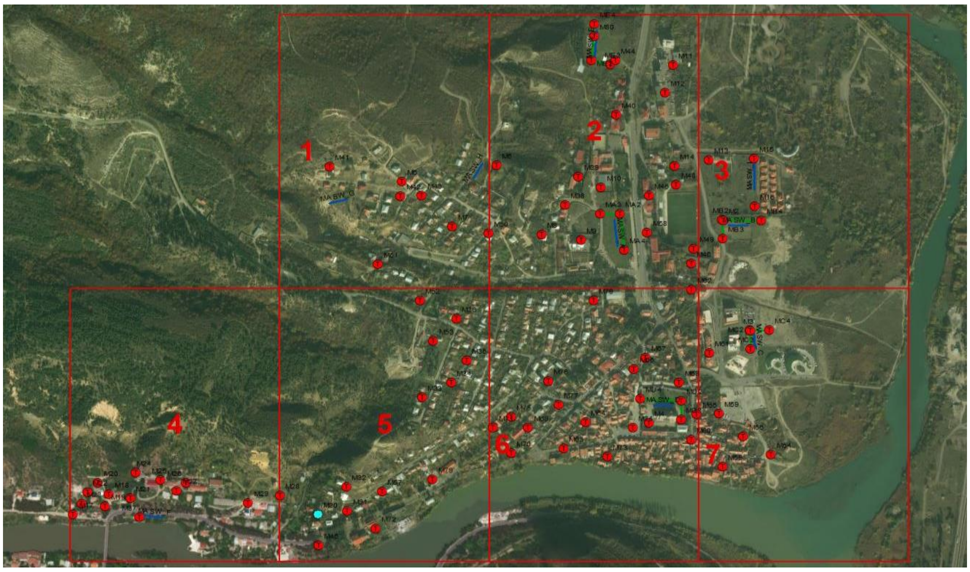



Fig. 3. Investigated areas of city Mtskheta for seisic microzonation

Finally investigated area were characterised by dominant frequency and $V_{S30}$.

## Seismic Risk Assessment

For seismic risk assessment first inventory of residential building were created for city Mtskheta.

The inventories of the built environment (building and lifeline system) was studied and converted into a GIS system with the following categories:

- Base map: Buildings, streets (street name and building number), parks, green areas, rivers, lakes, sports stadia etc (Fig. 1);
- Buildings: Building material, number of storeys, number of entrances, condition of building, building period of Tbilisi buildings, photos of old Tbilisi buildings, populatin numbe;
- Initial cost of bulding;
- Electricity system: Electric power transmission lines, operating stations and centrals;
- Water aqueducts and supply system: water transmission system, sanitary sewer system, pumping stations, and reservoirs;
- Relief of Mtskheta: Digital Elevation Model (DEM);
- Aerial photos of Mtskheta.

Based on inventory map, vulnaranilty of building were estimated according to [17].

Finally seismic risk in terms of damage, economic losses in GEL were estimated for scenario earthquakes with intensity I=7,8,9 at MSK 64 scale.

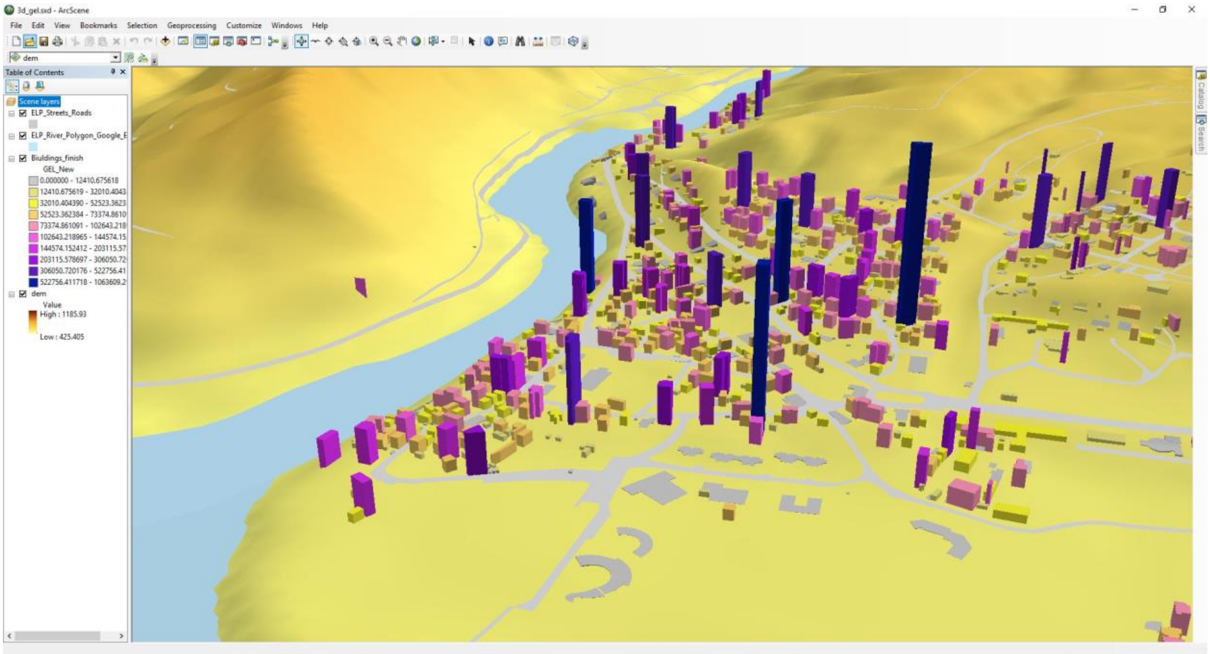


Fig. 4. Economic losses in GEL for Intensity I = 9 at MSK 64 scale

On bases of obtained investigation Map of the emergency limit condition was produced for the study area, underlining critical elements and priority order of intervention.

**Acknowledgements**: This work was supported by Shota Rustaveli National Science Foundation (SRNF) (Project 216758).

**References:**

[1] Danciu, L., Sesetyan, K., Demircioglu, M. B., Giardini, D., Erdik, M., Akkar, S., Gulen, L., Zare, M., Adamia, Sh., Ansari, A., Arakelyan, A., Askan, A., Avanesyan, M., Babayan, H., Chelidze, T., Durgaryan, R., Elias, A., Hamzehloo, H., Hessami, Kh., Kalafat, D., Kale, O., Karakhanyan, A., Khan, M. A., Mamadli, T., Al-Qaryouti, M., Sayab, M., Tsereteli, N.,Utkucu, M., Varazanashvili, O., Waseem, M., Yalcin, H., Yilmaz, M.T.The 2014 Earthquake Model of the Middle East: Seismogenic Sources. Bulletin of Earthquake Engineering. Volume 16, Issue 8, 1 August 2018, Pages 3465-3496.DOI: 10.1007/s10518-017-0096-8

[2] Sesetyan, K., Demircioglu, M., Gulen, L., Zare, M., Basili, R., Elias, A.,Adamia, Sh., Tsereteli, N., Yalcin, H., Utkucu, M., Asif Khan, M., Sayab, M., Hessami, Kh., Rovida, A. N., Stucchi, M., Burg, J. P., Karakhanian, A., Babayan, H. Avanesyan, M., Mammadli, T., Al-Qaryouti, M., Kalafat, D., Varazanashvili, O., Erdik, M., Giardini, D.The 2014 seismic hazard model of the Middle East: overview and results**.** Bulletin of Earthquake Engineering. Volume 16, Issue 8, 1 August 2018, Pages 3535-3566. DOI: 10.1007/s10518-018-0346-4
[3] Mehdi Zare , HamidehAmini, PouyeYazdi, Karin Sesetyan, Mine BetulDemircioglu, DoganKalafat, Mustafa Erdik, Domenico Giardini , M. Asif Khan , Nino Tsereteli. 2014. Recent developments of the Middle East catalog. Journal of Seismology. Volume 18, N4 , pp.749-772, July. DOI 10.1007/s10950-014-9444-1
[4] Cauzzi, C., Faccioli, E., Vanini, M., Bianchini, *A.* 2015a. Updated predictive equations for broadband (0.01–10 s) horizontal response spectra and peak ground motions, based on a global dataset of digital acceleration records. Bulletin of Earthquake Engineering 13 (6), 1587-1612.
[5] Campbell, K. W., and Bozorgnia, Y. 2014. NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5%-damped linear acceleration response spectra. Earthquake Spectra, 30(3): 1087–1115, Aug 2014. doi: 10.1193/062913EQS
[6] Chiou, B. and Youngs *R. R.* 2014. Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra. Earthquake Spectra: August 2014, Vol. 30, No. 3, pp. 1117-1153.
[7] Kotha, S.R., Bindi, D. and Cotton, F. 2016a. Magnitude and Region Dependent Correlation of Response Spectral Values for Site-specific Conditional Mean Spectra. Submitted to Bulletin of Earthquake Engineering 12.
[8] Bard, P.-Y.: Microtremor measurements: a tool for site effect estimation, in: The effects of surface geology on seismic motion, edite by: Irikura, K., Kudo, K., Okada, H., and Sasatani, T., Balkema, Rotterdam, 1251–1279, 1999.
[9] Bonnefoy-Claudet, S., Cotton, F., Bard, P.-Y., Cornou, C., Ohrnberger, M., and Wathelet, M.: Robustness of the H/V ratio peak frequency to estimate 1D resonance frequency, in: Proceedings of the 3rd International Symposium on the Effects of Surface Geology on Seismic Motion, 2006.
[10] Nogoshi, M. and Igarashi, T. (1970). On the propagation characteristics of microtremors. J. Seism. Soc. Japan 23, 264-280(in Japanese with English abstract).
[11] Nogoshi, M. and Igarashi, T. (1971). On the amplitude characteristics of microtremors. J. Seism. Soc. Japan. 24, 24-40(in Japanese with English abstract).
[12] Nakamura, Y. （1989）. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report Railway Tech. Res. Inst., 30:1, 25-30.
[13] Lachet C., Bard P.-Y. (1994). Numerical and Theoretical Investigations on the Possibilities and Limitations of Nakamura's Technique. J. Phys. Earth, 42, 377-397.
[14] Fäh, D., Rüttener, E., Noack, T. and P. Kruspan (1997). Microzonation of the City of Basel. Journal of Seismology, 1, 87-102.
[15] Maraschini M. Ernst F.E. Foti S. Socco L.V., 2010. A new misfit function for multimodal inversion of surface waves, *Geophysics*, 75 (4), G31–G43, doi:10.1190/1.3436539.
[16] Maraschini M. Foti S., 2010. A Monte Carlo multimodal inversion of surface waves, *Geophys. J. Int.*, 182(3) 1557–1556, oi: 10.1111/j.1365-246X.2010.04703.x.
[17] Nino Tsereteli, VakhtangArabidze, OtarVarazanashvili, TengizGugeshashvili, TeimurazMukhadze and Alexander Gvencadze. 2014. Vulnerability Analysis and GIS Based Seismic Risk Assessment Georgia Case. Improving Disaster Resilience and Mitigation - IT Means and Tools. ISBN:NATO Science for Peace and Security Series C: Environmental Security 143, pp.307-321. http://link.springer.com/chapter/10.1007/978-94-017-9136-6_20#page-1

# სეისმური საშიშროების შეფასება საქართველოსთვის და სეისმური რისკის ქალაქ მცხეთისთვის თანამედროვე მიდგომებით

ნ. წერეთელი, ო. ვარაზანაშვილი, ზ. გოგოლაძე,  ვ. არაბიძე, დ. სვანაძე, მ. კუპრაძე, ი. ხვედელიძე

**რეზიუმე**

სტატიაში მოკლედ არის წარმოდგენილი სამუშაოები, რომელიც ჩატარდა პროექტის - "სეისმური საშიშროების შეფასება საქართველოსთვის და სეისმური რისკის ქალაქ მცხეთისთვის თანამედროვე მიდგომებით" - ფარგლებში. სეისმური საშიშროებისა და რისკის შეფასება ძალიან მნიშვნელოვანია სამხრეთ კავკასიისთვის და განსაკუთრებით საქართველოსთვის. საზოგადოების მიზანია ისეთი ურბანული გარემოს შექმნა, რომელიც დაცული იქნება დამანგრეველი მიწისძვრებისაგან და შემცირებული იქნება მოსალოდნელი დანაკარგები. თუმცა, დანაკარგების სრული არიდება არარეალურია. ამის ერთ-ერთი მიზეზია ცოდნის დეფიციტი რეალური სეისმური საშიშროების, განაშენიანებისა და ინფრასტრუქტურის მოწყვლადობის შესახებ. ამასთან დაკავშირებით, მოცემული პროექტის ძირითადი მიზანი იყო  სეისმური საშიშროების სანდო შეფასების უზრუნველყოფა ნაციონალურ დონეზე და რისკის შეფასება საქართველოს სტრატეგიულად მნიშვნელოვანი ობიექტებისათვის (ქალაქები, კრიტიკული ობიექტები, სასიცოცხლო მნიშვნელობის ხაზები, კულტურული მემკვიდრეობის ძეგლები და სხვა). ჩვენ შემთხვევაში მნიშვნელოვან ობიექტად არჩეული იქნა ქალაქი მცხეთა. ისტორიული ქალაქი მცხეთა მდებარეობს საქართველოს აღმოსავლეთ ნაწილში და წარმოადგენს მცხეთა-მთიანეთისა მცხეთის მუნიციპალიტეტის ადმინისტრაციულ ცენტრს. მცხეთა არის ქალაქი-მუზეუმი და 1994 წელს შეტანილ იქნა მსოფლიოს დანატოვარის UNESCO-ს სიაში. მცხეთისთვის დამახასიათებელია მზარდი ურბანიზაცია, მოსახლეობის სიმკვრივე და ინფრასტრუქტურა. გარდა ამისა თუ მხედველობაში მივიღებთ რეალურად არსებულ მაღალ მოწყვლადობას, ამ პროექტის შედეგებმა  საშუალება მოგვცა შეგვემუშავებინა რეკომენდაციები ქალაქის ურბანული დაგეგმარების ახალ სტრატეგიასთან დაკავშირებით, შეგვეთავაზებინა კონკრეტული ზომები შედეგების შერბილებისათვის მაღალი სეისმური საშიშროების რაიონში, აგრეთვე ინფრასტრუქტურის დასაცავად მიწისძვრის შემთხვევაში.

# Оценка сейсмической опасности для Грузии и сейсмического риска для города Мцхета с современными подходами

**Н.С. Церетели, О.Ш. Варазанашвили, З.Р. Гоголадзе, В.Г. Арабидзе, Д.Т. Сванадзе, М.П. Купрадзе, И.Б. Хведелидзе**

**Резюме**

В статье кратко представлены работы, проведенные в рамках проекта - «Оценка сейсмической опасности для Грузии и сейсмического риска для города Мцхета с современными подходами». Оценки сейсмической опасности и риска очень важны для Южного Кавказа и особенно для Грузии. Цель общества - создать такую городскую среду, которая будет защищена от разрушительных землетрясений и будут уменьшатся ожидаемые потери. Однако полное устранение потерь - нереально. Одна из причин этого является дефицит знаний о реальной сейсмической опасности, уязвимости застроики и инфраструктуры. В связи с этим основной целью этого проекта была обеспечить достоверную оценку сейсмической опасности на национальном уровне и оценку риска для стратегически важных объектов Грузии (города, критические объекты, жизненно важные линии, памятники культурного наследия и т.д.). В нашем случае в качестве важного объекта был выбран город Мцхета. Исторический город Мцхета расположен в восточной части Грузии и является административным центром Мцхета-Мтианети и Мцхета муниципалитета. Мцхета - город-музей, который в 1994 году был включен в список мирового наследия ЮНЕСКО. Мцхета характеризуется растущей урбанизацией, плотностью населения и инфраструктурой. Кроме того, если учесть реально существующую высокую уязвимость, результаты этого проекта позволили нам разработать рекомендации для новой стратегии городского планирования, предложить конкретные меры по смягчению последствии в районе высокой сейсмической опасности, также для защиты инфраструктуры в случае землетрясения.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 12 -23*

# On the Probable Technical Reasons of the Devastating Flood in 2015 in Tbilisi

**[1]Zurab A. Kereselidze, [1]Irina B. Khvedelidze, [2]Giorgi V. Shergilashvili**

[1]*M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University, e-mail:z_kereselidze@yahoo.com*
[2]*Orion Studio*

***ABSTRACT***

The analysis of the possible technical reasons, which contributed catastrophic results of the flood on the Vere river 13.06.2015, which can become basis for the preventive actions in the case of repeating a similar extreme phenomenon in the future is carried out.

***Key words***: river Vere, flood

**Preface**. The river Vere is a typical mountain river with more than 40 km long gorge, about 1500 m water level difference and average yearly water flow Q $\approx$ 1m$^3$s$^{-1}$. The river is considered as one of the most dangerous in East Georgia due to frequent recurrent floods characterized by two orders of magnitude greater water flow than the average yearly value. The permanent complex meteorological-hydrological observations on the river flow regime include a period of more than half a century [1,2]. Besides, there are quite complete data on individual devastating floods, which occurred between the end of the 19th century and the second half of the 20th century. Usually, floods used to occur in the lower part of the Vere gorge near the boundary of Tbilisi city. In the Soviet period the flood zone was the area between the two tunnels (underground tubes) constructed in the first half of the last century. The first tube, which is nowadays situated under the Tamarashvili Highway, was 108 m long. The other tube was significantly longer, $l \approx$ 700 m. It occupied the natural bed of the river Vere before the junction with the river Mtkvari. Before 13.06.2015 night, for a long time, the flood taking place on 04.07.1960 was considered as the heaviest one. According to various assessments the flood was caused by the $h \approx 100$ mm precipitations, which fell during two and half an hour. According to approximate assessments, during this time period, the maximum water flow in the Vere bed could be $Q \approx$ 260 m$^3$s$^{-1}$ [3]. According to our assessments the water flow in the closed bed of the river Vere during the night of 13.07.2015 was probably the same as the one of the 04.07.1960 flood [4]. However, the result of the last one appeared much disastrous due to human life losses and enormous material damage.

Like other mountain rivers of Georgia the bed of the river Vere is curving. It is quite deep in its upper part and considerably wide in the lower part. There are numerous springs on the either sides of the Vere Gorge. The dry ravines, also met here, turn into gutters during precipitations. In the areas of Tbilisi the surface and underground waters of the city also join the river Vere. Therefore, in the case of intense precipitations the lower, part of the Vere gorge turns into a fairly large catchment basin. Consequently, there could be no doubts that changing the bed of the river could be followed by negative consequences. After constructing the part of the high-speed highway in 2010 in the lower part of the gorge, the river Vere appeared partially contained in the artificial closed bed consisting of several tunnels joined by open sectors. Therefore, the geometrical properties of the natural bed corresponding the orography of the gorge, was significantly changed. It is probable that the first changes in the natural flow of the river Vere, which took place during the Soviet period, changed the parameters of the river bed and it could eventually affect the consequences of the flooding on 04.07.1960. The new closed bed of the river Vere, instead of two, has seven tunnels with general length of 2100 m. The two tunnels, which had been constructed earlier, were partially elongated and as a result, nowadays the first tunnel is $l \approx$ 360 m and the other is $l \approx$ 1200 m long.

Figure 1 shows a scheme of modernized old  and new tunnels. The tunnels are placed along the natural bed of the river, from the Tamarashvili Highway to the junction with the river Mtkvari. The tunnels are complex structures made of concrete and corrugated steel sheets at straight sections. At curved sections the steel sheets are replaced with reinforced concrete. At cross section the tunnels look like a semicircular arch, which rests on a flat concrete base.

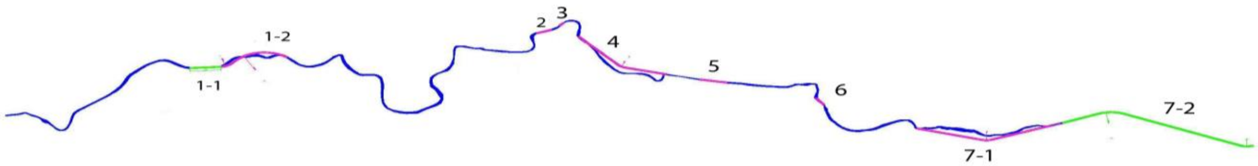



Fig. 1.

Scheme of modernized old (green sections) and new tunnels (red sections)

**Specification of the construction made of corrugated steel sheet**. The theory of the construction of water supply canals states that arched tunnels and bridges constructed from corrugated steel have a sufficiently high seismic stability. Therefore, according to their technical and economic characteristics, they are almost as stable as structures made of stone, reinforced concrete or metal. Moreover, large water pipes made of corrugated steel have some advantages over concrete ones due to technological simplicity and less labour-intensiveness for construction and installation works. It is known that one of the advantages of arched tunnels and bridges made of corrugated steel is their ability to gradually fracture, i.e. soft bedding in case of considerably strong and prolonged tremors. Therefore, in poor countries like Georgia, corrugated steel structures are usually used for hydraulic facilities in seismically active regions. Obviously, this quality is important, as far as according to the current seismic zoning map, the territory of Tbilisi belongs to the earthquake zone of intensity VIII motion. However, it should be noted that after earthquakes with intensity VII-VIII, restoration of arched tunnels and bridges constructed from corrugated steel is is not recommended [5-7]. Consequently, after such earthquakes they must be completely disassembled. Corrugated water pipes are often used under bridges crossing narrow rivers and ravines. However, they should not be used for hydrotechnical objects in regard to mountain rivers with fairly long closed riverbeds. Despite this, the structure of the closed and sufficiently long arched tunnels of the river Vere was made of corrugated steel sheets. In particular, the total length of the tunnels of the closed channel was 46% of the original length of the natural river bed between the Tamarashvili highway and the river Mtkvari.

**The security problem of the closed channel of the river Vere**. A project of any potentially dangerous civil engineering object, including large hydraulic structures, should contain an analysis of probable negative consequences of the construction. According to generally accepted rules, it is necessary to take into account the changes in external conditions that arise during the construction and operation of the structure. Any problem should be considered, evaluated and reflected in concluding of opinions of official responsible persons. It is obvious that the project of the section of the high-speed highway in the gorge of the river Vere could not be an exception to this rule. Moreover, its safe operating required the minimization of the real threat seen not only from the history of the river Vere, but also from the data obtained of detailed observations during half a century. It was probably assumed that the closed channel, in addition to the transport problem, could also solve the flood problem in the lower part of the Vere gorge. However, it seems that mistakes were made during the design process, the reason of which is disregard of the factor of the hydraulic resistance in the tunnels having corrugated inner surfaces. As a result, the closed riverbed turned into an even greater danger than the historically known river Vere. Proceeding from such a vision of the reason for the development of the events, we cannot agree with the widely spread opinion that the devastating flood on 13.06.2015 was caused by anomalously heavy precipitation. Firstly, after different estimates, an explicit amount of precipitation height has not been established so far. Secondly, it was well known about the frequent occurrence of very heavy floods in the Vere gorge. Therefore, when designing a closed channel, it was necessary to a priori consider the dangers that could arise in case of severe weather conditions. Due to the constant threat of flooding, it was obviously not reasonable to use such constructions that could reduce the capacity of the closed channel. It would be quite likely that there would be retrospective data on the 04.07.1960 flood in order to assess the degree of danger potentially threatening the urbanized gorge of the river Vere. There were also valuable data on series of floods that occurred in the subsequent period of time. First of all, it was quite possible to estimate how much the capacity of the new tunnels of the closed channel corresponded to the full load of the modernized first tunnel. As it is shown below, most likely the damming occurred not only before the first tunnel, but also in front of other tunnels. An important proof in favour of such an assertion is the fact that the water from the dam formed on Svanidze Street did not flow over the Tamarashvili highway. Consequently, this highway was a watershed, dividing the gorge into two parts. Therefore, we can assume that the flooding beyond the watershed began independently from the reason of damming of the first tunnel. For this, e. g, it was sufficient that water flow in any of the tunnels was reduced due to the increase in hydraulic resistance, and also because of the drain of urban storm water in the lower part of the gorge. As it is known, on 04.07.1960, flooding occurred in front of both tunnels.

**Hydraulic resistance in the tunnels of the closed channel**. It seems that during the design process of the sector of the high-speed highway in the Vere gorge, increase in the hydraulic resistance of tunnels of the closed channel under severe conditions was underestimated. Indeed, there was a physical reason for a sharp decrease in water flow, which was associated with the corrugated structure of the inner surface of the tunnels. The negative effect could also intensify due to the critical curvature of the new segment of the first tunnel, the length of which increased more than twice after modernization. According to the prevailing opinion, the cause of the devastating flood was precipitation of exceptional intensity, as well as trees, brought by the water flow and accumulated in front of the inlet of the first tunnel. However, it seems that such an explanation is insufficiently substantiated. Undoubtedly, the inlet of the first tunnel for some time was actually partially blocked that contributed to the flooding in Svanidze Street. However, it is especially noteworthy that from here the water did not flow over the Tamarashvili Highway, which turned out to be a watershed. After some time, the inlet of the first tunnel was released. Therefore, the previously partially blocked tunnel could not operate at its maximum throughput. Besides, there was a flood also in the area between the outlet of the first tunnel and the inlet of the last one. As far as the first tunnel was partially blocked, this could hardly have been caused only by the additional flow of water from urban drains and precipitation in the area of this part of the Vere gorge. Indeed, according to rough estimates, the area of the bottom of the gorge is $S \approx 3*10^5$ m$^2$. The catchment area corresponding to this part of the gorge is about an order of magnitude larger. Taking into consideration that on 13.06.2015 the precipitation height was $h \approx 100$-150 mm, then an additional volume of water, beyond the watershed, could be $V \approx (3\text{-}4.5)10^5$м$^3$. Such an amount could accumulate during 2.5-3 hours. This corresponds approximately to the flow rate of water $Q \approx$ 25-30 m$^3$ s$^{-1}$, which is about 10% of the estimated throughput of the first tunnel. However, the first tunnel was partially blocked for some time, and consequently its capacity was lower than the design one. Therefore, in spite of the additional volume of water received from the gutter, in the case of sufficiently effective operation of other tunnels (especially the last one), floods in the lower part of the gorge were unlikely to have occurred. At least, here the water could not rise by 15 m or more. In fact, the water rose to such extent that the tunnels were below its level. Therefore, even if this estimate of the amount of the flooded water is understated, this factor could not raise the water level so high if the capacity of the tunnels was at a sufficient level. Moreover, in design calculations the maximum value of the water flow in a closed channel was $Q \approx$ 260 m$^3$ s$^{-1}$, which fully corresponds to emergency situations. However, we need additional facts for proving our opinion. Thus, below is a brief qualitative analysis, the basis of which is the hydrodynamic theory of turbulent water flow in rough pipes.

**Modelling of the closed tunnels.** It is well known that the coefficient of hydraulic resistance in a circular pipe depends on the characteristic value of the Reynolds number and also on the curvature and roughness of the inner surface of the pipe. There must be a similar dependence for all natural and artificial channels, including tunnel water pipelines. Therefore, using the hydrodynamic similarity method, it is possible to correctly model the hydraulic resistance of a water channel of any shape. Consequently, it is possible to accurately determine the characteristic value of the coefficient of hydraulic resistance of the tunnels of the closed bed of the river Vere. To do this, it is necessary to approximate the closed channel (i.e., any of the tunnels) with a circular cross-section curved rough pipe. Obviously, such an analogy, both for a separate tunnel and for a closed channel as a whole, is physically fully justified. The analogy between a tunnel with a corrugated inner surface and a rough pipe is also evident. It enables to determine the coefficient of hydraulic resistance, the key parameter on which the flow of water in any water pipe depends. The main determinant of the degree of turbulence in the water flowing in the pipe is the dimensionless parameter, the Reynolds number $R_e = \frac{\bar{u}D}{\nu}$, where $\bar{u}$ is average water flow velocity, $D$ is the pipe diameter, $\nu$ is kinematic viscosity of water. Therefore, for the closed channel of the Vere, the linear characteristics of which is the constant hydraulic radius of the tunnels, the speed of the river flow determines the characteristic value of the Reynolds number.

It is known that inner surface of smooth pipes may become rough over time due to deposits of solid impurities in water. It is established that among the different types of roughness, in regard to reducing the fluid flow rate, corrugated roughness is the most negative factor. It is obvious that the corrugated steel surface of the closed channel is highly similar to the wavy-rough inner surface of a water pipe. The degree of flow turbulence in the tunnels of the closed channel must increase due to the roughness of the corrugated surface. In harsh conditions on 13.06.2015 this should have an effect on the fluid flow. Besides roughness, in the curvilinear sections of the tunnels, the hydraulic resistance must have been further increased due to the action of centrifugal forces. However, according to our estimates, exactly the corrugated surface was the main reason for the decrease in throughput rate in the tunnels of the closed channel.

Negative effect of roughness in water pipes was noticed long ago. This effect was modelled in numerous experiments, among which the laboratory experiments carried out by Prof. I. Nikuradze in the 30s of the last century are the most popular [8-10]. These researches determined that among the various types of roughness on the inner surface of water pipes, undulating roughness causes the maximum decrease in fluid flow. According to physical similarity, the analogy of the corrugated steel surface of the closed river Vere and undulating rough surface of water pipes is obvious. It is known that for different hydrotechnical objects the permissible relative roughness can vary within the limits of 0.2%-7% [7]. This parameter is the relation of the characteristic height of roughness to the radius of a pipe, or to the characteristic linear dimension of the cross-section of a water channel of any other shape. The existence of a sufficiently wide range of permissible relative roughness values at hydrotechnical objects of various purposes is caused by practical reasons, e.g., an ambiguous dependence of hydraulic resistance on the linear parameters of water pipes was established, and the Reynolds numbers were also obtained from the turbulence regime of the water flow. In the case of a water channel of a pipe shape, such an ambiguous parameter is the length. It is characteristic of the well-known Hagen-Poiseuille formula, which determines the flow of laminar fluid in a circular pipe. In this formula, the pressure gradient also enters as the main determinant. A special modification of the Hagen-Poiseuille formula is used for turbulent flow. The correctness of its use depends on the flow turbulence regime. The degree of turbulence, in addition to the level of the tube load, is also affected by the roughness of its internal surface. The longer the roughened tube, the lower the upper limit of the interval of subcritical values of the relative roughness. Intensification of flow turbulence, i.e. the transition from the initial stage to an increasingly developed turbulence, will be reflected in an increase in the characteristic value of the Reynolds number. However, in case the throughput of a smooth analogue of a pipe approximating the water supply considerably exceeds the volume of incoming water, the upper limit of the permissible relative roughness of the inner surface of the water pipe can be increased to 7%. Taking this qualitative fact into account, let us return to the closed channel of the river Vere, the characteristic diameter of which is $D \approx 8$ m. According to [1-3] in the lower part of the Vere gorge at the time of high-water flow, the average flow velocity is $\bar{u} = 3.5 \text{ ms}^{-1}$. Consequently, the Reynolds number in case of full load of the closed channel can reach $R_e \approx 2 * 10^7$ value. Therefore, according to the range of permissible relative roughness values, the minimum theoretical height of the absolute roughness, which can have an effective influence on the hydraulic resistance of tunnels of the closed channel, is equal to $k \approx 10$ mm. However, the actual height of the protrusion of the corrugated steel surface is $k=150$ mm, i.e., it is more than an order of magnitude greater than the minimum theoretical value. Consequently, the relative roughness of the inner surface of the closed channel actually amounted to $\approx 4\%$. It is known that such roughness for some hydraulic structures, for example, irrigation canals, does not exceed the technically permissible limits. However, this is hardly acceptable for objects such as the closed tunnel of the river Vere.

**Formation of the stagnation zone**. It should be assumed that in emergency situations floods in a closed channel in the future can be caused not only by factors of roughness and curvature, but also other negative mechanisms. Obviously, roughness, under harsh conditions, in all sufficiently long tunnels of the closed channel will always contribute to the intensification of the turbulence and initiation of return flows. Therefore, we assume that the increase in hydraulic resistance to the critical level in the tunnels of the closed channel was one of the reasons that led to the disaster on 13.07. 2015. In particular, at the initial stage the flood zone formed in front of the first tunnel, the reason of which, in addition to the hydraulic resistance, was also partial overlapping of the inlet of the tunnel by various household objects and trees brought by the water flow. As a result, the flood zone gradually expanded and, according to oure estimates, a reservoir of volume /3.1-4.4/$10^5$ $m^3$ rapidly formed and was kept long enough along the entire length of Svanidze Street. Such a factor of mechanical damping, but to a lesser extent than before the first tunnel, was observed for a certain time also in front of the second tunnel. However, in our opinion, it is necessary to pay special attention to the fact that the section of the gorge between the first and second tunnel was dammed while the water flow in the first tunnel was diminishing.

Thus, it becomes obvious that the initial flood in the lower part of the Vere gorge occurred before inlet of the first tunnel. Then, regardless of the rapidly formed reservoir along the Svanidze Street, the areas in front of other tunnels were apparently also flooding. For example, after the first tunnel such a place could be the inlet of the second tunnel, or the inlet of the longest, the last tunnel connecting the Vere to the main river Mtkvari. Probably, it was the joint action of all local flood zones that resulted in heavy flooding. However, regarding the probability of possible repetition of severe meteorological conditions in the future, it seems that the discussion of the technical causes of the devastating 13.06.2015 flood should be supplemented with the fact that the river Vere has a sharp bend in front of the second tunnel (Photo 1).


Photo 1.

Therefore, it can be assumed that together with the negative effect of the hydraulic resistance of the tunnel, this place inevitably became one of the initial flood areas during the devastating flood. In the process of reconstruction of the closed channel, it was evidently noticed. Therefore, seemingly, to avoid danger in the future, guiding walls were placed in front of the inlet of the second tunnel. Photo *2* shows that this additional structure resembles a funnel, the purpose of which, according to the plan, is to direct the water flow towards the tunnel. The first segments of these guide walls are parallel to the tunnel. The other segments, having a length of about 5 m, form following angles with the axis of the tunnel: $\gamma \approx 20$ ° and $\delta \approx 30$ °. However, contrary to the assumption of the designer, who completed this upgrade, we believe that this design, under severe conditions, will only cause reduction in the water flow in the tunnel. The fact is that the guiding walls, located at such angles, will definitely create counter flows that will collide near the inlet of this tunnel. The intensity of the colliding flows will increase in proportion to the increase in the water level. A direct confirmation of this conclusion is *Photo 3*, which enables to estimate the degree of filling of the second tunnel during a fairly intense rain on 07.07.2017. On this day, the precipitation level was about 20 mm, i. e. not more than 20% of the precipitation that fell during the devastating flooding on 13.06.2015. This fact is quite noteworthy and certainly ought to be taken into account. Therefore, below we give a concise form of an explanation of the physical essence of the phenomenon, the emergence of which is obviously the result of an insufficiently thought-out technical solution.

Photo 2

In the hydrodynamic theory of ideal incompressible jets, several analytical solutions to problems associated with the formation of stagnant zones or, in other words, zones of liquid stagnation, are known. These solutions are generally ambiguous, as they depend on some free parameter [11]. In problems of collision of ideal jets, this parameter is usually the angle between the directions of straight and backward flows. The physical essence of the ambiguity of analytical solutions in the problems of jet collision is shown in *Figure 2*.

It corresponds to the particular case of a collision at a right angle of two liquid jets having equal intensities. As a result of the collision, there are two jets that are also at right angles, of the same intensity as the original jets. In the area of the convergence of all jets, a zone of water stagnation with a finite linear dimension is formed. It is obvious that only such a particular solution, corresponding to the idealized case, is single-valued from the view point of determining the direction of divergent jets. In case when converging jets have different intensities and collide at an arbitrary angle, then any analytical solution obtained within the limits of the theory of ideal jets will be ambiguous. Nevertheless, for example, in irrigation problems, such a drawback may not be a fundamental obstacle to numerical simulation of the collision of intersecting water flows.

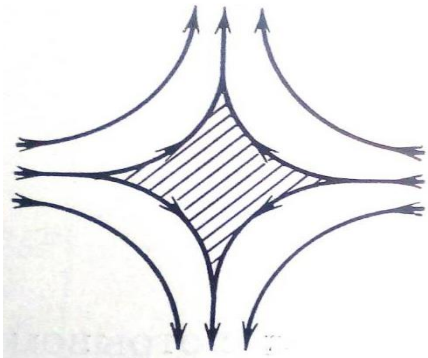


Fig.2

However, in the flat solutions obtained by the method of conformal mappings, the physical essence is, as a rule, concluded in the possibility of a thorough analysis of the asymptotic behaviour of the solution. An example of such an ambiguous solution is the mathematically indeterminate solution of the collision problem for two arbitrary jets $A_1$ and $A_3$, obtained in [12], which is schematically shown in Figure 3.

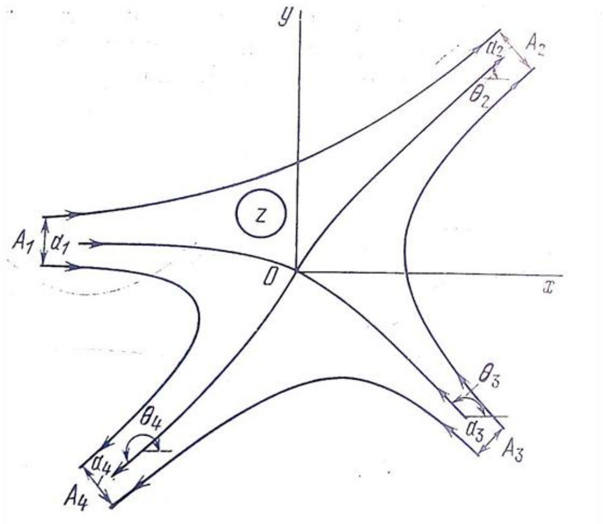



Fig.3

Several attempts to raise the practical value of this decision are known. In particular, it was substantially supplemented in work [13]. This synthesized analytical solution seems to be most suitable for simulating the flow before the second tunnel of the closed channel. In it, the problem of uncertainty was eliminated by estimating arbitrariness in the directions of the diverging jets $A_2$ and $A_4$, namely, the relation of the angle $\theta_2$ to the angle $\theta_4$ was established, which is a free parameter of the problem. Further, by the method of conformal mapping, having given values $\theta_2$ and $\theta_4$, for jets $A_1$ and $A_3$ colliding at the angle $\theta_3$, with flows $\boldsymbol{Q}_1$ and $\boldsymbol{Q}_3$, the flows of the diverging jets $\boldsymbol{Q}_2$ and $\boldsymbol{Q}_4$ were determined. Thus, an analytical solution of the nonlinear system of equations of the coupling between the parameters of the straight and backward jets was obtained. Despite the fact that this solution is flat, it is convenient for analyzing the effect of water stagnation in front of the second tunnel. This requires angles $\gamma$ and $\delta$, as well as an analytically reasonable interval of the intensity ratio of the colliding jets. The main result of the approximate quantitative analysis is the following: the intensity of the water flow entering the tunnel will always be less than the sum of the intensities of the flows colliding at the inlet. Consequently, it is inevitable that this effect will be followed by a decrease in water throughput and formation of a stagnation zone in front of the tunnel inlet. It means that in the case of intense precipitation, the stagnation zone will rapidly widen in this area, which can lead to heavy flooding between the first and second tunnels. In particular, according to the estimates made on the basis of the topographic parameters of the Vere gorge, the volume of the rapidly formed reservoir in the indicated place on the night of 13.06.2015 was ≈ 1.6 $10^5$м$^3$.


Photo 3

**Modelling of water flow in the closed bed**. As it was said above, in order to prove qualitative assumptions corresponding to quantitative estimates it is reasonable to use a special modification of the Hagen-Poiseuille formula for the case of turbulent flow

$$Q = \pi R^2 \bar{u} \quad , \qquad (1)$$

where $Q$ is the water flow in a circular pipe with radius $R$. Equation (1) also includes the average flow velocity, which is determined on the basis of the analytical expression [3-5]

$$\bar{u} = \sqrt{\frac{4R\Delta p}{\lambda \rho l}} \quad . \qquad (2)$$

This formula, together with the radius of the pipe, pressure drop $\Delta p$, length $l$ of the pipe and water density $\rho$ , obviously, also includes total hydraulic resistance $\lambda$ . Namely, the total hydraulic resistance of tunnels of the closed Vere channel, by analogy with the resistance of a rough curvilinear model pipe, must be an additive value : $\lambda = \lambda_r + \lambda_k$, where $\lambda_r$ is resistance, caused by curvature, $\lambda_k$ is resistance connected with roughness. At the same time, the ambiguous dependence of the flow regime on the length of the tunnels should also be taken into consideration, as far as it makes the long closed channel a special hydrotechnical object.

To determine the value of the hydraulic resistance caused by the curvilinearity of the tube, one can use semiempirical formula

$$\frac{\lambda_r}{\lambda_0} = 1 + 0.075R_e^{1/4}\left(\frac{R}{r}\right)^{1/2}, \qquad (3)$$

where, together with the Reynolds number, there is a hydraulic resistance of the smooth straight pipe, determined by expression

$$\lambda_0 = 0.0032 + \frac{0.221}{R_e^{0.237}}. \qquad (4)$$

In full load mode, the characteristic Reynolds number for the closed Vere channel is $R_e \approx 2 * 10^7$. Consequently, from formula (4) we will receive the following characteristic value of the hydraulic resistance of a smooth straight pipe $\lambda_0 \approx 0.73 * 10^{-2}$. Formula (3) includes relative curvature $\frac{R}{r}$, i.e., the correlation of the radius of the curved pipe to the radius of its curvature. According to the updated building codes and rules of the former USSR [7], which are valid up to the present day in Georgia, the permissible value of the relative curvature of waterworks depends on the value of the water flow rate and is limited by the maximum angular sector: $\varphi = 60^0$. As far as there is no available project of the high-speed highway section in open sources of information, we only indirectly estimate that in modernized first tunnel, which is the most curvilinear in the closed channel, the angular sector of curvature of the second segment does not exceed the maximum permissible value. In careful reasoning we can also assume that the flow velocity during the flood on 13.06.2015 reached the theoretical allowable value $V_{max} \approx 10$ мс$^{-1}$, determined both by indirect estimates and by the data of long-term observations. This limit value corresponds to the permissible relative curvature: $\frac{R}{r} \approx 0.17$, i.e., if $R_e \approx 2 * 10^7$, then from expression (3) we will receive $\frac{\lambda_r}{\lambda_0} \approx 3$. Therefore, since the absolute value of the coefficient of hydraulic resistance of a smooth pipe is $\lambda_0 \approx 0.73 * 10^{-2}$, for the coefficient of hydraulic resistance due to the curvature of the closed channel, we will have $\lambda_r \approx 0.022$ [4].

The coefficient of hydraulic resistance of a pipe with a rough inner surface, like $\lambda_r$, is also determined by semi-empirical formula [8-10].

$$\lambda_k = \frac{1.3}{ln^2\left(\frac{R}{k}\right)}. \qquad (5)$$

For the corrugated section of a closed channel the geometric roughness was $\frac{R}{k} \approx 26.6$, which corresponds to $\lambda_k \approx 0.12$. Thus, according to model estimates, during the devastating flood, the characteristic value of the total hydraulic resistance of the closed channel of the river Vere was equal to $\lambda = \lambda_r + \lambda_k \approx 0.14$.

To demonstrate mathematical correctness in estimating the degree of reduction of water flow in tunnels of a closed channel, let us consider two model pipes of different radii: $R_1$ and $R_2$. Let us consider that the first tube is smooth and rectilinear, the second is curved and rough. Let us suppose, having the same pressure gradients, the water flows in the pipes are the same. This assumption is physically justified in case of their full load under the condition of free gravitational flow of water. From the condition that the maximum water flows in the model tubes are equal, using expressions (1) and (2), we will have [4]

$$\frac{Q_1}{Q_2} = 1 = \frac{R_1^2}{R_2^2}\sqrt{\frac{R_1\lambda}{R_2\lambda_0}} = (\frac{R_1}{R_2})^{2.5}(\frac{\lambda}{\lambda_0})^{1/2}. \qquad (6)$$

This expression means that it can be satisfied only if the radius of the curved rough tube is much greater than the radius of the smooth one. Namely, as far as according to our estimates, the corresponding coefficients of hydraulic resistance are $\lambda_0 \approx 0.73 * 10^{-2}$ and $\lambda \approx 0.14$ we will have $\frac{R_2}{R_1} \approx 1.8$. It means that in order to meet the conditions of equal fluid flow in the model pipes, the area of the cross-section of the rough curved pipe must significantly exceed the area of the section of the smooth straight pipe $S_2 \approx 3.24\, S_1$. In other words, the throughput of two pipes of the same cross-section having different geometry and the degree of roughness of the inner surface will be different. Therefore, if such pipes are connected and the first one is smooth and straight, then in the case of its full load, the second, curved and rough pipe will inevitably become partially locked. Consequently, if these pipes are not rigidly connected, a flood zone will appear before the second pipe. Regarding the closed channel of the river Vere, this means that in the extreme flow regime there could be a sharp difference in the flow of water, not only between the inlet and outlet of the closed channel, but also between individual tunnels. In any case, the inevitable outcome of this would be a flood in the lower part of the Vere gorge, which happened on 13.06. 2015.

**Conclusion**. The reason for the devastating flood on 13.07.2015 in the gorge of the river Vere was both natural and artificial causes. It seems that an anomalous natural phenomenon was added to a technical factor associated with structural deficiencies in a closed river channel, which is an integral part of the project of a high-speed highway section in the lower part of the Vere gorge. Therefore, in conditions of frequently repeated intense precipitation, the gorge remains a real threat for Tbilisi city for several reasons in the future, namely:

1. After the devastating flood, the closed channel was restored in its original form, though after modernization, guiding walls were installed in some places. According to the plan, they are to direct the water flow into the tunnels, in particular, the most problematic second tunnel. However, such a modernization, instead of a positive action, may reduce the throughput of the second tunnel;
2. In our opinion, in the design of the high-speed highway passing in the lower part of the Vere gorge, the possibility of a critical increase in the hydraulic resistance of a closed channel under severe conditions was not taken into account. The neglect of this factor was probably caused by the theoretically insufficiently developed design of the closed channel, which is a combination of several tunnels of considerable length, made of corrugated steel sheets and, partially, reinforced concrete. The curvature of the first tunnel, according to construction standards, is likely awkward. The total effect of the roughness factors of the corrugated inner surface and the curvature of the closed channel, according to our model estimates, could be extremely negative. As a result, there was a critical increase in the hydraulic resistance of the tunnels, leading to a partial closure of the closed channel of the river Vere. It turned out to be the probable cause of the great flood, which led to the well-known tragic consequences. Obviously, recurrence of anomalously intense precipitation is probable in the future. Therefore, since after the devastating flood on June 13.06.2015 the closed channel was restored without any changes, the negative factor associated with the hydraulic resistance may reappear.

3. The analysis of the possible technical reasons that contributed to the disastrous results of the flood on the river Vere on 13.06.2015 may become the basis for preventive actions in case of a repeat of such a phenomenon in the future. In particular, in conditions of periodically repeated intense precipitation, only external monitoring of the water level in the riverbed cannot provide a realistic forecast of the vulnerable situation. For this purpose, simultaneous observation of the water level at critical locations of the closed channel, in particular, before the first and second tunnels, is quite effective. In these places, so-called stagnant zones, which serve as an indicator of the formation of recurrent currents, may appear. Stagnant zones can form even in case of medium intensity precipitation. As to the factor of hydraulic resistance, it will fully manifest itself in the case of extremely intense precipitation, i.e. under the condition of the maximum load of the tunnels of the closed channel. Consequently, until a certain moment, the zone of stagnation will not cause the decrease in the flow of water in the tunnels. Moreover, local water stagnation in front of the first and second tunnels can reduce, or simply prevent flooding in the area between the second and the following tunnels. To eliminate heavy flooding of this area, it is also reasonable to install a special adjusting water gate under the road passing over the second tunnel across the Vere gorge.

**References**

[1] მდინარე ვერეს 2015 წლის 13 ივნისის წყალმოვარდნა. ანგარიში «ტყის მდგრადი მართვა საქართველოში» პროექტის ფარგლებში, ADC მხარდაჭერით. პასუხისმგებელი რედაქტორი ჭ.ჯანელიძე, თბილისი, 2015, 35 გვ.
[2] კერესელიძე დ., ალავერდაშვილი მ., ცინცაძე თ., ტრაპაიძე ვ., ბრეგვაძე გ. რა მოხდა 2015 წლის 13 ივნისს მდინარე ვერეს წყალშემკრებ აუზში. საქართველოს ტექნიკური უნივერსიტეტის ჰიდრომეტეოროლოგიის ინსტიტუტის გამომცემლობა, თბილისი, 2015, 40 გვ.
[3] Kereselidze D., Alaverdashvili M., Kiknadze D., Tsintsadze N., Kokaia N. Devastating floods on the river Vere and the methods for their estimations. TSU transaction, series GEOGRAPHY, № 8-9, 2011, (in Georgian).
[4] Kereselidze Z., Shergilashvili G. Overflow of Vere river on 13 june 2015 and hydrodunamic problem of closed chanel. I.Javakhishvili Tbilisi State University M. Nodia Institute of Geophysics Transactions, vol. LXVI, 2016, pp. 199-221, (in Georgian).
[5] Building Norms and Rules – "Earthquake Engineering" (01.01-09), (in Georgian).
[6] Building Norms and Rules. Hydrotechnical tunnels. SNiP 2.06.09-84, (in Russian)
[7] SP 102.13330.2012. Hydrotechnical tunnels. Actualized publication, SNiP 2.06.09-8 (in Russian).
[8] Schlichting G. The theory of the boundary layer. Moscow, Publishing House NAUKA, v. XX, 1974, (in Russian).
[9] Loitsyanski L.G. Mechanics of fluid and gas. Moscow, Publishing House NAUKA, v. X, 1973, (in Russian).
[10] Landau L.D., Lifshitz E.M. Hydrodynamics. Moscow, Publishing House NAUKA, v. 4, 1988, (in Russian).
[11] Gurevich M. I. Theory of ideal fluid jets. Moscow, Nauka, 1979, 536, p.
[12] Birgkoff G., Sarantonello E. Jets, traces and caverns. Moscow, Mir, 1964.
[13] Belotserkovski P. On the collision of two free flat jets of ideal incompressible fluids. The materials of the USSR conference for marginal problems. Kazan, Kazan State University, 1970.

# 2015 წელს თბილისში მომხდარი დამანგრეველი წყალდიდობის შესაძლო ტექნიკური მიზეზები

ზ. კერესელიძე, ი. ხვედელიძე, გ. შერგილაშვილი

რეზიუმე

ჩატარდა ანალიზი მდინარე ვერეზე მომხდარი კატასტროფული წყალდიდობის ტექნიკური მიზეზების დასადგენად, რაც შეიძლება გახდეს საფუძველი პრევენციული მოქმედებებისათვის რათა მომავალში თავიდან იქნას აცილებული მსგავსი კატასტროფის გამეორება.

# О возможных технических причинах катастрофического паводка в городе Тбилиси в 2015 году

З.А. Кереселидзе, И. Б. Хведелидзе, Г. В. Шергилашвили

**Резюме**

Проведен анализ возможных технических причин, способствовавших катастрофическим результатам паводка на реке Вере 13.06.2015, который может стать основой для превентивных действий в случае повторения подобного экстремального явления в будущем.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 24 – 27*

# On the Growth of Vapour Bubble in Metastable Liquid as Variational Problem

**Anzor I. Gvelesiani**

*M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University,*
*1, Alexidze Str., 0160, Tbilisi, Georgia, e-mail:anzor_gvelesiani@yahoo.com*

***ABSTRACT***

Bubble growing process is considered theoretically when bubble consists saturated vapour of liquid and when we have vapour-gas bubble on the base of generalized Rayleigh-Plesset equation. For this purpose we use variational method with help of which we seek for those cases corresponding Euler-Poisson equations integral curves. Obtained EP- equations allow us to find extremals of our variational task. In conclusion, the Rayleigh-Taylor instability is considered general case of nonspherical perturbances for spherical bubbles and the case of the radial perturbances of bubbles.

***Key words***: Vapour-gas bubble, metastable liquid, variational task, Euler-Poisson equations, Rayleigh-Plesset equation, the Rayleigh-Taylor instability.

**Brief report**

**1.** Here we will proceed from generalized equation of Rayleigh-Plesset equation for description of bubbles dynamics [1]:

$$\frac{p_B(t)-p_\infty(t)}{\rho_L} = R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\frac{4\nu_L}{R}\frac{dR}{dt}+\frac{2\sigma}{\rho_L R}. \qquad (1)$$

where $R$ is radius of vapour bubble, $t$ is time, $p_B(t)$ is a pressure of saturated vapour in the bubble, $p_\infty(t)$ is a pressure in the liquid, $\rho_L$ is the saturated liquid density, $\nu_L$ is the kinematic viscosity of liquid, $\sigma$ is the surface tension of the bubble.

Having integral from both sides of the equation (1) over the time,

$$\int_{t_0}^{t_1}\frac{p_B(t)-p_\infty(t)}{\rho_L}dt = \int_{t}^{t_1}\left[R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\frac{4\nu_L}{R}\frac{dR}{dt}+\frac{2\sigma}{\rho_L R}\right]dt, \quad (2)$$

and reprisent it in the form of functional

$$U[R(t)] = \int_{t_o}^{t_1} F(t,R,R',R'')dt, \qquad (3)$$

where

$$F = RR''+\frac{3}{2}R'^2+\frac{4\nu_L}{R}R'+\frac{2\sigma}{\rho_L R}, \quad (4)$$

and the touch over $R$ denotes *dR/dt*.

Let investigate on extremum functional (3) where the function $F$ is supposed to be differentiate two times with respect to the time $t$ at the boundary conditions:

$$R(t_0) = R_0,\ R'(t_0) = R_0',\ R''(t_0) = R_0'';\ R(t_1) = R_1,\ R'(t_1) = R_1',\ R''(t_1) = R_1''. \quad (5)$$

By means of the functional variation on the curve realizing extremum we obtain:

$$\delta U = \int_{e_0}^{e_1} \left( F_R - \frac{d}{dt} F_{R'} + \frac{d^2}{dt^2} F_{R''} \right) \delta R dt = 0. \quad (6)$$

On arbitrary choice of $\delta R$, because of continuity of the expression in brackets with respect to time on the same curve *R(t)*, we obtain Euler-Poisson's equation

$$F_R - \frac{d}{dt} F_{R'} + \frac{d^2}{dt^2} F_{R''} = 0. \quad (7)$$

After determination all values introducing in equation (7)

$$F_R = R'' - \frac{4\nu}{R^2} R' - \frac{2\sigma}{\rho_L} \frac{1}{R^2},\ F_{R'} = 3R' + \frac{4\nu}{R},\ \frac{d}{dt} F_{R'} = 3R'' - \frac{4\nu}{R^2} R' \quad F_{R''} = R,\ \frac{d^2}{dt^2} F_{R''} = R'', \quad (8)$$

and substitution (8) into equation (7) we have following equation

$$R^2 R'' = -\frac{2\sigma}{\rho_L}. \quad (9)$$

After comparing equation (1) and (9) we obtain quadratic equation for $R'$

$$\frac{p_B(t) - p_\infty(t)}{\rho_L} = \frac{3}{2} R'^2 + \frac{4\nu_L}{R} R' \quad (10)$$

and its roots

$$R'_{1,2} = \frac{-\dfrac{4\nu_L}{R} \pm \sqrt{(4\nu_L / R)^2 + 6[p_B(t) - p_\infty(t)] / \rho_L}}{3}. \quad (11)$$

It is evident that the positive root gives less values of growth of the bubble, than according absolute value the negative root, which corresponds to fast decrease of bubble (with following collapse). In the first case, the bubble grows because of diffusion of vapour from the outside (naturally, under heating). In the second case (when the source of heating is switched off) there the condensation of vapour takes place in the bubble and the former diminishes at once.

Similar analysis may be provided on the basis of Euler-Poisson's equation for evolution of vapour-gas bubble.

**2.** Above-considered equations were connected with pure liquid and the bubbles contained only vapour of that liquid. In general case the bubbles contain some quantity of contaminant gas, whose partial pressure is $p_{G_0}$ at some reference size, $R_0$, and temperature, $T_\infty$, and, if there is no appreciable mass transfer of gas to or from the liquid, it follows that for polytropic process

$$p_B(t) = p_V(T_B) + p_{Go} \left( \frac{T_B}{T_{\infty\infty}} \right) \left( \frac{R_0}{R} \right)^{3k}. \quad (12)$$

Having substitute equation (12) into (1), we obtain the Rayleigh-Plesset equation in the following general form, [2]:

$$\frac{p_V(T_\infty)-p_\infty(t)}{\rho_L}+\frac{p_{Go}}{\rho_L}\left(\frac{R_0}{R}\right)^{3k}=RR''+\frac{3}{2}(R')^2+\frac{4\nu_L}{R}R'+\frac{2\sigma}{\rho_L R}, \qquad (13)$$

After transference the second term from the left side of this equation to the right side, investigate on extremum corresponding functional (3), having made successively the operations (5)-(8), we obtain (for k = 1, isothermal process):

$$F_R=R''-\frac{4\nu_L}{R^2}R'-\frac{2\sigma}{\rho_L}\frac{1}{R^2}+\frac{p_{G_0}}{\rho_L}\frac{R_0^3}{R^4},F_{R'}=3R'+\frac{4\nu_L}{R},\ \frac{d}{dt}F_{R'}=-\frac{4\nu_L}{R^2},F_{R''}=R,\frac{d^2}{dt^2}F_{R''}=R''. \qquad (14)$$

After substituting of the equation (14 into (7), we obtain

$$R^2R''=-\frac{2\sigma}{\rho_L}+3\frac{G}{R^2}, \qquad (15)$$

where $G=\frac{p_{G_0}}{\rho_L}R_0^3$. In the absence of the gas contamination in the bubble, instead of equation (15) we have the equation for extremal of pure vapour integral (9). Joint solution of the equations (13) and (15) yields

$$\frac{p_V(T_\infty)-p_\infty(t)}{\rho_L}=\frac{3}{2}R'^2+\frac{4\nu_L}{R}R'+2\frac{G}{R^3}. \qquad (16)$$

It is evident, that when the bubble consists only the vapour of liquid, then G = 0, and the equation (16) coincides with the equation (10). At last, the integration of the equations (10) and (16) will allowed us to find the extremals of this variational task.

**3**. Among others, the stability to nonspherical disturbances has been investigated from a purely hydrodynamic point of view by Birkhoff (1954) and Plesset and Mitchell (1956), [1]. These analyses essentially examine the spherical equivalent of the Rayleigh-Taylor instability; they do not include thermal effects. If the inertia of the gas in the bubble is assumed to be negligible, then the amplitude, $a(t)$, of a spherical harmonic distortion of order *n (n > 1)* will be governed by the equation

$$\frac{d^2a}{dt^2}+\frac{3}{R}\frac{dR}{dt}\frac{da}{dt}-\left[\frac{(n-1)}{R}\frac{d^2R}{dt^2}-(n-1)(n+1)(n+2)\frac{\sigma}{\rho_L R^3}\right]a=0. \qquad (17)$$

It is clear from (17) that the most unstable circumstances occur when $dR/dt < 0$ and $d^2R/dt^2 \geq 0$. These conditions will be met just prior to be rebound of a collapsing cavity. On the other hand, the most stable circumstances occur when $dR/dt > 0$ and $d^2R/dt^2 < 0$, which is the case for growing bubbles as they approach their maximum size.

**References**


[1] Brennen Chr. E. Cavitation and bubble dynamics. Oxford University Press, 1995, 64 p.

[2] Gvelesiani A. I. Statistical and thermal properties of geophysical thermodynamic systems. Transactions of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. LXIX, 2018, pp. 159-181, (in Russian).

[3] Elsgolts L. E. Variational calculation. M.: GITTL, 1958, 164 p., (in Russian).

[4] Birkhoff G. Note on Taylor instability. Quart. Appl. Math., v. 12, 1954, pp. 306-309.

[5] Plesset M. S., Mitchel T. P. On the stability of the spherical shape of a vapour cavity in a viscous fluid. Quart. Appl. Math., v. 13, No. 4, 1956, pp. 419-430.

[6] Skripov V. P. Metastable Liquids. M.: Nauka, GRFML, 1972, 312 p. (in Russian).

## მეტასტაბილურ სითხეში აიროორთქლოვანი ბუშტების ზრდაროგორც ვარიაციული ამოცანა

**ა. გველესიანი**

**რეზიუმე**

თეორიულად განიხილება ბუშტის ზრდის პროცესი შემთხვევაში, როდესაც ბუშტი შევსებულია მხოლოდ სითხის ორთქლით და აგრეთვე როდესაც ბუშტი წარმოადგენს ორთქლის და აირის ნარევს. პროცესი აღიწერება განზოგადებული რელეი-პლესეთის (რპ) განტოლებით, რომელიც ფუნქციონალის სახით შეისწავლება ვარიაციული აღრიცხვის მეთოდის გამოყენებით. ორივე შემთხვევისათვის მიღებულია ეილერ-პუასონის (ეპ) განტოლება, რომლის ექსტრემალების მოძებნა უფრო იოლია, ვიდრე (რპ)-ს ამოხსნა. დასასრულს ზოგად შემთხვევაში განიხილება სფერული ბუშტის რელეი-ტეილორის არამდგრადობა არასფერული შეშფოთებების დროს და, როგორც კერძო შემთხვევა, სფერული ბუშტის რადიალური შეშფოთება. განიხილება იზოთერმული. პროცესის შემთხვევა.

## Рост газо-паровых пузырьков в метастабильных жидкостях, как вариационная задача

**А.И. Гвелесиани**

**Резюме**

Теоретически рассматривается процесс роста пузырька в случае, когда пузырь заполнен паром чистой жидкости и в случае, когда в пузыре наряду с паром имеется газовая примесь. Исследование ведётся на основе обобщённого уравнения Релея-Плессета вариационным методом скорейшего спуска. Для обоих случаев получены соответствующие уравнения, интегрирование которых позволит найти экстремали поставленной вариационной задачи. В заключение рассматривается проблема устойчивости сферического пузырька в общем случае неустойчивости Релея-Тейлора при несферических возмущениях.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 28 – 33*

# Numerical Modeling of Zestafoni City Dust Dispersion in case of Western Wind

**Aleksandre A. Surmava**

*M. Nodia Institute of Geophysics, I. Javakhishvili Tbilisi State University;*
*Institute of Hydrometeorology, Georgian Technical University, Tbilisi; aasurmava@yahoo.com.*

***ABSTRACT***

Dispersion of dust emited in the atmospheric air of Zestafoni city is numerically modelled and studied in case of weakt background western winds. Dust spatial distribution patterns are obtained, and the influence of orography, horizontal and vertical turbulence and advective processes on dust distribution in the atmosphere is analyzed.

***Key words***: dust, numerically modeling

## 1. Introduction

Pollution of national environmental objects and related health status of population even today remains one of the topical issues both in general and for Georgia. Ecological state of the environment is especially complicated in those places, where large industrial enterprises are located. Zestafoni city draws attention in this context, where the object of ferrous metallurgy – Georgian Manganese LLC and other smaller enterprises of this profile are situated. Major trunk highway and railway road connecting the East and Europe, as well as oil- and gas pipe-lines pass the mentioned territory. Thousands of big and small vehicles move back and forth everyday on Transcaucasus highway, which is component part of the Silk Road. As a result large quantities of dust, manganese and other solid and gaseous aerosols are emitted in the atmosphere.

Except the industrial and administrative functions this region has also economic, cultural-recreational and touristic importance. Zestafoni is known for high-quality grapes for production of champagne and dry wines. Especially is worth to mention cultural, touristic and recreational significance of Zestafoni city and its adjacent territories. Within a radius of 50 km from Zestafoni are located Tskhaltubo and Sairme – resorts of international importance, as well as tourist attractions – Borjomi-Kharagauli and Ajameti national parks, Sataplia, Prometheus cave etc. That is why the knowledge of dispersion and spatial distribution of polluting agents is of great practical importance in order to carry out environmental protection measures. Respectively, application of numerical modeling methods for dispersion of polluting agents in the atmosphere is very effective for solution of the mentioned problem.

In the works [1–12] 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.

## 2. Formulation of the Problem

In the presented work the propagation and distribution of a dust at easthern part of Imereti Region emited in an atmosphere of Zestafoni Town using the numerical model [12] are studied. For the purpose the area 94.4×72 km$^2$ of size is considered, in the centre of which Zestafoni Town is placed, while to the west the Kolchi Lowland, north and north-east the ridges of Racha and Likhi, south - the Meskheti Range are placed (Fig. 1). Orography height varies from 50 m to 2.5 km.

As it is shown by Fig. 1 the relief is very complicated here. That is why for proper description of atmospheric processes is convenient to use the relief follow coordinate system $\zeta = (z - \delta)/h$, where z is vertical orthogonal coordinate, $\delta = \delta_0(x, y)$, $\delta_0$ - altitude of relief; h = H - $\delta$ ; $H(t, x, y)$ - tropopause height; t is a time; *x* and *y* – orthogonal coordinate axes directed to the east and north.

In the model [12] the Equation of atmospheric dust propagation in the taken (x, y, ζ) coordinate system is 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; $w_0$ - 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 coefficients in surface layer of atmosphere and in free atmosphere are defined by [12].

The data of National Environment Agency [13] are taken as the initial and boundary values of the monthly average concentrations at the height of 2 m in atmosphere in the territory Zestafoni.

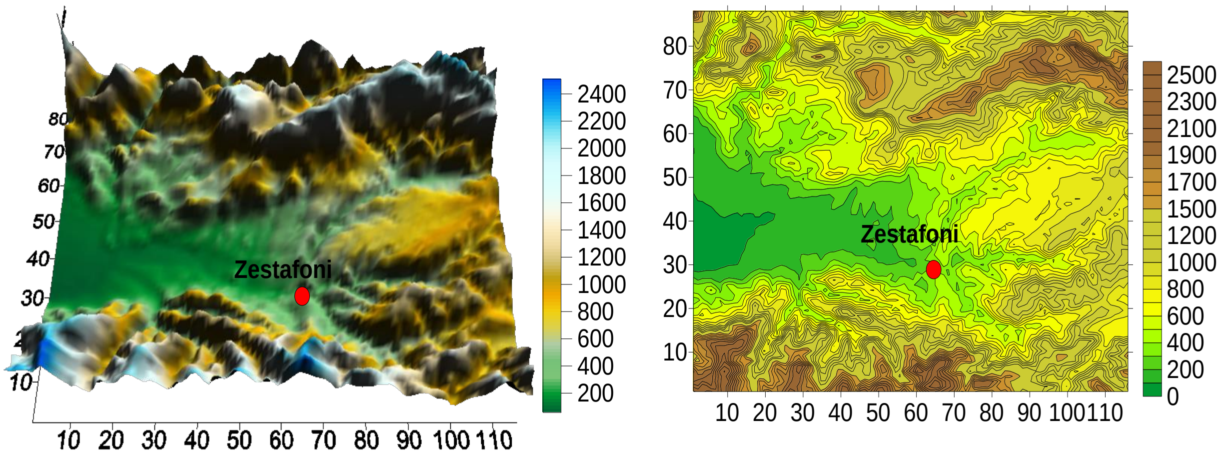



Fig. 1. The Zestafoni District topography and relief (heights in m).

Numerical integration of equation (1) with the use of corresponding initial and boundary conditions is executed using Crank-Nicolson method and using the splitting method and monotonous scheme [1]. The rectangular numerical grid with 118x90x31 points and the horizontal step equal to 800 m 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 2 days.

### 3. **Results of modeling**

Spatial distribution of dust concentrations in June during background weak western wind (1 m/c on z =10 m), when t = 16 hours, obtained by calculations, is shown on Fig. 2. Values are calculated in units of daily maximum allowable concentration (MAC = 0.15 mg/m$^3$) of dust.

As is seen from the Figure 2, dust concentrations at a height of 2 and 100 m are maximal at the territory of cities and in their direct vicinity (Fig. 2, a, b). In surface layer of the atmosphere dust cloud has the form of vertical deformed cylinder. Maximum concentration (1-2 MAC) is obtained directly in the vicinity of city at 2 km height, approximately in 12 km$^2$ area. This zone is gradually decreases with height increase and at 100 m height maximum concentration is obtained approx in 3 km$^2$ area. Dust is distributed both in windward direction and in the direction opposite to wind. Dust dispersion area in opposite direction is negligibly small that is caused by reciprocal action of horizontal turbulent and advective dispersion. To the contrary, in windward direction processes of advective and turbulent transfer have one and the same direction. Cloud form obtained by calculations shows that in the process of dust dispersion in surface layer of the atmosphere the share of turbulent diffusion and horizontal advection is roughly the same according to its value.

In the boundary atmospheric layer (Z > 100m) the area of dust distribution enlarges. Dust advection exceeds turbulent diffusion. As a result dust cloud becomes significantly deformed and takes oblong form, especially in the zones of local wind velocity increase – along the valleys of Kvirila and Chkherimela rivers (Fig. 2, c, d).

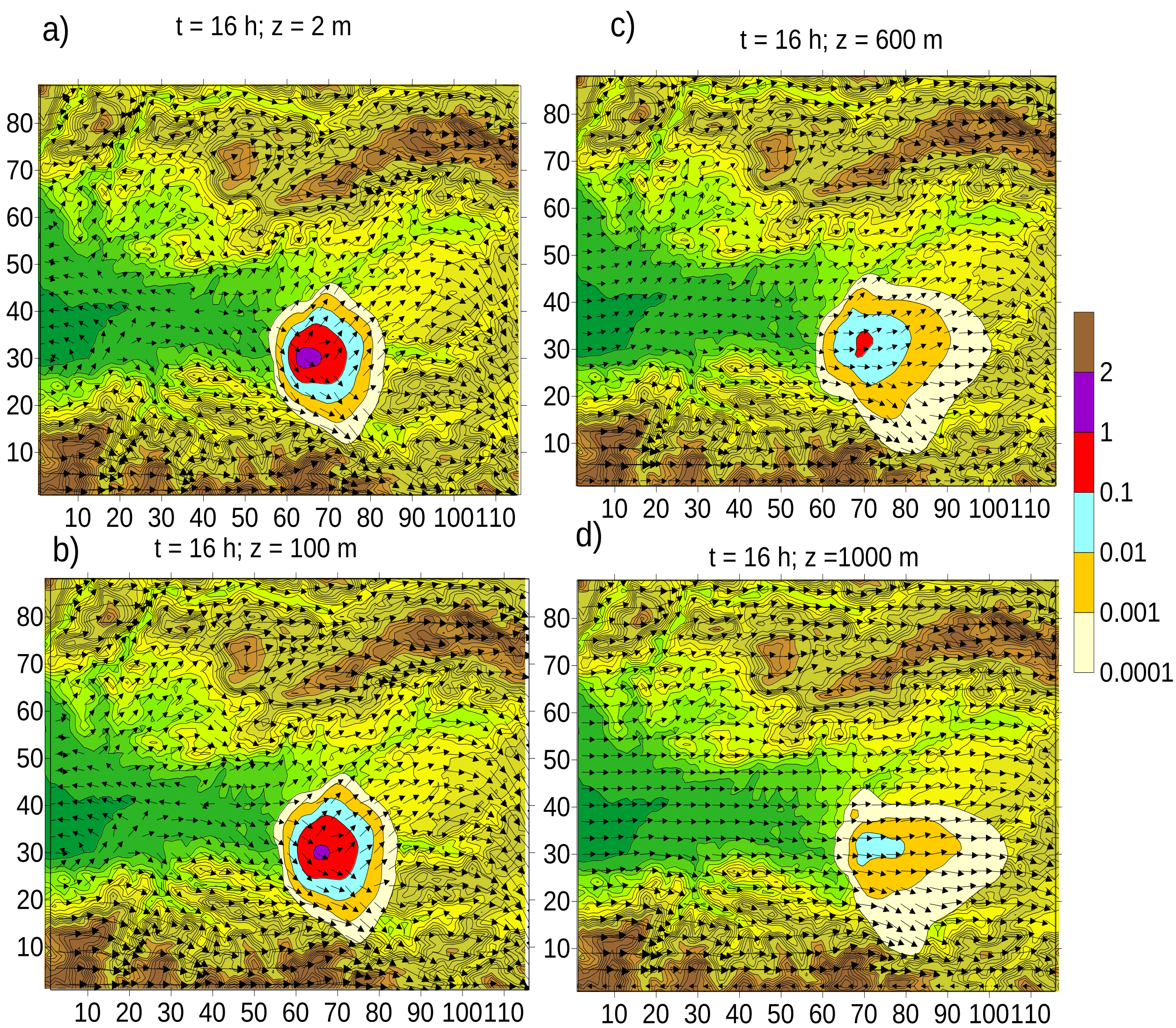



Fig. 2. Distribution of wind velocity and dust concentration C (in units of MAC) at z = 2, 100, 600 and 1000 m height from earth surface, when t = 16 h.

Mentioned effects are obviously seen on Fig. 3, where the distribution of zonal component of wind velocity and concentration of dust are shown in XOZ plane of zonal cross-section of atmosphere at 3 km height, which passes acros on Zestafoni (y=31). It is seen from Fig. 3 that dust is dispersed in 2 km surface layer of the atmosphere. 0,1-1 MAC concentration values are obtained in approx. 9 km long and 0,8 km thick layers of atmospheric air, 0,01-0,1 MAC values in 15 km long and 1,2 km thick layer and 0,01-0,001 MAC – in 20 km long and 2 km thick layer. In the windward side the dust is dispersed approx. at 5 km distance, while in the leeward side - at 20 km distance. Dust concentration distribution in the cloud is not uniform. Concentration is maximum in the central part of cloud and gradually decreases towards the periphery.

When t = 28h, dust distribution pattern in the atmosphere (Fig. 4) is qualitatively similar to distribution, which is shown on Fig. 2. The difference is quantitative one. During 12 hours took place dust transfer at larger territory and cloud becomes deformed according to daily variation of wind velocity. In 2-100 m layer dust was predominantly dispersed in north and south directions along the valleys of Kvirila and Chkherimela rivers. Above 100 m dust is dispersed basically in east and south-east directions.

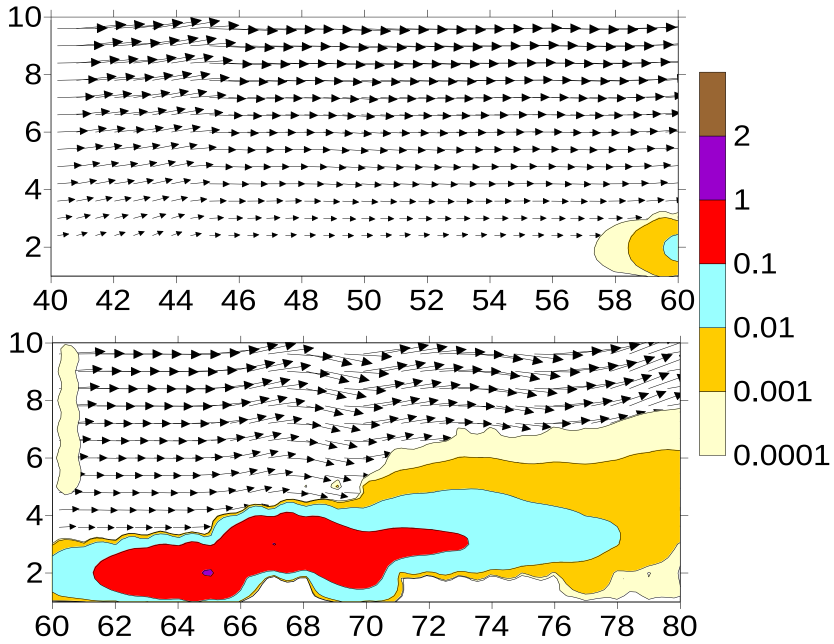



Fig. 3. Distribution of wind velocity zonal component and dust concentration C (in units of MAC) in atmospheric layer at 3 km height above Zestafoni city (y=31) in XOZ plane .

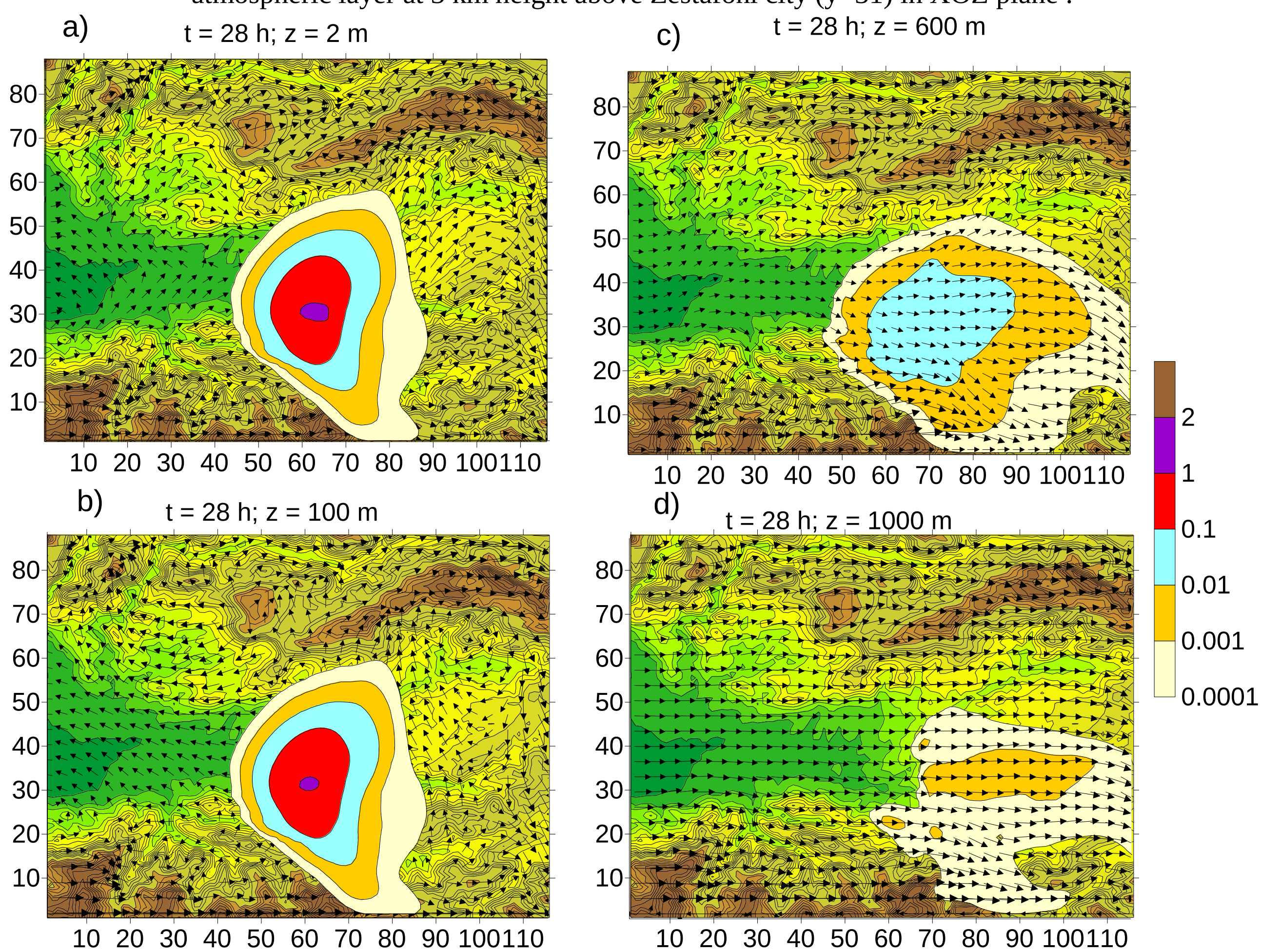



Fig. 4. Distribution of wind velocity and dust concentration C (in units of MAC) at z = 2, 100, 600 and 1000 m heights, when t = 28 h.

Along with horizontal dust transfer occurs dust deposit at the earth surface. On Fig. 5 is shown surface density of the dust deposited on the surface during 24 hours. It is seen that at 200 $km^2$ territory adjacent to Zestafoni the dust quantity deposited on 1 sq.m. area varies from 200 mg to 1 mg.

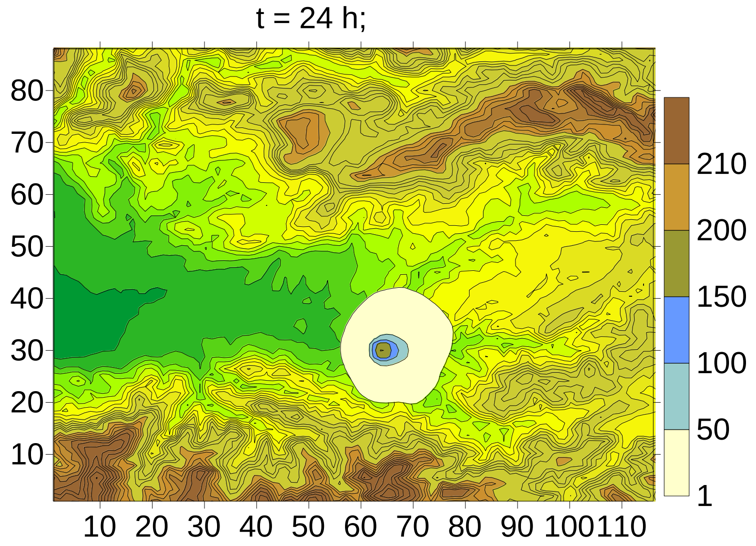



Fig. 5. Surface density of the dust deposited on the soil ($mg/m^2$).

## 3. Conclusion

Thus, a carried out numerical modeling has manifested some meteorological peculiarities, which are characteristic for dust dispersion process under urban conditions in Zestafoni region. In case of light western winds dust concentration in 100 m surface layer of the atmosphere above Zestafoni is roughly the same. Above the surface atmospheric layer this concentration rapidly decreases and at 3 km height becomes equal to zero. In vertical profile dust concentration is bigger in the centre of cloud and is getting smaller towards the periphery.

Orography causes deformation of pollution cloud. On the windward side of Likhi ridge, due to orography influence dust dispersion eastward is inhibited and starts to shift predominantly in north-east and south-east directions along the valleys of Kvirila and Chkherimela rivers. At that, on the windward side of the ridge upward movement caused by orography decreases dust sedimentation process. As a result the density of deposited dust at large distances from dust pollution sources is negligible.

Comparison of results obtained by calculations with actual results is very important. Natural observations at the territory adjacent to Zestafoni are scheduled for this end.

**Acknowledgment.** The work is performed by funding of the Shota Rustaveli National Science Foundation – Grant № PhD_F17_192.

**Reference**


[1] Marchuk G. I. Mathematical modeling in the environmental problem. Gidrometeoizdat, Leningrad, 1982. (in Russian).

[2] Penenko V. V., Aloyan A. E. Models and methods for environmental protection tasks. Nauka, Novosibirsk, 1985, (in Russian).

[3] Aloyan A. E., Penenko V. V., Kozoderov V. V. Mathematical modeling in environmental issues. Modern Problems of Computational Mathematics and Mathematical Modeling, 2005, 2: 279-351, (in Russian).

[4] Aloyan A. E., Arutinian V. O. Modeling of gaseous admixtures and aerosols evolution in atmosphetic disperse systems, 2008, www.sscc.ru/Conf/mmg2008/papers/aloyan.doc

[5] Aloyan A. E. Modeling of dynamics and kinetics of gaseous admixtures and aerosols in the atmosphere. Nauka, Moscow, 2008, (in Russian).

[6] Long J., Cheng S., Li J., Chen D., Zhou Y., et al. A Monitoring and Modeling Study to Investigate Regional Transport and Characteristic of $PM_{2,5}$ Pollution. Aerosol and Air Quality Research. 2013, 13: 943-956.

[7] Ginoux P., Chin M., Tegrn I., Prospero J. M., Holben B. et al. Sources and distributions of dust aerosols simulated with the GOCART model. J. of the Geophysical Research, 2001, 106: 255-273.
[8] Shlichkov V. A., Malbakhov V. M., Leghenin A. A. Numerical modeling of atmospheric circulation and transfer of contaminating impurities in Norilsk valley. Atmospheric and Oceanic Optic, 2005, 18: 490-496. (in Russian).
[9] Surmava A., Mishveladze B., Davitashvili T. Numerical modeling of the pollution transfer in the Caucasus atmosphere from hypothetical source in case of the background western wind. Journal of the Georgian Geophysical Society, 2009, 13B: 15-21.
[10] Surmava A. A. Numerical investigation of the modeling of transportation and deposition of the radioactive pollution in the Caucasian Region in case of the hypothetical accident on the Armenian Nuclear Power Plant. Journal of the Georgian Geophysical Society, 2012, 15B: 32-45.
[11] Surmava A. Numerical research of local circulations in the atmosphere of Kakheti in case of background eastern wind. Collection of works of the Nodia Institute of Geophysics. 2017, vol. LXVII: 20-36. (in Russian).
[12] Ed. Georgian National Environmental Agency. Short review of Georgia environment pollution. www.nea.gov.ge. (in Georgian).

## ქ. ზესტაფონის დამტვერიანების გავრცელების რიცხვითი მოდელირება დასავლეთის ქარის შემთხვევაში

ა. სურმავა

### რეზიუმე

რიცხობრივად მოდელირებული და შესწავლილია ქ. ზესტაფონში არსებულიი მტვერის გავრცელება ფონური სუსტი დასავლეთის ქარის შემთხვევაში. მიღებულია მტვერის სივრცული განაწილების სურათები, გაანალიზირბულია ოროგრაფიის, ჰორიზონტალური და ვერტიკალური ტურბულენტობისა და ადვექციური პროცესების გავლენა მტვერის გავრცელებაზე ატმოსფეროში.

## Численное моделирование распространения запыленности воздуха г. Зестафони при западном ветре

А. Сурмава

### Резюме

Численно смоделировано и изучено распространение в воздухе городской пыли г. Зестафони при фоновом западном ветре. Получены картины пространственного распределения пыли, проанализированы влияния орграфии, горизонтальной и вертикальной турбулентности и процесса адвекции на диффузию пыли в атмосфере.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 34 – 46*

# Milestones in the History of the Black Sea Oceanography

**Avtandil A. Kordzadze , Demuri I. Demetrashvili**

*Iv. Javakhishvili Tbilisi State University, M. Nodia Institute of Geophysics,*
*1, Alexidze Str., 0160, Tbilisi, Georgia, e-mail: demetr_48@yahoo.com*

***ABSTRACT***

In this paper the main stages in the history of the Black Sea oceanography are briefly described from the middle ages to the present. It is shown that modern knowledge on the Black Sea and our understanding of hydrophysical and biochemical processes of this unique sea basin is reached as a result of hard research activity of a lot of researcher-oceanographers during last centuries. Significant attention is paid to the modern operative oceanography using modern data-computing technologies and satellite remote sensing methods.

***Key words***: Black Sea oceanography, numerically modeling

## 1. Introduction

The Black Sea, which is located at the border of Europe and Asia, played a connecting role between the West and the East since ancient times. The Black Sea was one of the most important link of the great silk road and played a crucial role in economic and trade relations of the old Georgia with Greek world and other countries [1, 2], that in the legendary form is reflected in the myth of the Argonauts. The Black Sea has many times become an object of attention not only to researcher-oceanographers, but also to the general public. Hundreds of articles and monographs are devoted to the Black Sea, since the XIX century many scientific expeditions have been carried out. Modern knowledge of the physical and biochemical processes in the Black Sea was formed over several hundred years as a result of tireless work and scientific activity of many researchers. The oceanography achieved the great successes especially in recent decades, which is the result of rapid scientific and technological progress.

In this paper the main facts and milestones in the development of the Black Sea oceanography from the middle ages to the present including the achievements of the modern Black Sea operative oceanography are shortly considered.

### 2. The Black Sea oceanography in XVII-XIX centuries

The modern configuration and morphometric parameters of the Black Sea formed approximately 7600 years ago, when the connection between the Black Sea and the World Ocean was restored through the Bosporus Strait [3, 4]. The main specific features of the Black Sea are due to the weak water exchange with the Mediterranean Sea, existence of hydrogen sulphide layer below depth of 150-200 m and a powerful river runoff. The ancient Greeks knew the Black Sea and Georgia very well, which is reflected in their myths and written monuments [5, 6]. Especially the great interest of the ancient Greeks belongs to the 7th century BC, when the Greeks began founding of Greek colonies on the eastern coast of the Black Sea.

Despite the fact that since ancient times the Black Sea has been a place of intensive navigation, knowledge of the processes taking place in the Black Sea practically did not advance until the XVII century. The first significant discovery in the history of the Black Sea oceanography belongs to the famous Italian diplomat, military man and oceanographer Luigi Ferdinando Marsili (1658-1730). In 1679, during his journey from Venice to Istanbul, the 21-year-old Marsili discovered the lower and upper currents in the

Bosporus [7-11]. In the history of the Black Sea oceanography it was the first most important investigation conducted by the direct measurements in the sea. On the basis of direct measurements of water densities and scientific analysis Marsili established the Bosporus exchange currents between the Black Sea and the sea of Marmara. His measurements in the Bosporus showed the surface water of Black Sea origin to be significantly lighter than the water samples from the undercurrent, which had weight consistent with the Mediterranean water [9]. Based on these initial observations, Marsili reached a good understanding of the pattern of circulation of the Strait of Bosporus and successfully constructed the first theoretical explanation of its hydrodynamics [9].

In order to confirm his discovery - the Bosporus water exchange, Marsili carried out a laboratory simulation of the Bosporus Currents. He demonstrated this density difference by building a physical model that captured the salient features of the phenomenon (Fig.1). Marsili made a two-compartment box with the divider connected by two openings at top and bottom, and showed that waters of different densities in the two compartments would flow to the opposite side in a manner consistent with his with his observations. Marsili understood that the Bosporus currents were a simple consequence of the different water densities in the Black and Mediterranean Seas.

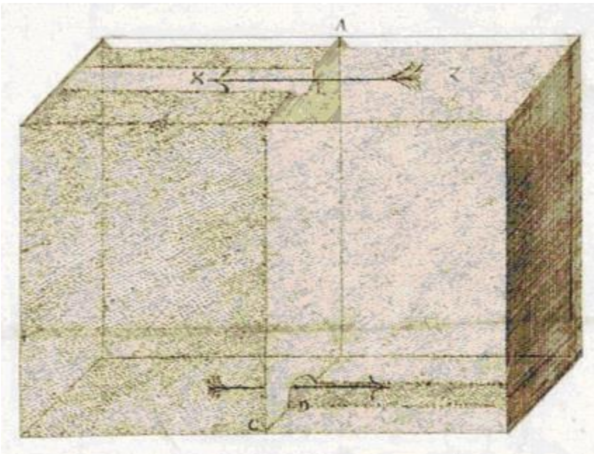


Fig.1. Luigi Ferdinando Marsili's physical model of Bosporus two-layer flow (Marsili's box) [7, 9].

The observations and experiments were published in the 1681 book by Luigi Ferdinando Marsili, originally published in Italian [7-10]. Thus the foundations of modern oceanography have been laid in Istanbul by Marsili, based on a series of first-time measurements in the Bosporus [11]. Subsequent studies have shown an important role of the Bosporus currents in the formation of the hydrological structure of the Black Sea.

In the XVIII century Russian sailors began a hydrographic description of the Azov and Black Seas [12]. These works continued in the XIX century. During the expedition (1825-1836) organized by a Russian military officer and hydrographer E. P. Manganary (1796-1868) mapping of the Black Sea and Azov coasts was carried out, resulting in the issuance of a map of the Black Sea atlas in 1842.

Systematic study of the Black Sea began in the second half of the XIX century, when it launched large-scale scientific expeditions. As D. M. Fillipov notes in his famous monograph [13], three stages in the Black Sea study are indicated in the manuscript of the famous Russian oceanographer N. I. Chigirin. The first stage - since the middle of the XIX century until 1890 was characterized by accidental hydrological observations conducted by Russian Black Sea Fleet Officers. As the beginning of the second stage should be considered the first Black Sea depth-measuring expedition led by Russian oceanographer and meteorologist I. B. Shpindler (1848-1919) in 1890-1891. The third stage begins since 1922, when the Azov-Black Sea research fishery expedition was organized under the leadership of N. M. Knipovich. At the same time a multi-year oceanographic expedition led by Russian scientist and oceanographer Yu. M. Shokalskiy (1856-1940) was organized. As the beginning of the modern stage can be considered 70-80s of the XX Century [14], The characteristic feature of this phase is the wide use of mathematical modeling methods and computing techniques in studying the Black Sea processes and developing modern remote (satellite) sensing and contact measurement methods.

At the first stage, as a result of the scientific works of F. F. Wrangell (1879), V. V. Maidel (1884), S. O. Makarov (1850), certain opinions were created on the surface circulation of the Black Sea, but at the same time a wrong opinion was formed about the great contribution of the rivers to the Black Sea circulation.

In 1885 famous oceanographer and the vice-admiral of the Russian fleet S. O. Makarov (1849-1904) has carried out detailed hydrological research of Bosporus two-layer current and thoroughly has established that less salty water of the Black Sea by the upper current enters into the sea of Marmara, and more salty water of the sea of Marmara by the deep current enters into the Black Sea. To conduct his research, Makarov used the Russian military vessel “Taman”, which was at the disposal of the Russian embassy in Istanbul. S. O. Makarov conducted detailed observations in the Bosporus Strait, including measurements of water temperature, salinity, velocity and direction of currents. Although the upper and lower currents of the Bosporus were known as a result of research conducted by Marsili, Makarov's merit should be considered a detailed hydrological study of the Bosporus flows and the substantiation for the hypothesis associated with the Bosporus two-layer current. He published the results of the researches conducted in the Bosporus Strait in the book "*On the exchange of waters of the Black and Mediterranean Seas*" awarded the prize of the Russian Academy of Sciences [12, 15].

Thus, researches carried out by L. F. Marsili and S. O. Makarov is an important event in the history of the Black Sea Hydrology, which strongly showed the existence of the Bosporus water exchange currents.

In 1870s started studies in the Black Sea biology. In this respect a major event was the establishment of the first marine biological station in Odessa (Soon the institute was transferred to Sevastopol) on the initiative of outstanding traveler, ethnographer and geographer Miklukho-Maclay (1846-1888). Its first director was Academician A. O. Kovalevsky. Nowadays it is a widely known institute of biology of the southern seas [12]. After the organization of the Sevastopol biological station, the study of the fauna and flora of the Black Sea became systematic. In the early XX century, based on the researches conducted in the biological station, the main knowledge of the Black Sea organic world were created. The absence of life was discovered in the deep Sea layers of the Black Sea Contaminated with hydrogen sulphide.

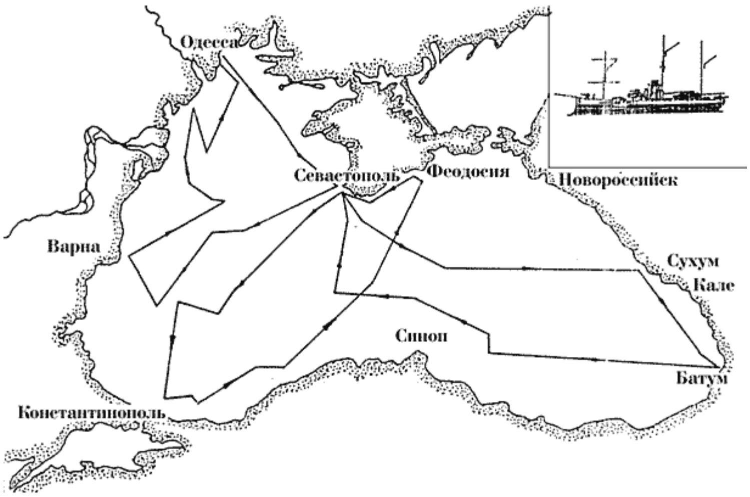



Fig.2. Spinldler’s expedition route in the Black Sea [16].

An important step forward in the study of the hydrology of the Black Sea was a complex depth-measuring oceanographic expedition during 1890-1891 led by I. B. Shpindler [4, 16, 17] by vessels “Chernomorec”, “ “Donec” and “Zaporotzec”. Hydrograph F. F. Wrangell, geologist N. I. Andrusov and chemist A. A. Lebedintsev participated in the expedition. In Fig. 2 the expedition route in the Black Sea is shown [16]. This expedition made a great contribution to the study of the Black Sea Hydropogy. During the expedition were made great discoveries, such as: 1) the cold intermediate layer at a temperature below $8^0$C, 2) contamination of deep layers of the Black Sea by hydrogen sulfide and the absence of fauna, 3) waters with high salinity (34%o) at the Bosporus, which flowed into the Black Sea with deep flow from the Sea of Marmara. With this, it became clear that the deep layers of the Black Sea are a mixture of waters of the Marmara and Black Seas, 4) it has been proven that the bottom of the central part of the sea like a flat bowl is with the greatest depth of up to 2245 m, 5) monotonous growth of temperature and salinity from the depth of 200 m to the bottom up to $9^0$C and 22,3%o, respectively.

One of the main results of the expedition was the discovery of a hydrogen sulfide zone below 200 m, but as is noted in [4], it was not the first discovery of hydrogen sulfide contamination in the Black Sea. In 1968 the exploratory expedition organized by the Hydrographic Department of the Maritime Ministry of the Russia, planned to investigate the routes of the international telegraph cable in the Feodosiya-Sukhumi section. During this expedition there was observed a difference between the surface and deep waters of the Black Sea, which was caused by the presence of hydrogen sulfide in deep layers. The great merit of the Shpindlers's expedition is that for the first time in the history of the Black Sea Oceanography the contamination of deep layers by hydrogen sulfide detailed and thoroughly investigated.

As a result of researches conducted during the expedition Shpindler came to the conclusion that the main cause of the sea surface circulation is wind. On the basis of the data received during the expedition he erroneously concluded that the Black Sea can be represented as a water body consisting of two parts - the surface and deep layers between which water exchange does not occur and deep layers of the sea are in a stagnant state. Such an opinion in the Black Sea Oceanography existed up to 30-40s of XX century [4]. Further studies have shown the incorrectness of such opinion. It turned out that the Black Sea is one whole system, where the water circulation occurs throughout the vertical from the sea surface to the bottom. In this respect there is very important the scientific article published by the famous marine biologist V. A. Vodianitskii, where on the basis of hydrobiological studies is formulated the scheme of vertical structure of the Black Sea general circulation [12, 18]. The principal provision of the author is that the whole thickness of the Black Sea represents one whole where the vertical and horizontal movements take place from the sea surface to the bottom, but the water exchange between the surface and deeper layers is slowly.

The expeditions led by Shpindler in 1890-1891 were the beginning of a systematic study of the Black Sea Hydrology, which essentially enriched the knowledge of the Black Sea and contributed to the study of general hydrology of the Black Sea. It should be noted that in 1892 the Russian Geographical Society awarded I. B. Shpindler and F. F. Wrangell with small gold medals for the successful expeditions and the great contribution to the Black Sea oceanography [4].

Up to the 20s of the XX century, large-scale complex oceanographic studies were no longer carried out, but in this period there were experimental studies of small scales. For example, in 1892 by A. A. Lebedintsev was carried hydrobiological and hydrological studies of the Black Sea from Odessa to Batumi section.

## 3. The Black Sea oceanography in XX century and at the beginning of XXI century

Since 1920s study of the structure and dynamics of the Black Sea have received very widespread development. In 1923-1935 a large oceanographic expedition was carried out, which was led by famous Russian scientist and oceanographer Yu. M. Shokalskiy (1856-1940). Since 1932 V. V. Shuleikin has become the leader of the expedition. The expedition work program was extensive and it consisted of standard hydrological examination to great depths, study of bottom and bottom sediments, hydrochemical studies, biologic studies of plankton and benthos, bacteriological investigations [12, 17, 19].

During the expedition, large-scale studies of the hydrochemical, biological and hydrological processes of the Black Sea were carried out. During the whole operation of the expedition 53 cruises were performed on various vessels, in which about 1600 oceanographic stations were made, more than 2000 biological and geological samples were collected. Most of the observations were made at the maximum depths of the sea (2000-2200 m). During the expedition, the first map of the Black Sea relief was drawn up, the general cyclonic nature of the Black Sea was established, the results obtained in previous studies about contamination of deep waters by hydrogen sulfides and the absence of living organisms were confirmed. Biological studies have shown the seasonal change of plankton and peculiarities of distribution of Benthos at the depth .

The ground samples taken under the expedition have become an important basis for geologists to study the history of the construction of the Black Sea Pavement and Development [12, 20].

The study of the vertical hydrological structure showed that the mixing process is carried out between the upper oxygen content and lower hydrogen sulfide layers, but with small intensity. Thus, the hypothesis of the existence of a standing zone in deep layers was refuted. It was found that in the open part of the Black Sea contaminated layer with hydrogen sulfide is up to 125 m depth, and close to the shores - up to 200 m.

It is interesting to note that Shokalskiy was a witness of a strong earthquake in Yalta on September 12, 1927, the epicenter of which was in the Black Sea close to the seashores. Despite the fact that he was not a seismologist, he gave a detailed description of this event and created a more complete picture of the Yalta earthquake [21].

The expeditions carried out in 1923-1935 were of great importancein the study of hydrophysical and biochemical processes. It should be noted that the works envisaged in the framework of the expeditions were entered into the second International Polar Year (1932-1933) Scientific Program.

Almost at the same time one of the most significant expedition in the history of the Black Sea oceanography was carried out in 1922-1928 – Azov-Black Sea research fishery expedition under the leadership of N. M. Knipovich. The main tasks planned in this expedition were biological, but the expedition plan included also hydrological observations [22]. The area of research and experimental activities of the expedition included the Azov Sea, the Kerch Strait and the coastal waters of the eastern part of the Black Sea.

By the expedition was obtained very extensive material covering the relief of the bottom, sea water temperature, salinity and the gas regime, the composition and distribution of plankton and benthos.The first monograph on the Black Sea hydrology belongs to N. M. Knipovich [23]. In his monograph the scheme of the surface circulation of the Black Sea is given, according to which the main elements of the surface circulation are the main cyclonic current, which surrounds the Black Sea on the periphery (the Rim Current), and two cyclonic eddies in the open part of the sea basin (so-called “Knipovich’s glasses”). The cupola-shaped form of salinity and density fields at the centers of these eddies were established. The subsequent researches have confirmed the basic conclusions given by Knipovich.

It should be noted that as a result of performed oceanographic expeditions at the end of XIX century and in the 20-30s of the XX century the Black Sea became one of the most studied seas in the World.

It is necessary to note the great contribution of the Academician V. V. Shuleikin (1895-1979) to the many spheres of the Black Sea oceanography. In 1929 he has based the Black Sea hydrophysical station in Kaciveli (Crimea). Further, on the basis of this station the Marine Hydrophysical Institute was based (Sevastopol) and the station itself became an experimental division of this institution. Currently, the Marine Hydrophysical Institute is a research organization of international importance, where the studies of the Black Sea hydrophysical processes actively and at a high scientific level take place using modern experimental and theoretical methods. The works in Kaciveli hydrophysical station under the guidance of V. V. Shuleikin included a wide range of oceanographic tasks: dynamics of sea currents, dynamics of tidal waves, dynamics of surface and internal waves, physical basis of climate and weather, sea optics, sea acoustics, etc [17]. It is interested to note that in 1938 by Shuleikin was elaborated the method, which provided physical modeling of generation and evolution of wind driven waves in laboratory conditions in an aerodynamic circular channel. V. V. Shuleikin made a major contribution to the study of the heat balance of the Black Sea, which laid the basis for the modern theory of the Heat Balance of the oceans and seas. The scientific results obtained in the Hydrophysical Station during the nearly ten years are generalized in his fundamental monograph "Physics of the sea" [24]. The scientific results obtained by Academician V.V. Shuleikin received high recognition, which was confirmed by the fact that in 1942 he was awarded the title of laureate of the Stalin Prize for the major contribution to oceanography.

The leading role in the study of the Black Sea in the former Soviet Union played Scientific-research institutes in Sevastopol – Marine Hydrophysical Institute and the Institute of Biology of South Seas, that were equipped with scientific-research vessels "Mikhail Lomonosov", "Academician Vernadskiy", “Professor Vodianitskiy", etc. Significant scientific and research works also were carried out by the State Oceanographic Institute (Moskow) and M. Lomonosov Moscow State University, research vessels of which were based in Sevastopol. In the sea city of Gelendzhik the south branch of Shirshov Inctitute of Oceanology of the Academy of Sciences of USSR was functioning, which carried out the scientific expeditions by the research vessels “Academician Shirshov” and “Academician S.Vavilov”.

The knowledge acquired for the 60s of the XX century about the Black Sea is reflected in the book “*Regional Oceanography* “ by A. K. Leonov [25] and in the monograph “*Circulationand structure of waters of the Black Sea*“ by D. M. Fillipov [13].

Since 50-60s of the last century, the study of the Black Sea has become deeper and more completed. In 1957-1959, in the framework of the International Geophysical Year Program, oceanographic expeditions were carried out in the former Soviet Union where the observations were conducted on the polygons. This made it possible to study the mesoscale variability of the Black Sea thermochaline structure and flows [12].

In the former USSR in 1976-1978, a joint program of Black Sea Complex Studies (SKOICH) was implemented. A wide range of rich scientific materials collected, analyzed and theoretical generalized in the scope of this program were published in a number of publications. First of all it should be noted the monograph by A. S. Blatov, N. P. Bulgakov, et al [26], where a broad spectrum of hydrophysical processes of the Black Sea is discussed. Here are the peculiarities of the average multi-year season changeability of the main hydrophysical fields - temperature, salinity, density and flow.

It is very important the contribution of the Bulgarian scientists to the study of Black Sea Oceanography, which carries out at the Institute of Fish Resources and the Institute of Oceanology of the Academy of Sciences of Bulgaria in Varna. Studies are mainly focused on the oceanography of the western part of the sea and the Bosporus region. The resulting findings are reflected in the collective work of Bulgarian scientists [27].

Research in Black Sea Oceanography in Romania carries out at Grigol Antipa Institute of Sea Studies in Constanta. The main attention is paid to the shelf zone and the Danube river delta.

Turkey's scientific and educational centers - the Center for Sea Science and Technology (Izmir), the Middle East Technical University (Ankara) and others have a major role in the study of hydrology and ecosystem of the Black Sea Anatolian coast.

The interest of American scientists with the Black Sea is very high. By the end of the 60s and in 70s-80s of the last century, they conducted a number of oceanographic experiments on the Black Sea, mainly related to the geological problems of the Black Sea [12]. A lot of publications of American scientists are devoted to mathematical modeling of the Black Sea dynamics (for example, [ 28-30]).

Obviously, it is not possible to receive the quantitative characteristics of the dynamics of the entire Black Sea basin only by observations. In this case it is necessary to apply the theoretical analysis methods.

Since 40-50s of the last century wide use of physical and mathematical methods in study of the Black Sea dynamics began, but fast development of computer facilities considerably has promoted numerical modeling of hydrophysical processes since 60-70s.

The modern stage of the study of the Black Sea, beginning since 70s of the last century, is distinguished with applying both the experimental and theoretical methods. The numerical modeling of the physical processes of the Black Sea, based on the full equation system of ocean hydrothermodynamics, was initially started in the former USSR during this period, particularly, at the Computing Center of the Siberian Branch of the Academy of Sciences of USSR (Novosibirsk, Akademgorodok) under the guidance of Academician G. I. Marchuk.

The method of mathematical modeling implies the description of the study object or process through differential equations that can be solved using appropriate boundary and initial conditions. This method enables to simulate processes and events ongoing in the nature (numerical experiments on a personal computer), evaluate various factors impact on the development of the study process and, finally, to predict it.

There are a lot of number of publications dedicated to mathematical modeling of physical processes in the Black Sea. The review and analysis of these publications are given in monographs [31, 32], which reflect the state of the problem for the 80s of the last century. There were developed two types of numerical models: diagnostic and prognostic. Among them diagnostic models are relatively simple in which the density field is determined based on the observation data. This allows simplification of the equation system, as it is not necessary to consider the equations of heat and salinity transfer. As input data for the diagnostic models the average multi-year seasonal sea density fields and atmospheric pressure above the sea were used. The first calculations were carried out using a diagnostic model on the basis of a stationary barotropic model for the north-western part of the Black Sea [33]. The calculations for the whole Black Sea Basin using the diagnostic models are also presented in [34-37]. A review and analysis of such models are in the monograph [38]. Calculations carried out by the diagnostic method have shown that movement of water in the Black Sea takes place throughout the thickness of the sea from the surface to the bottom. Vertical velocity received on the basis of the continuity equation demonstrated the rise of water masses above the central areas of the sea and lowering in the peripheral part of the sea at a rate of $10^{-4}$ cm /s [34].

diagnostic models are limited to explain the main features of the sea dynamics. In this respect prognostic models are very promising, in which the density field is given not on the basis of observational data, but is determined in the process of integrating the model equations. Prognostic models are divided into one-component and two-component models. One-component models were proposed in [39-42]. In [39], instead of the equations of heat and salinity, the equation for the density was used, and in [40-42] the density was determined only by the temperature field. For the Black Sea, such an assumption is rather crude, since, as is well known, the formation of a density field in the Black Sea basically depends on the salinity field.

Two-component prognostic models are more complete. They are based on a full system of ocean hydrothermodynamics equations. In this case the density field is determined by temperature and salinity fields. The first works in this direction were made at the Computing Center of the Siberian Branch of the Academy of Sciences of USSR (Novosibirsk, Academgorodok) in [32, 43-46]. In these works, the model equation system is formulated for deviations of thermodynamic values from the standard vertical distribution. For solution of the equation system the two-cycle splitting method with respect to physical processes, coordinate lines and planes is used proposed by Academician G. I. Marchuk to solve the dynamics and ecological tasks of the ocean and atmosphere [47, 48]. This was the first prognostic model of the Black Sea dynamics based on a full system of ocean hydrothermodynamics equations, the results of which confirmed the general cyclonic nature of the Black Sea circulation and showed a significant role of the bottom relief in circulation, particularly in the north-west part of the Black Sea. The maximum concentration of salinity was obtained in the central part of the sea, while the peripherals were relatively small, giving evidence of saline deeper water in the central areas of cyclonic rotation. It was also shown that the density and salinity fields in the Black Sea are in good correlation with each other.

The level of computing techniques of the 70s of the last century did not provide realization of non-stationary spatial tasks with the desired resolution. Therefore, the Black Sea dynamics prognostic baroclinic model was realized for the Black Sea basin with a horizontal grid step of 37 km, while 13 calculated levels were taken on a vertical [32, 43-46].

The two-component prognostic models of the Black Sea dynamics were also proposed in [49-51]. As a result of realization of the model [49] using Bryan's numerical scheme [52] the average annual and seasonal fields of hydrophysical characteristics were calculated. Comparison of model fields with observation data showed that the model satisfactorily reflected the peculiarities of hydrophysical fields. It should be noted that the Rim current was well reflected in the average annual picture of the calculated flow, but at the same time the internal cyclone eddies in the open part of the basin practically did not observed.

In [50-51] the model system of equations was solved using the two-cycle splitting method, as well as in [32, 43-46]. Numerous numerical experiments showed that the model well reflected the general features of the general circulation of the Black Sea.

In 70-80s of the last century large horizontal spacing applied in the numerical models did not allow description of small coastal eddies. The modern observations show existence of mesoscale and submesoscale eddies in coastal waters [53, 54], whose identification require very high resolution of mathematical models. The fast development of computational facilities since 1990s gave the opportunities for computer realization of these models with higher resolution, which have allowed reproducing dynamic processes in the Black Sea by the great adequacy.

Since 1990s at M. Nodia Institute of Geophysics of the National Academy of Sciences of Georgia the perfection of the Black Sea dynamics model [32, 43-46] was carried out by considering the main physical factors and simultaneously increasing the horizontal resolution of the model as in the horizontal (5 km horizontal), as well as in vertical direction (32 calculated level). The modern version of the model [55-57] provides the following key factors:

- quasi-real sea bottom relief and configuration of the sea basin,
- atmospheric wind and thermohaline impacts,
- solar radiation absorption by the upper layer of the sea,
- water exchange through the Bosporus Strait with Mediterranean Sea,
- Danube river runoff,
- space-temporal Changeability of turbulent viscosity and diffusion coefficients.

Performed numerical experiments in conditions of alternation of climatic wind fields typical for the Black Sea basin showed that surface circulation is constantly changing throughout the year. Strong atmospheric winds over the Black Sea have a smoothing effect on the surface sea circulation and the processes of vortex formations are less intense. In such cases, the speed of the sea current may exceed 100 cm/s. Later this basin-scale model was adapted to the easternmost water area of the Black Sea (including Georgian coastal zone) with increasing space resolution to 1 km.

The numerical modeling of the Black Sea dynamics is particularly intensively developing in the last 20 years and the number of publications devoted to this problem increases (for example, [58-65]). The results of mathematical modeling, hydrological observations and satellite remote sensing data clarified the traditional picture of the Black Sea circulation, obtained by N. M. Knipovich [23], and improved our knowledge of the dynamic processes taking place in the Black Sea. The Black Sea circulation is one of the major factors determining distribution of thermohaline fields and some substances of anthropogenic and natural origins. On the basis of modern research it became possible to establish the main regularities of the Black Sea circulation, which can be characterized as follows: the circulation of the Black Sea as a whole is cyclonic, the main element of which is the main Black Sea current (the Rim Current) by a cyclonic ring, which covers the Black Sea basin on the periphery over the continental slope and represents a jet flow with width about 40-80 m. Along the Rim Current jet around the basin flow speeds are about 25-30 cm/s, but the maximum speed of the flow at a strong atmospheric wind can exceed 100 cm/s. The Rim Current is observed throughout the year and is strengthened and stabilized during the autumn-winter period. The essential feature of the Black Sea surface circulation is also formation of some interior cyclone eddies in the western and eastern open parts of the Black Sea. the Rim current is hydrodynamically unstable and as a result of interaction with the relief it experiences meandering, especially during the warm period from April to November. This event is due to the weakening of the atmospheric winds and a number of calm situations during the warm period of the year. The meandering promotes generation of coastal anticyclonic eddies between the Rim Current and the coast over the entire perimeter of the seaside line. Such coastal eddies are: Bosporus, Sevastopol, Crimea, Caucasus, Sakaria, Sinop, Batumi eddies, etc. Among these eddies Batumi anticyclonic eddy is more intensive and stable formation, especially in the warm season. The coastal anticyclonic eddies and interior cyclonic eddies schematically are presented in Fig. 3 [66]. Characteristic sizes of coastal eddies are in a wide range about within 20 - 200 km, which play an important role in ventilation of coastal waters [67].

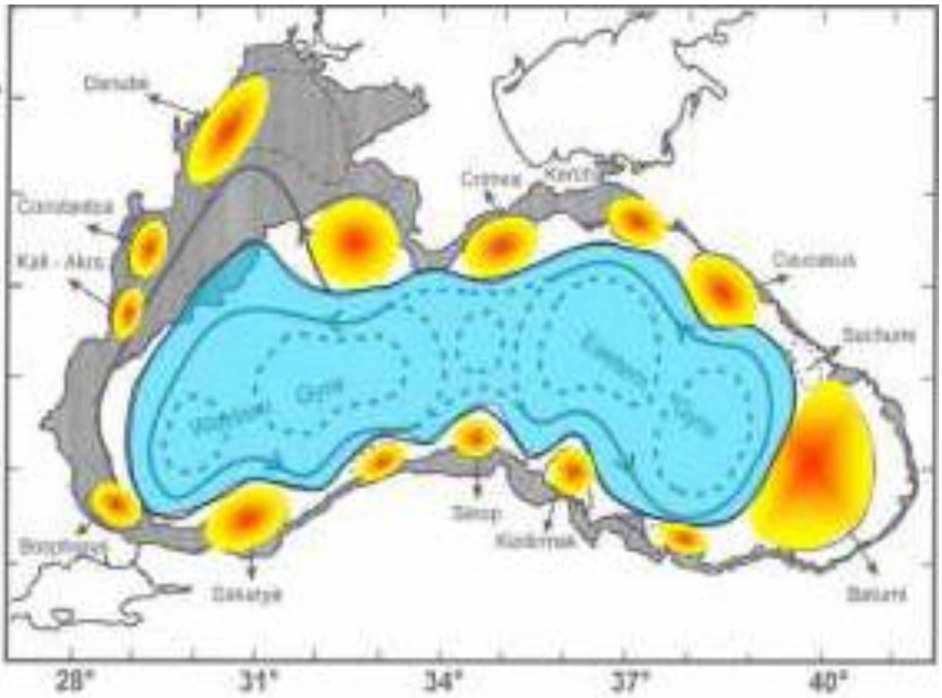



Fig. 3. A schematic structure of the Black Sea upper layer circulation [66] by showing of the Rim Current and cyclonic and anticyclonic eddies. By blue color cyclonic eddies are shown and by yellowish-reddish color - coastal anticyclonic eddies.

Approximately during last two decades the Black Sea oceanography achieved significant successes. Development of in-situ and remote sensing methods and effective data-computing technologies promoted creation of the Black Sea Nowcasting/Forecasting system, which is the large scientific and technical achievement of the Black Sea operative oceanography [68-72]. Such system allows to carrying out continuous control over the current state of the Black Sea and its change for some days forward. At present the Black Sea nowcasting/forecasting system is functioning in the near-real time and provides the short-range forecast of basic hydrophysical fields – the current, temperature, salinity and sea level. The main components of this system are basin-scale model of the Black Sea dynamics of MHI and some high-resolution models of coastal dynamics. In Fig. 4 the regional water areas of Bulgaria, Romania, Ukraine, Russia and Georgia are presented, where calculation of regional forecasts are carried out [70]. One of them is an easternmost water area including Georgian coastal zone. For this area operates the regional forecasting system developed at M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University [73-78] within EU international scientific projects ARENA and ECOOP. The regional forecasting system, which is one of the main components of the Black Sea nowcasting/forecasting system, consists of hydrodynamic and ecological blocks. The hydrodynamic block includes M. Nodia Institute of Geophysics high-resolution 3D regional model of the Black Sea dynamics with 1 km resolution which is nested in the basin-scale model of the Black Sea dynamics with 5 km resolution of Marine Hydrophysical Institute (MHI, Sevastopol) [62]. The ecological block includes 2D and 3D transport models of polluting substances.

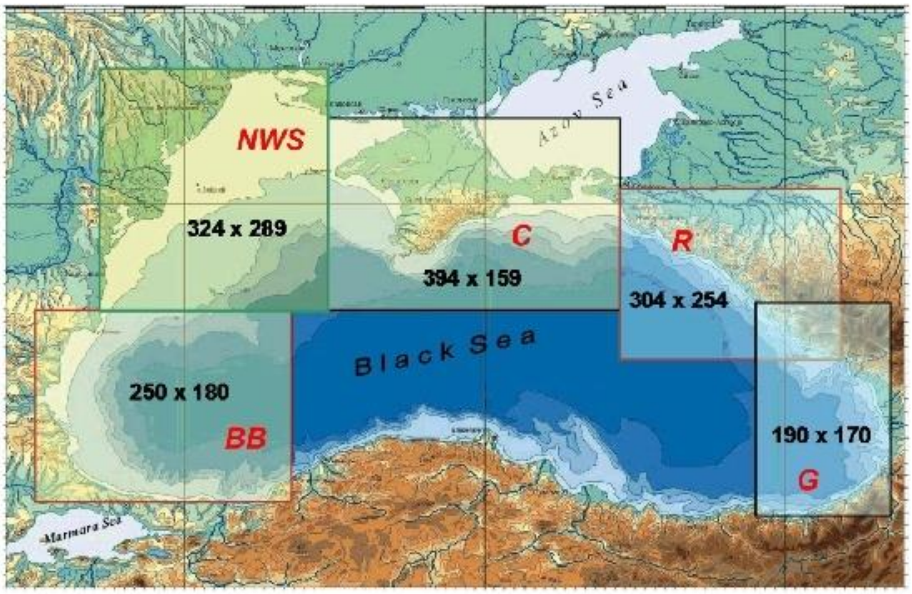



Fig.4. Black Sea coastal regions where are calculated regional forecasts with high-Resolution [70].

The regional forecasting system provides 3 days' forecast of main hydrophysical fields - the current, temperature and salinity with 1 km spacing in the Georgian sector of the Black Sea and surrounding water area, but in accidental situations – also the forecast of spreading oil and other polluting substances.

## 4. Conclusions

The Black Sea, which is typical inland water body, since ancient time was in focus by geographers and travelers, but its systematic and intense scientific study began in the second half of the XIX century. Though the first significant discovery occurred in the XVII century, when the famous Italian diplomat, military man and oceanographer Luigi Ferdinando Marsili in 1679 discovered the lower and upper currents in the Bosporus Strait.

The largest contribution to the Black Sea oceanography was made by expeditions led by I. B. Shpindler (1890-1891), Yu. M. Shokalskiy (1928-1935), N. M. Knipovich (1922-1928). the results obtained in these expeditions made the Black Sea the most studied sea in the World.

The development of remote sensing from artificial earth satellites, the elaboration of high-resolution mathematical models and assimilation methods of observational data in the last two decades have provided the creation of the Black Sea nowcasting/forecasting system, which is a large achievement of the modern Black Sea oceanography.

## References


[1] Beradze Sh. A role of the Black Sea in the foreign-trade relations of Georgia (historical overview). Proceed. of the 2nd International Silk Road Symposium "BSEC Studies", 6, 7 May, 2005, Tbilisi, Georgia, pp.71 -75.

[2] Alasania G. The Black Sea. Proceed. of the 2nd International Silk Road Symposium "BSEC Studies", 6, 7 May, 2005, Tbilisi, Georgia, pp.39-43.

[3] Dimitrov P., Dimitrov D. Black Sea, flood and ancient myths. Varna, Slavena, 2008, 90 p, (in Russian).

[4] Grishin M. G., Sizov A. A. Black Sea depth-measuring expedition (1890-1891). Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2011, Iss. 25, vol. 2, pp. 444-450, (in Russian).

[5] Strabon. Geografiya. Moskva, Nauchno-izdatelskii Centr "Ladimir", 1994. 943 p (in Russian. http://naturalhistoryl.narod.ru/Person/Lib/Strabon/Index.htm.

[6] Flavius Arrianus. Mogzauroba shavi zgvis garshemo (Periplus Pontou Euxeinus), Tbilisi, 1961 (in Georgian).

[7] Soffientino B., Pilson M. E. Q. The Bosporus Strait. A special place in the history of oceanography, vol. 18, № 2, pp.17-23.
[8] Pinardi N., Moroni F., Ozsoy E., Marsili's first scientific ceanographic cruise (1679-1680) and exposition of Bosphorus density currents. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id=20&Itemid=35 .
[9] Ozsoy E., Pinardi N., Moroni F. Marseli's current measurements in the Bosphorus. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id =19&Itemid=34.
[10] Ozsoy E., Pinardi N., Moroni F. A. Scientific biography of Luigi Ferdinando Marsili. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id =16&Itemid=31.
[11] Ozsoy E., Sozer A., Gurses O., Tutsak E., Gunduz M., Sannino G. The leading role of the Turkish Straits system in ocean science and the environmental degradation imposed on unique Natural-Cultural Heritage by Canal Istanbul. https://www.academia.edu/19447211/The_Leading_Role_of_the_Turkish_StraitsSystem_in_Ocean_Science_and_the_Environmental_Degradation_Imposed_on_Unique_Natural-Cultural_Heritage_by- Canal_%C4%B0stanbul.
[12] Ivanov V. A., Kosarev A. N., Tutzilkin V. S. To history of expeditionary oceanographic studies in the Black Sea. Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2004, Iss.10, pp. 9-16 (in Russian).
[13] Fillipov D. M. Circulation and structure of waters of the Black Sea. Moskva, Nauka, 1968, 132 p (in Russian).
[14] Hydrometeorology and Gydrochemistry of the USSR seas. t. IV, the Black Sea. Iss.1 (Eds. A. I. Simonov, E. M. Altman), Sankt-Peterburg, Gidrometeoizdat, 1991, 428 p (in Russian).
[15] Makarov S. O. On the exchange of waters of the Black and Mediterranean Seas. Oceanograficheskie raboty, Moskva, Gidrometeoizdat, 1990, pp.31-93 (in Russian).
[16] Ignatiev C. M. Amazing sea body. Priroda, 2001, № 5, pp. 92-96 (in Russian).
[17] Grishin M. G. Research of physical properties of the Black Sea in 1920-1930. Short review. Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2011, Iss.25, vol.2, pp.435-443 (in Russian).
[18] Vodyanitskiy B. A. The main water exchange and the history of formation of the salinity of the Black Sea. Procced. of Sevastopol biological station. 1948, t. 6, pp.386-432 (in Russian).
[19] Zubov N. N. Domestic seafarers - researchers of the seas and oceans. Moskva, 1965, 474 c., (in Russian).
[20] Arkhangelskiy A. D., Strakhov N. M. Geological structure and development of the history of the Black Sea. Leningrad, AN CCCR Press, 1938, 149 p (in Russian).
[21] Shokalskiy Yu. M. Earthquake of September 12, 1927, Priroda, Moskva, 2006, № 9, pp.67-70 (in Russian).
[22] Pakhotnic A. F. A brief history of expeditionary researches in physical oceanology in the USSR. Moskva, Hayka, 1970, pp. 75-155 (in Russian).
[23] Knipovich N. M. Hydrological studies in the Black Sea. Proceed. of Azov-Black Sea research fishery expedition, 1932, issue 10, 272 p (in Russian).
[24] Shuleikin V. V. Physics of the Sea. Moskva, Nauka, 1968, 1083 p.
[25] Leonov A. K. Regional oceanography. Part 1. Leningrad, Gidrometeoizdat, 1960, 765 p (in Russian).
[26] Blatov A. S., Bulgakov N. P., Ivanov A. N., Kosarev V. S., Tutzilkin V. S. Variability of hydrophysical fields of the Black Sea. Leningrad, 1984, 240 p (in Russian).
[27] Black Sea. Leningrad, Gidrometeoizdat, 1983, 240 p (in Russian)
[28] Kara A. B., Hurlburt H. E., Wallcraft A. J. Black Sea mixed layer sensitivity to various wind and thermal forcing products on climatological time scales. Journal of climate, 2005, .18, № 24, pp.5266-5293.
[29] Kara A. B., Wallcraft A. J., Hurlburt H. E. Sea surface temperature sensitivity to water turbidity from simulations of the turbid Black Sea using HYCOM. J. Physic. Oceanography, 2005, v.35, №1, pp.33-54.
[30] Kara A. B., Wallcraft A. J., Hurlburt H. E. How does attenuation depth affect the ocean mixed layer? Water turbidity and atmospheric forcing impacts on the simulation of seasonal mixed layer variability in the turbid Black Sea. J. Climate. 2005, v.18, № 2, pp.389-409.
[31] Stanev E., Truhchev D., Roussenov V. The Black Sea circulation and its numerical modeling. Universitetsko izdatelstvo "Kliment Oxridski", Cofiya, 1988, 220 p (in Russian).
[32] Kordzadze A. A. Mathematical modeling of dynamics of sea currents (Theory, algorithms, numerical experiments), Moskva, 1989, 218 p (in Russian).
[33] Tolmazin D. M., Shnaidman V. A. et al. Problems of dynamics of waters of the north-western part of the Black Sea. Kiev, Naykova dumka, 1969, 130 p (in Russian).

[34] Barishevskaya G. I. Vertical movements of water masses in the Black Sea. Proceed. of BGMO CHAM, 1967, issue 5, pp.3-18 (in Russian).
[35] Gamsakhurdiya G. R. Investigation of three-dimensional circulation of the Black Sea waters by numerical models in the framework of diagnostic model. Moskva, Institute of oceanology of Academy of Science of USSR, 1975, Dep.in VINITI, № 1832-75, 27 p.
[36] Gamsakhurdiya G. R., Sarkisian A. C. Diagnostic calculations of current velocities on 11 horizons for the Black Sea. Okeanologia, 1975, t. 15, № 2, pp. 239-244 (in Russian).
[37] Djioev T. Z., Sarcisian A. C. Prognostic calculations of the currents in the Black Sea. Izv. AN CCCR, Fizika atmosfery i okeana, 1976, t.12, № 2, pp. 217-223 (in Russian).
[38] Sarcisian A. S. Fundamentals of the theory of calculating ocean currents. Leningrad, 1966, 123 p (in Russian).
[39] Djioev T. Z. Investigation of circulation of the Black Sea waters by numerical methods. Dissertation for the degree of candidate of physical and mathematical sciences. Moskva, 142 p (in Russian).
[40] Girgvliani A. G. Numerical study of dependence of hydrological characteristics of the Black Sea on seasonal variability of atmospheric processes. Preprint № 537, Novosibirsk, VC CO AN CCCR, 1984, 13 p (in Russian).
[41] Zalesny V. B., Kordzadze A. A., Girgvliani A. G. Numerical modeling of seasonal variability of hydrothermodynamics of the Black Sea. In: Numerical solution of ocean dynamics problems. Novosibirsk, 1982, pp. 25-36 (in Russian).
[42] Kordzadze A. A.,Girgvliani A. G. Perspectives of use of hydrodynamics models in problems of the Black Sea ecology. In: Materials of Conference “Ecology and regional use of the natural resources of the south region of Ukraine”, Sevastopol, part 3, pp. 449-454 (in Russian).
[43] Marchuk G. I., Kordzadze A. A., Skiba Yu. N. Calculation of main hydrophysical fields of the Black Sea on the bases of a splitting method. Izv. AN CCCR, Fizika atmosfery i okeana, 1975, t.11, № 4, pp. 379-393 (in Russian).
[44] Kordzadze A. A., Skiba Yu. N. About one numerical method of solving two-dimensional baroclinic problem of ocean circulation. VTs CO AN CCCR, Novosibirsk, 1972, pp.98-122 (in Russian).
[45] Marchuk G. I., Kordzadze A. A., Zalesny V. B. A Problem of mathematical modeling of sea and ocean currents. In: Differential and Integral equations, Tbilisi, 1979, pp. 99-151(in Russian).
[46] Marchuk G. I., Kordzadze A. A. Numerical modeling of sea dynamics on the basis of splitting method. In: Numerical modeling of climate of the World ocean. OVM AN CCCR, 1986, pp.151-163 (in Russian).
[47] Marchuk G. I. Numerical methods in weather prediction. Leningrad, Gidrometeoizdat, 1967, 356 p (in Russian).
[48] Marchuk G. I. Numerical solution of the problems of atmosphere and ocean dynamics. Leningrad, Gidrometeizdat, 1974, 303p (in Russian).
[49] Stanev E. V., Rusenov V. Numerical modeling of seasonal variability of sea currents. In: Complex global monitoring of the World ocean. Leningrad, Gidrometeoizdat, 1985, pp. 120-129 (in Russian).
[50] Girgvliani A. The Coriolis force parameterization in numerical model of the Black Sea dynamics. J. Georgian Geophys. Soc., 1999, v.4b, pp.15-27.
[51] Girgvliani A. Claculation of the effect of the Bosporus Channel on the Black Sea hydropogi. J. Georgian Geophys. Soc., 1999, v.4b, pp.28-39.
[52] Bryan K. A. A numerical method for the study of the circulation of the World ocean. J. Computational Physics. 1969, v.4, № 3, pp. 347-256.
[53] Zatsepin A. G., Baranov V. I., Kondrashov A. A., Korzh A. O., Kremenetskiy V. V., Ostrovskii A. G., Soloviev D. M. Submesoscale eddies at the Caucasus Black Sea shelf and the mechanisms of their generation. Okeanologiya, 2011, v. 51, № 4, pp. 592-605 (in Russian).
[54] Demishev S. G., Dymova O. A. Numerical analysis of mesoscale peculiarities in the coastal zone of the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 2013, t.49, № 6, pp.655-663 (in Russian).
[55] Kordzadze A., Demetrashvili D. Numerical modeling of inner-annual variability of the hydrological regime of the Black Sea with taking into account of alternation of different types of the wind above its surface. Proceed. of Intern. Conference: A year after Johqanesburg-Ocean Governance and Sustainable Development: Ocean and Coasts – a Glimpse into the Future. Kiev, Ukraine, October 27-30, 2003, pp.495-505.
[56] Kordzadze A. A., Demetrashvili D. I., Surmava A. A. Numerical modeling of hydrophysical fields of the Black Sea under the conditions of alternation of atmospheric circulation processes. Izvestiya RAN, Fizika atmosfery i okeana, 2008, t.44, pp.213-224 (in Russian).

[57] Demetrashvili D. I. Modeling of hydrophysical fields in the Black Sea. J. Georgian Geophys. Soc., 2003, v. 8b, pp.19-27.
[58] Oguz T., Latun V. S., Latif M. A. et al. Circulation in the surface and intermediate layers in the Black Sea. Deep Sea Research, 1993, v.1, №40, pp.1597-1612.
[59] Oguz T., Malanote-Rizzoli P., Aubrey D. Wind and thermohaline circulation of the Black Sea driven by yearly mean climatological forcing. J. Geophys. Res., 1995, v.100, №C4, pp. 6845-6863
[60] Stanev E. V. Understanding Black Sea dynamics: Overview of recent numerical modeling. Oceanography, 2005, v.18, № 2, pp.52-71.
[61] Staneva J. V., Dietrich D. E., Stanev E. V., Bouman M. J. Mesoscale circulation in the Black Sea: New results from DiaCast model simulation. J. Mar. Systems., 2001, v.31, pp.137-157.
[62] Dorofeev V. L., Korotaev G. K. Assimilation of satellite altimetry data in the eddy-resolving model of the Black Sea circulation. Morskoy gidrofisiceskiy zhurnal, 2004, 1, 52-68. (in Russian)
[63] Demishev S. G., Numerical model of operative forecast of the currents in the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 2012, t.48, №1, pp.137-149 (in Russian).
[64] Demishev S. G., Korotaev G. K. Numerical modeling of seasonal course of the synoptical changability in the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 1996, t.32, № 1, pp.108-116 (in Russian).
[65] Korotaev G. K., Oguz T., Nikiforov A., Koblinsky C. Seasonal, interannual and mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. J. Geophys. Res., v. 108, NO. C4, 3122, 2003, doi:10.1029/2002JC001508, pp.19-1 – 19-15.
[66] State of the environment of the Black Sea (2001-2006/7). A report by the Commission on the Protection of the Black Sea Against Pollution. 2008-3, Istanbul, Turkey, 419 p.
[67] Titov V. B. About role of vortexes in the forming of current mode on the shelf of the Black Sea and in ecology of the coastal zone. Okeanologia, 1992, t. 32, № 1, pp.39-48 (in Russian).
[68] Korotaev G. K., Dorofeev V. L., Motyzhev S. L., Belokopytov V.N., Palazov A., Malciu V., Zatsepin A.Z., Nesterov E., Stanichny S. V., Ratner Y.B., Suetin V.S., Suslin V. V. Contribution of the Black Sea observing system to ECOOP. Ocean Sciense Discuss., 8, 1695 1722. 2011, www.ocean-sci-discuss.net/8/1695/2011/, doi:10.5194/osd-8-1695-2011.
[69] Korotaev G. K., Oguz T., Dorofeyev V. L., Demyshev S. G., Kubryakov A. I., Ratner Yu. B. Development of Black Sea nowcasting and forecasting system. Ocean Science, 2011, 7, pp. 629-649. doi:10.5194/os-7-629-2011/.
[70] Kubryakov A. I., Korotaev G. K., Dorofeev V. L., Ratner Y. B., Palazov A., Valchev N.,Malciu V., Matescu R., Oguz T. Black Sea Coastal forecasting system. Ocean Science, 2012, 8, pp.183-196.
[71] Gruzinov V. M., Borisov E. V., Grigoriev A. V. Applied Oceanography. Moskva, 2012, 383 p (in Russian).
[72] Marchuk G. I., Paton B. E., Korotaev G. K., Zalesny V. B. Data – computing technologies: A new stage in the development of operational oceanography. Izvestiya RAN, Fizika atmosfery i okeana, 2013, t.49, № 6, pp.629-642 (in Russian).
[73] Kordzadze A. A., Demetrashvili D. I. Some results of forecast of hydrodynamic processes in the easternmost part of the Black Sea. J. Georgian Geoph. Soc., 2010, 14b, p.37-52.
[74] Kordzadze A. A., Demetrashvili D. I. Operational forecast of hydrophysical fields in the Georgian Black Sea coastal zone within the ECOOP. Ocean Science, 2011, 7, pp.793-803, www.ocean-sci.net/7/793/2011/.
[75] Kordzadze A. A., Demetrashvili D. I., Kukhalashvili V. G. Circulation processes in the easternmost part of the Black Sea in 2011-2012. Results of simulation and forecast. J. Georgian Geoph. Soc.,2011-2012, v.15b, pp.3-12.
[76] Kordzadze A. A., Demetrashvili D. I. Coastal forecasting system for the easternmost part of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences. 2012, 12, pp.471-477. www.trjfas.org.
[77] Kordzadze A. A., Demetrashvili D. I. Simulation and forecast of oil spill transport processes in the Georgian Black Sea coastal zone using the regional forecasting system. J. Georgian Geoph. Soc., 2014, v.17b, pp.3-14.
[78] Kordzadze A. A., Demetrashvili D. I. The Black Sea oceanography in the past and at current stage. Tbilisi State University Press, 2017, 187p (in Georgian).

# ძირითადი ეტაპები შავი ზღვის ოკეანოგრაფიის ისტორიაში

ა. კორძაძე, დ. დემეტრაშვილი

**რეზიუმე**

სტატიაში მოკლედაა აღწერილი ძირითადი ეტაპები შავი ზღვის ოკეანოგრაფიის ისტორიაში შუა საუკუნეებიდან დღემდე. ნაჩვენებია, რომ თანამედროვე ცოდნა შავი ზღვისა და ამ უნიკალური ზღვის აუზში მიმდინარე ჰიდროფიზიკური და ბიოქიმიური პროცესების შესახებ ყალიბდებოდა მრავალი მკვლევარ-ოკეანოლოგების დაუღალავი საქმიანობის შედეგად ბოლო რამოდენიმე საუკუნის მანძილზე. მნიშვნელოვანი ყურადღება ეთმობა თანამედროვე ოპერატიულ ოკეანოგრაფიას თანამედროვე ინფორმაციულ-გამოთვლითი ტექნოლოგიებისა და თანამგზავრული დისტანციური ზონდირების მეთოდების გამოყენებით.

# Основные этапы в истории океанографии Черного моря

А. Кордзадзе, Д. Деметрашвили

**Резюме**

В данной статье кратко описываются основные этапы в истории океанографии Черного моря со средних веков до настоящего. Показано, что современное знание о Черном море и гидрофизических и биохимических процессах, происходящих в этом уникальном морском бассейне, достигнуто в результате упорной деятельности исследователей-океанологов в течение последних нескольких веков. Значительное внимание удаляется современной оперативной океанографии с использованием современных информационно-вычислительных технологий и спутниковых дистанционных методов зондирования.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v.21(2), 2018, pp. 47 – 60*

# Pollution of the Black Sea by Oil Products. Its Monitoring and Forecasting

**Avtandil A. Kordzadze, Demuri I. Demetrashvili**

*Iv. Javakhishvili Tbilisi State University, M. Nodia Institute of Geophysics,*
*1, Alexidze Str., 0160, Tbilisi, Georgia, e-mail: demetr_48@yahoo.com*

***ABSTRACT***

In the paper the current state of the Black Sea pollution by oil products is reviewed. The significant attention is paid to a satellite radar monitoring of the sea surface pollution. The paper contains also short description of the numerical models on simulation and forecasting of oil spill dispersion in the sea environment. Some result on simulation of oil pollution distribution in the Georgian water area based on advection-diffusion equation in conditions of real regional circulation is presented.

***Key words***: Black Sea, pollution by oil products, numerically modeling

## 1. Introduction

In recent decades an intensive pollution of many regions of the World Ocean with oil products and other highly toxic substances of anthropogenic origin takes place. In this regard a special place is held by inland water bodies which are particularly sensitive to anthropogenic loads due to their low water exchange with the World Ocean. Primarily, the aforementioned fact may be referred to the Black Sea, whose pollution level progresses significantly. It is well known that the Black Sea is one of the most contaminated basins of the World Ocean due to anthropogenic impact and hydrological features. The Black Sea is the inland sea most isolated from the World Ocean, it is only connected to the Mediterranean through the Turkish Straits and to the Sea of Azov – through the Kerch Strait. Specific features of the Black Sea make it very vulnerable to the anthropogenic loading leading to a significant increase in pollution level of the Black Sea with different pollutants. According to modern observations a pollution of the Black Sea by substances of anthropogenic origin is progressing [1-5]. Among the polluting substances oil and oil products are more dangerous and widespread components for the Black Sea environment as well as for the World Ocean [2, 4-6]. Besides that they can cause a serious damage to the marine living organisms, they can break a natural hydrological cycle and, consequently, cause anthropogenic climate changes. If on the big square of the ocean surface oil and oil products in a considerable quantity are poured, they will promote reduction of evaporation and simultaneously will decrease salt fluxes in the atmosphere because of decrease wind waves and splashes [7]. It is well known that salt particles play a role of the centers of condensation and consequently their deficiency will block processes of cloud's formation [8].

The degree of risk is especially great for shelf and coastal zones due to intensive human economic activity. In this respect Georgian coastal zone is not exception. Through the Black Sea passes the international transport corridor TRACECA (Transport Corridor Europe-Caucasus-Asia) and in the coming years shipping intensity is expected to increase. This fact creates a sufficient potential threat for the Black Sea and especially for the Georgian coastal zone.

At present, there is no such region in the World Ocean that would not be affected by the pollution of water with oil products. According to modern estimates, annually 1.7-8.8 million tons oil are released in the World Ocean.

Crude oil is a mixture of different fractions, whose main components are hydrocarbons (80-90%). In the marine environment, oil and oil products are in the form of oil films, dissolved and emulsified petroleum products, oil aggregates [3]. Significant concentrations of oil products in sea water are observed in the area of estuaries of large rivers - the Danube, Dnieper, Dniester and in the waters of the ports.

In conditions of growing anthropogenic loading on the sea ecosystems it is obvious that a reliable operational monitoring and forecast of pollution areas and concentrations in accidental situations is a very important problem. At present the modern satellite radar technologies provide to carry out monitoring of oil pollution of the sea surface with high space resolution [6].

The Black Sea crisis calls for a concerted international approach. Protection and environmental safety of marine ecosystems became an object of great attention in the 50s of the last century. The first international agreement was concluded in 1954 in London/United Kingdom on the prevention of oil pollution of the seas (1954 London Convention).This agreement imposed certain obligations on states to protect the marine environment.

Since 1990s the international cooperation between the Black Sea countries has entered into a new phase. On 30 November 1990 in London the International Convention on Oil Pollution Preparedness, Response and Co-operation (known as the OPRC Convention) was adopted. The Convention obliges its participating States including Georgia to ensure the readiness of the oil spills to be adequately reacted. In 1992 in Bucharest/Romania the six coastal countries (Bulgaria, Georgia, Romania, the Russian Federation, Turkey and Ukraine) signed and ratified the convention on the Protection of the Black Sea against Pollution. Since then, the commission on the Protection of the Black Sea against Pollution (the Black Sea Commission/BSC), acting on the mandate of the Black Sea countries, is responsible for the sustainable management of the Black Sea.

In this paper the current state of pollution of the Black Sea by oil products is reviewed. The significant attention is paid to a satellite monitoring of the sea surface oil pollution. The paper contains also short description of the numerical models on simulation and forecasting of oil spill dispersion in the sea environment. Some result of simulation of oil pollution distribution based on advection-diffusion equation in the Georgian water area in conditions of real regional circulation is presented.

## 2. The current state of the Black Sea oil pollution

In addition to the fact that covering the sea surface with oil spots significantly affects the characteristic parameters of sea-atmospheric interaction, oil pollution has a substantial impact on a number of hydrochemical and hydrobiological processes and consequently on the marine ecosystems. The consistency of oil can cause surface contamination and smothering of marine biota, and its chemical components can cause acute toxic effects and long-term accumulative impacts [9]. The environmental impact does not only depend on the size of the spill but also on the spread of the oil slick, the toxicity and persistence of the oil and the sensitivity of the environmental region affected.

In the 70-80s of the last century, researches conducted at the Novorossiysk Biological Station showed that oil pollution of the Novorossiysk Bay caused significant changes in the distribution of seaweed and animal species [3]. For example, water-plants Zostera and Cystoseira, which previously developed rapidly in the shallow parts of the sea, retreated to a depth of 3 m. Mussel, widely distributed earlier in the middle of the bay, now lives only in the open deep sections, where the waters are less polluted [3].

The main sources of oil pollution of the Black Sea are river runoff, direct discharges of domestic and industrial wastewaters, atmospheric deposition, port operations in the sea ports, accidental inflows and unauthorized spills from oil ships. At present the Black and Azov Seas are the marine region with the largest anthropogenic press in Europe [3]. Nowadays the Black Sea plays a role of corridor for oil transportation from the East to the West, and in the coming years this transportation is expected to increase. This fact creates a sufficient potential threat of even greater ecosystem pollution with oil products.

According to the data given in [2], the annual quantity of oil emissions into the Black sea for 2003 was 110000 tons. Particularly large anthropogenic load is experienced by the shallow north-western part of the Black Sea. A significant contribution to the level of oil pollution in the northwestern part of the sea is made by the Danube River. In one of the documents prepared by the Parliamentary Assembly of the Council of Europe [10], where the contribution of large rivers to the Black Sea pollution is quantified, it is mentioned that only the Danube annually carries out into the sea 50000 tons of oil products.

According to the data presented in [6], by 2007 about 170 million tons of oil and petroleum products passed through the Black Sea ports. According to statistics, from 0.1% to 0.5% transported oil is discharged to the ocean as a result of the discharge of washing and ballast water to the open sea. Considering this fact, the volume of oil products entering the Black Sea in the form of oil spots should be more than 150000 tons per year.

Among the major oil spills in the Black Sea in last decades, we can note an emergency spill near Novorossiysk on November 1999, when, due to damage to the terminal, 39 tons of oil spilled into the sea [2].

Fig.1. Oil patches on the Tuzla Spit on November 12, 2007 [11].

Large emergency spill occurred in the Kerch Strait as a result of a storm on 10 and 11 November 2007 [11]. The strong storm hit the Kerch Strait located between Ukraine in the West and Russia in the East, and linking the Sea of Azov with the Black Sea. Extremely severe conditions lasted 9 hours. Winds exceeding 30 m/sec produced the over 4 meter-high waves. A strong storm resulted in thirteen vessels being sunk and damaged. The incident caused loss of life, or property, and environmental harm. According to the data provided by the Ukrainian Ministry of Transport, the total amount of the immediate spillage was 1300 tonnes of heavy fuel oil, 2,3 tonnes of oil lubricants, 25 tonnes of marine diesel fuel oil and 5,5 tonnes of heating oil. Fig. 1 Illustrates pollution of the coast of Tuzla island by oil after emergency on November 12, 2007.

The Kerch accident became the most studied oil spill event in the world – numerous inspection trips on coast and at-sea and more than 60 complex cruises were organized.

Over the past 50 years in the Black Sea and especially in the Bosporus Strait, there have been many major oil spills than it was in the Kerch Strait. In October 1977 in Bosporus Strait as a result of damage to the Soviet tanker 20000 tons of oil spilled into the sea. In November 1979, as a result of the collision of the Romanian and Greek tankers 64000 tons of oil spilled into the sea. The largest in the past 20 years oil spill in the Black Sea occurred when the *Nassia* tanker and the *shipbroker* cargo vessel collided in the Bosporus Strait on 13 March 1994. *Shipbroker* got totally burnt. The major part of *Nassia's* cargo was spilled over into the sea and together with 20000 tons of burnt oil caused severe marine and air pollution on the Bosporus, and in the Black and Marmara Seas [11].

In the Marmara sea, nearly 450 different scale accidents were reported within the last 40 years. Several ship accidents happened during the past 20 years by the Black Sea coast of Bulgaria, Romania, Russia and Ukraine, however, they mostly brought small-scale oil spills or other kind of pollution [11].

On 24 December 2014 The pipeline near the city of Tuapse burst. According to Chernomor "Transneft" a subsidiary of Russia's main oil transport company "Transneft" the wall of the pipeline broke due to... a landslide. The company said in a statement, adding that the rupture caused 8.4 cubic meters to leak out into the Tuapse River, which empties into the Black Sea. Environmentalists warned however that the volume of the spill could be nearly 100 times greater than claimed by “Transneft”. By estimation of World Wildlife Fund the surface area and characteristics of the spill indicated that there could be as much as 500 to 700 tons of oil in the Black Sea, which would be approximately 100 times as much as originally reported [12]. In Fig.2 oil leaks at the Tuapse River on December 14, 2014 are shown.

Fig. 2. Oil leaks at the Tuapse River in the Russian Black Sea coastal town of Tuapse, December 24, 2014. (Reuters photo).

The most serious pollutants of the marine environment in the Black Sea coast of Turkey are petroleum hydrocarbons. Water pollution by oil was the main cause of environmental degradation in the western part of the sea in 1970-1995 [13]. Oil fractions and crude oil fall into the marine environment as a result of emergency spills, leakage of petroleum products from transport vessels, urban and river run-offs and the discharge of contaminated water from tanker ballast tanks. Oil stains on the water ruined a lot of sea gulls and other species of birds. The ecological situation in this part of the sea has gradually improved, after the Turkish Coast Guard service has been prevented the discharge of ballast waters from the ships [13].

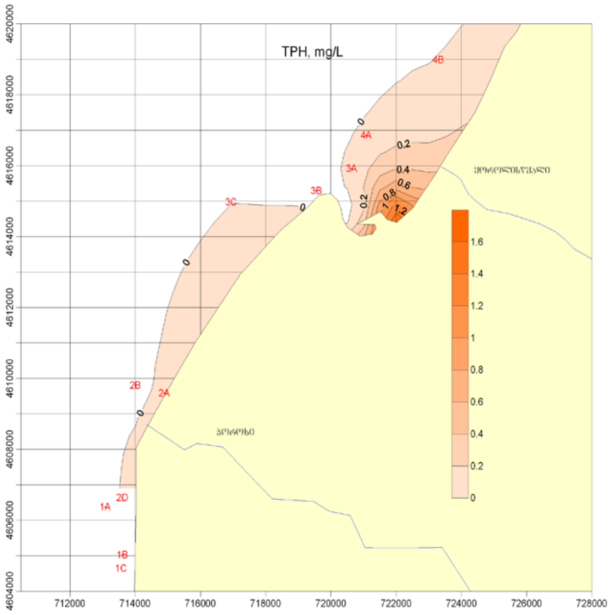



Fig. 3. Content of petroleum hydrocarbons in seawater at Gonio-Natanebi water area [14].

Studies carried out in Batumi-Gonio coastal zone (Georgian Sector of the Black Sea) in 2008-2009 [14] showed that the concentration of petroleum hydrocarbons were within 0,04-1,74 mg/l. Maximum value 1,74 mg/l was at the confluence of the Bartskhana river to the Black Sea. These studies also showed that major polluters of the Black Sea by oil products are rivers Bartskhana, Korolistskali, Supsa and Khobi. According to the data for 2009 concentration of oil hydrocarbons in Korolistskali 161 times higher than the permissible norm – 0.3 mg/l. In the internal water area of Batumi port was observed 0,52 mg/l. The map of distribution of petroleum hydrocarbons, created on the basis of measured data, is shown in Fig.3 [14].

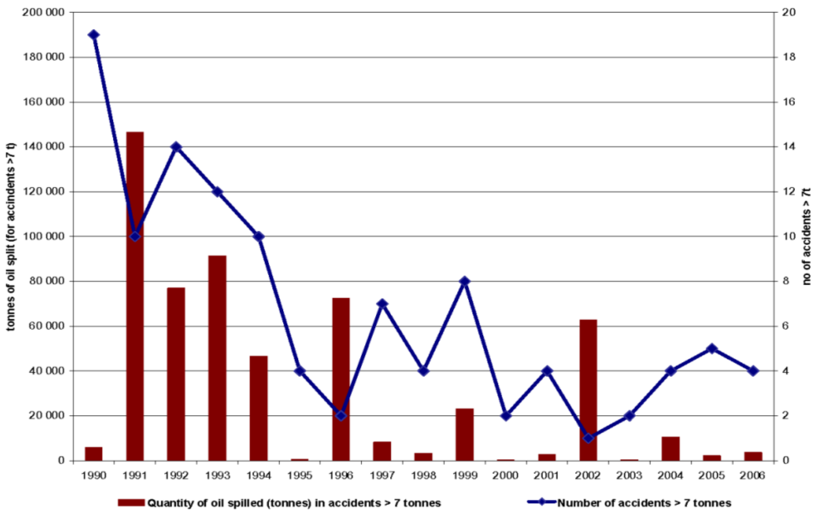



Fig. 4. Accidental oil tanker spills (above 7 tonnes per spill) in European seas during 1990-2006 [9].

It should be noted that according to European Environment Agency accidental oil tanker spills into the European Seas have decreased significantly during 1990-2006 [9]. Fig. 4 clearly illustrates this fact [9]. Despite the decreasing number of accidental oil spills in European waters (the Northeast Atlantic, Baltic, Mediterranean and Black Sea) major accidental oil tanker spills (i. e. those greater then 20000 tonnes) still occur at irregular intervals.

## 3. Satellite monitoring of oil pollution

In recent years the use of modern satellite remote sensing methods and satellite technologies in Earth Sciences has led to better understanding and study of the ongoing geophysical processes on our planet [4, 6, 15-23]. Over the last decades the development of remote sensing methods of sea surface from the Earth's artificial satellites has reached a completely new level. These methods made a revolutionary leap into the field of marine science and gave them completely new qualities. As the authors write in [15], now is impossible to imagine carrying out environmental monitoring without using information obtained with the help of remote diagnostic devices installed on various satellites specialized in remote sensing of the Earth. At present, remote sensing equipment makes it possible to carry out various regular observations of the ocean surface with high space resolution and high time frequency.

Because the Black Sea ecosystem is experiencing increased anthropogenic impact, which is importantly associated with oil contamination, therefore it is very important and urgent to implement an operational satellite radar monitoring system that will effectively identify the areas of spillage and sources. With this purpose the modern satellite radiolocation has great importance, which is very effective tool to identify oil pollution zones and sources in basin scale operatively [4, 6, 17, 18]. The satellite technology has such advantages as high resolution, simultaneous monitoring over the large territory at any weather conditions, etc. High spatial resolution of modern space borne radars with synthesized aperture (SAR) installed on the satellites *ERS-2* and *Envisat* of the European Space

Agency allow us to accurately detect film contaminations of even a relatively small size and evaluate their parameters.

Spilled oil on the sea surface forms an oil spot, which leads to damping of the gravitational-capillary component of surface waves and forms areas of smoothing, called slicks. They are displayed in a dark tone on the radar images. However, there are a number of natural factors limiting the applicability of space radar to solve the problem of identifying oil spills. At a weak wind of 1-2 m/s oil films do not differ on a background of a dark sea surface. In a strong wind they disappear from the surface due to intense wave mixing. The wind speed between 3 m/s and 8 m/s is ideal for detecting oil contamination [6]. In this case, slicks look dark on the background of light agitated surface of the sea.

Slick on the sea surface can be formed not only because of oil pollution, but the cause of slicks can be various organic compounds. Sources of organic matter in the ocean are animals and plants, as well as natural sources of crude oil [24]. Biogenic substances form on the surface of the sea films in several monomolecular layers $10^{-7}$-$10^{-6}$ cm thick, accumulating in areas of high biological activity. Biogenic films are the result of the life activity of marine organisms and plants, mainly phyto and zooplankton, as well as bacteria. They are formed in the sea as a result of complex biochemical reactions in the process of vital activity and decomposition of marine organisms, and can not be considered as sea pollution. Organic films remain in the sea at weak winds for a long time and begin to break down when the wind speed exceeds 6-7 m/s. After the termination of the strong wind, organic substances are again carried to the surface and form slicks. Not only oil and oil products form anthropogenic films on the sea surface, but also various technical and household oils, fatty acids and alcohols, synthetic surfactants contained in domestic, industrial and sewage. Spilled into the sea, oil forms films of varying thickness, since oil and its products are complex mixtures. Due to its physico-chemical properties, oil can exist in the ocean for a long time in the form of films, in emulsified form or in the form of aggregates. With a strong wind, the stain is destroyed and an oil emulsion appears in the layer of wind mixing. Unlike organic matters, oil never spreads to monomolecular layers, and its films have a large thickness.

Among numerous papers devoted to satellite radar monitoring of the sea surface pollution it should be noted [15], where results obtained in the course of multiyear satellite monitoring of oil pollution in the Baltic, Caspian and Black seas are summarized. An integrated approach to detection and spreading forecast of oil pollution is based on joint analysis of various data of satellite remote sensing of the sea surface. As a result of the analysis of various data of satellite remote sensing of the sea surface areas worst affected by oil pollution were revealed. The greatest part of anthropogical pollution of the surface in the Baltic and Black Seas detected during monitoring activities is accidental spills and deliberate discharges of liquid oil products along the main ship routes. For three years 2009-2011 of satellite observations more than 600 cases of pollution of the Black Sea surface by oil products as a result of ship discharges have been revealed in the Sea water area.

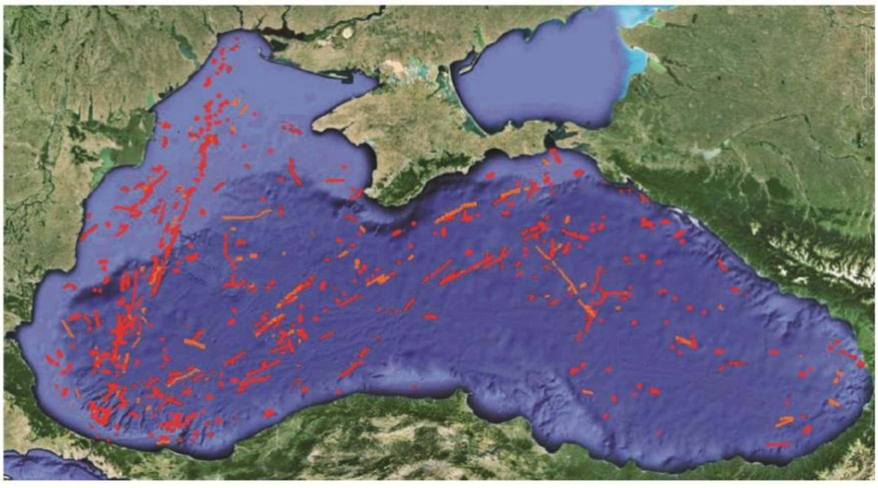


Fig.5. Map of oily ship discharges to the Black Sea, detected as a result of the analysis of satellite radar data in 2009-2011 [15].

In Fig.5 a generalized map of oil pollution of the Black Sea water area, obtained on the basis of deciphering satellite radar data for 2009-2011, is presented. This Figure shows the cumulative map of oil-containing spills revealed from satellite radar data in the aquatic area of the Black Sea for three years. Year-by-year numbers of oil spills detected are 286, 253, and 247 correspondingly. All these pollution events are caused by spillages of oil-containing waters from moving ships. As expected, spillages are concentrated along the main shipping routes such as Istanbul-Novorossiysk, Istanbul-Odessa and Istanbul-Tuapse. Besides these routes, a large amount of spills is observed near the major ports of Bulgaria, Turkey, Romania and Ukraine as well as near oil loading terminals [16].

In Fig. 6 satellite radar images obtained from satellite ERS-1 and ERS-2 on 12 and 13 May 1996 for some water area of the Caspian Sea are presented where by dark color oil stains on the sea surface are clearly visible [6]. Often vessels produce multiple discharges of polluted waters in motion. Fig. 7 shows an example of such a phenomenon and illustrates the trace of the oil spill along the trajectory of the ship fixed from the satellite in the Japanese Sea on the radar image of the ERS-1 satellite.

(a) (b)

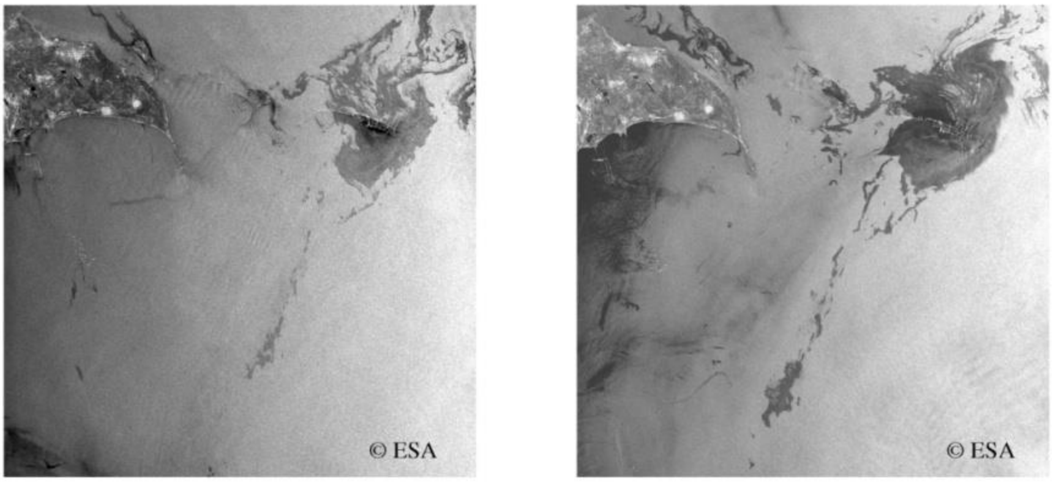



Fig. 6. Satellite radar imageries of oil slicks on the Caspian Sea surface received from satellites -ERS-1 on May 12 (a) and ERS-2 on May 13 (b), 1996 [6].

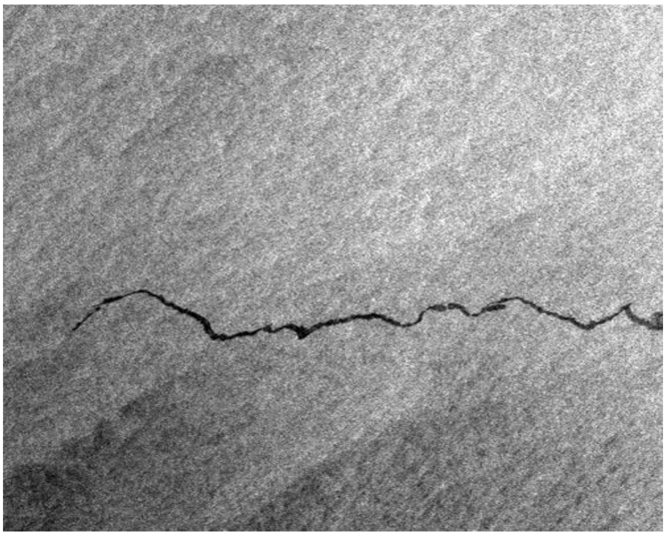


Fig.7.Trace of an oil spill along the trajectory of a ship in the Japanese Sea on a radar image received from a satellite (20.05.1994, 14:20 UTC) [25]

In [15, 21] it is noted that illegal discharges of ballast water containing oil products are so common for the Black Sea that in aggregate they cause much greater damage to the ecosystem of the Black Sea than individual catastrophic oil spills.

In [15, 16] the results of a long-term satellite monitoring of the Black Sea revealing sea surface pollution by oil as well as manifestations of biogenic and anthropogenic surface films are presented. It turns out that in case of the Black Sea, the detection of oil spills caused by ship discharges is more complicated as compared with other seas due to intensive phytoplankton bloom and to natural hydrocarbons seeps that can be detected in various areas of the Black Sea.

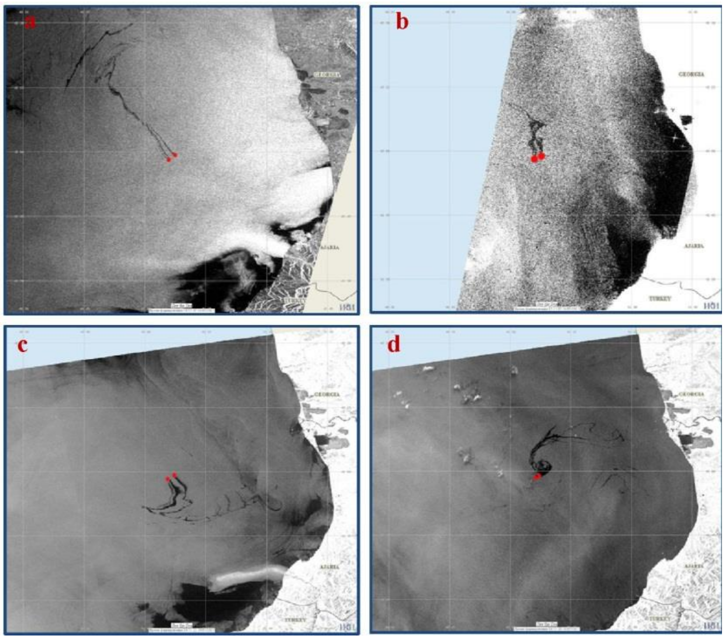



Fig. 8. Surface slicks in the continental slope area offshore Georgia as seen in satellite radar imagery on 27.10.2010 at 07:32 UTC (a), 17.09.2011 at 07:21 UTC (b), 08.11.2014 at 15:10 UTC (c), and on 15.10.2014 at 15:10 UTC (d) [15, 16].

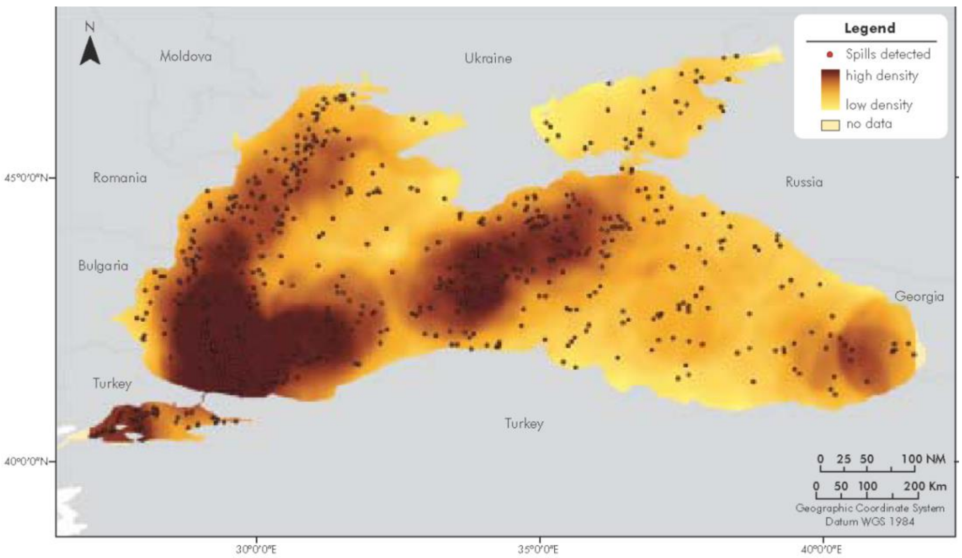



Fig. 9. Map of detected oil spills and oil spill density in the Black Sea during 2000-2002 [26]

With the purpose of illustrating Fig. 8 gives some examples of patterns of oil pollution detected in SAR (synthetic aperture radar) images taken over the continental slope area offshore Georgia.

Surface slicks in Georgian water area are caused by natural hydrocarbon seepages from the sea bottom. Certain types of surface pollution detected in sea surface radar imagery (Fig.8) are caused by natural hydrocarbon seeps at the Black Sea bottom. Researches carried out in the Georgian continental slope are showed that four cold methane seeps are located on the sea floor in this area. The presence of oil traces in bottom sediments is a distinguishing feature typical of these seeps [15, 16].

In Fig. 9 detected oil spills and oil spill density in the Back Sea during years 2000 to 2002 are shown. From this Figure is visible that the most pollution areas are south-western and central part of the sea basin. Oil polluting area is also in the Georgian sector, but with less intensity [26].

At present, the system of operational satellite monitoring is working successfully in the different regions of the World Ocean – in the Russian sector of the Black Sea, in the south-eastern part of the Baltic Sea, in the north part of the Caspian Sea, etc.

## 4. Forecasting methods of oil pollution

The development of oil pollution forecasting methods is one of the urgent problems of contemporary applied oceanology [2, 6, 11]. A reliable operational forecast of distribution and concentration areas of pollutants in case of accidental oil spills will allow to optimize the effectiveness of performing measures in order to bring down to the minimum the possible negative consequences caused by oil pollution.

The spread of oil spills in the sea is a very complex process, depending on a large number of factors that determine both the state of the environment and the properties of petroleum hydrocarbons. The forecast of oil spill transport in the sea environment requires first of all forecast of sea circulation processes.

The mechanism of distribution and transformation of oil spilled in the marine environment is described in sufficient detail in [2, 27-29]. In addition to advective transfer and turbulent diffusion, in the first days after the spillage oil concentrations are also affected by evaporation, emulsification, and dissolution processes. A sufficient number of works is dedicated to the modeling of oil patch transfer in the Black Sea and in other seas (e. g. [2, 30- 41]). We will mention some of them. In [2] an integrated model of the Black Sea water circulation and oil patch drift on the basis of the random walking particles approach, which allows tracking the motion of single particles (sum total of them makes an oil slick). Circulation parameters were derived from DiaCAST model [42] adapted for the Black Sea. The model from [2] was also used for the Caspian Sea [31-33], but the fields of currents and turbulence were reproduced by means of POM model [43] adapted for the Caspian Sea.

As advanced model of oil pollution drift [34], which is an additional module to the operational model of ocean circulation, was developed at Danish Meteorological Institute. Turbulent motion is described by Monte Carlo method. This model is used for the North and Baltic Seas and allows forecasting not only the oil slick spread on the sea surface, but also the amount of oil immersed in the lower layers.

3D oil pollution model MOTHY [35-37] connected to the model of ocean circulation was developed by French meteorological service *Meteo-France*. MOTHY model is used for the Aegean Sea, the Mediterranean Sea and for other regions of the World Ocean. The adaptation of this model to the Bourgas bay [38] was performed by Bulgarian national meteorological service. Nowadays MOTHY is a component of a system of operational marine forecasts in Bulgaria and it can be used in case of emergencies.

In [39] a system of the weather, wind-induced waves and sea current simulation, in which the model of oil slick drift is included, was developed. MMS model [44] is used for operational weather forecasting in the Black Sea region, for the simulation of wave-induced waves – *WAVEWATCH*III [ 45 ], and the Black Sea hydrodynamics is calculated by means of POM model [43]. The simulation system is implemented for the north-western shelf of the Black Sea and for estuaries of the Dnieper and the Bug.

In [41] a 3D numerical model for transport and fate of oil spills in seas based on the particle approach is presented. The amount of oil released at sea is distributed among a large number of particles tracked individually. Horizontal and vertical diffusion are taken into account using a random walk technique. The model takes into account: advection, surface spreading, evaporation, dissolution, emulsification, turbulent diffusion, the interaction of the oil particles with the shoreline, sedimentation and the temporal variations of oil viscosity and surface tension. The model has been applied to simulate the oil spill accident in the bohai Sea.

In [46-48] the process of oil propagation all over the Black Sea spilled on the sea surface in large quantity was simulated on the basis of a 2D advection-diffusion equation for non-conservative impurity. The components of the sea current velocity corresponded to the annual mean climatic conditions and were calculated by the nonlinear barotropic sea dynamics model [49]. Numerical experiments performed at different location of pollution sources showed that the Rim Current having cyclonic character predetermines the principal features of the oil pollution distribution; on expiration of a certain time (about 1,5-2 months) after emission, the process of distribution of oil concentrations practically does not depend on the location of the oil pollution source, pollution is distributed over the whole water area of the Black Sea and tendency to alignment of concentrations is noticed.

At present the model [46-48] is adapted for the easternmost part of the Black Sea and included in the easternmost Black Sea regional forecasting system as a separate module [50-54]. This regional system is a subsystem of the basin-scale nowcasting/forecasting system. The current field used in the oil spill transport model is calculated from the regional model of the Black Sea dynamics, which is a core of the regional forecasting system. The forecasting system permits to forecast oil pollution zones and oil concentrations for 3 days with spatial resolution 1 km in the Georgian Black Sea coastal zone. Numerical experiments performed for the cases of various locations of a hypothetic pollution source occurring under actual circulation modes, showed a significant role of dynamic processes in formation of some features of spatial-temporal pollution distribution.

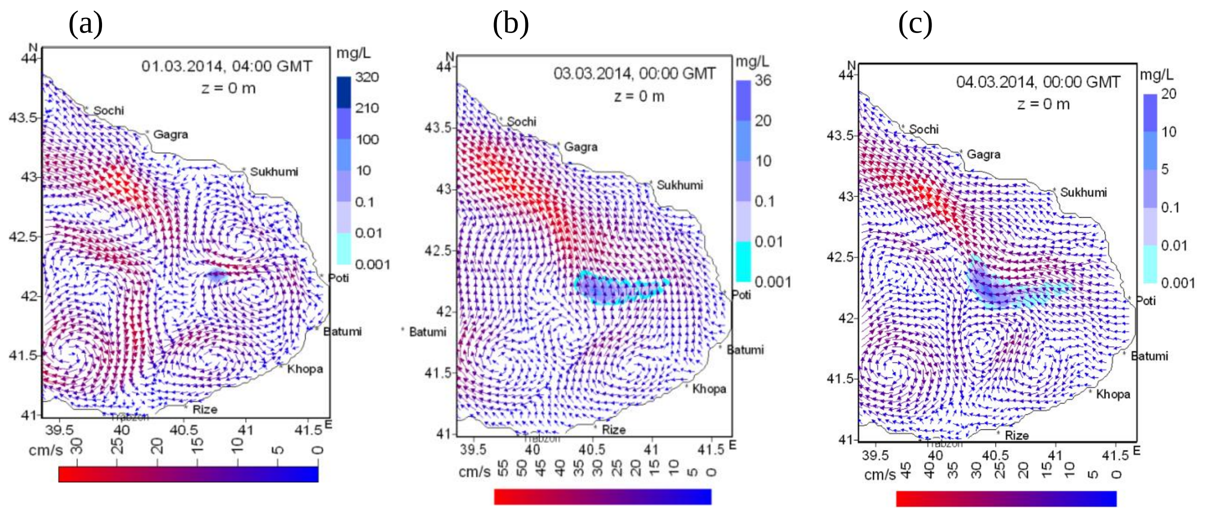



Fig.10. The surface current and simulated oil spill transport at different time moments (after start of oil spillage): (a) - 4 h, (b) - 48 h, (c) - 72 h. (The forecasting period: 00:00 GMT, 1-4 March, 2014), [53].

Fig. 10. illustrates forecasted regional circulation in the easternmost part of the Black Sea and drifting of oil slick in case when 50 t oil was abnormally spilled during 2h on distance about 65 km from Poti shoreline. The forecasting period was 00:00 GMT, 1-4 March 2014. From Figure it is well that in the eastern part of the considered area the triplet structure consisting of two anticyclonic vortexes and middle cyclonic vortex is formed on 1-2 March 2014. During the forecasting interval the current is substantially transformed – the triplet structure gradually breaks up and the current directed to the north-west is formed, but there are also some vortexes with relatively small sizes. Such circulating reorganization is essentially reflected on moving of the oil spill. In the course of migration the oil slick deforms and concentrations gradually decrease that is caused by diffusion expansion and other nonhydrodynamic factors.

## 5. Conclusions

Currently, the Black Sea is the marine region with the greatest press in Europe and its pollution with various anthropogenic substances is progressing. The main polluters of the Black Sea are oil and oil products. In addition to river and coastal runoff, which gives chronic pollution of the marine environment, the transportation of oil and oil products by the sea and the operation of oil terminals is a major potential threat to the sea ecosystem. Conducted studies and assessments show that for the Black Sea a frequent release of ballast and wash waters from tankers are serious source of pollution by oil products. It is expected that in the near future the transport role of the Black Sea will be increased which creates a serious potential threat to the marine ecosystem.

The development and functioning of the high resolutions operational satellite radar monitoring systems for the World Ocean including the Black and other regional seas is very actual and important problem of the modern operational oceanography. Performed observations have demonstrated a clear necessity of implementing operational satellite monitoring of water area pollution, which are able to determine the source of pollution, conduct quantitative assessment of its scale and predict its drift parameters. In [15] it is hoped that the appearance on the satellites of new highly sensitive sensors and the development of techniques for processing the satellite data will contribute to a more reliable identification of oil slicks and the determination of their thickness.

A real time prediction of oil spill transport and fate is very important for clean-up operations and to estimate its impact on the marine environment. A lot of publications are devoted to the modeling of oil spill transport in the Black Sea and in other seas. Some of them are used in a operational mode for some regions of the world ocean. The oil spill transport model based on a solution of the 2D advection-diffusion equation is a component of the easternmost Black Sea regional forecasting system [50-54], which enables to forecast for 3 days the main 3D dynamic fields – the current, temperature and salinity with 1 km resolution in the Georgian sector of the Black Sea and surrounding water area, but at accidental oil spills the forecasting system provides also to forecast oil pollution zones and concentrations.

## References


[1] Fabry V., Frohlich K., Osvath I. Environmental pollution of the Black Sea: a search for answers. IAEA Bulletin, 1993, 2, pp. 20-24.

[2] Korotenko K. A., Dietrich D. E., Bowman M. J. Modeling of circulation and oil spill transport in the Black Sea. Okeanologia, 2003, t 43, № 3, pp. 367-378 (in Russian).

[3] Gubanov E. P., Ievleva M. N. Oil pollution of the Black Sea and its influence on the ecosystem. 2006, 16 p (in Russian), http://www.ceemar.org/dspace/bitstream/ 11099/1132/1/article-13.pdf.

[4] Mityagina M. I., Lavrova O. Yu., Bocharova T. Yu. Satellite monitoring of oil pollution of the sea surface. Covremennye problemy dictancionnogo zondirovaniya zemli iz kosmosa, 2015, v.12, № 5, pp.130-149 (in Russian).

[5] Ecological problems of the Black Sea. http://ria.ru/spravka/20071031/86018545.html

[6] Lebedev S. A. Estimation of the background pollution by oil products of the Black and Caspian Sea using remote sensing data and model calculations.2009, 21 p (in Russian), http://www.mkgtu.ru/docs/KONF_SEM/lebedev.pdf.

[7] Perry A. H., Walker J. M. The ocean-atmosphere system. Leningrad, Gidrometeoizdat, 1979, 195 p (in Russian).

[8] Kraus E. B. Atmosphere-ocean interaction. Leningrad, Gidrometeoizdat, 1976, 295 p (in Russian).

[9] Accidental oil spills from marine shipping. European Environmental Agency. https://www.eea.europa.eu/data-and-maps/indicators/en15-accidental-oil-spills-from

[10] Mironescu L. The fight against harm to the environment in the Black Sea. Parlamentary Assembly Recommendation 1837, Doc.11632, 2008, http://assembly.coe.int.

[11] Oil spill accident in the Kerch Strait in November 2007. Edited by A. Korshenko, Y. Ilyin,V. Velikova. Black Sea commission publications. Moscow,Nauka, 2011, 288 p.

[12] Russia battles to contain Black Sea oil spill. http://timesofindia.indiatimes.com/home/ environment/pollution/Russia-battles-to-contain-Black-Sea-oil-spill/articleshow/ 45642295. cms.
[13] Topkuogly S. Ecology of the Black Sea. Study of pollution of the sea environment of Turkey. Bulletin МАГАТЭ, 2000, 42, 4, pp. 12-14 (in Russian).
[14] Benashvili N. Issues of ecogeochemistry of the Georgian Sector of the Black Sea. Dissertation for the academic degree of ecology doctor. Tbilisi, 2012, 164 p (in Georgian).
[15] Mityagina M. I., Lavrova O. Yu., Bocharova T. Yu. Satellite monitoring of oil pollution of the sea surface. Sovremennye problemy distancionnogo zondirovania zemli iz kosmosa.2015, т. 12, № 5, с. 130-149 (in Russian). http://www.iki.rssi.ru/asp/dep_proj/ pr555_12.pdf
[16] Mityagina M., Lavrova O. Satellite monitoring of the Black Sea surface pollution. Proceed. of Geoscience and Remote Sensing Intern. Symposium (IGARSS), 2015, 26- 1July 2015, Milan, Italy, pp.2291-2294.
[17] Lavrova O. Yu.,Karimova S. S.,Mityagina M. I., Bocharova T. Yu. Operational satellite Monitoring of the Black, Baltic and Caspian Seas in 2009-2010. (in Russian), http://d33.infospace. ru/d33_conf/ sb2010t3/168-185.pdf.
[18] Bedritskiy A. I., Asmus V. V., Krovotyntsev V. A. et al. Satellite monitoring of pollution of Russian sector of the Black and Azov Seas in 2003-2007. Meteorologia i Gidrologia, 2007, № 11, pp. 5-13 (in Russian).
[19] Ginsburg A. I., Kontar E. A., Kostianoj A. G. et al. A system of synoptic vortices over a steep continental slope in the northwestern part of the Black Sea in the summer of 1993 (satellite and ship observations), okeanologia, 1998, t.38, № 1, pp.51-58 (in Russian).
[20] Lavrova O. Yu., Kostyanoj A., G., Lebedev C. A., Mityagina M. I., Ginzburg A. I., Sheremet N. A. Complex Satellite Monitoring of the seas of Russia. Institute of Space Researches of RAS, Moscow, 2011, 480 p (in Russian).
[21] Mityagina M. I., Lavrova O. Yu. Radar observations of surface film contaminations in coastal zone of the Black and Azov Seas. Sovremennye problemy distancionnogo zondirovania zemli iz kosmosa.2007, vip. 4, t. 1, c. 317-324 (in Russian)
[22] Pustovoytenko V. V., Zapevalov A. S., Terekhin Yu. V. Satellite means of operational oceanography: Radar side vision systems. Morskoy Gidrofizicheskiy zhurnal, 2011, № 24, pp. 308-340 (in Russian).
[23] Pustovoytenko V. V., Zapevalov A. S. Operational Oceanography – the current state, prospects and problems. Sevastopol, 2012, 218 p (in Russian).
[24] Oil pollution and organic films. http://www.geogr.msu.ru/science/aero/acenter/ int_sem7/Oil_pollution.htm
[25] Oil pollutions. http://oceanfromspace.scanex.ru/index.php/ocean/oilpollution
[26] Chronic oil pollution in Europe. Royal Netherlands Institute for sea research. A status report. 85 p. http://www.ifaw.org/united-states/node/6260
[27] Himiya okeana. v.1, Ed. by Bordovskiy O. K., Ivanenkov B. N. 1979, Moskva, Nauka, 518 p (in Russian).
[28] Vragov A. V. Methods for detection, assessment and oil spill response. Novosibirsk State University, 2002, 224 p (in Russian).
[29] Zhurbas V. M. The basic mechanisms of the spread of oil in the sea.,Moskva, VINITI, 1978,vol. 12, pp. 144-159 (in Russian).
[30] Ozmidov P. V. Diffusion of contaminations in the ocean. Leningrad, Gidrometeoizdat, 280 p (in Russian).
[31] Korotenko K. A., Mamedov R. M., Mooers C. N. K. Prediction of the dispersal of oil transport in the Caspian Sea resulting from a continuous release. Spill Science and Technology Bulletin, 2001, v.6, N5/6, pp. 323-339.
[32] Korotenko K. A., Mamedov R. M. Modeling of oil slick transport processes in coastal zone of the Caspian Sea. Oceanology, 2001, 41, pp. 37-48.

[33] Korotenko K. A., Mamedov R. M., Mooers C. N. K. Prediction of the transport and dispersal of oil in the south Caspian Sea resulting from blowouts. Environmental Fluid Mechanics 2001, v.1, № 4, pp. 383-414.
[34] Christiansen B. M. 3D oil drift fate forecast at DMI. Technical report no 03-36., Denmark,Danish Meteorological Institute, 2003.
[35] Daniel P. Forecasting oil spill drift at Meteo-France. Proceed.of the 1997 Intern. Oil Spill Conference. American petroleum Institute, Washington. D. C., pp.990-993.
[36] Daniel P., Kortchev G., Mungov G., Forecasting oil spill drift in the Black Sea. Proceed. of oil spills in the Mediterranean and Black Sea regions. *MEDOSC.* University of Manchester ,UK, 1998, pp. D011-8.
[37] Daniel P., Gilbert T., Hackett et al. Operational metocean products and services in support of marine pollution emergency response operations. Proceed. of the 2008 Intern. Oil Spill Conference. American Petroleum Institute. 2008, Washington D. C.
[38] Galabov V., Oil spill drift operational forecasts for Bulgarian coastal area and numerical study of potential oil; pollution in the bay of Burgas. In: Abstracts of 3nd biannual BS Scientific Conference and UP-GRADE BS-SCENE Project joint Conference. 2011, Odessa, Ukraine.
[39] Brovchenko I., Kuschan A., Maderich V. et al. The modeling system for simulation of the oil spills in the Black Sea in the Black Sea. In: Proceed. of 3$^{nd}$EuroGOOS Conference. 2002, Athens/Greece.
[40] Reed M., Johanson O., Brandvik P. J. et al. Oil spill modeling toward the close of the 20$^{th}$ century: overview of the state of the art. Spill Science and Techn. Bull. 1999, pp. 3-16.
[41] Shou-Dong Wang, Yong-Ming Shen, Ya-Kun Guo et al. Three-dimensional numerical simulation for transport of oil spills in seas. Ocean Engineering. 2008, no.35, pp. 503-510.
[42] Dietrich D. I., Lin C. A., Mestas-Nunez A. et al. A high-resolution numerical study of Gulf of Mexico fronts and eddies. Meteorol. Atmos. Physics, no. 64, pp. 187-201.
[43] Blumberg A. F., Mellor G. I. A. description of a three-dimensional coastal ocean circulation model. In: Three-Dimensional Coastal Ocean Models. American Geophysical Union. Washington. 1987, no.4, pp. 1-16.
[44] Grell G., Dudhia A. J., Stauffer D. R. A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). NCAR Technical Note. NCAR/TN-398+STR.
[45] Tolman H. I. User manual and system documentation of WAVEWATCH-III version 1.18. NOAA/NWS/NCEP/OMB Technical Note 166. 1999.
[46] Kordzadze A., Demetrashvili D. Numerical modeling of distribution of the oil pollution in the Black Sea. J. Georgian Geophys. Soc., 2000, no. 5b, pp.15-20.
[47] Demetrashvili D., Kordzadze A. Numerical modeling of distribution of pollution substances in the Black Sea. Reports of enlarged sessions of the seminar of I. Vekua Institute of applied mathematics of I. Javakhishvili Tbilisi State University. vol. 17, N 3, 2002, pp. 44-57.
[48] Kordzadze A., Demetrashvili D., Surmava A. A numerical study of spreading of the oil pollution in the natural environment. Environmental ecology and life safety. Kiev, Ukraine, 2005, № 2, pp.77-84.
[49] Kordzadze A., Demetrashvili D., Kvaratskhelia D. J. On the specification of the eddy viscosity coefficient in the Black Sea dynamics barotropic problems. J. Georgian Geophys. Soc., 1998, v.3b, pp.59-65.
[50] Kordzadze A. A., Demetrashvili D. I. Modeling of mesoscale circulation and oil spill transport in the Georgian water area of the Black Sea. Bulletin of the Georgian National Academy of Sciences, 2014, N4.
[51] Kordzadze A. A., Demetrashvili D. I., Kukhalashvili V. G. Short-range forecast of dynamical processes and spreading of admixtures in the eastern part of the Black Sea. Transactions of Mikheil Nodia Institute of Geophysics, vol. LXV, 2014 (in Russian).

[52] Kordzadze A. A., Demetrashvili D. I. Forecast of circulation processes and propagation of oil pollution in the eastern Black Sea based on the regional complex model. Morskoij Gidrofizicheskij tzurnal, Sevastopol, Ukraine, 2015, № 1, pp.3-11(in Russian)
[53] Kordzadze A., Demetrashvili D., Kukhalashvili V. Easternmost Black Sea forecasting system. Proceed. of the 12 th Intern. Conference on the Mediterranean Coastal Environment MEDCOAST 2015, 6-10 October 2015, Varna, Bulgaria, pp.769-780.
[54] Kordzadze A., Demetrashvili D. The Black Sea oceanography in the past and at current stage. Tbilisi State University, 2017, 187 p (in Georgian).

## შავი ზღვის ნავთობპროდუქტებით დაჭუჭყიანების შესახებ. მისი მონიტორინგი და პროგნოზი

ა. კორძაძე , დ. დემეტრაშვილი

### რეზიუმე

სტატიაში მიმოხილულია ნავთობპროდუქტებით შავი ზღვის დაჭუჭყიანების თანამედროვე მდგომარეობა. მნიშვნელოვანი ყურადღება ეთმობა ზღვის ზედაპირის ნავთობით დაჭუჭყიანების თანამგზავრულ მონიტორინგს. სტატია შეიცავს აგრეთვე ზღვის გარემოში ნავთობის ლაქის გავრცელების მოდელირებისა და პროგნოზის რიცხვითი მოდელების მოკლე აღწერას. წარმოდგენილია რეალური რეგიონული ცირკულაციის პირობებში შავი ზღვის საქართველოს აკვატორიაში ნავთობით დაჭუჭყიანების გავრცელების მოდელირების ზოგიერთი შედეგი, რომელიც მიღებულია ადვექცია-დიფუზიის განტოლების საფუძველზე.

## О загрязнении нефтепродуктами Черного моря. Его мониторинг и прогноз

**А. Кордзадзе , Д. Деметрашвили**

### Резюме

В статье обозревается современное состояние загрязнения Черного моря нефтепродуктами. Значительное внимание уделяется спутниковому мониторингу нефтяного загрязнения поверхности моря. Статья содержит также краткое описание численных моделей распространения и прогноза нефтяного загрязнения в морской среде. Представлены некоторые результаты моделирования распространения нефтяного загрязнения на основе уравнения переноса-диффузии в грузинской акватории Черного моря при реальной региональной циркуляции.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp. 61 - 69*

# Preliminary Results of the Analysis of Radar and Ground-Based Monitoring of Dust Formation in Atmosphere Above the Territory of Eastern Georgia on 27 July 2018

**[1]Avtandil G. Amiranashvili, [2]Nino T. Berianidze, [1]Victor A. Chikhladze, [1,3]Mikheil N. Mitin, [2]Ana A. Mtchedlishvili**

*[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
*1, M. Alexidze Str., 0160, Tbilisi, Georgia, e-mail:* avtandilamiranashvili@gmail.com
*[2]Ivane Javakhishvili Tbilisi State University*
*[3] State Military Scientific-Technical Center "DELTA"*

***ABSTRACT***

There are represented the preliminary results of the radar analysis and ground-based monitoring of dust formation in the atmosphere above the territory of eastern Georgia on the 27th of July, 2018. Distance monitoring was accomplished with the aid of the meteorological radar «METEOR 735CDP10». The dust concentration was hourly measured (PM10 and PM2.5) in surface boundary layer in three points of Tbilisi city. There are given Radar data about the movement of dust formation in the atmosphere above that investigated territories. It is shown that in second half of day there was noted the strong growth of PM10 and PM2 on the earth's surface 5.

***Key Words:*** Radar monitoring, dust, PM10, PM2.5

## Introduction

M. Nodia Institute of Geophysics conducts experimental laboratory, theoretical studies of atmospheric aerosols during many decades fields (stationary and mobile monitoring) [1-4]. In particular, we studied different physical characteristics of mineral and secondary aerosols, and also their changeability in the time and connection with some atmospheric processes (distribution according to the sizes [1,3], weight and numerical concentrations [2-7], coagulation, washing, ice-forming properties [1], vertical distribution of aerosols in the lower troposphere [8-10], processes of the photochemical smog formation [2], influence of the ionizing radiation on the secondary aerosols formation [2,11], aerosols optical properties [12-14,18], long-term changeability of the aerosol optical depth of the atmosphere (AOD) [15-18], connection of AOD with the content of surface aerosols [19], connection of aerosols with atmospheric ozone content [1,2,6,20], ecological aspects of atmospheric aerosols [2-7,18,2], influence of aerosols on the changeability of climate, including of thunderstorm and hail processes [18,22,23], numerical simulation of the aerosols distribution from different sources [1,24], simulation of the aerosol optical depth distribution above territory of Georgia in the correspondence with the methodology of the combined analysis of satellite and ground-based measurements of AOD in Tbilisi [25-27 ], etc.).

In recent years in connection with the renewal of anti-hail works in Kakheti [28-31], it's appeared the possibility of the radar monitoring of the atmosphere above the eastern Georgia and adjacent countries

(Armenia, Azerbaijan, Russia, Turkey) [28,30,32]. Anti-hail service is equipped with contemporary meteorological radar “METEOR 735CDP10”, capable of recording the significant number of atmospheric formations [33,34].

The radar is usually used for monitoring of the hail processes [35-37] and strong showers [38]. Together with this aid of the radar there is a possibility for monitoring of movement in the space above the large territories of powerful dust formations (the dust storms, volcanic ejections, etc.) [33]. This makes it possible to enlarge the represented above [1-27] area of studying atmospheric aerosols.

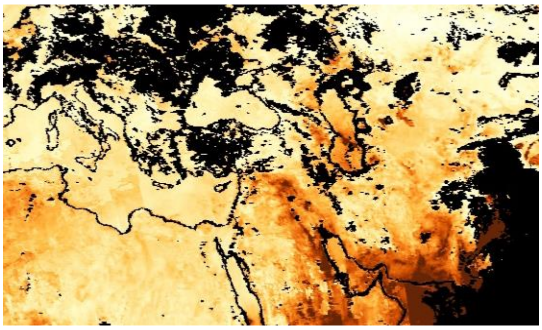
This paper depicts the radar monitoring example of the dust formation movement in the atmosphere above the territory of eastern Georgia on the 27th of July, 2018.

A dust cloud covered Baku on the 26th of July (Fig. 1a, [Photo *Vesti.az,* https://jam-news.net/тбилиси-накрыло-пылью-специалисты-го/?lang=ru]). The Ministry of Ecology of Azerbaijan said that the cloud had come to Azerbaijan from Turkmenistan (https://jam-news.net/tbilisi-covered-in-dust-cloud-experts-say-there-is-no-danger/). Residents of Tbilisi were exhibiting this cloud on the 27th of July (Fig. 1b, [Photo Irakli Oragvelidze, http://agenda.ge/en/news/2018/1594]).

Fig.1a. Baku, 26.07.2018 Fig.1b. Tbilisi, 27.07.2018 – 15:33 hour

On the presence of powerful dust formation in the atmosphere on the south Black Sea-Caspian region from the 20th of July through the 4th of August, 2018 testify the data of the satellite monitoring of the aerosol optical depth in atmosphere.

(Fig. 2a, 2b, [https://neo.sci.gsfc.nasa.gov/servlet/RenderData?si=1749095&cs= rgb&format=JPEG&width=3600&height=1800]).



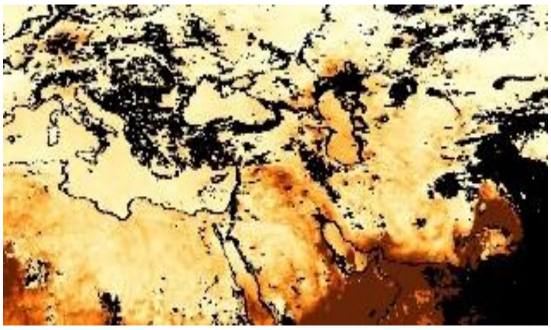


Fig.2a. AOD, July 20 - 27, 2018 Fig.2b. AOD, July 28 - August 4, 2018


In the maps (Fig. 2a, 2b) dark brown pixels show high aerosol concentrations, while tan pixels show lower concentrations, and light yellows areas show little or no aerosols. Black ones show where the sensor could not make its measurement.

In particular, as it follows from Fig. 2a, between the 20th and 27th of July, 2018, dusty cloud covers of the territories of Turkmenistan, Azerbaijan and eastern Georgia. During the following week (Fig. 2b) this cloud is noticeable.

Below the figures there is represented the preliminary results of radar analysis and ground-based monitoring of dust formation in the atmosphere above the territory of eastern Georgia on the 27th of July, 2018.

## Material and methods

In the work there are used the data of radar "METEOR 735CDP10" about the dust objects in the atmosphere (product MPPI(ET) [33]). In addition, we used the data of Georgian National Environmental Agency about the dust concentration (atmospheric particulate matter - PM2.5 and PM10) in three points of Tbilisi city (http://nea.gov.ge/ge/service/haeris-monitoringi/14/haeris-dabindzurebis-yoveldgiuri-biuletini/).

In Table. 1 and Fig. 1 Are presented Coordinates and locations of air pollution measurements points in Tbilisi.

Table 1

Coordinates of air pollution measurements points in Tbilisi

| Location | Latitude, N° | Longitude, E° | H, m |
|---|---|---|---|
| 1. Tsereteli str. | 41.742539 | 44.779069 | 423 |
| 2. Kazbegi str. | 41.724767 | 44.752956 | 467 |
| 3. Varketili | 41.699947 | 44.871611 | 518 |

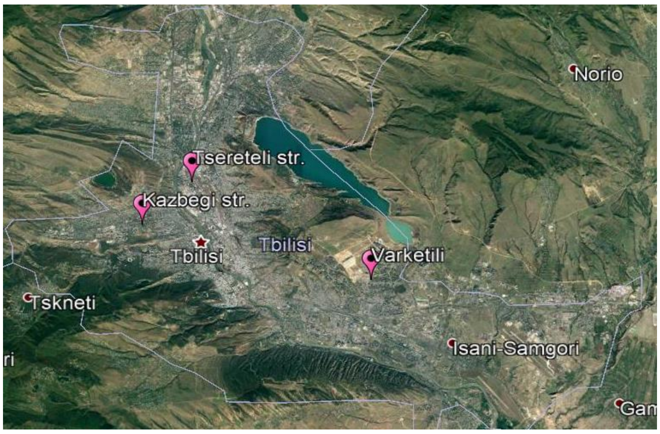



Fig.3. Locations of air pollution measurements points in Tbilisi.

In the correspondence with the standards of the World Health Organization maximum permissible concentration (MPC) composes for PM2.5: annual mean - 0.01 mg/m³, 24-hour mean - 0.025 mg/m³ and for PM10: annual mean - 0.02 mg/m³, 24-hour mean - 0.05 mg/m³ [39].

## Results and discussion

Results are presented in the Fig. 4-5 and Table 2.

In the Fig. 4 radar data shows about migration of dust formation in the atmosphere above the territory of eastern Georgia on the 27th of July, 2018 from 09:58 to 17:00 hour (8 moments of time, green color). As follows from this figure dust cloud into the indicated time interval is located above the significant part of Kakheti and it is revealed also above Tbilisi in the second half of day.

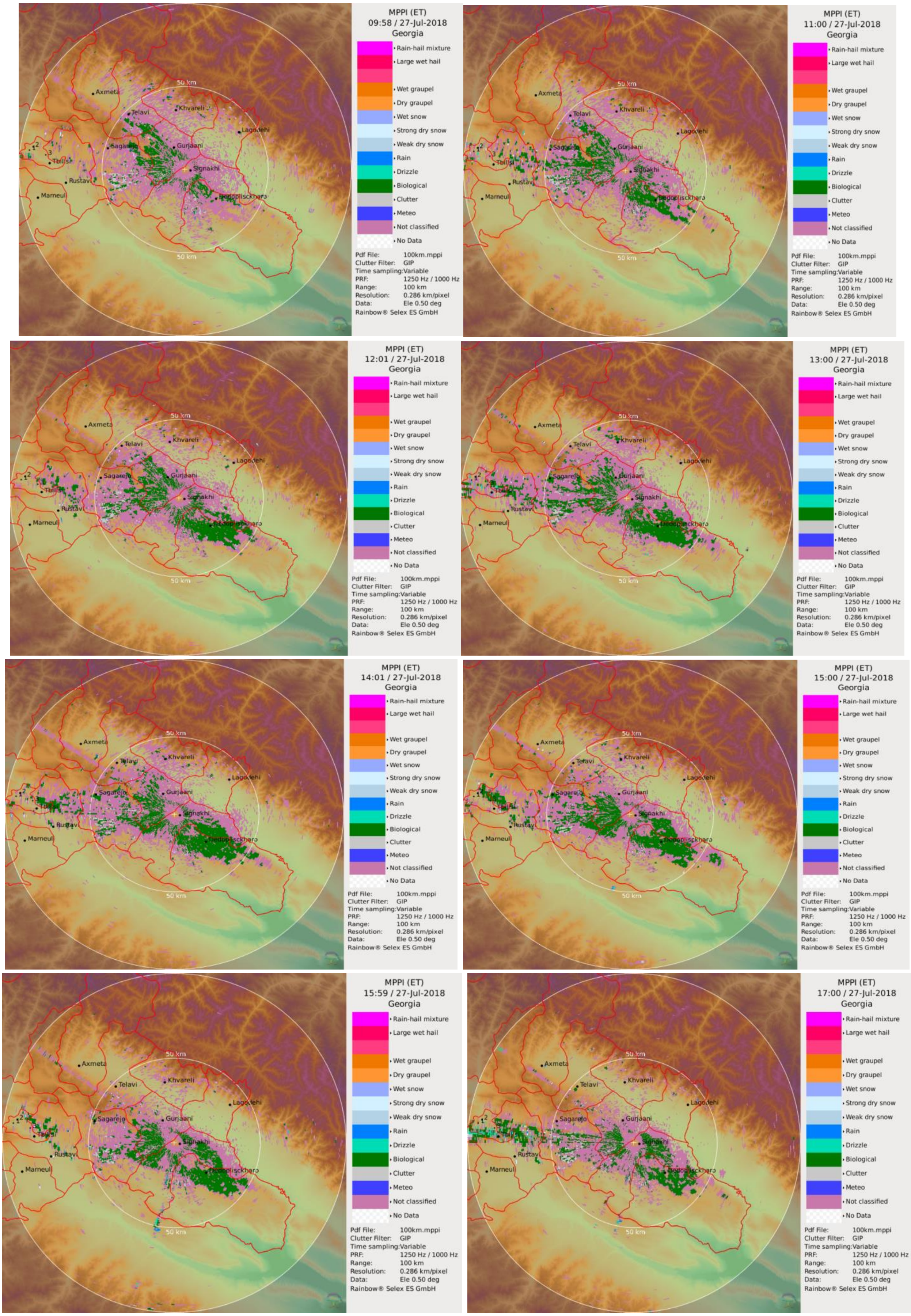



Fig.4. Migration of dust formation in the atmosphere above the territory of eastern Georgia on the 27th of July, 2018 from 09:58 to 17:00 hour.

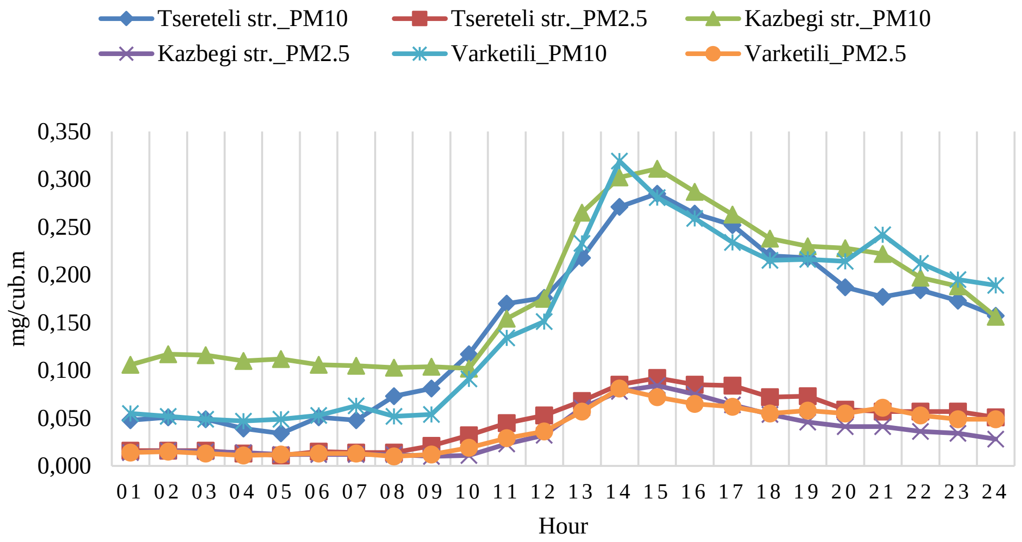



Fig.5. Dust Concentration in Three Locations of Tbilisi 27.07.2018

The propagation of dust formation above Tbilisi led to a strong increase in the concentration of solid particles in surface boundary layer (Fig. 5). As follows of this figure we noted all three points of measurement of increasing the dust particles concentration by diameter less than 2.5 and 10 µm (respectively - PM2.5 and PM10).

Table 2

Statistical characteristics of dust concentration in three locations of Tbilisi 27.07.2018 (mg/m³)

| Location | 1.Tsereteli str. | | 2.Kazbegi str. | | 3.Varketili | |
|---|---|---|---|---|---|---|
| Parameter | PM10 | PM2.5 | PM10 | PM2.5 | PM10 | PM2.5 |
| Min | 0.034 | 0.011 | 0.102 | 0.010 | 0.047 | 0.010 |
| Max | 0.285 | 0.092 | 0.311 | 0.084 | 0.319 | 0.081 |
| Mean | 0.148 | 0.046 | 0.179 | 0.034 | 0.152 | 0.038 |
| Range | 0.251 | 0.081 | 0.209 | 0.074 | 0.272 | 0.071 |
| St Dev | 84.3 | 27.9 | 72.6 | 23.8 | 90.7 | 23.7 |
| Cv, % | 57.1 | 60.6 | 40.5 | 69.4 | 59.5 | 62.3 |
| Mean/24-hour mean MPC | 2.96 | 1.84 | 3.58 | 1.36 | 3.04 | 1.52 |

There is presented [In Table 2] statistical characteristics of dust concentration in three locations of Tbilisi. In particular, as it follows from this Table, on the different points of measurement on the 27$^{th}$ of July, 2018 the 24-hour mean values of PM10 and PM2.5 exceeded their maximum permissible concentrations into 2.96-3.58 and 1.36-1.84 times respectively.

## Conclusion

In the prospect besides the radar "METEOR 735CDP10" what we use in the work of anti-hail service, also can be used for early warning of population about the danger of aerosol air pollution during the action of the large sources of dust.

## References


[1] Amiranashvili A.G., Gzirishvili T.G. Aerosols and Ice Crystals in the Atmosphere. Tbilisi, Metsniereba, 1991, 113 p. (in Russian).

[2] Amiranashvili A., Bliadze T., Chikhladze V. Photochemical smog in Tbilisi. Monograph, Trans. of Mikheil Nodia institute of Geophysics, ISSN 1512-1135, vol. 63, Tbilisi, 2012, 160 p., (in Georgian).

[3] Kirkitadze D., Nikiforov G., Chankvetadze A., Chkhaidze G. Some Results of Studies of Atmospheric Aerosols in M. Nodia Institute of Geophysics in the Recent Three Decades. Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. 66, Tbilisi, 2016, pp. 178-185, (in Russian).

[4] Berdzenishvili N., Davitashvili M. Aerosol effect in the atmosphere. Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. 69, Tbilisi, 2018, pp. 228-234, (in Russian).

[5] Kharchilava D.F., Lomaia O.V., Bukia G.N. The Conditions of Aerosols Formation and Accumulation in Cities. Proc. 3th Int. Aerosol Conf., Kyoto, Japan, Pergamon, vol. 2, 24-27 September, 1990, p. 986-989.

[6] Amiranashvili A.G., Chikhladze V.A., Kharchilava J.F., Buachidze N.S., Intskirveli L.N. Variations of the Weight Concentrations of Dust, Nitrogen Oxides, Sulphur Dioxide and Ozone in the Surface Air in Tbilisi in 1981-2003, Proc. 16th International Conference on Nucleation&Atmospheric Aerosols, Kyoto, Japan, 26-30 July 2004, pp. 678-681.

[7] Bliadze T.G., Kirkitadze D.D., Tchankvetadze A. Sh., Chikhladze V.A. Comparative Analysis of Air Pollution in Tbilisi and Kutaisi. International Scientific Conference „Modern Problems of Ecology", Proceedings, ISSN 1512-1976, v. 6, Kutaisi, Georgia, 21-22 September, 2018, pp. 157-160.

[8] Styra B., Amiranashvili A. Aerosol Distribution above Georgia Investigations. Institute of Physics of the Academy of Sciences of the Lithunian SSR, Atmospheric Physics, ISSN 0135-1419, vol. 8, Vilnius, Mokslas, 1983, pp. 18-24, (in Russian).

[9] Amiranashvili A.G., Gzirishvili T.G., Kartsivadze A.I., Nodia A.G. Aircraft investigations of the distribution of aerosols in the lower troposphere. Proc. 9th Int. Conf. on Atmospheric Aerosols, Condensation and Ice Nuclei, Budapest, Hungary, 3-8 September, vol.1, 1984, p. 148-153.

[10] Amiranashvili A., Amiranashvili V., Chochishvili K., Kirkitadze D. The Distribution of Aerosols over the Georgian Territory in the Lower Troposphere, Journal of Georgian Geophysical Society, ISSN 1512-1127, Jssue B. Physics of Atmosphere, Ocean and Space Plasma, Vol. 8 B, 2003, Tbilisi, 2004, pp. 70-76.

[11] Amiranashvili A., Chargazia Kh. Intra-Annual and Seasonal Variations of Sub-Micron Aerosols Concentration and their Connection with Radon Content in Surface Boundary Layer of Tbilisi City. Bulletin of the Georgian National Academy of Sciences, vol. 10, N 2, 2016, p. 72-78.

[12] Amiranashvili V. Numerical Calculation of the Spectral Aerosol Optical Depth Using Data on Integral Irradiance of the Direct Solar Radiation. Abstr. IUGG 99, 19-30 July 1999, Birmingham UK, p. A.236.

[13] Amiranashvili V. Modelling of Solar Radiation Transfer in the Atmosphere with Allowance to Aerosol Diffusion. J. Aerosol Sci., Vol. 30, Suppl 1, Pergamon Press, 1999, p. S625-S626.

[14] Tavartkiladze K, Shengelia I., Amiranashvili A., Amiranashvili V. The influence of relative humidity on the optical properties of atmospheric aerosols, J.Aerosol Sci, Pergamon, vol.30, Suppl.1, 1999, S639-S640.
[15] Amiranashvili A., Amiranashvili V., Tavartkiladze K. Dynamics of the aerosol pollution of the atmosphere in Georgia in 1956-1990, J.Aerosol Sci, Pergamon, vol.30, Suppl.1, 1999, S667-S668.
[16] Amiranashvili A., Amiranashvili V., Khurodze T., Tavartkiladze K., Tsitskishvili M. Some Characteristics of the Aerosol Pollution of the Atmosphere Over the Territory of Kakheti in the Warm Season. Proc. Int. Conf. Dedicated to Memory of Prof. A. Sutugin, Moscow, Russia, June 26-30, 2000, p. 128-129.
[17] Amiranashvili A.G., Amiranashvili V.A., Kirkitadze D.D., Tavartkiladze K.A. Some Results of Investigation of Variations of the Atmospheric Aerosol Optical Depth in Tbilisi, Proc. 16th Int. Conf. on Nucleation&Atmospheric Aerosols, Kyoto, Japan, 26-30 July 2004, pp. 416-419.
[18] Amiranashvili A.G., Amiranashvili V.A., Gzirishvili T.G., Kharchilava J.F., Tavartkiladze K.A. Modern Climate Change in Georgia. Radiatively Active Small Atmospheric Admixtures, Institute of Geophysics, Monograph, Trans. of M.Nodia Institute of Geophysics of Georgian Acad. of Sci., ISSN 1512-1135, vol. LIX, 2005, 128 p.
[19] Amiranashvili A.G., Amiranashvili V.A., Kirkitadze D.D., Tavartkiladze K.A. Connection Between Atmospheric Aerosol Optical Depth and Aerosol Particle Number Concentration in the Air in Tbilisi, Proc. 17th Int. Conf. on Nucleation&Atmospheric Aerosols, Galway, Ireland, 13-18 August 2007, pp. 865-870.
[20] Amiranashvili A., Bliadze T., Kirkitadze D., Nikiforov G., Nodia A., Kharchilava j., Chankvetadze A., Chikhladze V., Chochishvili K., Chkhaidze G.P. Some Preliminary Results of the Complex Monitoring of Surface Ozone Concentration (SOC), Intensity of Summary Solar Radiation and Sub-Micron Aerosols Content in Air in Tbilisi in 2009-2010. Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. 62, Tbilisi, 2010, pp. 189-196, (in Russian).
[21] Amiranashvili A.G., Amiranashvili V.A., Kirkitadze D.D., Tavartkiladze K.A. Weekly Distribution of the Aerosol Pollution of the Atmosphere in Tbilisi, Proc. 17th Int. Conf. on Nucleation&Atmospheric Aerosols, Galway, Ireland, 13-18 August 2007, pp. 756-760.
[22] Budagashvili T., Karchava J., Gunia G., Intskirveli L., Kuchava T., Gurgenidze M., Amiranashvili A., Chikhladze T. Inventory of Greenhouze Gas Emissions and Sinks, Georgia's Initial National Communication on Under the United Nations Framework Convention on Climate Change, Project GEO/96/G31, Tbilisi, 1999, pp. 33-45.
[23] Amiranashvili A.G. Issledovaniye grozo-gradovykh protsessov v Gruzii i ikh svyazey s aerozol'nym zagryazneniyem atmosfery. Avtoreferat dissertatsii na soiskaniye uchenoy stepeni doktora fiz.-mat nauk po spetsial'nosti 04.00.23 – geofizika(fizika atmosfery i gidrosfery), Institut geofiziki im. M.Z. Nodia, Tb.:, 2006, 53 s. http://dspace.gela.org.ge/bitstream/123456789/4920/1/Amiranashvili_Avtoreferat_2006.pdf
[24] Surmava A., Gigauri N., Gverdtsiteli L., Intskirveli L. Numerical Modeling of Zestafoni City Dust Distribution in Case of Background Western, Light Air, Gentle and Fresh Breezes. Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. 69, Tbilisi, 2018, pp. 182-191, (in Georgian).
[25] Stankevich S. A., Titarenko O., V., Amiranashvili A., G., Chargazia Kh., Z. Analysis of the Atmosphere Aerosol and Ozone Condition Over Tbilisi Using Satellite Data and Ground Truth Measurements. 14th Ukrainian Conference on Space Research, Uzhgorod, September, 8-12, 2014, Abstracts, Kyiv, 2014, p. 161.
[26] Stankevich A.S., Titarenko O.V., Amiranashvili A.G., Chargazia Kh. Z. Determination of Distribution of Ozone Content in Lower Troposphere and Atmospheric Aerosol Optical Thickness over Territory of Georgia Using Satellite Data and Ground Truth Measurements. Journal of the

Georgian Geophysical Society, Issue (B). Physics of Atmosphere, Ocean, and Space Plasma, ISSN: 1512-1127, v.17b, 2014, pp. 26-37.
[27] Stankevich S., Titarenko O., Amiranashvili A., Chargazia Kh. Determination of Atmospheric Aerosol Optical Depth over Territory of Georgia during Different Regimes of Cloudiness Using the Satellite and Ground-Based Measurements Data. Bulletin of the Georgian National Academy of sciences, v. 9, No. 3, 2015, pp. 91-95.
[28] Amiranashvili A.G., Chikhladze V.A., Dzodzuashvili U.V., Ghlonti N.Ya., Sauri I.P. Reconstruction of Anti-Hail System in Kakheti (Georgia). Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, Tbilisi, vol.18B, 2015, pp. 92-106.
[29] Amiranashvili A., Burnadze A., Dvalishvili K., Gelovani G., Ghlonti N., Dzodzuashvili U., Kaishauri M., Kveselava N., Lomtadze J., Osepashvili A., Sauri I., Telia Sh., Chargazia Kh., Chikhladze V. Renewal Works of Anti-Hail Service in Kakheti. Trans. of Mikheil Nodia institute of Geophysics, ISSN 1512-1135, Tbilisi, vol. 66, 2016, pp. 14 – 27, (in Russian).
[30] Amiranashvili A.G., Dzodzuashvili U.V., Ghlonti N.Ya., Kaishauri M.N., Sauri I.P., Chargazia Kh.Z., Chikhladze V.A. Obnovlennaya Sluzhba Bor'by s Gradom v Kakhetii i perspektivy razvitiya rabot po modifikatsii pogody v Gruzii. Doklady Vserossiyskoy konferentsii po fizike oblakov i aktivnym vozdeystviyam na gidrometeorologicheskiye protsessy, 23-27 oktyabrya 2017 g., chast' 2, FGBU «Vysokogornyy Geofizicheskiy Institut», Nal'chik, ISBN 978-5-00109-257-5 ch.2; ISBN 978-5-00109-258-2, 2017, s. 135-162, (in Russian), http://dspace.gela.org.ge/bitstream/123456789/6498/1/
Амиранашвили...Конф_ВГИ_2017_Часть_2_с._155-162.pdf
[31] Amiranashvili A.G. History of Active Effects on Atmospheric Processes in Georgia. In the book: Essays of the History of Weather Modification in the USSR and the Post-Soviet Territory, ISBN 978-5-86813-450-0, St. Petersburg, RSHMU, 2017, 352 pp., ill., pp. 234-254, (in Russian), http://mig-journal.ru/toauthor?id=4644.
[32] Abaiadze O., Avlokhashvili Kh., Amiranashvili A., Dzodzuashvili U., Kiria J., Lomtadze J., Osepashvili A., Sauri I., Telia Sh., Khetashvili A., Tskhvediashvili G., Chikhladze V. Radar Providing of Anti-Hail Service in Kakheti. Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, Tbilisi, vol. 66, 2016, pp. 28-38, (in Russian).
[33] Selex ES GmbH · Gematronik Weather Radar Systems. Rainbow®5 User Guide, 2015, 464 p., www. gematronik.com
[34] Avlokhashvili Kh., Banetashvili V., Gelovani G., Javakhishvili N., Kaishauri M., Mitin M., Samkharadze I., Tskhvediashvili G., Chargazia Kh., Khurtsidze G. Products of Meteorological Radar «METEOR 735CDP10». Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, Tb., vol. 66, 2016, pp. 60-65, (in Russian).
[35] Banetashvili V., Grebentsova A., Javakhishvili N., Jamrishvili N., Kaishauri M., Mitin M., Saginashvili N., Khurtsidze G., Tsereteli A., Chargazia Kh., Chkhaidze B. Some examples of hail processes in Kakheti according to the data of radar surveillance in 2015**.** Trans. of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, Tbilisi, 2016, vol. 66, pp. 66-74, (in Russian).
[36] Javakhishvili N.R. Radar Characteristics of the Hail Process on 10 June 2017 in Rustavi Municipality (Georgia). Journal of the Georgian Geophysical Society, ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(1), 2018, pp. 41-47.
[37] Jamrishvili N. K., Javakhishvili N.R., Sauri I. P., Tavidashvili Kh. Z., Telia Sh. O. Comparison of the Radar and Ground-Level Characteristics of the Hail Process on 10 June 2017 in Tbilisi. International Scientific Conference „Modern Problems of Ecology“, Proceedings, ISSN 1512-1976, v. 6, Kutaisi, Georgia, 21-22 September, 2018, pp. 134-137.
[38] Amiranashvili A., Kereselidze Z., Mitin M., Khvedelidze I., Chikhladze V. Alarming Factors of the Microclimate of the Vere River Valley and their Influence on the Floods Intensity. Trans. of

Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, Tbilisi, vol. 69, 2018, pp. 204-218, (in Georgian).
[39] WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005 Summary of risk assessment. World Health Organization, 2006, 22 p., http://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid=48F380E7090ADBB4A166AC7A8610624A?sequence=1

# აღმოსავლეთ საქართველოს ტერიტორიაზე ატმოსფეროში 2018 წლის 27 ივლისს მტვრის წარმონაქმნის რადიოლოკაციური და მიწისპირა მონიტორინგის ანალიზის წინასწარი შედეგები

ა.ამირანაშვილი, ნ. ბერიანიძე, ვ. ჩიხლაძე,
მ.მიტინი, ა. მჭედლიშვილი

### რეზიუმე

წარმოდგენილია აღმოსავლეთ საქართველოს ტერიტორიაზე ატმოსფეროში 2018 წლის 27 ივლისს მტვრის წარმონაქმნის რადიოლოკაციური და მიწისპირა მონიტორინგის ანალიზის წინასწარი შედეგები. დისტანციური მონიტორინგი «METEOR 735CDP10» ტიპის მეტეოროლოგიური რადიოლოკატორის მეშვეობით ხდებოდა. მტვრის კონცენტრაცია (PM10 და PM2.5) ჰაერის მიწისპირა ფენაში ქალაქ თბილისის სამ პუნქტში ყოველ საათს იზომებოდა. მოყვანილია ატმოსფეროში საკვლევი ტერიტორიის თავზე მტვრის წარმონაქმნის გადაადგილების რადიოლოკაციური მონაცემები. ნაჩვენებია, რომ დღის მეორე ნახევარში დედამიწის ზედაპირთან PM10 და PM2.5-ის ძლიერი ზრდა აღინიშნებოდა.

# Предварительные результаты анализа радиолокационного и наземного мониторинга пылевого образования в атмосфере над территорией Восточной Грузии 27 июля 2018 года

**А.Г. Амиранашвили, Н.Т. Берианидзе, В.А. Чихладзе,
М.Н. Митин, А.А.Мчедлишвили**

### Резюме

Представлены предварительные результаты анализа радиолокационного и наземного мониторинга пылевого образования в атмосфере над территорией Восточной Грузии 27 июля 2018 года. Дистанционный мониторинг осуществлялся с помощью метеорологического радиолокатора «METEOR 735CDP10». Концентрация пыли (PM10 и PM2.5) в приземном слое воздуха ежечасно измерялась в трех пунктах города Тбилиси. Приведены радиолокационные данные о перемещении пылевого образования в атмосфере над исследуемой территорий. Показано, что во второй половине дня у земной поверхности отмечался сильный рост PM10 и PM2.5.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp 70 - 76*

# Advanced Method for Small-Size Targets Detection in Hyperspectral Image

**Vitaly V. Andronov**

*Scientific Research Institute, Ukraine*
vav77@ukr.net

***ABSTRACT***

The advanced method for subpixel detection of small-size targets on hyperspectral image is described. The method is based on matched filtering model with the succeeding correction of determined pixel fractions. Correction consists of two stages. First one is a statistical adjustment for actual set of targets/backgrounds in a scene and second one is a pixel-wise consideration of radiometric separability of spectra. The proposed advanced method provides more exact subpixel detection of small-size targets in hyperspectral image.

***Key Words.*** Hyperspectral imagery, matched filtering, subpixel target detection, pixel fraction.

**Introduction.** The hyperspectral imagery possibilities to detect subpixel targets are based on spectra's fine structure analysis. It is especially important for distinction of targets similar to natural backgrounds [1]. The special methods and algorithms need for processing of tremendous data amount in hyperspectral images. In particular, an immediate visual interpretation of hyperspectral imagery is inefficient because the three-dimensional color representation delivers only a small part of the full spectral information which is contained in hyperspectral image. Direct interpreting features such as a shape and details are, as a rule, inaccessible owing to insufficient spatial resolution.

The minimum size of target which can be detected on the image by routine classification is determined by the geometrical detailing i.e. a ground sample distance (GSD) on the land surface. At the same time there is an inverse relation between providing GSD and number of imaging spectral bands in the known multispectral systems of remote sensing. The larger size of GSD in hyperspectral imagery leads to a possibility of several different targets capture inside one pixel. It causes identification errors.

**Problem.** Pixel fractions of the target spectra which contain in current pixel have to be result of subpixel detection of small-sized objects in hyperspectral image. At that the target spectra can be several, i.e. more than one. Herewith it is considered that only target spectra – the spectral reflectance of target covers – are known. Other spectra within scene remain unknowns.

For ensuring acceptable level of reliability of target detection by their spectral reflectance the accuracy of the quantitative determining of pixel fractions of target spectra should be as high as possible compared to the best known methods [2].

Thus, the purpose of the paper is improvement of a method for subpixel detection of small-size targets in hyperspectral image.

**State-of-the-art.** One of features of hyperspectral images a possibility of targets resolving even inside pixel if their exact spectral signatures are available. This process is called as subpixel detection [3].

Methods for subpixel detection are used to determine a detected target fraction in each pixel of the hyperspectral image. In case of high spectral contrast between target and background the detection of target which occupy some percent of the pixel area is possible [4]. Methods for subpixel detection include the linear unmixing and the matched filtering.

The *linear unmixing* is based on representation of a spectrum in any pixel by result of mixing of several spectra. Mixing in this context is understood as weighing of spectra of all covers within pixel. Weights of each spectrum are proportional to fractions of the pixel area with this covers [5].

If spectra of all covers in scene are known, then their fractions within each pixel can be calculated by spectrum of this pixel. Unmixing is carried out by solving of the *m* linear equations for each pixel where *m* is number of spectral samples in the hyperspectral image. In order for the system of these equations to be solved, it is necessary that *m* is more than total number of spectra.

For this reason unmixing is possible on hyperspectral data and almost is never applied to usual multispectral imagery. The output of the linear unmixing is a set of spatial distributions of pixel fractions for each of input spectra.

The *matched filtering* is a method for selection from the image only the target spectra chosen by the user. Unlike the linear unmixing, it isn't obligatory that all occurred spectra are known therefore the matched filtering is often called also as partial unmixing.

Originally the matched filtering was developed for selection of rather rare targets in a scene, for example artificial. For rather widespread targets the results of the matched filtering require the some correction.

The matched filtering allocates in the input image the pixels, close to a target spectrum, and suppresses a response from all other spectra which are considered as the complex unknown background [6]. As with the linear unmixing, the output of the matched filtering is a target spectrum fraction inside pixel. The potential problem of the matched filtering consists in determining the similarity threshold between examined and target spectrum.

The solution of this problem consists in statistical estimation of noise in hyperspectral image [7]. So, the matched filtering is the most suitable method for subpixel target detection in hyperspectral images.

The known algorithms for subpixel target detection in hyperspectral image are based on separation of target and background spectra [8]. Therefore the spectra of targets which should be detected are necessary before hyperspectral image analysis. For this purpose the spectra retrieval from pre-developed spectral library of typical targets and backgrounds has to be carried out [9].

The mix of a target spectrum (or few spectra) and undesirable background spectra is considered during subpixel detection [10]. Generally it is possible to separate all target and background spectra one from another with an accuracy which is depended on spectral resolution of input hyperspectral data [11].

The linear models of spectral unmixing are most often used for this purpose. Such models provide determination of weights of the known spectra in proportion to their fractions inside pixel [12]. Methods and algorithms for spectral unmixing are developed for decades [13], but there are still some difficulties in practical applications for subpixel target detection. First, the composition of all spectra which are present in scene is almost never unknown. Therefore, the methods which allow occurrence of uncertain background spectra are necessary [14]. Second, the majority of the existing methods which meet the first condition – the matched filters, don't guarantee keeping of physical restrictions for fractions of target spectra [15].

**Model.** Each *i*-th pixel of the hyperspectral image can be represented as an $x_i$ *m*-dimensional vector of spectral samples, and *j*-th target spectrum – as an $y_j$ *m*-dimensional vector, $j = 1 .. p$. Let *Y* is a matrix of target spectra dimension of $m \times p$, and $\alpha_i = (\alpha_1, \alpha_2 .. \alpha_p)^T$ is a vector of fractions of target spectra inside *i*-th pixel. The linear model of spectral mix for $x_i$ pixel is described by the equation:

$$x_i = Y \alpha_i + z_i \tag{1}$$

where $z_i$ is a residue vector which can be considered as the additive noise.

The main limitation of unmixing (1) is to exceed the number of spectral bands in hyperspectral image over the number of spectra which are unmixed: $m \geq p$.

If all components of *Y* matrix are known, then the problem comes down to the overdetermined linear equation system solving with constrains of NCLS (non-negatively constrained least squares), SCLS (sum-to-one constrained least squares), or both at once – FCLS (fully constrained least squares). In [16] paper the rigorous algorithm with FCLS constrains is developed.

Unfortunately, in practice the described state nearly always is idealized as the full composition of all spectra in scene of observation is a priori unknown. In such case, the model should be applied that detects one or more known target spectra, while the rest are regarded as undesirable [17].

The most perfect of such models is the TCMI (target-constrained minimum interference) matched filter proposed by Kwan et al. in [18] paper. In it the estimate of fractions sum of target spectra inside *i*-th pixel of image equals $\alpha^T x_i$, where $x_i$ is the full spectral signal in this pixel, and α is the solution of a minimization problem:

$$\begin{cases} \alpha^{T} y_j = \begin{cases} 1 \text{ if } j \text{ is target} \\ 0 \text{ otherwise} \end{cases} \\ j = 1..p \\ \sum_{i=1}^{n} (\alpha^{T} x_i)^2 \quad \to \quad \min \end{cases} \tag{2}$$

To calculate a *j*-th spectrum fraction, it is possible to apply the TCMI filter, considering some spectra as target, and the others ones as undesirable. Estimate of fractions in *i*-th pixel will be:

$$\alpha^{T} = (Y^{T} X^{-1} Y)^{-1} Y^{T} X^{-1} x_i \tag{3}$$

Here α is a *p*-dimensional vector.

The TCMI model can be reduced to the linear transformation of spectra matrix and following application of least squares method:

$$\alpha^{T} = \text{pinv}(X^{-1/2} Y)^{-1} X^{-1/2} x_i \tag{4}$$

where by pinv (·) a pseudo-inversion of matrix is denoted.

Vector's $\alpha_i$ elements can be the negative. In order to avoid the negative values of estimates of spectra fractions it is necessary to ensure the NCLS constrains [19].

The combination of the TCMI-NCLS models consists in finding the spectra fractions in *i*-th pixel of image as critical point with respect to $\alpha_i$ in minimization problem:

$$\begin{cases} (x_i - Y\alpha_i)^{T} X^{-1} (x_i - Y\alpha_i) \quad \to \quad \min \\ \alpha_{ij} \geq 0 \\ j = 1..p \end{cases} \tag{5}$$

Similar to TCMI, the TCMI-NCLS model comes down to multiplication of spectra by $X^{-1/2}$ matrix and ensuring the NCLS constrains.

The significant exceeding of the pixel area over the target area should be considered as the typical case for hyperspectral imaging of small-size targets. Therefore, the pixel fraction of target spectrum will be small. In this case the NCLS constrains seem quite intrinsic, while the stronger FCLS constrains are overmuch. At the same time the NCLS constrains allow to preserve the physical nature requirements of unmixing. It is important advantage over the pure TCMI model.

So, the TCMI-NCLS model is the most suitable for small-size targets detection in hyperspectral image [20].

**Method.** Above the TCMI-NCLS (5) model was chosen as essential core of the developed method for subpixel target detection. However the accuracy of calculation of target spectra fractions provided by it significantly depends on targets and backgrounds composition in scene as well as on reliability of the close spectra separation. Therefore the TCMI-NCLS model requires the correction the kernel of which is the adjustment to specific set of target/background spectra to be detected (the first level of correction) as well as incorporation the reliability of close spectra separating (the second level of correction).

The first level of correction is based on numerous experiments and represented by regression dependence between the corrected pixel fraction *e* and initial one α. As simulation shows, the best in mean accuracy is provided by exponential type regression of:

$$e(\alpha) \approx b \times [1 - \exp(-k \times (\alpha + c)^{q})] \,, \tag{6}$$

where $b$, $c$, $k$, $q$ are regression parameters.

The second level of correction should in any way consider a possibility of correct separating of close spectra in mix. This level practically is always present at classification of hyperspectral imagery [21] and can use for the preliminary estimates various informational and statistical metrics, such as information divergence [22], Bhattacharyya statistical distance [23], or spectral-topological classifier [24].

The separability of optical signals is closely related to contrast; therefore for the analysis of multidimensional optical fields the Bhattacharyya distance which is an analogue of optical contrast [25] usually is engaged. However the available practical experience of signal detection in multi- and hyperspectral images testifies that such indicator as the contrast signal-to-noise ratio (CSNR) $\psi$ provides the better efficiency and convenience [26].

Correction of pixel fractions of target spectra depending on CSNR in each pixel of hyperspectral image at a first approximation can be described by signal-dependent additive term $f(\alpha)$ taking into account the error probability $\varepsilon(\psi)$:

$$f(\alpha) = \begin{cases} \alpha - \alpha \cdot \varepsilon(\psi) & \alpha \le 0.5 \\ \alpha + (1-\alpha) \cdot \varepsilon(\psi) & \alpha > 0.5 \end{cases} \tag{7}$$

where the error probability $\varepsilon(\psi)$ is evaluated by pixel CSNR value $\psi$ as [27]:

$$\varepsilon(\psi) \cong \frac{1}{2}\left(1 - \operatorname{erf}\frac{\psi}{\sqrt{2}}\right) \tag{8}$$

Thus, three stages of calculation of target spectra pixel fractions are implemented sequentially in the developed method for subpixel detection of small-size targets in hyperspectral image. At first the matched filtering with the TCMI-NCLS model [20] which provides the initial guess of pixel fractions is carried out. Then the regression adjustment of their values by statistics collected within the hyperspectral imaging total area is conducted. And at last, the fine equalizing of the adjusted values of pixel fractions by the contrast signal-to-noise ratio in each hyperpixel of image is performed.

The described three-stage model is more flexible in comparison with the TCMI-NCLS one and the more so with the pure TCMI. Therefore it is able to provide more exact subpixel detection of small-size targets in hyperspectral image.

**Results.** Testing of the developed method over the AVIRIS actual hyperspectral aerial image (Fig. 1) demonstrates its superiority over well-known methods – centered matched filter (CMF) [28], CEM and TCMI.

Fig. 1. ER-2/AVIRIS hyperspectral aerial image

Mojave (USA) power station, September 6, 2018, pseudo-natural color composite, spectral bands 36 (684 nm), 20 (550 nm), and 10 (453 nm), GSD 5.8 m

The pixel fractions accuracy of the target spectrum detection was estimated by the mean absolute error (MAE). Table 1 provides the accuracy estimates for the CMF method, joint one for CEM and TCMI methods (they are equivalent in the case of single target spectrum) and for the developed method with correction.

Table 1. The accuracy of pixel fractions of the target spectrum

| Method | Target pixel fraction MAE | False pixel fraction MAE |
|---|---|---|
| CMF | 0.149 | 0.021 |
| CEM/TCMI | 0.040 | 0.027 |
| Proposed | 0.033 | 0.014 |

As can be seen from the table 1, the proposed method provides the best performances for both target spectrum detection and false alarm compared to known methods.

**Conclusions**

The advanced method for subpixel detection of small-size targets in hyperspectral image is proposed. In addition to the core TCMI-NCLS matched filter it includes a further two-level correction chain for values adjustment of target spectra pixel fractions. At the first level of correction an adjustment to specific set of target and background spectra which are subject to detection is carried out. At the second level of correction the refinement of values of target spectra pixel fractions in each pixel of hyperspectral image is performed. The model of exponential regression is the kernel for the first level correction. The second level of correction is conducted in relation with the contrast signal-to-noise ratio in each pixel.
Fulfilled demo subpixel target detection in actual hyperspectral image shows the 17.5% increase in accuracy relative to known CEM and TCMI methods.

**References**

[1] Bekő L., Hunyadi G. Laakso K., Nygrén P. Identification of materials using aerial hyperspectral images // Acta Carolus Robertus, 2016.– Vol.6.– No.1.– P.19-26.
[2] Cohen Y., August Y., Blumberg D.G., Rotman S.R. Evaluating subpixel target detection algorithms in hyperspectral imagery // Journal of Electrical and Computer Engineering, 2012.– Vol.12.– A.103286.– 15 p.
[3] Chang C.-I. Hyperspectral Imaging: Techniques for Spectral Detection and Classification.– N.Y.: Kluwer Academic/Plenum Publishers, 2003.– 396 p.
[4] Manolakis D., Siracusa C., Shaw G. Hyperspectral subpixel target detection using the linear mixing model // IEEE Transactions on Geoscience and Remote Sensing, 2001.– Vol.39 – No.7.– P.1392-1409.
[5] Bateson C.A., Asner G.P., Wessman C.A. Endmember bundles: A new approach to incorporating endmember variability into spectral mixture analysis // IEEE Transactions on Geoscience and Remote Sensing, 2000.– Vol.38.– No.2.– P.1083-1094.
[6] Plaza A., Martinez P., Perez R., Plaza J. A Quantitative and comparative analysis of endmember extraction algorithms from hyperspectral data // IEEE Transactions on Geoscience and Remote Sensing, 2004.– Vol.42.– No.3.– P.650-663.
[7] Lukin V.V., Ponomarenko N.N., Zelensky A.A., Kurekin A.A., Lever K. Compression and classification of noisy multichannel remote sensing images // Proceedings of the SPIE, 2008.– Vol.7109.– A.71090W.– 12 p.
[8] Bitar A.W., Cheong L.-F., Ovarlez J.-P. Target and background separation in hyperspectral imagery for automatic target detection // Proceedings of International Conference on Acoustics, Speech and Signal Processing (ICASSP 2018).– Calgary: IEEE, 2018.– P.1598-1602.
[9] Wei Y., Zhu X., Li C., Guo X., Yu X., Chang C., Sun H. Applications of hyperspectral remote sensing in

ground object identification and classification // Advances in Remote Sensing, 2017.– Vol.6.– No.3.– P.201-211.
[10] Kerekes J.P., Baum J.E. Spectral imaging system analytical model for subpixel object detection // IEEE Transactions on Geoscience and Remote Sensing, 2002.– Vol.40.– No.5.– P.1088-1101.
[11] Melesse A.M. Remote sensing sensors and applications in environmental resources mapping and modelling / A.M. Melesse, Q. Weng, P.S. Thenkabail, G.B. Senay // Sensors, 2007.– Vol.7.– No.12.– P.3209-3241.
[12] Nielsen A.A. Spectral mixture analysis: Linear and semi-parametric full and iterated partial unmixing in multi- and hyperspectral image data // International Journal of Computer Vision, 2001.– Vol.42.– No.1-2.– P.17-37.
[13] Eismann M.T., Hardie R.C. Stochastic spectral unmixing with enhanced endmember class separation // Applied Optics, 2004.– Vol.43.– No.36.– P.6596-6608.
[14] Meola J. Examining the impact of spectral uncertainty on hyperspectral data exploitation / Proceedings of the SPIE, 2018.– Vol.10644.– A.106440L.– 12 p.
[15] Villa A., Chanussot J., Benediktsson J.A., Jutten C. Unsupervised classification and spectral unmixing for sub-pixel labelling // Proceedings of International Geoscience and Remote Sensing Symposium (IGARSS 2011).– Vancouver: IEEE, 2011.– P.71-74.
[16] Stankevich S.A., Shklyar S.V. Land-cover classification on hyperspectral aerospace images by spectral endmembers unmixing // Journal of Automation and Information Sciences, 2006.– Vol.38.– No.12.– P.31-41.
[17] Dadon M.M., Rotman S.R., Blumbergn D.G., Adler-Golden S., Conforti P. Target detection in the presence of multiple subpixel targets in complex backgrounds // Proceedings of the 8th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS 2016).– Los Angeles: IEEE, 2016.– P.51-54.
[18] Kwan C., Ayhan B., Chen G., Wang J., Ji B., Chang C.-I. A Novel approach for spectral unmixing, classification, and concentration estimation of chemical and biological agents // IEEE Transactions on Geoscience and Remote Sensing, 2006.– Vol.44. – No.2. – P.409-419.
[19] Stankevich S.A., Shklyar S.V. Advanced algorithm for endmembers unmixing on hyperspectral image // Proceedings of the 1st Ukrainian Conference with International Participation “Earth Observations for Sustainable Development and Security”.– Kiev: Naukova Dumka, 2008.– P.85-89, (in Ukrainian).
[20] Stankevich S.A., Kharytonov M.M., Kozlova A.A., Korovin V.Yu., Svidenyuk M.O., Valyaev A.M. Soil contamination mapping with hyperspectral imagery: Pre-Dnieper chemical plant (Ukraine) case study / Hyperspectral Imaging in Agriculture, Food and Environment / A.I.L. Maldonado, H. Rodriguez-Fuentes, J.A.V. Contreras (Eds).– London: IntechOpen, 2018.– P.121-136.
[21] Fauvel M., Chanussot J., Benediktsson J.A. Decision fusion for hyperspectral classification // Hyperspectral Data Exploitation: Theory and Applications / C.-I. Chang (Ed).– N.Y.: John Wiley, 2007.– P.315-352.
[22] Popov M.A., Stankevich S.A., Lischenko L.P., Lukin V.V., Ponomarenko N.N. Processing of hyperspectral imagery for contamination detection in urban areas // Environmental Security and Ecoterrorism / H. Alpas, S.M. Berkowicz, I.V. Ermakova (Eds).– Dordrecht: Springer, 2011.– P.147-156.
[23] Jolad S., Roman A., Shastry M.C., Gadgil M., Basu A. A new family of bounded divergence measures and application to signal detection // Proceedings of the 5th International Conference on Pattern Recognition Applications and Methods (ICPRAM 2016).– Rome: Sapienza Università di Roma, 2016.– Vol.1.– P.72-83.
[24] Stankevich S.A. Algorithm for statistical classification of remote sensing objects by their spectral-topological features // Scientific Bulletin of National Mining University, 2006.– No.7.– P.38-40, (in Ukrainian).
[25] Goudail F. Bhattacharyya distance as a contrast parameter for statistical processing of noisy optical images / F. Goudail, P. Réfrégier, G. Delyon // Journal of the Optical Society of America, 2004.– Vol.21.– No.7.– P.1231-1240.

[26] Yao S., Lin W., Ong E.P., Lu Z. Contrast signal-to-noise ratio for image quality assessment // Proceedings of International Conference on Image Processing (ICIP'05).– Genova: IEEE, 2005.– Vol.1.– P.397.
[27] Treibitz T., Schechner Y.Y. Resolution loss without imaging blur // Journal of the Optical Society of America A, 2012.– Vol.29.– No.8.– P.1516-1528.
[28] Manolakis D., Marden D., Shaw G.A. Hyperspectral image processing for automatic target detection applications // Lincoln Laboratory Journal, 2003.– Vol.14.– No.1.– P.79-116.

# ჰიპერსპექტრალურ გამოსახულებებზე მცირეზომიანი ობიექტების აღმოჩენის გაუმჯობესებული მეთოდი

ვ. ანდრონოვი

### რეზიუმე

აღწერილია ჰიპერსპექტრალურ გამოსახულებებზე მცირეზომიანი ობიექტების სუბპიქსელური აღმოჩენისათვის გაუმჯობესებული მეთოდი. მეთოდი დაფუძნებულია შეთანხმებული გაფილტვრის მოდელზე გარკვეული პიქსელური წილების შემდგომ კორექციაზე. კორექტირება შედგება ორ სტადიიდან: სცენაში სპექტრების ობიექტების/ფონების კონკრეტული ანაკრეფის სტატისტიკური აწყობა და სპექტრების რადიომეტრიულ განყოფადობის პიქსელური აღრიცხვა. შემოთავაზებული გაუმჯობესებული მეთოდი უზრუნველყოფს ჰიპერსპექტრალურ გამოსახულებებზე მცირეზომიანი ობიექტების უფრო ზუსტ აღმოჩენას.

# Усовершенствованный метод обнаружения малоразмерных объектов на гиперспектральных изображениях

**В.В. Андронов**

### Резюме

Описан усовершенствованный метод для субпиксельного обнаружения малоразмерных объектов на гиперспектральных изображениях. Метод основан на модели согласованной фильтрации с последующей коррекцией определённых пиксельных долей. Коррекция состоит из двух стадий: статистическая настройка на конкретный набор объектов/фонов спектров в сцене и попиксельный учёт радиометрической разделимости спектров. Предложенный усовершенствованный метод обеспечивает более точное субпиксельное обнаружение малоразмерных объектов на гиперспектральных изображениях.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp. 77 - 94*

# Changeability of the Meteorological Parameters Associated with Some Simple Thermal Indices and Tourism Climate Index in Adjara and Kakheti (Georgia)

**[1]Avtandil G. Amiranashvili, [2]Liana G. Kartvelishvili, [3]Tamari V. Khakhutashvili, [2]Lia D. Megrelidze**

*[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
*1, M. Alexidze Str., 0160, Tbilisi, Georgia, e-mail:*avtandilamiranashvili@gmail.com
*[2]National Environmental Agency of Georgia*
*[3]Association 4Science*

***ABSTRACT***

The statistical data about the meteorological parameters, associated with some simple thermal indices and Tourism Climate Index (TCI) (mean monthly and mean monthly maximum air temperature, mean monthly and mean monthly minimum air relative humidity, total monthly precipitation, sunshine duration, wind speed) in eight points of Adjara (Batumi, Kobuleti, Khulo, Goderdzi) and Kakheti (Telavi, Dedoplistskaro, Kvareli, Sagarejo) in the period from 1961 through 2010 are represented. In particular, the changeability of the indicated meteorological parameters into 1986÷2010 in comparison with 1986÷2010 for above enumerated points is studied.

***Key Words:*** Meteorological parameters, Tourism Climate Index.

## Introduction

In the recent decades in view of the unprecedented rate of growth in the air temperature the problem of climate change on our planet acquired special urgency [1,2]. In this case a change in the air temperature and other climatic elements has essential (spatial) three-dimensional and temporary heterogeneities both in the global (Global Land, Global Land of the Northern and Southern Hemisphere, Zonal territories, etc.) [1-5] and regional (even territory of the small countries with the complex relief) [5-8] scales.

For example, in the work [6] was to identify any possible temperature changes within the last 50 years in the North-Western Italian Alps by examining data from 16 high-altitude weather stations in the period 1961-2010. The analysis of the temperature values showed an increase in temperature, particularly at high altitudes sites. In fact, the stations located above 1600 m a.s.l. revealed a rise in temperatures and a decrease in the number of cold periods. For the maximum temperatures have been observed greater increases in spring and winter, for minimum temperatures in the summer.

This problem great value has also in Georgia, because of the variety of climatic regions in its territory. In particular, the research carried out shows that during last decades the mean temperature in the Eastern Georgia is rising and in Western Georgia it is decreasing [9-12].

For the steady development of different areas of national economy, including health resort- tourist industry, accounting for climate change has vital importance.

Since the health resort- tourist potential of locality in many respects is determined by its bioclimatic conditions, it is important to reveal the existing and forthcoming variations in these conditions under the effect of climate change

In particular, information about the changeability of the different simple thermal indices and Tourism Climate Index developed by Mieczkowski TCI [13] in the recent decades in different countries (including some locations of Georgia) is represented in [8,14-22].

Simple thermal indices include more than one meteorological parameter and consider the combined action on the human organism of the air temperature, humidity, wind speed etc. [23-29]. For determining of mean monthly values of TCI following data are necessary: mean and mean maximum air temperature, mean and mean minimum relative humidity, precipitation, sunshine duration and wind speed [13].

In this work results of investigating of changeability of the mean monthly values of meteorological parameters, used for determining of TCI values [13] and different simple thermal indices [23-29, etc.] on the territories of Adjarian Autonomous Republic (below – Adjara) and Kakheti in the period from 1961 through 2010 are represented.

## Study Area, material and methods

Studies for four cities of Adjara (Batumi, Kobuleti, Khulo, Goderdzi) and four cities of Kakheti (Telavi, Dedoplistskaro, Kvareli, Sagarejo) are carried out. Table 1 presents information about coordinates and heights of the locality of 8 meteorological stations (below – point) in Adjara and Kakheti, whose data were used in the work. Fig. 1 for the clarity depicts the map of the arrangement of the indicated meteorological stations.

Table 1

Coordinates and heights of the 8 meteorological stations in Adjara and Kakheti

| Location | Latitude, N° | Longitude, E° | Height, m, a.s.l. |
|---|---|---|---|
| Adjara | | | |
| Batumi | 41.64 | 41.64 | 9 |
| Kobuleti | 41.82 | 41.78 | 3 |
| Khulo | 41.64 | 42.3 | 921 |
| Goderdzi | 41.63 | 42.52 | 2025 |
| Kakheti | | | |
| Telavi | 41.93 | 45.48 | 568 |
| Dedoplistskaro | 41.47 | 46.08 | 800 |
| Kvareli | 41.97 | 45.83 | 449 |
| Sagarejo | 41.73 | 45.33 | 802 |

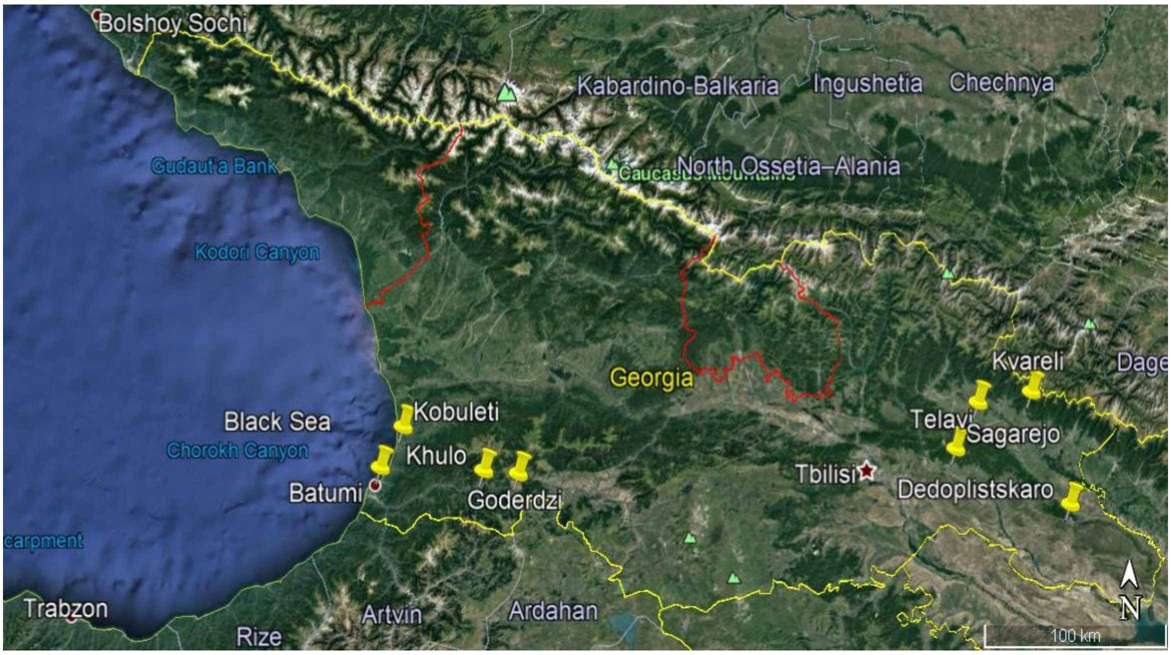



Fig. 1. Locations of eight meteorological stations in Adjara and Kakheti

In the work data of Georgian National Environmental Agency about monthly mean values of meteorological parameters in the period from 1961 through 2010 are used.

For the data analysis the standard statistical methods of the studies were used [30]. Designations and reduction – conventional. The difference between the mean values of the meteorological parameters into 1986-2010 and 1961-1985 with the use of Student's criterion was determined (level of significance not worse than 0.15).

The following designations are used below: $T_{mean}$ - mean air temperature (°C), $T_{max}$ - mean maximum air temperature (°C), $RH_{mean}$ - mean relative humidity (%), $RH_{min}$ - mean minimum relative humidity (%), P sum precipitation - (mm), $S_d$ - daily sunshine duration (hour), V - mean wind speed (m/s).

$\Delta T_{mean}$ ….. $\Delta V$ - the difference between the mean values of the meteorological parameters into 1986-2010 and 1961-1985.

## Results and discussion

Results in the Table 2-8 and Fig. 2-15 are presented.

### *Mean air temperature*

Detailed information about the mean annual, half year and monthly air temperature ($T_{mean}$) in eight points of Adjara and Kakheti in Table 2 and in Fig. 2 are represented.

In particular, averaged on the stations Batumi and Kobuleti (coast of Black sea) the air temperature in all months of cold half-year on 0.6-2.5 °C above average the value of $T_{mean}$ in Kakheti. In the warm half-year vice versa - on the average to the station in Kakheti of the value of $T_{mean}$ on 0.3-2.4 °C it is higher than in Batumi and Kobuleti (Table 2).

Table 2

Data of $T_{mean}$ (°C) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 14.5 | 10.1 | 19.0 | 1.8 | 26.5 | 6.9 | 22.8 |
| Kobuleti | 13.9 | 8.9 | 18.9 | 1.7 | 26.5 | 5.5 | 23.1 |
| Khulo | 10.4 | 5.1 | 15.7 | -4.1 | 23.5 | 1.2 | 19.1 |
| Goderdzi | 2.6 | -3.3 | 8.5 | -12.3 | 17.4 | -7.7 | 12.5 |
| Telavi | 12.3 | 5.6 | 19.0 | -4.8 | 27.5 | 1.2 | 23.5 |
| Dedoplistskaro | 11.0 | 4.1 | 17.8 | -6.0 | 26.3 | -0.2 | 22.6 |
| Kvareli | 13.0 | 6.2 | 19.7 | -4.1 | 27.6 | 1.8 | 24.1 |
| Sagarejo | 11.4 | 4.9 | 17.9 | -5.0 | 26.2 | 0.7 | 22.4 |

The intra-annual distribution of the values of $T_{mean}$ for both geographical regions takes the classical form, characteristic for the northern hemisphere - unimodal distribution close to the symmetrical. January is the coldest month for all eight points, whereas August is the hottest month in Adjara, and in Kakheti - July (Fig.2).

In different months the significant changeability of the mean monthly air temperature for the investigated points of Adjara in 16 cases is observed (for all cases - increase in the values of $\Delta T_{mean}$), and for Kakheti - in 22 cases (including for 20 cases - an increase in the values of $\Delta T_{mean}$).

Let us examine in more detail the nature of the changeability of the values of $\Delta T_{mean}$ in separate points (Fig. 3).

Batumi - increase in the values of $\Delta T_{mean}$ (July- October); Kobuleti and Goderdzi - increase (June-October); Khulo – increase (July, August). In Adjara a maximum and minimum increase in this parameter is observed in Kobuleti (1.6 °C August and 0.5 °C, June).

Telavi - decrease of the values of $\Delta T_{mean}$ (-0.5 °S, May), increase (June, August - October); Dedoplistskaro - decrease (-0.6 °S, May), increase (March, June - October); Kvareli and Sagarejo - increase of the values of $\Delta T_{mean}$ (March, June, August - October). In Kakheti a maximum increase of the indicated parameter into Dedoplistskaro (1.7 °C, August), and minimum - in Telavi and Kvareli (0.6 °C, September) is observed.

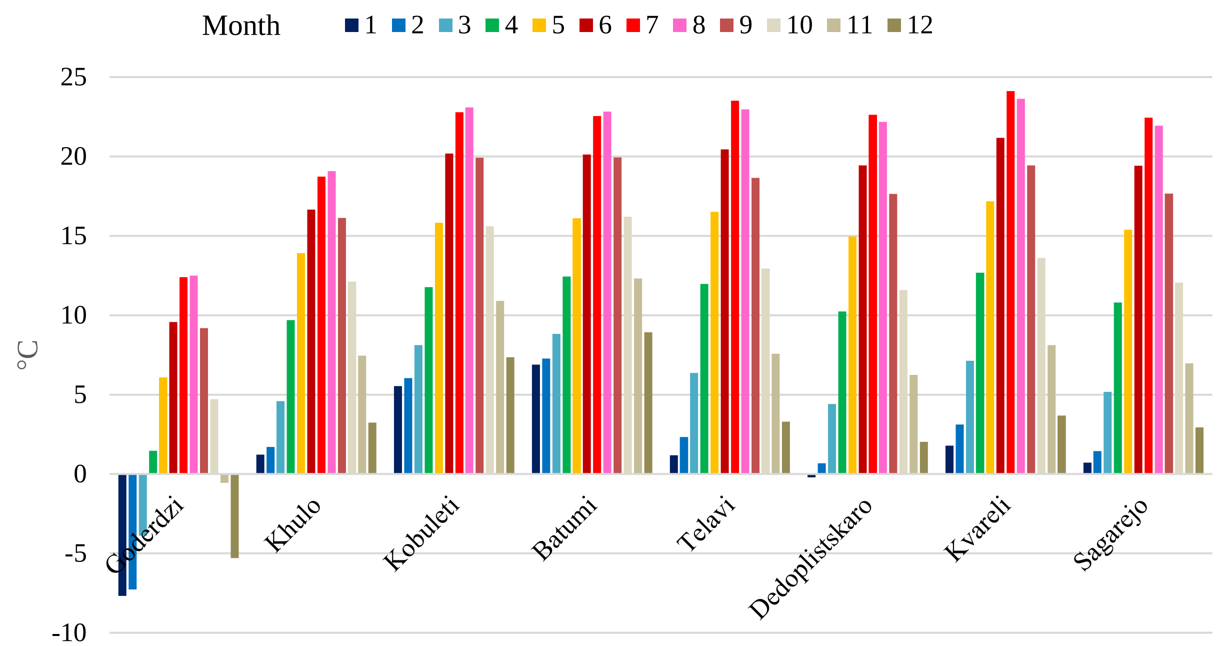



**Fig. 2. Mean values of $T_{mean}$ in eight locations of Adjara and Kakheti in 1961-2010**

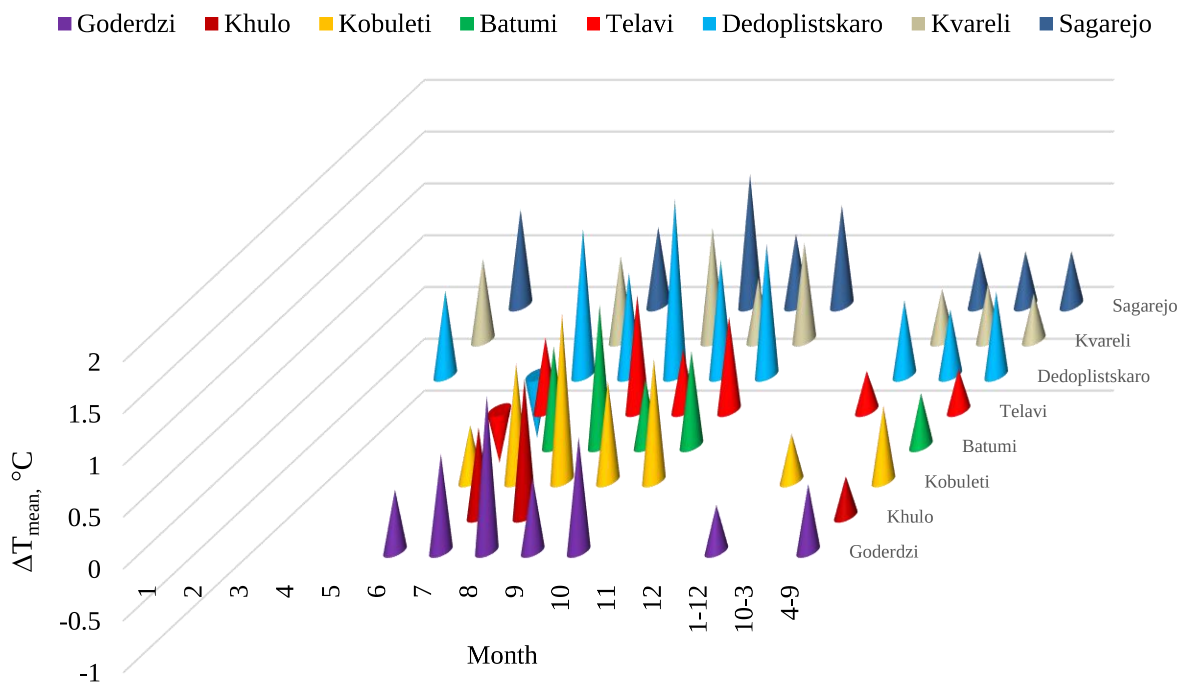



**Fig. 3. Difference between the mean values of $T_{mean}$ into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

Thus, in both investigated regions is noted the explicit process of the warming-up of climate. In Adjara the values of $\Delta T_{mean}$ are varied from 0.5 to 1.6 °C, amplitude - 1.1 °C, while in Kakheti - from -0.6 to 1.7 °C, amplitude - 2.3 °C. On the average to the station with the significant changeability of the mean monthly air temperature in Adjara the value of $\Delta T_{mean}$ grows on 1.0 °C, while in Kakheti - on 0.8 °C.

### *Mean maximum air temperature*

Data about the mean annual, half year and monthly maximum air temperature ($T_{max}$) in table 3 and Fig. 4 are represented.

Averaged on the stations of Batumi and Kobuleti value of $T_{max}$ from April through October on 0.6-2.2 °C above average the value of the maximum air temperature in Kakheti. The average to the station in Kakheti value of $T_{max}$ on 0.6-3.6 °C it is higher than in the Batumi and Kobuleti in the warm half-year (Table 3).

Table 3

Data of $T_{max}$ (°C) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 18.7 | 14.4 | 23.0 | 5.1 | 30.5 | 10.8 | 26.4 |
| Kobuleti | 18.7 | 14.1 | 23.3 | 5.8 | 31.1 | 10.4 | 27.0 |
| Khulo | 16.0 | 9.9 | 22.1 | -0.1 | 31.4 | 5.3 | 25.4 |
| Goderdzi | 6.8 | 0.3 | 13.4 | -9.2 | 23.4 | -4.6 | 17.5 |
| Telavi | 17.7 | 10.5 | 24.9 | 0.0 | 34.6 | 5.7 | 29.4 |
| Dedoplistskaro | 16.4 | 9.2 | 23.7 | -0.8 | 34.0 | 4.6 | 28.5 |
| Kvareli | 18.7 | 11.4 | 26.0 | 0.3 | 35.5 | 6.6 | 30.6 |
| Sagarejo | 17.0 | 10.0 | 24.0 | -0.8 | 33.3 | 5.4 | 28.4 |

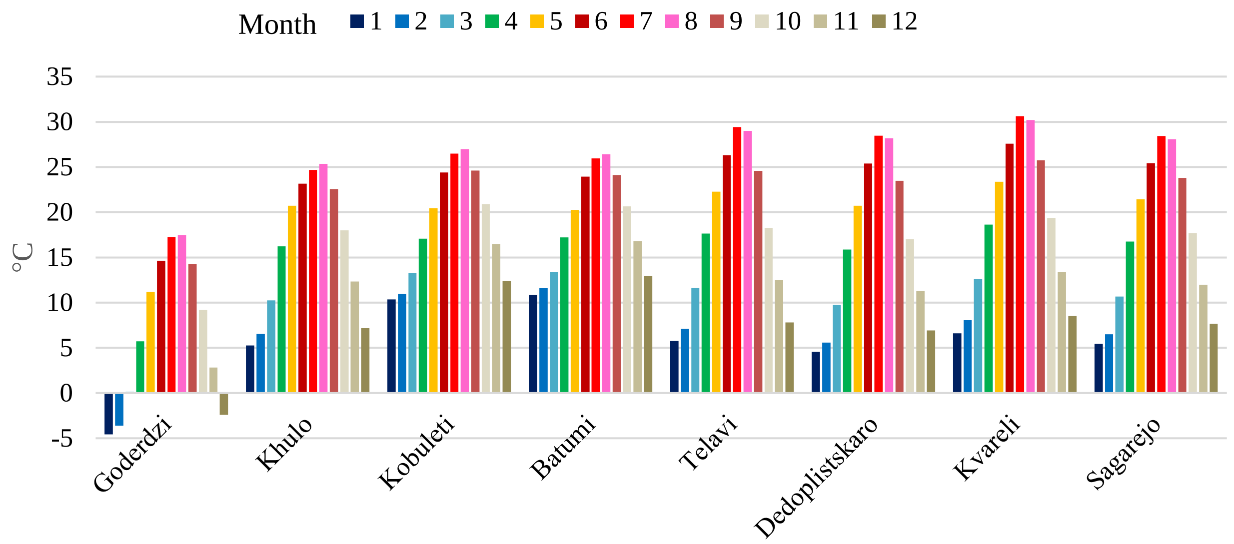



**Fig. 4. Mean values of $T_{max}$ in eight locations of Adjara and Kakheti in 1961-2010**

The intra-annual distribution values of $T_{max}$ is analogous to the motion of the values of $T_{mean}$ for all 8 points of Adjara and Kakheti (Fig. 4). As in the preceding case, the smallest values of $T_{max}$ for all eight points during January are observed, and the greatest values of $T_{max}$ in Adjara during August, and in Kakheti - during July are observed (Fig. 4).

The changeability of the mean monthly maximum air temperature for four points of Adjara in 11 cases (including for 10 cases - increase of the values of $\Delta T_{max}$), and for Kakhetii - in 18 cases (including for 17 cases - an increase on the values of $\Delta T_{max}$ ) are observed.

The information about the changeability of the values of $\Delta T_{max}$ in separate points is presented lower (Fig. 5).

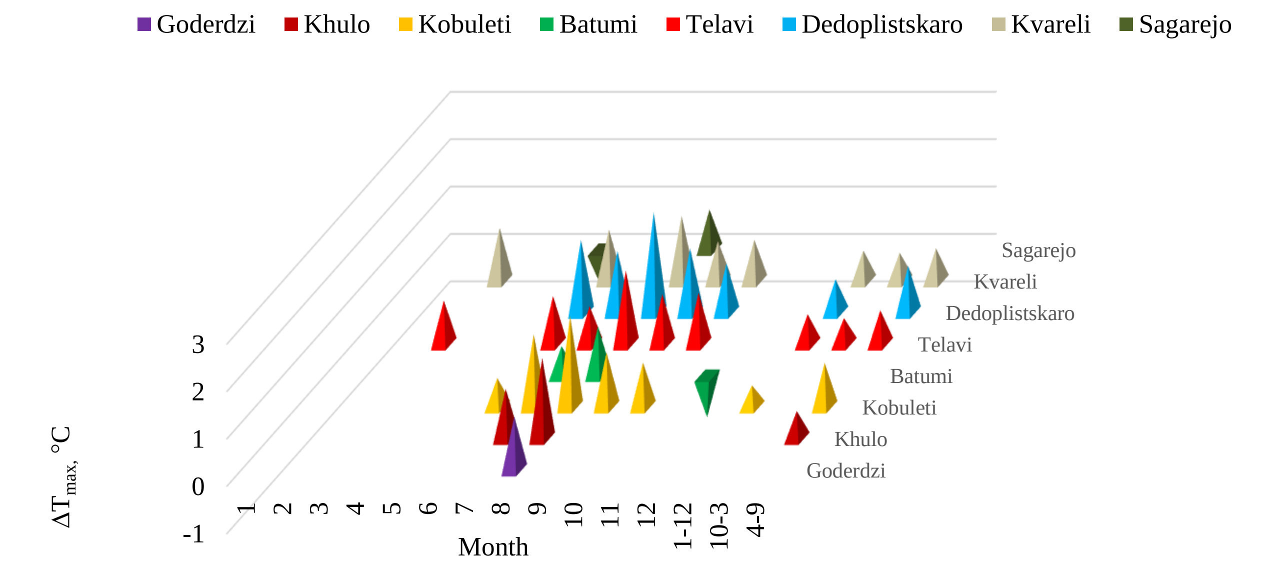



**Fig. 5. Difference between the mean values of $T_{max}$ into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

Batumi - increase of the values of $\Delta T_{max}$ (July, August), decrease (-0.9 °C, November); Kobuleti - increase (June - October); Khulo - increase (July, August); Goderdzi - increase (August). In Adjara a maximum increase of the values of $\Delta T_{max}$ into Kobuleti (1.9 °C, August), the minimum - in Kobuleti and by Batumi (0.6 °C, June and July respectively) are observed.

Telavi – increase of the values of $\Delta T_{max}$ (March, June- October); Dedoplistskaro - increase (June-October); Kvareli - increase (March, June, August - October); Sagarejo - decrease (-0.7 °C, May), increase (August). In Kakheti the greatest increase of the values of $\Delta T_{max}$ is noted into Dedoplistskaro (2.1 °C, August), smallest - in Telavi and Kvareli (0.8 °C, July and September respectively).

As a whole, in Adjara the values of $\Delta T_{max}$ change from -0.9 to 1.9 °C, amplitude - 2.8 °C, while in Kakheti - from -0.7 to 2.1 °C, amplitude - also 2.8 °C. On the average to the station with the significant changeability of the mean monthly maximum air temperature in Adjara the values of $\Delta T_{max}$ grows on 1.0 °C, while in Kakheti - on 1.1 °C.

### *Mean air relative humidity*

Data about the mean annual, half year and monthly air relative humidity ($RH_{mean}$) in Table 4 and Fig. 6 are represented.

Averaged for Batumi and Kobuleti the air relative humidity from March through October by 1.7-15.1% higher than the values of $RH_{mean}$ in Kakheti. During November and December the values of $RH_{mean}$ in Batumi and Kobuleti for 1.6 and 0.3 % are lower than on the average for four points of Kakheti. During January the differences is not observed (Table 4).

Table 4

Data of $RH_{mean}$ (%) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 75.2 | 71.3 | 79.0 | 54.6 | 89.0 | 67.5 | 80.7 |
| Kobuleti | 82.6 | 82.1 | 83.1 | 72.7 | 90.0 | 80.4 | 84.2 |
| Khulo | 71.9 | 70.2 | 73.7 | 38.2 | 91.0 | 65.6 | 79.0 |
| Goderdzi | 87.5 | 88.9 | 86.0 | 61.3 | 99.6 | 83.3 | 91.9 |
| Telavi | 70.3 | 73.2 | 67.4 | 46.5 | 88.5 | 64.7 | 75.8 |
| Dedoplistskaro | 76.1 | 79.9 | 72.3 | 44.1 | 95.4 | 67.7 | 81.4 |
| Kvareli | 75.2 | 79.4 | 71.1 | 51.4 | 91.6 | 68.0 | 81.9 |
| Sagarejo | 67.1 | 69.7 | 64.4 | 46.0 | 90.0 | 61.6 | 72.9 |

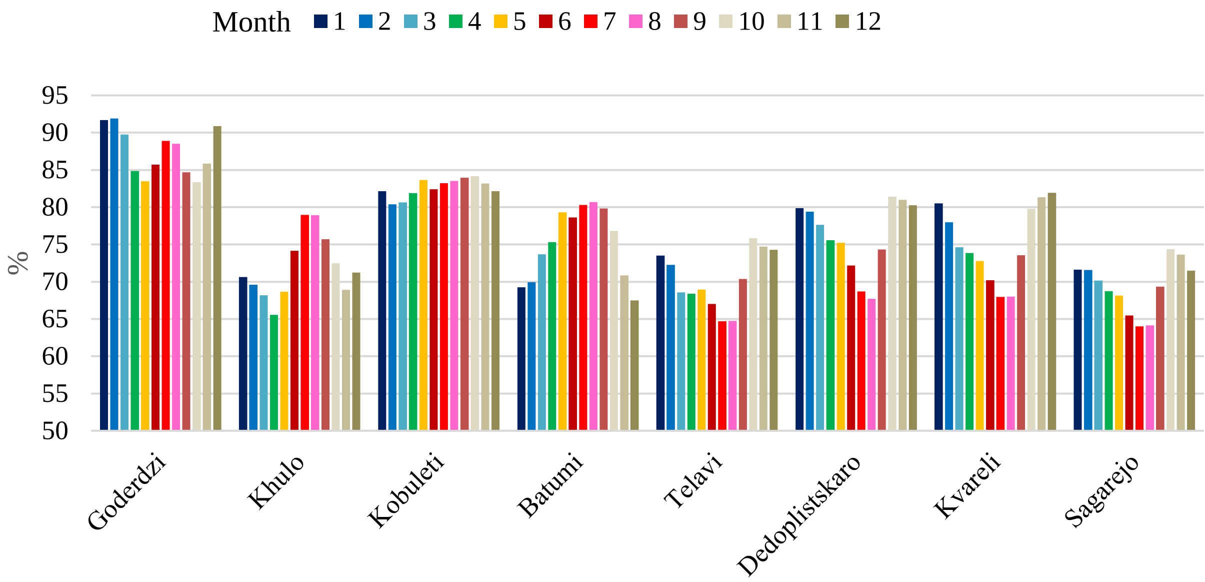



**Fig. 6. Mean values of $RH_{mean}$ in eight locations of Adjara and Kakheti in 1961-2010**

The intra-annual distribution of mean monthly air relative humidity in Batumi significantly differs from the intra-annual motion of the values of $RH_{mean}$ in Kobuleti, Khulo, Goderdzi and four points of Kakheti (Fig. 6).

In Batumi the distribution of $RH_{mean}$ it is close to the unimodal with the plateau (greatest values) from May through September (79-81%) and the minimum in January - December (68-69%); amplitude - 13%. In Kobuleti this distribution is close to the uniform with the maximum during October (84%) and the minimum during February (80%); amplitude - 4 %. In Khulo distribution of $RH_{mean}$ is unimodal with the weak peaks on the edges, has maximum during July-August (79%) and smallest values during April and November (69%); amplitude - 10 %. In the point Goderdzi this distribution is close to the wave with the basic maximum in January - February (92%), the second maximum during July - August (89%) and two minimums - during May and October (83%); amplitude - 9 %.

In Kakheti for all points the intra-annual distribution of $RH_{mean}$ takes the form of the asymmetrical inverted bell, with the right displacement. For the indicated points of Kakheti in the intra-annual course of relative humidity the minimum is observed in July-August (64-69 %), and the greatest values of $RH_{mean}$ - in winter (72-81%); amplitude - 17 %.

In different months the significant changeability of the mean monthly air relative humidity for the indicated points of Adjara in 16 cases (including for 8 cases - increase of the values of $\Delta RH_{mean}$) are observed, and for Kakheti - in 24 cases (including for 14 cases - an increase of the values of $\Delta RH_{mean}$).

The changeability of the values of $\Delta RH_{mean}$ in the separate points is the following (Fig. 7).

Batumi - increase of the values of $\Delta RH_{mean}$ (January), decrease (May, July - September); Kobuleti - increase (June), decrease (July - September); Khulo - decrease (September); Goderdzi - increase (February-April, June, July, December). In Adjara a maximum increase of the values of $\Delta RH_{mean}$ is observed in Goderdzi (3.1 %, April), minimum - in Kobuleti (0.8 %, June).

Telavi - decrease of the values of $\Delta RH_{mean}$ (March), increase (October - December); Dedoplistskaro - decrease (March); Kvareli - increase (all months, except July); Sagarejo - decrease (February- September). In Kakhetii a maximum increase of the values of $\Delta RH_{mean}$ is observed in Kvareli (5.4 %, January), minimum - in Kvareli and Telavi (2.5 %, September and October respectively). The greatest decrease of the values of $\Delta RH_{mean}$ is observed into Sagarejo (-5.8 %, March), smallest - also into Sagaredzho (-2.1 %, May).

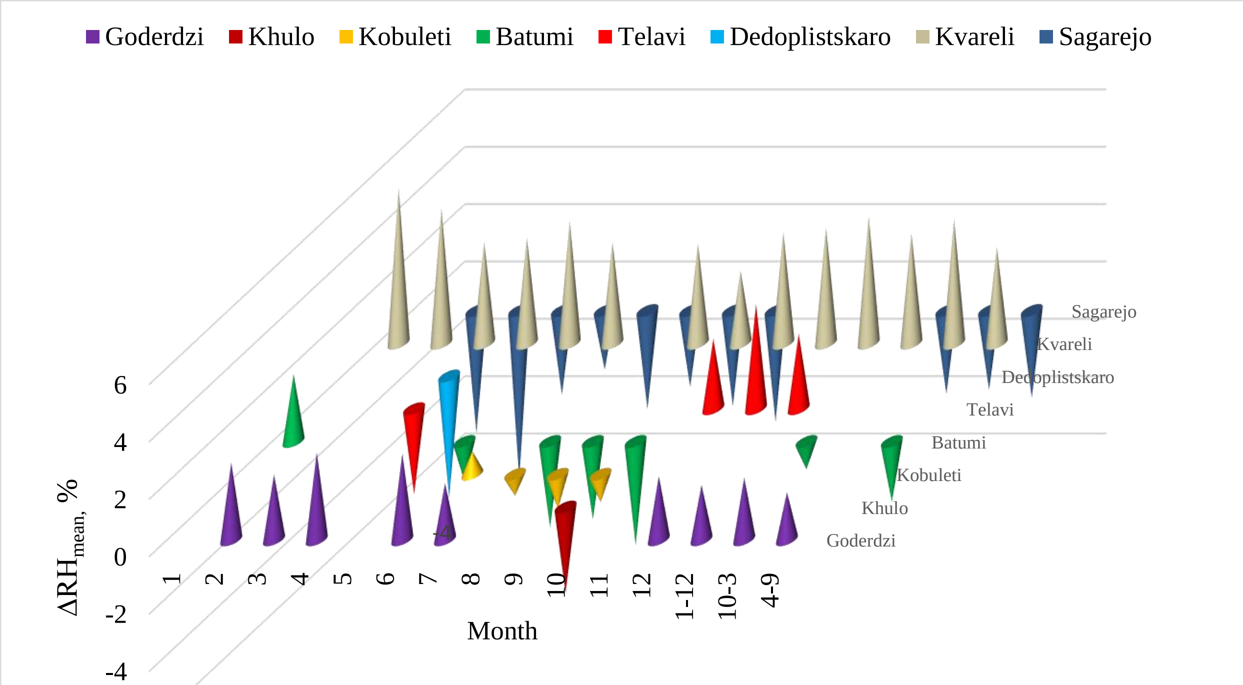



**Fig. 7. Difference between the mean values of $RH_{mean}$ into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

In Adjara the values of $\Delta RH_{mean}$ varyed from -3.6 to 3.1 %, amplitude - 6.7 %, while in Kakheti - from -5.8 to 5.4 %, amplitude - 11.2%. On the average to the station with the significant changeability of the average monthly air relative humidity in Adjara the value of $\Delta RH_{mean}$ grows by 0.1 %, while in Kakheti - to 0.7 %.

### *Mean minimum air relative humidity*

Data about the mean annual, half year and monthly minimum air relative humidity ($RH_{min}$) in Table 5 and Fig. 8 are represented.

Average for Batumi and Kobuleti the minimum air relative humidity for all months of year by 1.8-18.7% is higher than the values of $RH_{min}$ in Kakheti.

Table 5

Data of $RH_{min}$ (%) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 69.2 | 66.4 | 71.9 | 48.4 | 82.1 | 63.8 | 73.7 |
| Kobuleti | 73.5 | 72.3 | 74.6 | 57.2 | 85.3 | 71.4 | 76.5 |
| Khulo | 60.8 | 62.2 | 59.4 | 33.2 | 86.8 | 53.2 | 66.9 |
| Goderdzi | 80.4 | 84.2 | 76.7 | 48.0 | 99.3 | 72.8 | 89.5 |
| Telavi | 56.9 | 61.6 | 52.2 | 32.0 | 78.2 | 48.7 | 65.5 |
| Dedoplistskaro | 63.7 | 67.9 | 59.5 | 36.2 | 88.5 | 55.4 | 69.8 |
| Kvareli | 60.3 | 66.1 | 54.5 | 32.9 | 87.0 | 51.4 | 70.9 |
| Sagarejo | 53.7 | 57.7 | 49.7 | 31.4 | 78.8 | 46.8 | 60.3 |

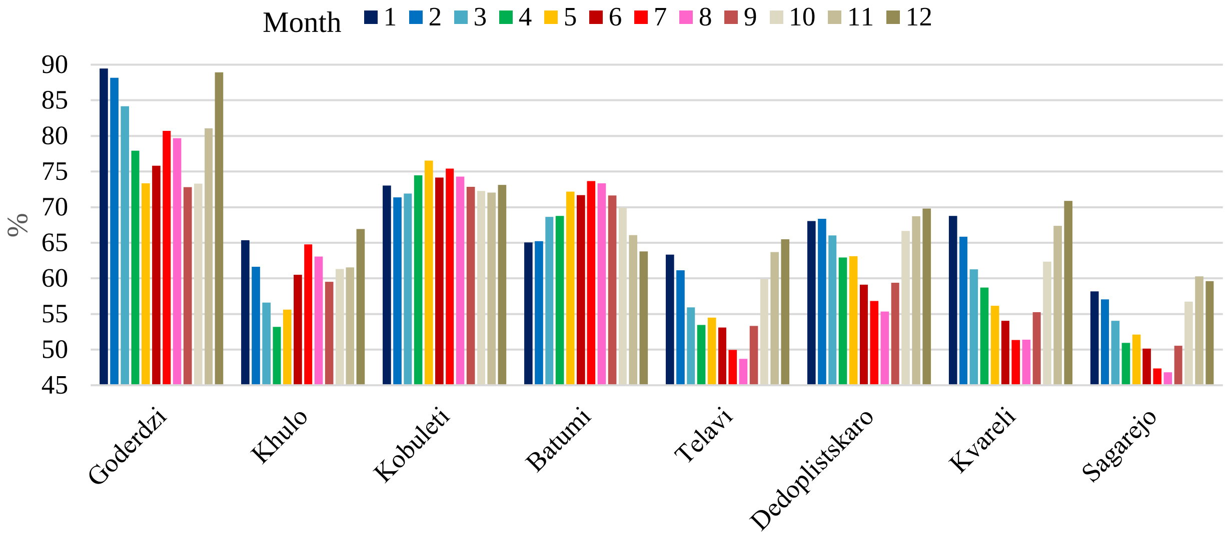



**Fig. 8. Mean values of $RH_{min}$ in eight locations of Adjara and Kakheti in 1961-2010**

In Batumi distribution of $RH_{min}$ is close to the unimodal with the maximum during July (74%) and the minimum during December (64%); amplitude - 10 %. As in the preceding case, in Kobuleti this distribution closely to the uniform with the maximum during May (77%) and the minimum during February (71 %); amplitude - 6%. In Khulo the intra-annual distribution of $RH_{min}$ takes the form of asymmetrical wave with the maximum during December (67 %) and the smallest value during April (53 %); amplitude - 14 %. In Goderdzi this distribution it takes the form of the convex inverted bell with the basic maximum in December - January (89%), the second maximum during July - August (80-81 %) and two minimums - during May and September - October (73%); amplitude - 8 % (Fig. 8).

For all points of Kakheti the intra-annual distribution of $RH_{min}$ is similar to the motion of $RH_{mean}$ (Fig. 6). In the intra-annual course of minimum relative humidity the smallest values it is observed in July-August (47-57 %), and the greatest values of $RH_{mean}$ - in winter (57-71 %); amplitude - 24 % (Fig. 8).

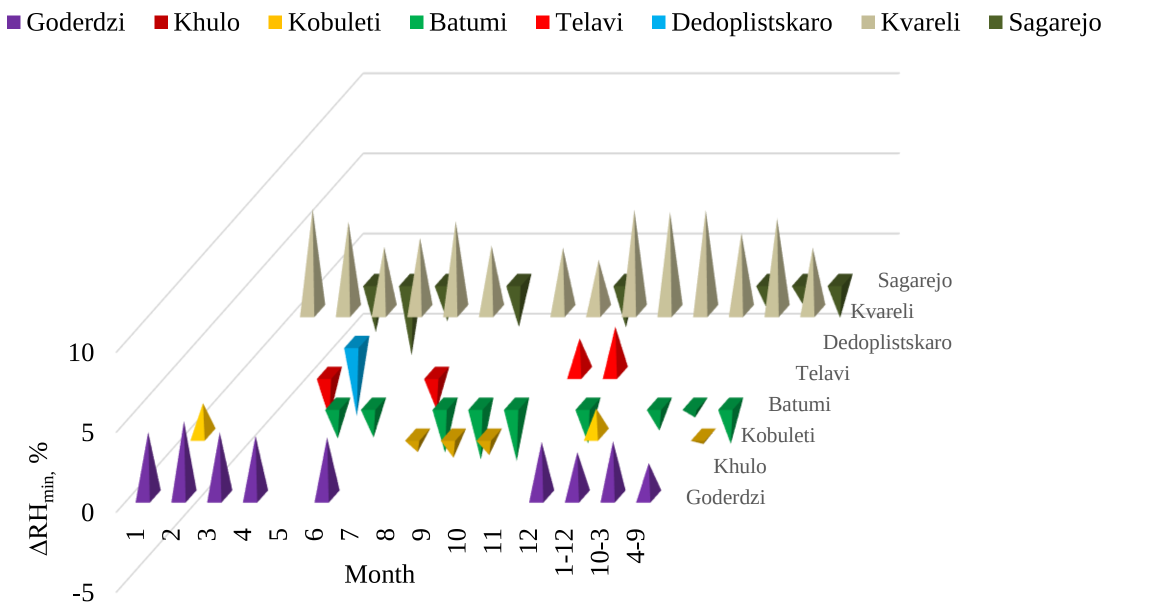



**Fig. 9. Difference between the mean values of $RH_{min}$ into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

In different months the significant changeability of the mean monthly minimum air relative humidity for four points of Adjara is observed in 17 cases (including for 8 cases - increase of the values of $\Delta RH_{min}$), and for Kakheti - in 21 case (including for 13 cases - an increase of the values of $\Delta RH_{min}$).

In the separate points the nature of the changeability of the values of $\Delta RH_{min}$ is following (Fig. 9).

Batumi - decrease of the values of $\Delta RH_{min}$ (April, May, July - September, November); Kobuleti - increase (January, December), decrease (July- September); Khulo - changes are not meant; Goderdzi - increase (January - April, June, December). In Adjara a maximum increase of the values of $\Delta RH_{min}$ is observed in Goderdzi (4.7 %, February), minimum - in Kobuleti (1.6 %, December). The greatest decrease of the values of $\Delta RH_{min}$ is observed in Batumi (-3.6 %, September), smallest - in Kobuleti (-1.1 %, July).

Telavi - decrease of the values of $\Delta RH_{min}$ (March, June), increase (October, November); Dedoplistskaro - decrease (March); Kvareli - increase (all months, except July); Sagarejo - decrease (February- April, June, September). In Kakheti a maximum increase of the values of $\Delta RH_{min}$ is observed in Kvareli (6.4 %, January), minimum - in Telavi (2.2 %, October). The greatest decrease of the values of $\Delta RH_{min}$ is observed into Sagarejo (-4.7 %, March), smallest - in Telavi (-2.3 %, June).

In Adjara values of $\Delta RH_{min}$ changes from -3.6 to 4.7 % (amplitude - 8.3 %), while in Kakheti - from -4.7 to 6.4 % (amplitude - 11.1 %). On the average to the station with the significant changeability of the mean monthly minimum air relative humidity in Adjara the value of $\Delta RH_{min}$ grows by 0.4 %, while in Kakheti - to 1.7 % (Fig. 9).

### *Sum of atmospheric precipitations*

Data about mean annual, half year and monthly minimum monthly total precipitation (P) in table 6 and Fig. 10 are represented.

Averaged for the Batumi and Kobuleti monthly total precipitation from January through April and from June through December on 7.2-143.7 mm higher than the values of P in Kakheti. Only during May value of P in Batumi and Kobuleti on 21.9 mm lower than on the average for four points of Kakheti.

Table 6

Data of P (mm) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 207.4 | 244.3 | 170.5 | 0.0 | 657.8 | 89.6 | 310.1 |
| Kobuleti | 194.2 | 216.6 | 171.8 | 10.0 | 627.9 | 86.1 | 286.2 |
| Khulo | 116.3 | 148.6 | 83.9 | 0.5 | 627.6 | 68.1 | 174.5 |
| Goderdzi | 108.8 | 114.6 | 102.9 | 7.7 | 361.4 | 82.2 | 130.2 |
| Telavi | 64.2 | 41.5 | 86.9 | 0.0 | 240.1 | 25.6 | 113.6 |
| Dedoplistskaro | 50.8 | 35.7 | 65.9 | 0.0 | 213.8 | 24.3 | 96.8 |
| Kvareli | 80.8 | 57.5 | 104.0 | 0.0 | 313.9 | 36.2 | 126.9 |
| Sagarejo | 64.0 | 45.5 | 82.5 | 0.0 | 286.6 | 28.5 | 104.7 |

In Batumi and Kobuleti the intra-annual distribution total precipitation takes the form of the asymmetrical inverted bell with the left displacement and with the plateau from the right edge. In Batumi the minimum of value P is observed during May (90 mm) and greatest values - in September - December (290-310 mm); amplitude - 220 mm. In Kobuleti this distribution has the more clearly expressed maximum during September (286 mm) and a minimum also during May (86 mm); amplitude - 200 mm. In Khulo distribution of P has the type of the flattened inverted bell with the convexity during June (94 mm) and plateau in November - December (171-174 mm). It is observed by the minimum of values of P during July-August (68-69 mm); amplitude - is 106 mm. In Goderdzi this distribution has a nature, similar to the two-wave, with basic maximum during June and October (125 and 130 mm), and by two minimums - during April and August (82 and 95 mm); amplitude - 48 mm (Fig. 10).

For all points of Kakheti the intra-annual motion of monthly total precipitation takes the bimodal form with the left asymmetry, with the extrema in May-June (89-127 mm) and in August - October (53-94 mm) and by the minimum - in December- January (25-47 mm); amplitude - 102 mm (Fig. 10).

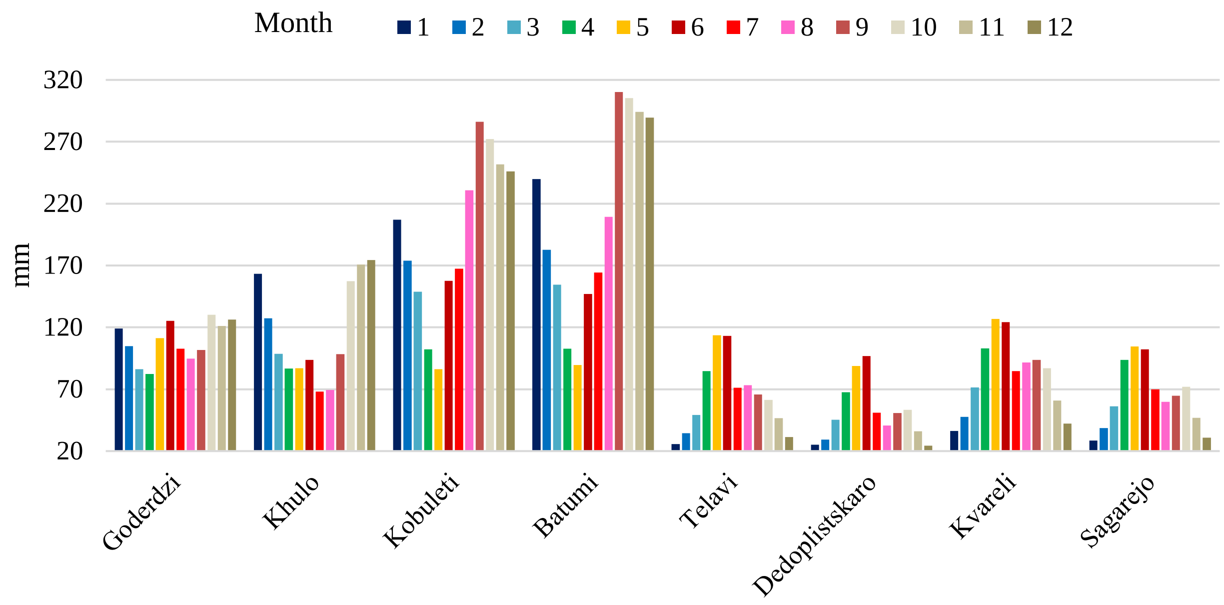



**Fig. 10. Mean values of P in eight locations of Adjara and Kakheti in 1961-2010**

In different months the significant changeability of mean monthly total precipitation for four points of Adjara is observed in 10 cases (including only for 3 cases - increase in the values of ΔP), and for Kakheti - in all in 6 cases (including only for 2 cases - an increase in the values of ΔP).

In the separate points the following changeability of mean monthly total precipitation is observed (Fig. 11).

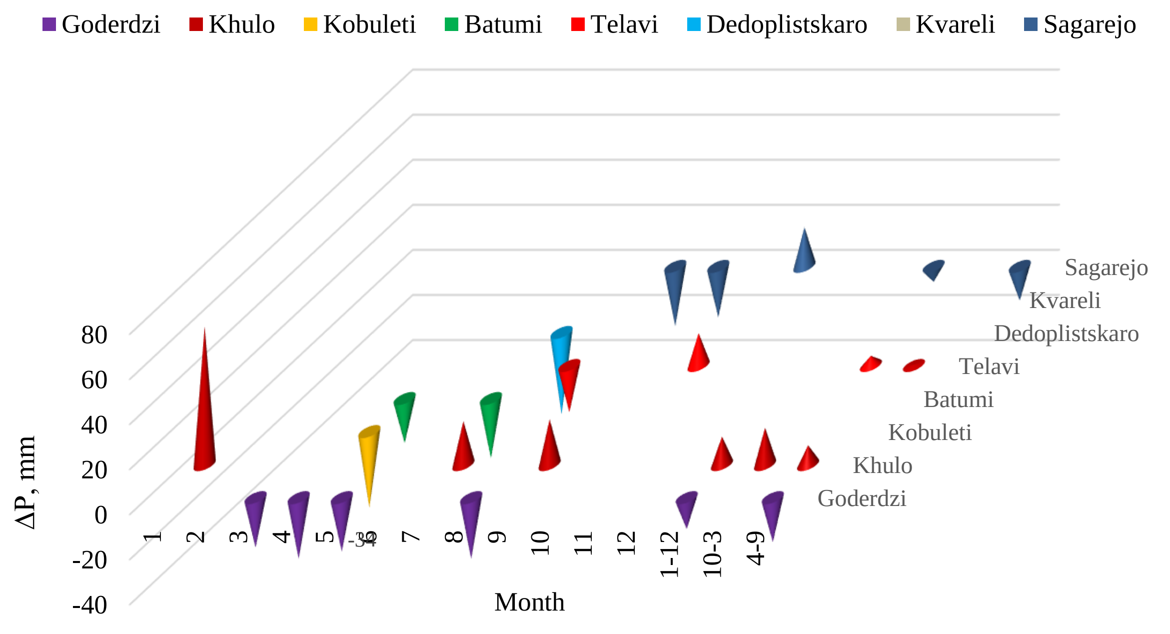



**Fig. 11. Difference between the mean values of P into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

Batumi - decrease of the values of ΔP (April, June); Kobuleti - decrease (April); Khulo - increase (January, July, September); Goderdzi - decrease (March- May, August). In Adjara a maximum increase of the values of ΔP is observed into Khulo (61 mm, January), the minimum - also in Khulo (19 mm, July). The greatest decrease of the values of ΔP is observed into Kobuleti (-34 mm, April), the smallest - in Batumi (-20 mm, April).

Telavi - decrease of the values of ΔP (July), increase (October); Dedoplistskaro - decrease (June); Kvareli - the significant changes is not observed; Sagarejo - decrease (July, August), increase (October). In Kakheti a maximum increase in the values of ΔP is observed into Sagarejo (17 mm, October), minimum - in Telavi (14 mm, October). The greatest decrease of the values of ΔP is observed into Dedopltstskaro (-36 mm, June), smallest - in Telavi (-21 mm, July).

In Adjara the values of ΔP is varied from -34 to 61 mm (amplitude - 95 mm), while in Kakheti - from -36 to 17 mm (amplitude - 53 mm). On the average to the station with the significant variability of monthly precipitation in Adjara the value of ΔP diminishes on 8 mm, while in Kakheti - on 12 mm.

### *Monthly daily sunshine duration*

The data about the mean annual, half year and monthly daily sunshine duration ($S_d$) in Table 7 and Fig. 12 are represented.

Averaged for Batumi and Kobuleti monthly daily sunshine duration during April and from September through November by 0.2-0.7 hour of higher than the values of $S_d$ in Kakheti; during February the differences is not observed. In the remaining months of value of $S_d$ in Batumi and Kobuleti for 0.3-2.5 hour lower than on the average for four points of Kakheti.

Table 7

Data of $S_d$ (hour) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 5.2 | 4.0 | 6.4 | 1.2 | 9.8 | 3.2 | 7.5 |
| Kobuleti | 5.2 | 4.0 | 6.5 | 1.2 | 10.2 | 3.1 | 7.9 |
| Khulo | 5.6 | 4.4 | 6.7 | 1.2 | 10.0 | 3.3 | 7.7 |
| Goderdzi | 5.4 | 4.2 | 6.6 | 1.2 | 9.7 | 3.3 | 7.3 |
| Telavi | 5.7 | 4.2 | 7.3 | 1.5 | 12.0 | 3.6 | 8.5 |
| Dedoplistskaro | 5.7 | 4.1 | 7.3 | 1.3 | 11.6 | 3.4 | 8.4 |
| Kvareli | 5.8 | 4.0 | 7.6 | 1.3 | 11.7 | 3.2 | 8.8 |
| Sagarejo | 6.1 | 4.6 | 7.6 | 2.1 | 11.9 | 3.9 | 8.9 |

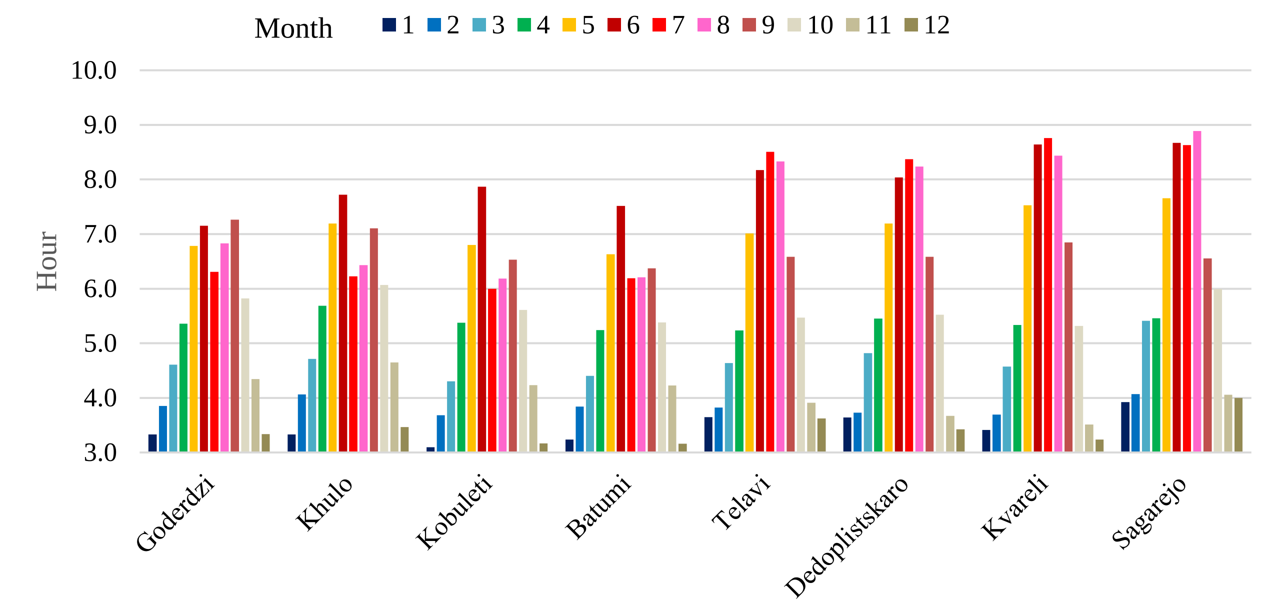



**Fig. 12. Mean values of $S_d$ in eight locations of Adjara and Kakheti in 1961-2010**

In Adjara the intra-annual distribution of monthly daily sunshine duration takes the bimodal form with the extrema during June and September, respectively: Batumi - 7.5 and 6.4 hour; Kobuleti - 7.9 and 6.5 hour; Khulo - 7.7 and 7.1 hour; Goderdzi - 7.2.and 7.3 hour. Minimum values of $S_d$ for all points of Adjara are observed in December - January (3.1-3.5 hour). Amplitude: Batumi - 4.4 hour, Kobuleti - 4.8 hour, Khulo - 4.4 hour, Goderdzi - 3.9 hour (Fig. 12).

In Kakheti intra-annual distribution of $S_d$ for all points takes the single-modal form close to the symmetrical with the plateau during June-August. Values of $S_d$ in these months comprise: in Telavi - 8.2-8.5 hour; Dedoplistskaro - 8.0-8.4 hour; Kvareli - 8.4-8.8 hour; Sagarejo - 8.6-8.9 hour. The smallest values of $S_d$ in Kakheti in December - January (3.2-4.0 hour) are observed. Amplitude: Telavi - 4.9 hour; Dedoplistskaro - 5.0 hour; Kvareli - 5.5 hour; Sagarejo - 5.0 hour (Fig. 12).

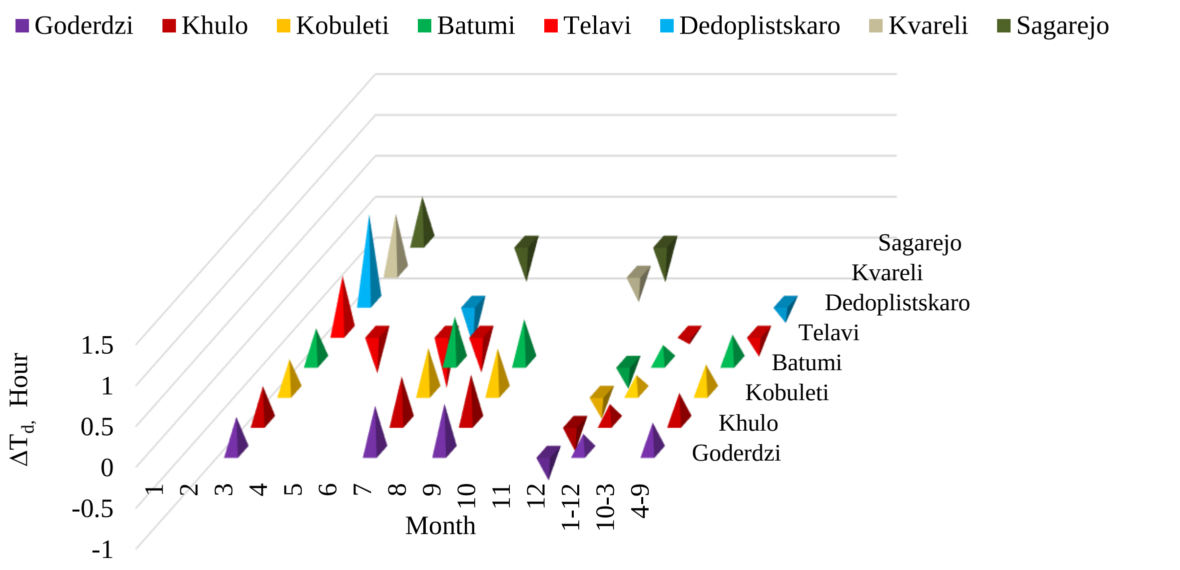



**Fig. 13. Difference between the mean values of $S_d$ into 1986-2010 and 1961-1985 in eight locations of Adjara and Kakheti**

In different months the significant changeability of the values of $\Delta S_d$ for four points of Adjara is observed in 16 cases (including for 12 cases - increase in the values of $\Delta S_d$), and for Kakheti - in 11 cases (including only for 4 cases - an increase in the values of $\Delta S_d$ for all points during March).

The changeability of the values of $\Delta S_d$ in the separate points is the following (Fig. 13).

Adjara - an increase of the values of $\Delta S_d$ is observed for all points during March, July and September (range - from 0.4 to 0.6 hour), and decrease, also for all points - during December (range - from -0.3 to - 0.4 hour).

Telavi – increase of the values of $\Delta S_d$ (March), decrease (April, June, July); Dedoplistskaro - increase (March), decrease (June); Kvareli - increase (March), decrease (October); Sagarejo - increase (March), decrease (June, October). In Kakheti a maximum increase of the values of $\Delta S_d$ is observed into Dedoplistskaro (1.1 hour, March), minimum - into Sagarejo (0.6 hour, March). The greatest decrease of the values of $\Delta S_d$ is observed in Telavi (-0.7 hour, June), smallest - in Kvareli (-0.4 hour, October).

In Adjara the values of $\Delta S_d$ change from -0.4 to 0.6 hours (amplitude - 1.0 hour), while in Kakheti - from -0.7 to 1.1 hour (amplitude - 1.8 hour). On the average to the station with the significant changeability of mean monthly daily sunshine duration in Adjara the value of $\Delta S_d$ grows by 0.3 hour, while in Kakheti - it diminishes for 0.1 hour.

### *Mean wind speed*

Data about mean annual, half year and monthly values of wind speed (V) in Table 8 and Fig. 14 are represented.

Averaged for Batumi and Kobuleti wind speed for all months of year on 0.8-1.5 m/s is higher than the values of V in Kakheti.

Table 8

Data of V (m/s) in eight locations of Adjara and Kakheti

| Location | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Batumi | 1.7 | 1.8 | 1.7 | 0.5 | 3.0 | 1.5 | 2.1 |
| Kobuleti | 3.0 | 3.1 | 2.9 | 1.4 | 5.9 | 2.6 | 3.5 |
| Khulo | 1.9 | 2.1 | 1.7 | 0.7 | 3.8 | 1.5 | 2.3 |
| Goderdzi | 4.8 | 5.4 | 4.2 | 1.9 | 9.6 | 4.0 | 6.3 |
| Telavi | 1.4 | 1.3 | 1.5 | 0.3 | 3.2 | 1.2 | 1.7 |
| Dedoplistskaro | 1.5 | 1.5 | 1.5 | 0.2 | 4.6 | 1.3 | 1.8 |
| Kvareli | 0.9 | 0.9 | 1.0 | 0.2 | 2.1 | 0.7 | 1.1 |
| Sagarejo | 1.6 | 1.6 | 1.5 | 0.4 | 4.4 | 1.4 | 1.7 |

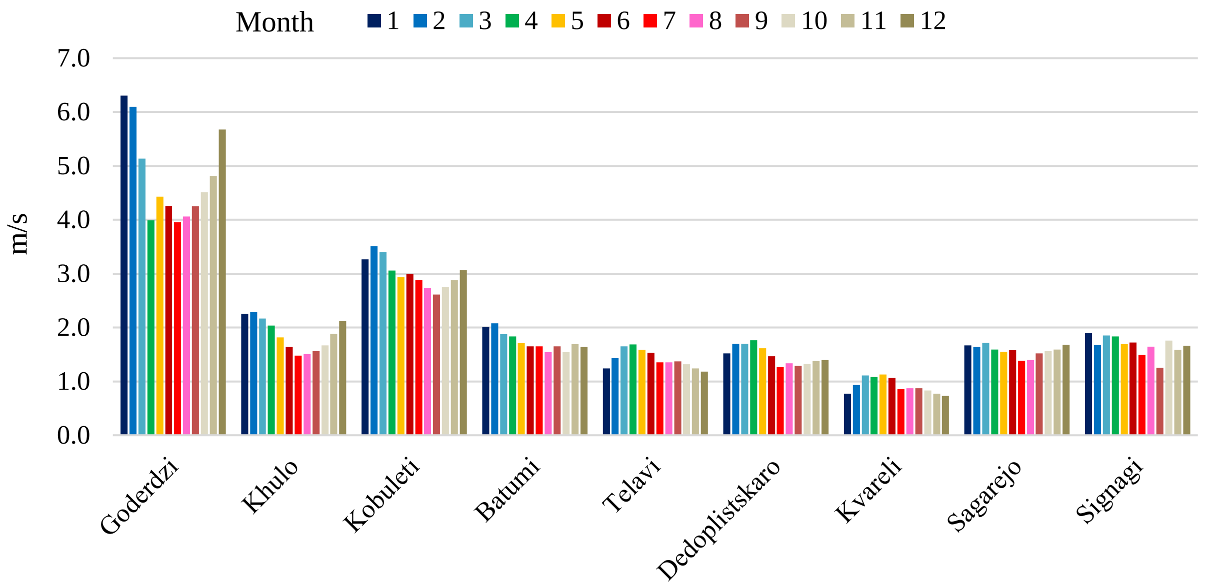



**Fig. 14. Mean values of V in nine locations of Adjara and Kakheti in 1961-2010**

In Batumi the intra-annual distribution of mean monthly value of wind speed is close to the uniform. In Kobuleti this distribution takes the form of weak asymmetrical wave. In Khulo distribution of values of V has the type of the flattened inverted bell. In Goderdzi this distribution takes the form of the asymmetrical inverted bell with the convexity in May-June. Boundary values of V respectively comprise: in Batumi - 2.1 m/s (October) and 1.5 m/s (August), the amplitude - 0.6 m/s; Kobuleti - 3.5 m/s (January) and 2.6 m/s (September), amplitude - 0.9 m/s; Khulo - 2.3 m/s (January) and 1.5 m/s (July, August), amplitude - 0.8 m/s; Goderdzi - 6.3 m/s (January) and 4.0 m/s (April, August), amplitude - 2.3 m/s (Fig. 14).

In Kakheti the intra-annual distribution of values of V for Telavi takes the form close to the unimodal with the left asymmetry. In Dedoplistskaro and Kvareli this distribution is close to the bimodal, also with the left asymmetry. In Sagarejo the intra-annual distribution of values of V takes the form of the asymmetrical inverted bell with the extrema during December-February and the minimum during July-August (Fig. 14).

In different months of the significant changeability of mean monthly wind speed for the investigated points of Adjara are observed in 30 cases (including for 27 cases - decrease of values of ΔV), and for Kakheti - in 44 cases (decrease of values of ΔV for all points). In the separate points the changeability of values of ΔV is following (Fig. 15).

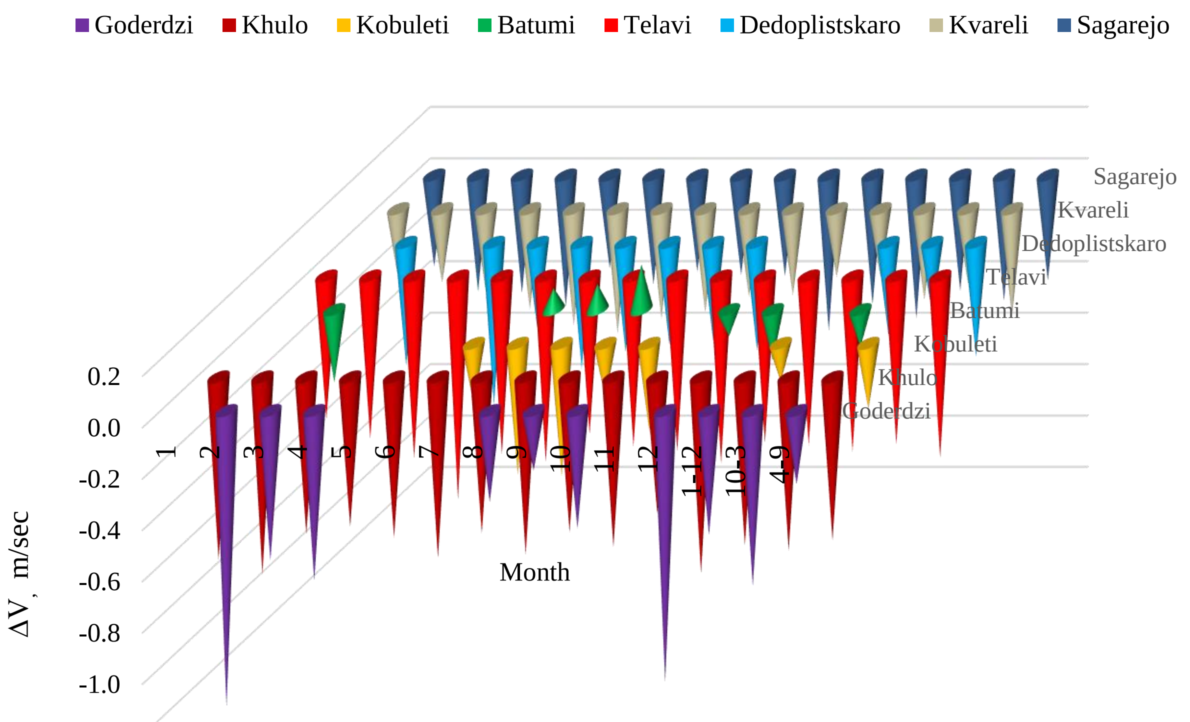



**Fig. 15. Difference between the mean values of V into 1986-2010 and 1961-1985 in eight locations of Adjara Kakheti**

Batumi - decrease of values of ΔV (February, November, December), increase (July - September); Kobuleti - decrease (June - October); Khulo - decrease (all months); Goderdzi - decrease (February - April, August - October, December). In Adjara a maximum and minimum increase of the values of ΔV is observed in Batumi (0.2 m/s, September and 0.1 m/s, July, August). The greatest decrease of values of ΔV is observed in Goderdzi (-1.2 m/s, February), smallest - in Batumi (-0.1 m/s, November).

In Kakheti at all stations is noted the decrease of values of ΔV, in Telavi, Kvareli and Sagarejo - for all months, into Dedoplistskaro - during February and from May through October. In Adjara values of ΔV are varied from -1.2 to 0.2 m/s (amplitude - 1.4 m/s), while in Kakheti - from -0.9 to -0.3 m/s (amplitude - 0.6 m/s). On the average to the station with the significant changeability of wind speeds both in Adjara and in Kakheti values of ΔV decrease on 0.5 m/s.

## Conclusion

The carried out analysis again testifies about the variety of the climatic conditions of the Georgia and their uniqueness. Even in the limits of one and the same locality on the adjacent points are essential differences in the values of different meteorological parameters and their changeability. Accordingly, this causes the need for a detailed study of the climatic and connected with them bioclimatic conditions and their changeability in different geographical regions of the Georgia both from the point of view of action to the health of population and in the aspect of the development of different branches of the national economy of state, including of health resort- tourist industry.

**References**


[1] Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel of Climate Change. http://www.ipcc.ch.

[2] Stocker, T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V., Midgley P.M. (eds.). IPCC. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013, 29 p.

[3] Barriopedro D, García-Herrera R, Lupo AR et al. A climatology of Northern Hemisphere blocking. Journal of Climate 19, 2006, pp.1042-1063.

[4] Gruza G.V., Meshcherskaya A.V. Izmemenia klimata v Rossii za period instrumentalnih nabliudeni, 2008, http://climate2008.igce.ru/v2008/v1/vI-3.pdf.

[5] Amiranashvili A., Chargazia Kh., Trofimenko L. Dynamics of the thirty-year moving average values of the air temperature in Tbilisi and St.-Petersburg with 1851 to 2010 and their extrapolation to 2051-2080. International Conference "Applied Ecology: Problems, Innovations", ICAE-2015. Proceedings, Tbilisi-Batumi, Georgia, ISBN 978-9941-0-7644-2, 7-10 May, 2015, Tbilisi, 2015, pp. 12-16, http://icae-2015.tsu.ge/

[6] Acquaotta F., Fratianni S., Garzena D. Temperature Changes in the North-Western Italian Alps from 1961 to 2010. Theoretical and Applied Climatology, ISSN 0177-798X, Elettronico, 122:3, 2015, pp. 619-634, DOI 10.1007/s00704-014-1316-7

[7] Rybak O. O., Rybak E. A. Changes in the Regime of Air Temperature and Precipitation Rate in the Black Sea Region in the 20th Century. Nauchnyj zhurnal KubGAU . – Krasnodar: KubGAU, - №90 (06), 2013, 21 p., http://ej.kubagro.ru/2013/06/pdf/15.pdf , (in Russian).

[8] Rybak O. O., Rybak E. A. Application of Climatic Indices for Evaluation of Regional Differences in Tourist Attractiveness. Nauchnyy zhurnal KubGAU, №121(07), 2016, 24 p., http://ej.kubagro.ru/2016/07/pdf/16.pdf , (in Russian).

[9] Budagashvili T., Karchava J., Gunia G., Inyskirveli L., Kuchava T., Gurgenidze M., Amiranashvili A., Chikhladze T. Inventory of Greenhouze Gas Emissions and Sinks, Georgia's Initial National Communication on Under the United Nations Framework Convection on Climate Change, Project GEO/96/G31, Tbilisi, 1999, 33-45.

[10] Tavartkiladze K., Begalishvili N., Kharchilava J., Mumladze D., Amiranashvili A., Vachnadze J., Shengelia I., Amiranashvili V. Contemporary climate change in Georgia. Regime of some climate parameters and their variability. Monograph, ISBN 99928-885-4-7, Tbilisi, 2006, 177 p., (in Georgian).

[11] Amiranashvili A., Matcharashvili T., Chelidze T. Climate Change in Georgia: Statistical and Nonlinear Dynamics Predictions, Journ. of Georgian Geophysical Soc., Iss. (A), Physics of Solid Earth, ISSN: 1512-1127, v. 15a, 2011-2012, pp. 67-87.

[12] Elizbarashvili E.E. Climate of Georgia. Monograph, ISBN 978-9941-0-9584-9, Tbilisi, 2017, 360 p., (in Georgian).

[13] Mieczkowski Z. The Tourism Climate Index: A Method for Evaluating World Climates for Tourism. The Canadian Geographer 29, 1985, pp. 220-233.

[14] Scott D., Mc Boyle G. Using a "Tourism Climate Index" to Examine the Implications of Climate Change for Climate as a Tourism Resource. International Society of Biometeorology, Proceedings of the First International Workshop on Climate, Tourism and Recreation. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/ report.htm, 2001.

[15] Matzarakis A.Climate, thermal comfort and tourism. Climate Change and Tourism-Assessment and Coping Strategies, 2007, pp.139-154.
[16] Amiranashvili A.G., Kartvelishvili L. G. Long-Term Variations of Air Effective Temperature in Tbilisi. Trans. Of the Institute of Hydrometeorology, vol. 115, ISSN 1512-0902, Tb., 2008, pp. 214–219, (in Russian).
[17] Amiranashvili A.G., Kartvelishvili L.G., Saakashvili N.M., Chikhladze V.A. Long-Term Variations of Air Effective Temperature in Kutaisi. “Modern Problems of Using of Health Resort Resources”, Collection of Scientific Works of International Conference, Sairme, Georgia, June 10-13, 2010, ISBN 978-9941-0-2529-7, Tbilisi, 2010, pp. 152-157, (in Russian).
[18] Ghanbari S., Karimi J. The Review of Changes in Tourism Climate Index (TCI) Isfahan (2005-1976). Journ. of Regional Planning, vol. 3, No 12, Winter 2014, pp. 71 – 82.
[19] Roshan G., Yousefi R., Fitche J.M. Long-Term Trends in Tourism Climate Index Scores for 40 Stations Across Iran: The Role of Climate Change and Influence on Tourism Sustainability. Int. J. Biometeorol., 2015, DOI 10.1007/s00484-015-1003-0
[20] Amiranashvili A., Chargazia Kh., Matzarakis A., Kartvelishvili L. Tourism Climate Index in the Coastal and Mountain Locality of Adjara, Georgia. International Scientific Conference “Sustainable Mountain Regions: Make Them Work”. Proceedings, Borovets, Bulgaria, ISBN 978-954-411-220-2, 14-16 May,2015, pp.238-244, http://geography.bg/MountainRegions_Sofia2015
[21] Mihăilă D., Piticar A., Briciu A. E., Bistricean P. I., Lazurca L. G., Puţuntică A. Changs in bioclimatic indices in the Republic of Moldova (1960–2012): consequences for tourism. Boletín de la Asociación de Geógrafos Españoles, 77, 2018, pp. 521–548. doi: 10.21138/bage.2550
[22] Amiranashvili A.G, Kartvelishvili L.G., Matzarakis A. The Statistical Characteristics of Tourism Climate Index in Kakheti (Georgia). Journal of the Georgian Geophysical Society, ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp. 95-112.
[23] Landsberg H.E. The Assessment of Human Bioclimate. A Limited Review of Physical Parameters. Technical Note No 123, WMO, No 331, 1972, 37 p.
[24] BSR/ASHRAE Standard 55P, Thermal Environmental Conditions for Human Occupancy 2/24/03 Most Current Draft Standard, 2003, 50 p.
[25] Tkachuk S.V. The Indexes of Weather Comfort Conditions Review and their Relation to Mortality. Proceedings of Hydrometcentre of Russia, Vol. 347, 2012, pp. 223–245, (in Russian).
[26] Freitas C. R., Grigorieva E. A. A Comprehensive Catalogue and Classification of Human Thermal Climate Indices. Int. J. Biometeorol, 59, 2015, pp. 109–120, DOI 10.1007/s00484-014-0819-3
[27] Khazaradze K. R. Comparative Analysis of Mean-Daily Value of Air Equivalent-Effective Temperature in Tbilisi and Kojori. Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, v. 20B, 2017, pp. 65–72.
[28] Amiranashvili A.G., Japaridze N.D., Khazaradze K.R. On the Connection of Monthly Mean of Some Simple Thermal Indices and Tourism Climate Index with the Mortality of the Population of Tbilisi City Apropos of Cardiovascular Diseases. Journal of the Georgian Geophysical Society, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, ISSN: 1512-1127, v. 21(1), 2018, pp.48-62
[29] Amiranashvili A., Japaridze N., Kartvelishvili L., Megrelidze L., Khazaradze K. Statistical Characteristics of the Monthly Mean Values of Air Effective Temperature on Missenard in the Autonomous Republic of Adjara and Kakheti (Georgia). Transactions of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. LXIX, 2018, pp. 118-138, (in Russian).
[30] Kobisheva N., Narovlianski G. Climatological processing of the meteorological information, Leningrad, Gidrometeoizdat, 1978, 294 p., (in Russian).

# ზოგიერთ მარტივ თერმულ ინდექსსა და ტურიზმის კლიმატურ ინდექსში შემავალი მეტეოროლოგიური პარამეტრების ცვლილების დადგენა აჭარასა და კახეთის რეგიონში

ა.ამირანაშვილი, ლ.ქართველიშვილი, თ. ხახუტაშვილი, ლ. მეგრელიძე

**რეზიუმე**

წარმოდგენილია ზოგიერთ მარტივ თერმულ ინდექსსა და ტურიზმის კლიმატურ ინდექსში შემავალი მეტეოროლოგიური პარამეტრების (ჰაერის საშუალო თვიური და საშუალო თვიური მაქსიმალური ტემპერატურა, ჰაერის საშუალო თვიური და საშუალო მინიმალური თვიური ტენიანობა, ატმოსფერულ ნალექთა ჯამი, მზის ნათების ხანგრძლივობა, ქარის სიჩქარე) სტატისტიკური მახასიათებლები აჭარასა და კახეთის რეგიონში 1961-2010 წწ. დაკვირვების პერიოდისათვის. კერძოდ, შესწავლილია აღნიშნული მეტეოროლოგიური პარამეტრების ცვლილება 1986÷2010 წლებში 1961÷1985 წლებთან შედარებით.

# Изменчивость метеорологических параметров, ассоциированных с некоторыми простыми термальными индексами и климатическим индексом туризма, в Аджарии и Кахетии (Грузия)

**А.Г. Амиранашвили, Л.Г. Картвелишвили, Т.В. Хахуташвили, Л.Д. Мегрелидзе**

**Резюме**

Представлены статистические данные о метеорологических параметрах, ассоциированных с некоторыми простыми термальными индексами и климатическим индексом туризма (среднемесячная и среднемесячная максимальная температура воздуха, среднемесячная и среднемесячная минимальная относительная влажность воздуха, месячная сумма осадков, продолжительность солнечного сияния, скорость ветра) в восьми пунктах Аджарии (Батуми, Кобулети, Хуло, Годердзи) и (Кахетии Телави, Дедоплисцкаро, Кварели, Сагареджо) в период с 1961 по 2010 гг. В частности, изучена изменчивость указанных метеорологических параметров в 1986÷2010 гг. по сравнению с 1961÷1985 гг. для перечисленных выше пунктов.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp. 95 - 112*

# The Statistical Characteristics of Tourism Climate Index in Kakheti (Georgia)

**[1]Avtandil G. Amiranashvili, [2]Liana G. Kartvelishvili, [3]Andreas Matzarakis**

*[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
*1, M. Alexidze Str., 0160, Tbilisi, Georgia, e-mail:*avtandilamiranashvili@gmail.com
*[2]National Environmental Agency of Georgia*
*[3]University of Freiburg, Meteorological Institute, Germany*

***ABSTRACT***

The statistical characteristics of the monthly mean, annual and half year values of the Tourism Climate Index of tourism (TCI) and its components for four points of Kakheti (Telavi, Dedoplistskaro, Kvareli and Sagarejo) in the period from 1961 through 2010 are represented. In particular, the changeability of the indicated bioclimatic parameters into 1986÷2010 in comparison with 1961÷1985 is studied, and also the trends of values of TCI for higher enumerated points are investigated.

***Key Words:*** Bioclimate, Tourism Climate Index.

## Introduction

Tourism industry is an important segment of the world economy and its development in many respects it depends on the geographical arrangement of locality, topography, landscape, plant cover, fauna, ecological state of environment, weather, climate, etc. Weather and climate form biometeorological and bioclimatic composing of human living environments and in many respects define the attractiveness of locality both for the inhabitants of this locality and for visitors (Matzarakis, 2006 [1]).

There are more than 200 biometeorological and bioclimatic indices, which determine the influence of meteorological and climatic factors on the health of people (Air Equivalent-Effective Temperature – EET, Air Effective Temperature - ET, Wet-Bulb-Globe Temperature - WBGT, Wind Chill – WCI, Cooling Power – CP, Subjective temperature index –STI, Perceived temperature - PMV, Physiologically Equivalent Temperature - PET, Standard Effective Temperature - SET, Physiological Subjective Temperature and Subjective Temperature - MENEX, Universal Thermal Climate Index – UTCI, etc.) [2-5, http://www.igipz.pan.pl/Bioklima-zgik.html]. With the use of different indices in the last century a study of bioclimate in many countries of world [5-18], including Georgia [19-24] is carried out.

For example, in the work [13] using the thermal stress of 288 synoptic stations, the bioclimatic conditions throughout Iran were interpolated using a Simple Kriging method. The results of this study showed that the bioclimatic conditions are immensely varied spatially and temporally, such that in specific times all bioclimatic conditions can be seen in Iran. Also, during the year, each place can experience different bioclimatic conditions. Based on UTCI, extreme cold and extreme heat stress are the only bioclimatic conditions that do not exist during the year. However, based on PET, all bioclimatic conditions exist during the year. Also, July and January, respectively, are the hottest and coldest months of the year. Based on UTCI in April, October and November, more than 70% of Iran has comfortable conditions, whereas PET showed that in March and October 24.6 and 23.7% experienced comfortable conditions respectively. It seems that the obtained results of PET index have high efficiency in relationship with UTCI index to show Iran's bioclimatic conditions.

The estimation of thermal stress for the athletes - participants of the forthcoming Summer Olympic Games in Tokyo in 2020 is carried out in [15]. For the analysis, indices like Physiologically Equivalent Temperature (PET) and mPET (modified PET) are applied. The results show that this kind of event may not be appropriate for visitors, if it is placed during months with extreme conditions. For Tokyo, this is the period from May to September, when conditions cause strong heat stress to the visitors for the vast majority of hours of the day. A more appropriate time would be the months from November to February or the early morning and the late afternoon hours, when thermally comfortable conditions are much more frequent. The methods that are applied here can quantify the thermal conditions and show limitations and possibilities for specific events and locations. Should the organizers still want to have these competitions organized during these months with extreme conditions, they should promote and propose all possible countermeasures for the spectators, workforce, and athletes.

In the work [23] the comparative analysis of mean-daily values of EET into Tbilisi (3 meteorological stations - Vashlijvari, Tbilisi state university, Tbilisi airport) and in Kojori (mountain health resort settlement in 10 km from the center of Tbilisi) is carried out. In particular it is shown that values of EET in the urbanized part of the city (Vashlijvari, State University) differ significantly from their values after the feature of city (Airport, Kojori); in Kojori are not observed negative for the health of people high values EET, which fall into the range by "Warmly".

Results of the statistical analysis of the mean monthly data about the values of air effective temperature on Missenard (ET) in two diametrically opposite located on the latitude geographical regions of Georgia: autonomous republic of Adjara (below - Adjara) and Kakheti region (below - Kakheti) in the work [24] are represented. The period of a study: 1961-2010. Values of ET expected according to the data of four meteorological stations of Adjara (Batumi, Kobuleti, Khulo, Goderdzi crossing) and Kakheti (Telavi, Dedoplistskaro, Kvareli, Sagarejo). The intra-annual distribution of values of ET is studied, their repetition on the categories of ET is obtained, detailed information about the categories of mean monthly values of ET, and also their upper and lower levels 99% of confidence interval is given, etc.

Several indices have been developed to assess the suitability of climate for tourism activities [9, 25-33]. The most widely known and applied index is the tourism climate index proposed by Mieczkowski [26]. This index is combination of seven factors and parameters. Mieczkowski's "Tourism Climate Index" (TCI) was designed to use climate data, being widely available for tourist destinations worldwide. Data about TCI are using for the information of "Average Tourist" and can be useful for the planning developments of mass tourism.

In some work the criticism of TCI is noted. Thus, in the paper [39] the Holiday Climate Index (HCI) was developed and discuss the design of the HCI and how the limitations of the TCI were overcome. It then presents an inter-comparison of the results from HCI:Urban and TCI for geographically diverse urban destinations across Europe. The results illustrate how the HCI:Urban rates the climate of many cities higher than the TCI, particularly in shoulder seasons and the winter months, which is more consistent with observed visitation patterns. The authors note, that the results empirically demonstrate that use of the TCI should be discontinued.

However, in our opinion, until is revealed united bioclimatic index for the tourism, use of TCI, in spite of its deficiencies, it is nevertheless useful (at least, is a possibility of the comparison of the level of bioclimatic comfort for the "Average Tourist" in the different countries).

TCI (frequently together with other bioclimatic indices) sufficiently long ago is used in many countries of the world [25, 27, 29-40], including Black Sea-Caspian region countries, such as Moldova [16], Iran [41-48], Turkey [49,50], Russia (Sochi, Krasnaya Polyana, Anapa, Tuapse, Primorsko-Akhtarsk, Taganrog, Kislovodsk, Makhachkala) [51]. Many studies are executed into the latter several years [16, 35-38, 40, 45-48, 51, 56-59, etc.].

Article [36] focuses on the role of climate in tourism seasonality and attempts to assess the impacts of climate resources on China's tourism seasonality by using TCI. Seasonal distribution maps of TCI scores indicate that the climates of most regions in China are comfortable for tourists during spring and autumn, while the climate conditions differ greatly in summer and winter, with "Excellent", "Good", "Acceptable" and "Unfavorable" existing almost by a latitudinal gradation. The number of good months throughout China varies from zero (the Tibetan Plateau area) to 10 (Yunnan Province), and most localities have five to eight good months. Moreover, all locations in China can be classified as winter peak, summer peak and bi-modal shoulder peak. The results will provide some useful information for tourist destinations, travel agencies, tourism authorities and tourists.

To assess Tourism Climate Index in Iran, 54 weather stations were selected [48]. The results have been generalized in 12 monthly world maps using ArcGIS10.1. According to the results, April and October are the best time for tourism during the year, actually more area of Iran has the good potential during these months. In January and February, potential of TCI decreased and the lowest area are located in suitable class. While, based on Scott and Mc Boyle classification summer peak, dry season peak, Bi-modal shoulder peak and winter peak can be seen in Iran, most of Iran is classified in Bi-modal shoulder peak. South, south east and west of Iran have the best condition in winter peak. The peak in dry seasons including dry and without rainy seasons have the best situations in west north and east parts of Iran. Bi-modal shoulder peak, in spring and autumn, are seen in north, all east and center of Iran toward west and west east.

In the South and Nord Caucasus regions the average monthly values of TCI were calculated for Georgia (Tbilisi, Batumi, Anaklia, Telavi, etc.), Armenia (Yerevan), Azerbaijan (Baku), Russia (Kislovodsk, Pyatigorsk, Nalchik, etc.) [51-59].

Results of investigation of monthly values of the Tourism Climate Index (TCI) in some localities of Georgia (21 localities) and North Caucasus (Russia, 6 localities) in [58] are represented. Height of these localities varied from 3 to 2194 m above sea level. Correlation and regression analysis of the connection of mortality by cardiovascular deceases in Tbilisi with the values of TCI and its separate components is carried out. This analysis confirmed the representativeness of the use of the scale of TCI as bioclimatic indicator for the investigated region (as a whole, with an increase of values of TCI it is noted the decrease of mortality). The statistical characteristics of values of TCI are represented. In particular it is obtained that with an increase of the height of locality, as a whole occurs the passage of bimodal intra-annual distribution of TCI to the single-modal. The vertical distribution of values of TCI on the average in the year, in the warm and cold periods, and also in the central months of year is studied. The detailed information about the categories of TCI for all investigated localities is represented.

The number of works is dedicated to the study of the influence of climate change to the TCI changeability [16, 27,31,45,47,51,56, etc.].

In the work [16] it is noted, that the actual values of TCI and the ones anticipated for the future indicate, for the Republic of Moldova, an increasing bioclimate favorability for all forms and types of tourism.

The paper [47] first calculates the monthly TCI for 40 cities across Iran for each year from 1961 to 2010. Changes in the TCI over the study period for each of the cities are then explored. Increases in TCI are observed for at least one station in each month, whilst for some months no decreases occurred. For October, the maximum of 45 % of stations demonstrated significant changes in TCI, whilst for December only 10 % of stations demonstrated change. The stations Kashan, Orumiyeh, Shahrekord, Tabriz, Torbat-e-Heidarieh and Zahedan experienced significant increases in TCI for over 6 months. The beginning of the change in TCI is calculated to have occurred from 1970 to 1980 for all stations. Given the economic dependence on oil exports, the development of sustainable tourism in Iran is of importance. This critically requires the identification of locations most suitable for tourism, now and in the future, to guide strategic investment.

Analysis of the dynamics of the "Excellent (80-89)" TCI values did not reveal any changes during 1977-2014 [51]. The number of "Ideal (90-100)" days increased insignificantly in all points except Sochi.

In the work [56] it was shown that in period 1986-2010 in comparison with period 1961-1985 in average for 4 seaside and alpine points of Adjara (Batumi - capital of Adjarian Autonomous Republic, Kobuleti, Khulo and Goderdzi) substantial changes of the values of TCI was not observed.

This study develops a long-term average TCI for 4 stations of Kakheti region of Georgia and explores the trends in TCIs over a 50-year period (1961-2010), monthly, seasonally and annually, for each of the cities studied.

**Study Area, material and methods**

Study area - Kakheti region of Georgia (below - Kakheti). Kakheti is located in the eastern part of Georgia. Area - 11375 $km^2$, population - 314.7 thous. pers., (including of urban - 71.4 thous. pers.), the capital of region - Telavi (population - 19.8 thous. pers.) [www.geostat.ge].

A visit to Kakheti can be a fascinating experience because of its beautiful mountain landscapes, stunning regions, ancient world temples and monasteries, picturesque valleys and rivers and home to amber grapes that grows under the warmth of the sun. Kakheti is not only famous as a tourism destination, but it is also locally recognized as Georgia's center for winemaking.

Studies for four cities of Kakheti (Telavi, Dedoplistskaro, Kvareli and Sagarejo) are carried out. Table 1 presents information about coordinates and heights of the locality of 4 meteorological stations in Kakheti, whose data were used in the work. Fig. 1 for the clarity depicts the map of the arrangement of the indicated meteorological stations. These cities that are located from 450 to 800 meters above sea level, are open to fresh and pure air because of this.

Table 1

Coordinates and heights of the 4 meteorological stations in Kakheti

| Location | Latitude, N° | Longitude, E° | Height, m, a.s.l. |
|---|---|---|---|
| Telavi | 41.93 | 45.48 | 568 |
| Dedoplistskaro | 41.47 | 46.08 | 800 |
| Kvareli | 41.97 | 45.83 | 449 |
| Sagarejo | 41.73 | 45.33 | 802 |


Fig.1. Locations of four meteorological stations in Kakheti

In the work the Tourism Climate Index (TCI) developed by Mieczkowski [26] is used. TCI is a combination of seven parameters, three of which are independent and two in a bioclimatic combination:

$$TCI = 8 \cdot Cld + 2 \cdot Cla + 4 \cdot R + 4 \cdot S + 2 \cdot W$$

Where Cld is a daytime comfort index, consisting of the mean maximum air temperature Ta, max (°C) and the mean minimum relative humidity RH (%), Cla is the daily comfort index, consisting of the mean air temperature (°C) and the mean relative humidity (%), R is the precipitation (mm), S is the daily sunshine duration (h), and W is the mean wind speed (m/s).

In contrast to other climate indices, every contributing parameter is assessed. Because of a weighting factor (a value for TCI of 100), every factor can reach 5 points. TCI values >= 80 are excellent, while values between 60 and 79 are regarded as good to very good. Lower values (40 – 59) are acceptable, but values < 40 indicate bad or difficult conditions for understandable to all tourism.

Table 2 presents information about the categories of TCI depending on its values. In the right column of table are given frequently used below the shortened versions of these categories.

Table 2

Categories of TCI

| TCI | Category | Categ. | TCI | Category | Categ. |
|---|---|---|---|---|---|
| 90 ÷ 100 | Ideal | Ideal | 40 ÷ 49 | Marginal | Marg. |
| 80 ÷ 89 | Excellent | Excell. | 30 ÷ 39 | Unfavorable | Unfavor. |
| 70 ÷ 79 | Very Good | Very Good | 20 ÷ 29 | Very Unfavorable | Very Unfavor. |
| 60 ÷ 69 | Good | Good | 10 ÷ 19 | Extremely Unfavorable | Extr. Unfavor. |
| 50 ÷ 59 | Acceptable | Accept. | - 30 ÷ 9 | Impossible | Imposs. |

For the indicated localities the monthly average values of TCI in the period from 1961 through 2010 with the use data of Georgian National Environmental Agency [60] are calculated.

For the data analysis the standard statistical methods of the studies were used [61]. Designations and reduction – conventional. The difference between the mean values of TCI into 1986-2010 and 1961-1985 with the use of Student's criterion was determined (level of significance not worse than 0.15).

## Results and discussion

Results in the Table 3-7 and Fig. 2-12 are presented.

Table 3 and in Fig. 2-4 presents the generalized statistical data about the values of TCI and its components for four points of Kakheti. The results of the analysis of these data are given below.

***TCI (Table 3, Fig. 2,3).***

Mean annual values of TCI varied from 60.4 (Kvareli, Good) to 63.3 (Sagarejo, Good). Range of a change of the mean values of TCI into the cold half-year - from 50.6 (Dedoplistskaro, Accept.) to 52.0 (Telavi, Accept.). In the warm half-year the smallest mean value of TCI is observed in Kvareli (69.0, Good), and greatest - into Sagarejo (75.2, Very Good).

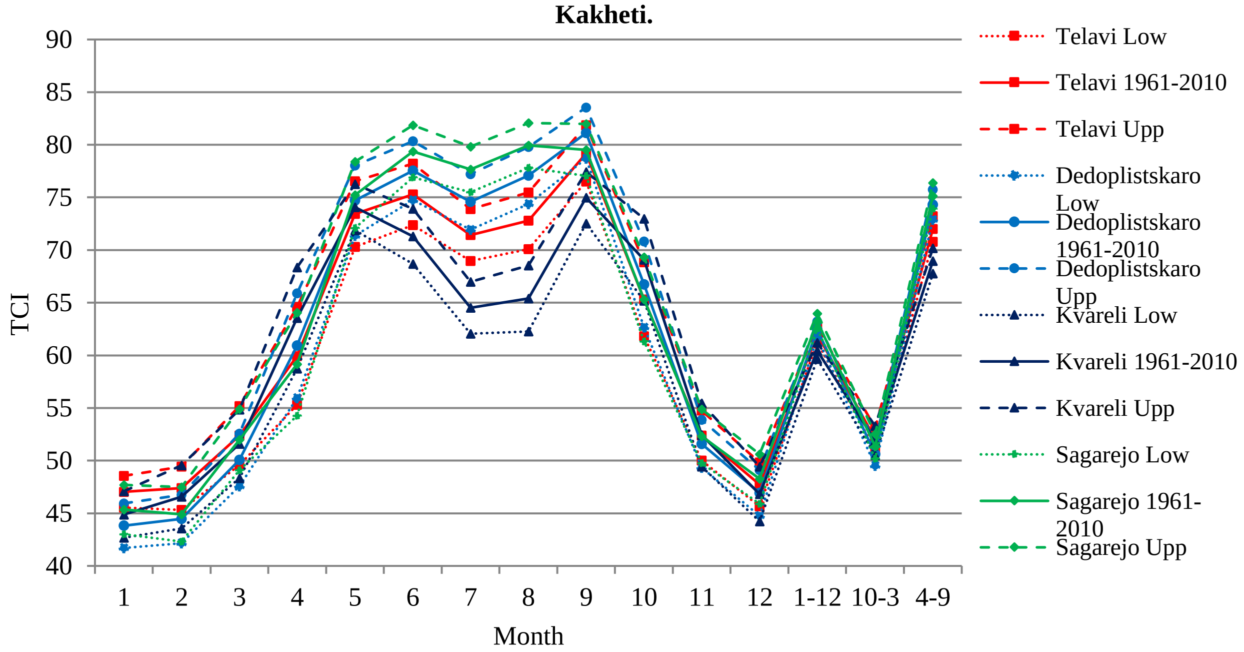
Minimum and maximum monthly value of TCI according to all data of observations (600 cases) is noted into Sagarejo and respectively compose 27 (Very Unfavor.) and 96.0 (Ideal). Minimum and maximum mean in 50 years value of TCI is observed into Dedoplistskaro, respectively: (43.8, Marg.) and (81.1, Excell.).

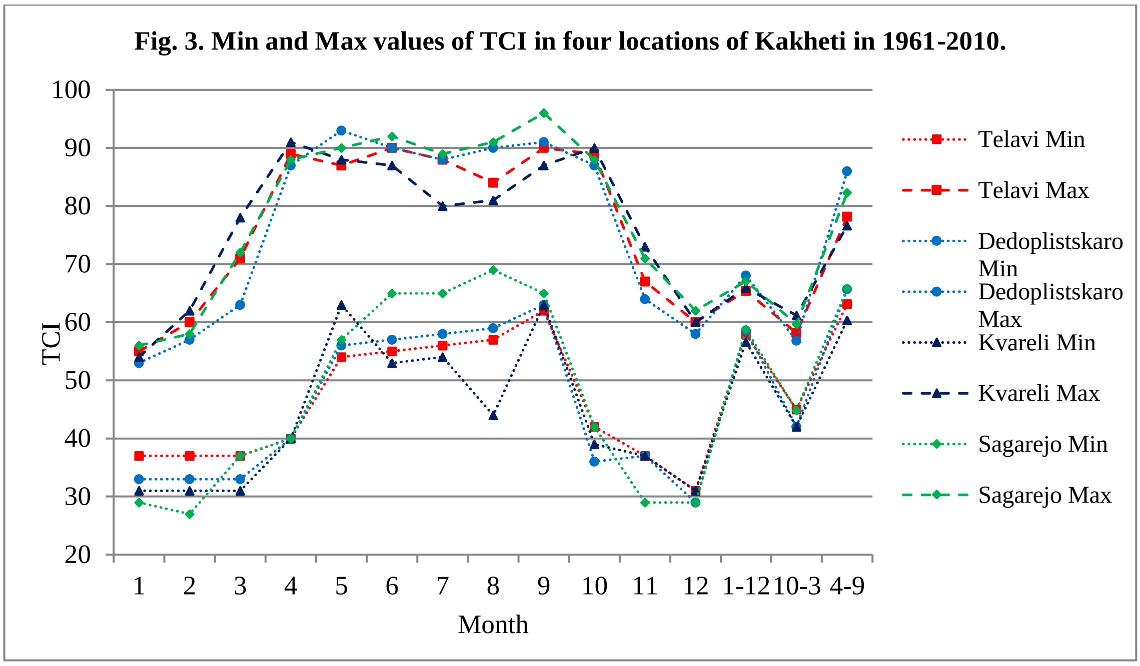
Table 3

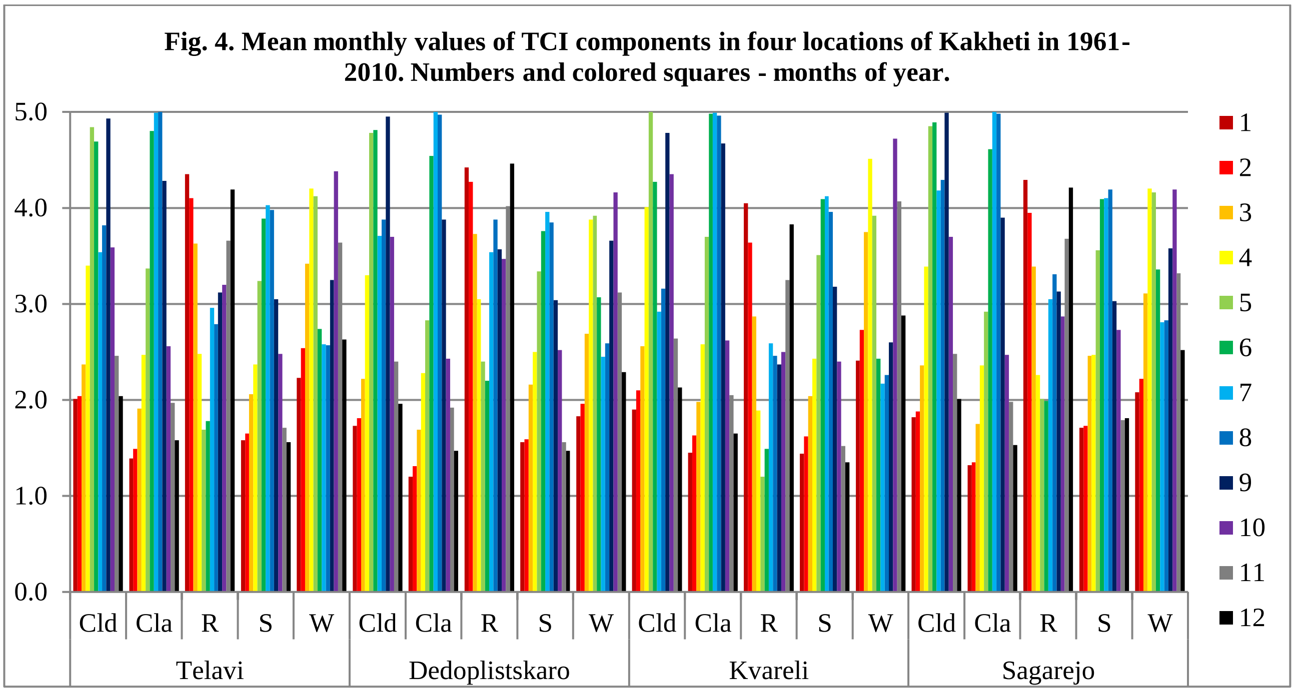
Data of TCI and TCI components in four locations of Kakheti

| Parameter | All data | | | | | Mean 1961-2010 | |
|---|---|---|---|---|---|---|---|
| | Mean Year | Mean Cold | Mean Warm | Min | Max | Min | Max |
| Telavi | | | | | | | |
| TCI | 62.0 | 52.0 | 72.0 | 31.0 | 90.0 | 47.0 | 79.2 |
| Cld | 3.3 | 2.4 | 4.2 | 1.5 | 5.0 | 2.0 | 4.9 |
| Cla | 3.0 | 1.8 | 4.2 | 1.0 | 5.0 | 1.4 | 5.0 |
| R | 3.2 | 3.9 | 2.5 | 0.0 | 5.0 | 1.7 | 4.4 |
| S | 2.6 | 1.8 | 3.4 | 0.5 | 5.0 | 1.6 | 4.0 |
| W | 3.2 | 3.1 | 3.2 | 1.5 | 5.0 | 2.2 | 4.4 |
| Dedoplistskaro | | | | | | | |
| TCI | 62.5 | 50.6 | 74.3 | 29 | 93 | 43.8 | 81.1 |
| Cld | 3.3 | 2.3 | 4.2 | 1.0 | 5.0 | 1.7 | 5.0 |
| Cla | 2.8 | 1.7 | 3.9 | 0.0 | 5.0 | 1.2 | 5.0 |
| R | 3.6 | 4.1 | 3.1 | 0.0 | 5.0 | 2.2 | 4.5 |
| S | 2.6 | 1.8 | 3.4 | 0.5 | 5.0 | 1.5 | 4.0 |
| W | 3.0 | 2.7 | 3.3 | 0.0 | 5.0 | 1.8 | 4.2 |
| Kvareli | | | | | | | |
| TCI | 60.4 | 51.9 | 69.0 | 31.0 | 91.0 | 44.9 | 75.0 |
| Cld | 3.3 | 2.6 | 4.0 | 1.0 | 5.0 | 1.9 | 5.0 |
| Cla | 3.1 | 1.9 | 4.3 | 1.0 | 5.0 | 1.5 | 5.0 |
| R | 2.7 | 3.4 | 2.0 | 0.0 | 5.0 | 1.2 | 4.1 |
| S | 2.6 | 1.7 | 3.5 | 0.5 | 5.0 | 1.4 | 4.1 |
| W | 3.2 | 3.4 | 3.0 | 1.5 | 5.0 | 2.2 | 4.7 |
| Sagarejo | | | | | | | |
| TCI | 63.3 | 51.4 | 75.2 | 27.0 | 96.0 | 44.9 | 79.9 |
| Cld | 3.4 | 2.4 | 4.4 | 1.0 | 5.0 | 1.8 | 5.0 |
| Cla | 2.8 | 1.7 | 4.0 | 1.0 | 5.0 | 1.3 | 5.0 |
| R | 3.2 | 3.7 | 2.6 | 0.0 | 5.0 | 2.0 | 4.3 |
| S | 2.8 | 2.0 | 3.6 | 1.0 | 5.0 | 1.7 | 4.2 |
| W | 3.2 | 2.9 | 3.5 | 1.5 | 5.0 | 2.1 | 4.2 |

**Fig. 2. Mean values of TCI and their 99% confidence interval in four locations of Kakheti.**






The range of changes of TCI for four points of Kakheti (Fig. 2, table 4) is the following:

Telavi, mean monthly values of TCI - from 47.0 (January) to 79.2 (September); Low – 45.3÷76.5; Upp – 48.6÷81.8; mean annual value of TCI - 61.3≤62.0≤62.7; TCI into the cold half-year - 51.0≤52.0≤53.1; TCI into the warm half-year - 770.8≤ 72.0≤73.2.

Dedoplistskaro, mean monthly values of TCI - from 43.8 (January) to (81.1, September); Low – 41.7÷78.7; Upp – 45.9÷83.5; mean annual value of TCI – 61.7≤62.5≤63.2; TCI into the cold half-year – 49.5≤50.6≤51.7; TCI into the warm half-year – 72.9≤74.3≤75.8.

Kvareli, mean monthly values of TCI – from 44.9 (January) to (75.0, September); Low – 42.7÷72.5; Upp – 47.1÷77.4; mean annual value of TCI – 59.7≤60.4≤61.2; TCI into the cold half-year – 50.5≤51.9≤ 53.3; TCI into the warm half-year – 67.8≤69.0≤70.2

Sagarejo, mean monthly values of TCI – from 45.4 (January) to (79.9, August); Low – 42.3÷77.8; Upp – 47.5÷82.1; mean annual value of TCI – 62.5≤63.3≤64.0; TCI into the cold half-year – 50.2≤51.4≤52.5; TCI into the warm half-year – 73.9≤75.2≤76.4.

The intra-annual distribution of mean monthly values of TCI in the indicated points is the following: Telavi - bimodal with the extrema in May-June and September; Dedoplistskaro - bimodal with the extrema during June and September; Kvareli - bimodal with the extrema during May and September; Sagarejo - unimodal with the plateau from June through September. All four distributions, as in Tbilisi, Baku and Yerevan [55], take the form of ninth power polynomial (Fig. 2 and 5, Table 4).

**Fig. 5. Intra-annual motion of calculated values of TCI in four locations of Kakheti.**

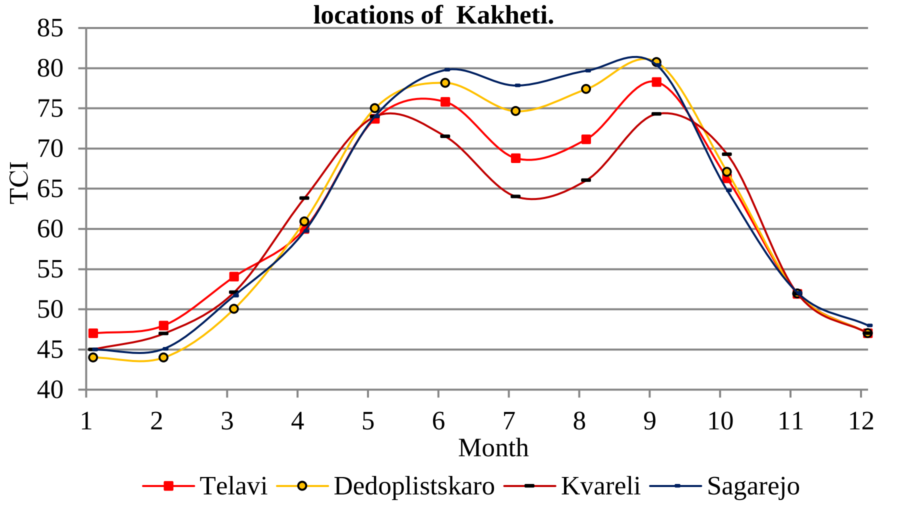



Table 4

Coefficients of the equation of the regression of the intra-annual motion of mean monthly values of TCI for four points of Kakheti

| Equation of regression, coefficients | $TCI = a \cdot X^9 + b \cdot X^8 + c \cdot X^7 + d \cdot X^6 + e \cdot X^5 + f \cdot X^4 + g \cdot X^3 + h \cdot X^2 + i \cdot X + j$, (X-Month) | | | |
|---|---|---|---|---|
| | Telavi | Dedoplistskaro | Kvareli | Sagarejo |
| a | -0.000315 | -0.000212 | -0.000133 | -0.000238 |
| b | 0.01834 | 0.01215 | 0.00763 | 0.01378 |
| c | -0.4526 | -0.2953 | -0.1843 | -0.3383 |
| d | 6.1767 | 3.9584 | 2.4329 | 4.5958 |
| e | -50.995 | -31.997 | -19.161 | -37.804 |
| f | 261.87 | 160.37 | 92.426 | 193.59 |
| g | -828.6 | -494.5 | -271.0 | -611.6 |
| h | 1542.5 | 899.2 | 465.5 | 1139.2 |
| i | -1509.7 | -865.0 | -421.5 | -1118.6 |
| j | 626.2 | 372.2 | 196.5 | 475.8 |
| $R^2$ | 0.9974 | 0.9998 | 0.9979 | 0.9989 |

Table 5

Category of mean monthly values of TCI and their 99% confidence interval in four locations of Kakheti in 1961-2010

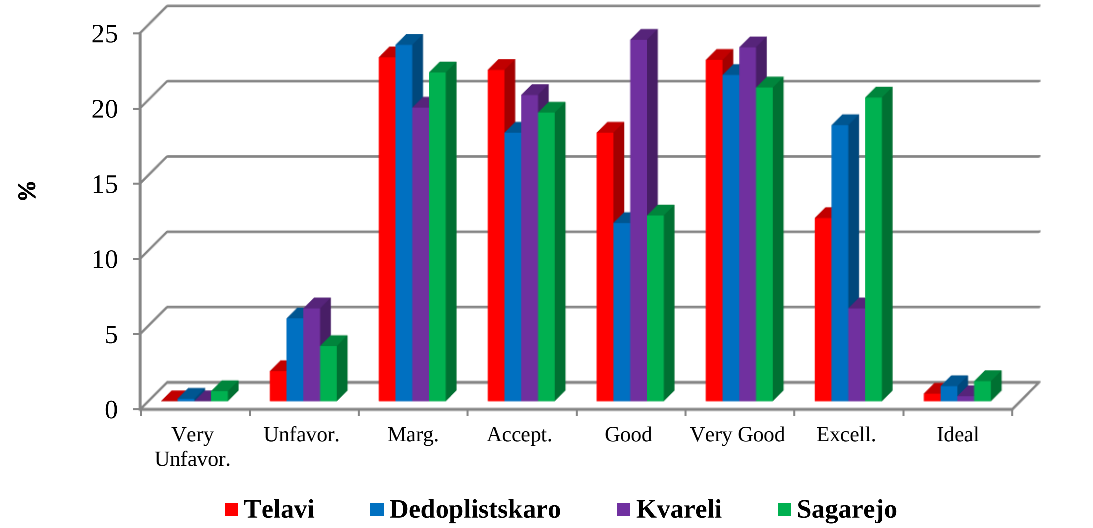
| Location | | Cold period | | | | | |
|---|---|---|---|---|---|---|---|
| | Month | 1 | 2 | 3 | 10 | 11 | 12 |
| | Low | | | Marg. | | | |
| Telavi | Mean | Marg. | Marg. | Accept. | Good | Accept. | Marg. |
| | Upp | | | Accept. | | | |
| | Low | | | Marg. | Good | Marg. | |
| Dedoplistskaro | Mean | Marg. | Marg. | Accept. | Good | Accept. | Marg. |
| | Upp | | | Accept. | Very Good | Accept. | |
| | Low | | | Marg. | Good | Marg. | |
| Kvareli | Mean | Marg. | Marg. | Accept. | Good | Accept. | Marg. |
| | Upp | | | Accept. | Very Good | Accept. | |
| | Low | | | Marg. | | Marg. | Marg. |
| Sagarejo | Mean | Marg. | Marg. | Accept. | Good | Accept. | Marg. |
| | Upp | | | Accept. | | Accept. | Accept. |
| | | Warm period | | | | | |
| | Month | 4 | 5 | 6 | 7 | 8 | 9 |
| | Low | Accept. | | | Good | Very Good | Very Good |
| Telavi | Mean | Accept. | Very Good | Very Good | Very Good | Very Good | Very Good |
| | Upp | Good | | | Very Good | Good | Excell. |
| | Low | Accept. | | Very Good | | | Very Good |
| Dedoplistskaro | Mean | Good | Very Good | Very Good | Very Good | Very Good | Excell. |
| | Upp | Good | | Excell. | | | Excell. |
| | Low | Accept. | | Good | | | |
| Kvareli | Mean | Good | Very Good | Very Good | Good | Good | Very Good |
| | Upp | Good | | Very Good | | | |
| | Low | Accept. | | Very Good | | Very Good | Very Good |
| Sagarejo | Mean | Accept. | Very Good | Very Good | Very Good | Very Good | Very Good |
| | Upp | Good | | Excell. | | Excell. | Excell. |

Table 6

Category of Min and Max values of TCI in four locations of Kakheti in 1961-2010

| Location | | Cold period | | | | | |
|---|---|---|---|---|---|---|---|
| | Month | 1 | 2 | 3 | 10 | 11 | 12 |
| Telavi | Min | Unfavor. | Unfavor. | Unfavor. | Marg. | Unfavor. | Unfavor. |
| | Max | Accept. | Good | Very Good | Excell. | Good | Good |
| Dedoplistskaro | Min | Unfavor. | Unfavor. | Unfavor. | Unfavor. | Unfavor. | Very Unfavor. |
| | Max | Accept. | Accept. | Good | Excell. | Good | Accept. |
| Kvareli | Min | Unfavor. | Unfavor. | Unfavor. | Unfavor. | Unfavor. | Unfavor. |
| | Max | Accept. | Good | Very Good | Ideal | Very Good | Good |
| Sagarejo | Min | Very Unfavor. | Very Unfavor. | Unfavor. | Marg. | Very Unfavor. | Very Unfavor. |
| | Max | Accept. | Accept. | Very Good | Excell. | Very Good | Good |
| | | Warm period | | | | | |
| | Month | 4 | 5 | 6 | 7 | 8 | 9 |
| Telavi | Min | Marg. | Accept. | Accept. | Accept. | Accept. | Good |
| | Max | Excell. | Excell. | Ideal | Excell. | Excell. | Ideal |
| Dedoplistskaro | Min | Marg. | Accept. | Accept. | Accept. | Accept. | Good |
| | Max | Excell. | Ideal | Ideal | Excell. | Ideal | Ideal |
| Kvareli | Min | Marg. | Good | Accept. | Accept. | Marg. | Good |
| | Max | Ideal | Excell. | Excell. | Excell. | Excell. | Excell. |
| Sagarejo | Min | Marg. | Accept. | Good | Good | Good | Good |
| | Max | Excell. | Ideal | Ideal | Excell. | Ideal | Ideal |

**Fig. 6. Repetition of monthly values of TCI category in four locations of Kakheti.**




Tables 5 and 6 present detailed information about the categories of the values of TCI (mean, min, max, 99% confidence interval) in four points of Kakheti in different months. As it follows from this table, as a whole, minimum values TCI correspond category "Very Unfavor.", and maximum - "Ideal". On the average, intra-annual variations of the values of TCI in Kakheti correspond to categories "Marg." and " Very Good – Excell.". For the clarity Fig. 6 depicts the histogram of repetition in four points of Kakheti of categories TCI. As it follows from this figure, in the overwhelming majority of the cases the categories in the range "Marg." - "Ideal" are observed. Thus, bioclimatic conditions in Kakheti for the so-called "Average Tourist " are favorable entire year.

**Fig. 7. Difference between the mean values of TCI into 1986-2010 and 1961-1985 in four locations of Kakheti.**

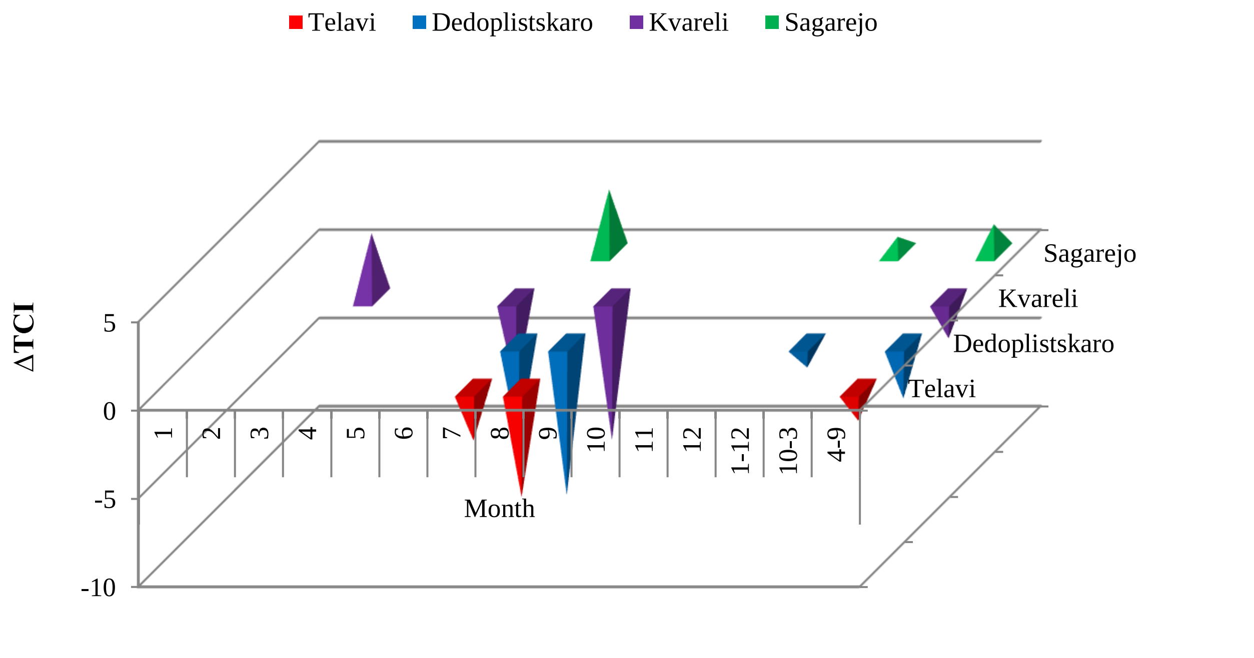


**Fig.8. Trend of TCI in Telavi.**

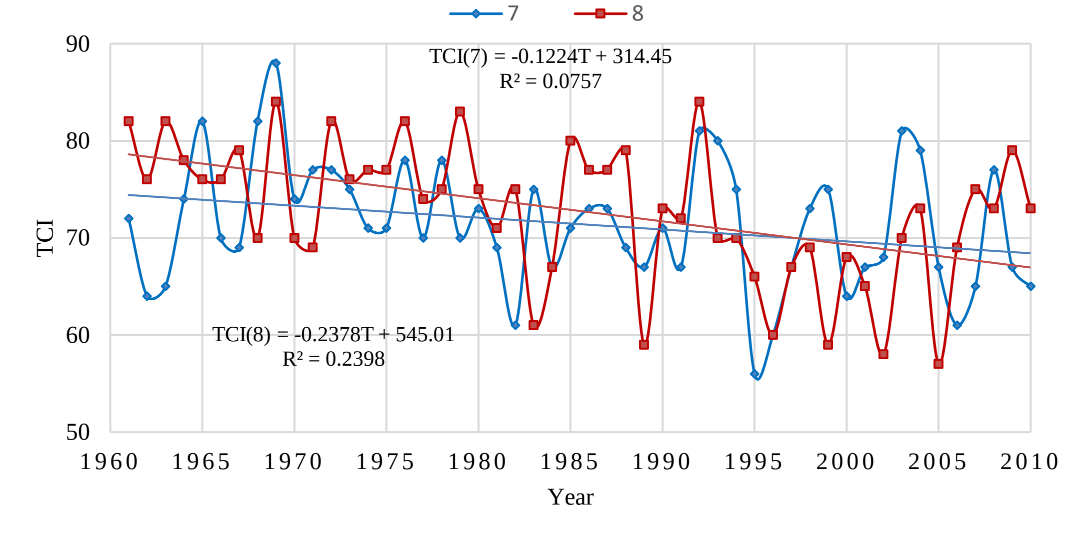



**Fig. 9. Trend of TCI in Dedoplistskaro.**

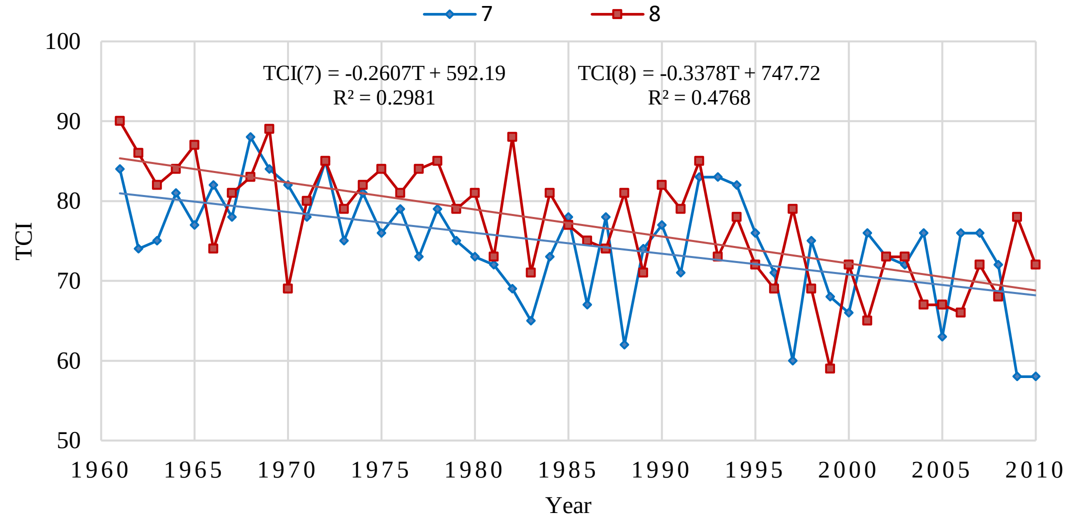
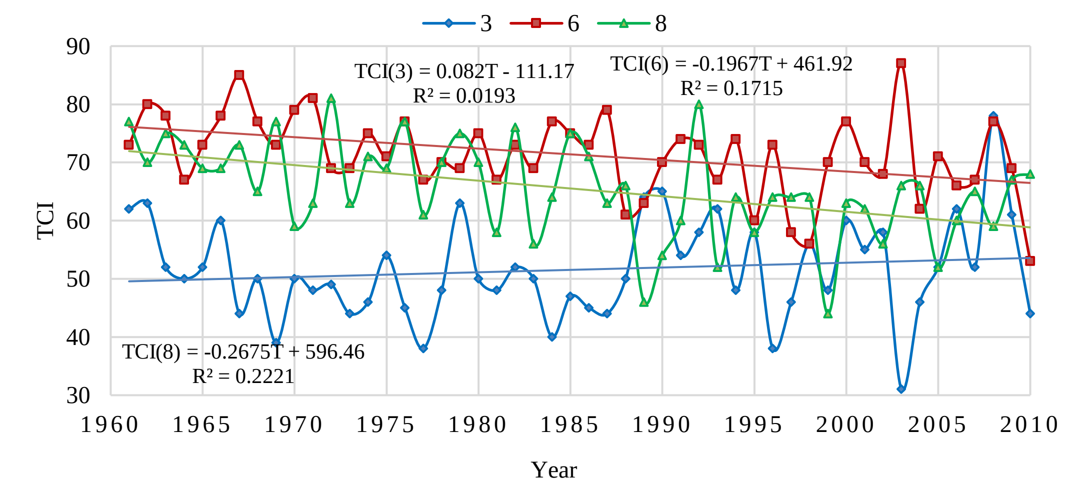
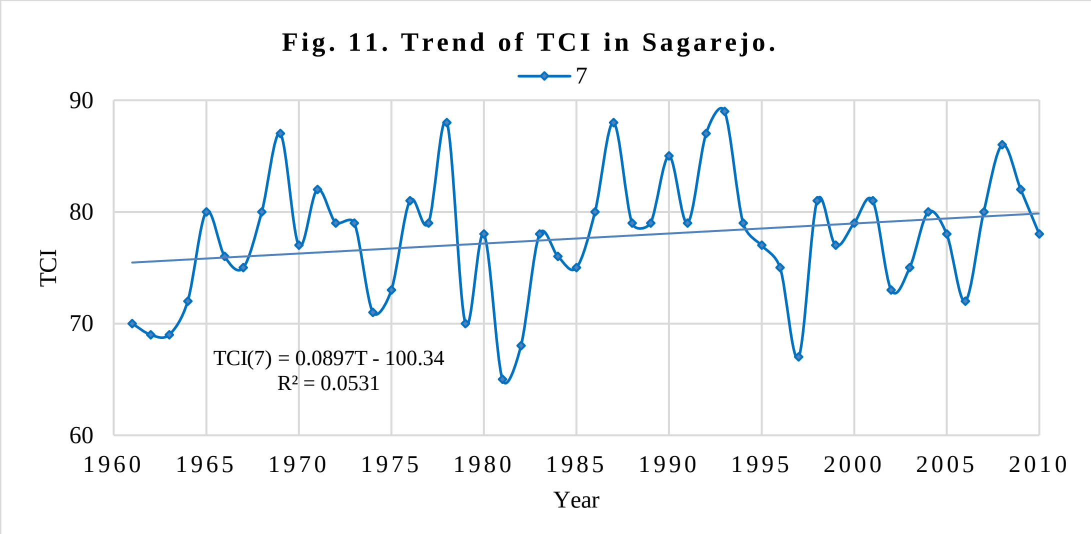



**Fig. 10. Trend of TCI in Kvareli.**






The changeability of mean monthly values of TCI in 1986-2010 in comparison with 1961-1985 in the enumerated points of Kakheti in the separate months is the following (Fig. 7): Telavi - July and August (in both cases - decrease, with reduction in the category to one step); Dedoplistskaro - July and August (in both cases - decrease, with the decrease of category TCI to one step during August); Kvareli - March (increase, with an increase in the category TCI by one step), June and August (decrease, with reduction in the category to one step during June); Sagarejo - July (increase in the limits of one and the same category). The graphs of linear trend of TCI in the period from 1961 through 2010 for the indicated points in Fig. 8-11 are depicted.

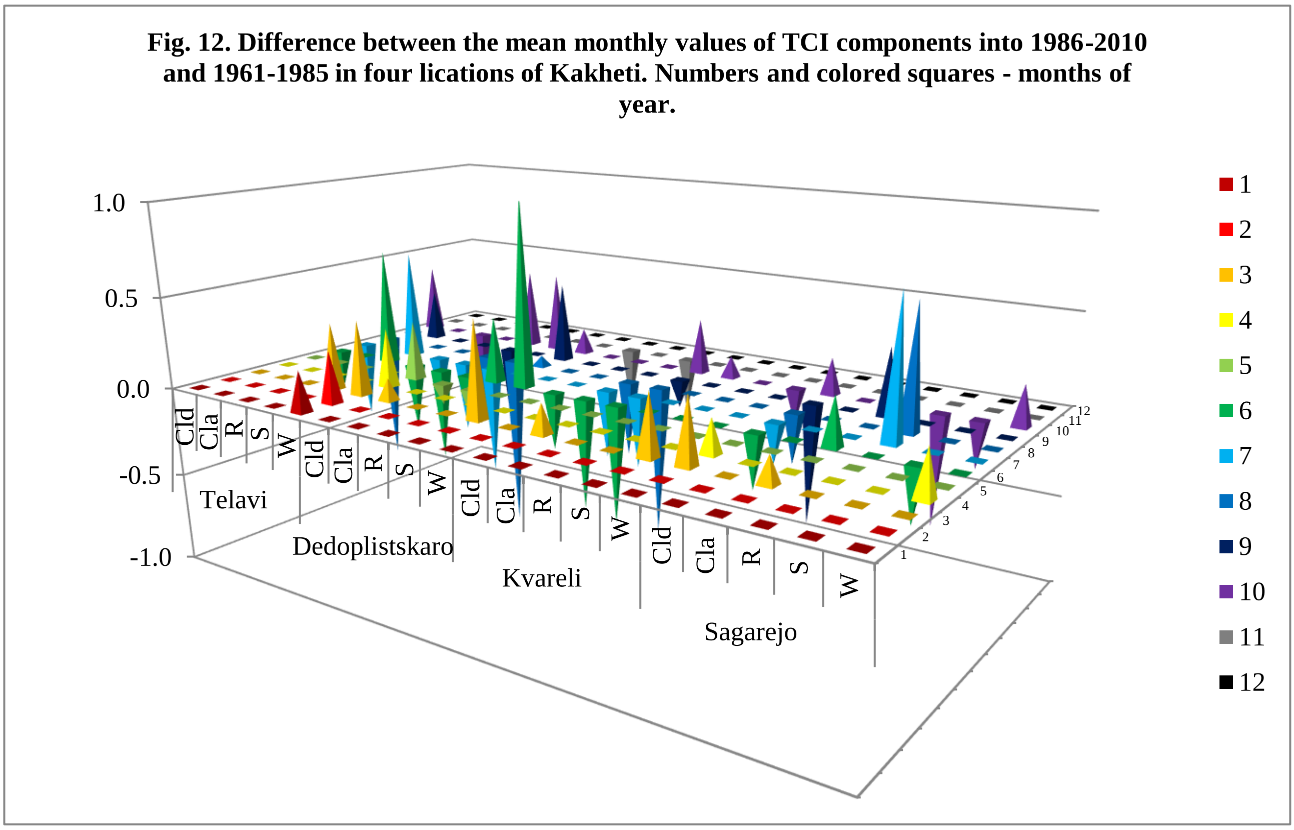


Table 3 and Fig. 4,12 presents information about the values of the components of the Tourism Climate Index and their changeability in 1986-2010 in comparison with 1961-1985. In particular, the range of mean for entire period observations of the values of components of TCI and their changeability in the second period of time in comparison with the first for four points of Kakheti are following:

***Telavi***

Cld: 2.0÷4.9 (January, February, December and September respectively). Changeability is observed from June through August (decrease), also, during October (increase);

Cla: 1.4÷5.0 (January and July, August respectively); Changeability is observed only during September (increase);

R: 1.7÷4.4 (May and January, respectively). Changeability is observed during June and July (increase), and also during October (decrease);

S: 1.6÷4.0 (December, January and July, August respectively). Changeability is observed during March (increase) and during June, July (decrease);

W: 2.2÷4.4 (January and October respectively). Changeability is observed in January- May, and October increase), and also in June- September (decrease).

***Dedoplistskaro***

Cld: 1.7÷5.0 (January and September, respectively). Changeability is observed during March and October (increase), and also from May through August (decrease);

Cla: 1.2÷5.0 (January and July - August, respectively); Changeability is observed during May (decrease), and also during June and August - September (increase);

R: 2.2÷4.5 (June and December, respectively). Changeability is observed during June (increase) and November (decrease);

S: 1.5÷4.0 (December and July, respectively). Changeability is observed during March (increase) and during June (decrease);

W: 1.8÷4.2 (January and October respectively). Changeability is observed during June-August and during November (decrease).

***Kvareli***

Cld: 1.9÷5.0 (January and May, respectively). Changeability is observed during March and October (increase), and also from June through September (decrease);

Cla: 1.5÷5.0 (January and June-August, respectively). Small changeability is observed only during October (increase);

R: 1.2÷4.1 (May and January, respectively). Changeability is not observed;

S: 1.4÷4.1 (December, January and June-July, respectively). Changeability is observed during March (increase) and during October (decrease);

W: 2.2÷4.7 (July and October, respectively). Changeability is observed during March, April and October (increase), and also in June- September (decrease).

***Sagarejo***

Cld: 1.8÷5.0 (January and September, respectively). Changeability is not observed;

Cla: 1.3÷5.0 (January and July-August respectively); Changeability is observed during March, June and September (increase);

R: 2.0÷4.3 (May-June and January, respectively). Changeability is observed during July-August (increase) and during October (decrease);

S: 1.7÷4.2 (January- February and August, respectively). Changeability is observed during June and October (decrease);

W: 2.1÷4.2 (January, and also April- May and October, respectively). Changeability is observed during April and October (increase).

Table 7

Number of days in year of various category of TCI in four locations of Kakheti in 1961-2010, 1961-1985 and 1986-2010

| Location | Telavi | | | Dedoplistskaro | | | Kvareli | | | Sagarejo | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | 1961-2010 | 1961-1985 | 1986-2010 | 1961-2010 | 1961-1985 | 1986-2010 | 1961-2010 | 1961-1985 | 1986-2010 | 1961-2010 | 1961-1985 | 1986-2010 |
| Very Unfavor. | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 2 | 2 |
| Unfavor. | 7 | 9 | 6 | 20 | 17 | 23 | 23 | 24 | 21 | 17 | 17 | 10 |
| Marg. | 83 | 78 | 89 | 86 | 84 | 89 | 71 | 67 | 75 | 77 | 77 | 83 |
| Accept. | 80 | 86 | 74 | 65 | 72 | 58 | 74 | 75 | 73 | 78 | 78 | 62 |
| Good | 65 | 57 | 73 | 43 | 35 | 51 | 88 | 85 | 90 | 41 | 41 | 49 |
| Very Good | 83 | 82 | 84 | 79 | 69 | 89 | 86 | 89 | 83 | 74 | 74 | 78 |
| Excell. | 44 | 52 | 37 | 67 | 83 | 51 | 23 | 23 | 22 | 71 | 71 | 77 |
| Ideal | 2 | 1 | 2 | 4 | 5 | 2 | 1 | 1 | 1 | 5 | 5 | 5 |
| Marg.-Ideal | 358 | 357 | 359 | 345 | 348 | 341 | 343 | 341 | 345 | 349 | 346 | 353 |
| % from year | 98.0 | 97.7 | 98.3 | 94.3 | 95.3 | 93.3 | 93.8 | 93.3 | 94.3 | 95.7 | 94.7 | 96.7 |
| Month in year (mean) | 11.8 | 11.7 | 11.8 | 11.3 | 11.4 | 11.2 | 11.3 | 11.2 | 11.3 | 11.5 | 11.4 | 11.6 |

Table 7 presents the data about the average number of days per annum in Kakheti with different category of TCI in three periods of time. As follows from this Table, in 1986-2010 in comparison with 1961-1985 the average number of days per annum with the categories of TCI "Marg." and higher, with those causing for the "Average Tourist" favorable bioclimatic situation, in the separate investigated points it changed as follows: Telavi - practically invariability (357 and 359 days, respectively); Dedoplistskaro - insignificant decrease (348 and 341 days, respectively); Kvareli - practically invariability (341 and 345 days, respectively); Sagarejo - small increase (346 and 353 days, respectively).

Thus, the greatest effect of the process of climate change in the conditions of Kakheti [60] appeared in the changeability of the number of days per annum with the categories of TCI "Marg." and higher in Dedopdistskaro and Sagarejo. In this case, into Dedoplistskaro is observed insignificant worsening in the favorable bioclimatic conditions for the "Average Tourist " (decrease of favorable days to 2.0 %), and into Sagarejo - small improvement (increase in the favorable days by 2.0 %).

It is remarkable, which under the conditions of Kakheti of this significant changeability of the TCI as in some points of Adjara (Khulo and Goderdzi [56]), is not observed. I.e., it is present the need for the detailed study of climate change (and also bioclimate) not only on global, but also regional and local scales.

## Conclusion

Climate has a strong influence on the tourism and recreation sector and in some regions represents the natural resource on which the tourism industry is predicated. In this work the determination of the climatic potential of tourism to four location of Kakheti (Georgia) into the correspondence with that frequently utilized in other countries of the “Tourism Climate Index” (TCI) is carried out.

In the future we plan a more detailed study of the climatic resources of this and others regions of Georgia for the tourism (mapping the territory on TCI, long-term prognostication of TCI, determination of other contemporary climatic and bioclimatic indices for tourism).

## References

[1] Matzarakis A. Weather - and Climate-Related Information for Tourism. Tourism and Hospitality Planning & Development, Vol. 3, No. 2, August, 2006, pp. 99–115.
[2] Landsberg H.E. The Assessment of Human Bioclimate. A Limited Review of Physical Parameters. Technical Note No 123, WMO, No 331, 1972, 37 p.
[3] BSR/ASHRAE Standard 55P, Thermal Environmental Conditions for Human Occupancy 2/24/03 Most Current Draft Standard, 2003, 50 p.
[4] Freitas C. R., Grigorieva E. A. A Comprehensive Catalogue and Classification of Human Thermal Climate Indices. Int. J. Biometeorol, 59, 2015, pp. 109–120, DOI 10.1007/s00484-014-0819-3
[5] Matzarakis A., Rutz F., Mayer H. Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int. J. Biometeorol., 54(2), 2010, pp. 131–139.
[6] Houghton F.C., Yagloglou C.P. Determination of the Comfort Zone. ASHVE, Transactions, 29, 1923, 361.
[7] Missenard F.A. Température effective d'une Atmosphere Généralisation Températurerés ultante d'un Milieu. Encyclopédie in dustrielleet Commerciale, Etude physiologique et technique de la ventilation. Librerie de l'Enseignement Technique, Paris, 1933, 131-18.
[8] Missenard A. L' Homme et le Climat, Paris, 1937, 186 p.
[9] Sheleykhovski G.V. Mikroklimat yuzhnykh gorodov, M., 1948, 118 s.
[10] Tkachuk S.V. Comparative Analysis of Bioclimatic Indexes for Prediction Using a Mesoscale Model. Uchenie Zapiski Rossiiskogo Gosudarstvennogo Gidrometeorologicheskogo Universiteta, No 20, 2011, pp. 109-118, (in Russian), http://weatherlab.ru/sites/default/files/library/ Sravn_ind.pdf
[11] Farajzadeh H., Saligheh M., Alijani B., Matzarakis A. Comparison of selected thermal indices in the northwest of Iran. Natural Environment Change, v. 1, N 1, 2015, pp. 61- 80.
[12] Roshan G., Yousefi R., Kovács A., Matzarakis A. A Comprehensive Analysis of Physiologically Equivalent Temperature Changes of Iranian Selected Stations for the Last Half Century. Theor. Appl. Climatol., ISSN: 0177-798X,eIISSN 1434-4483, 2016, https://doi.org/10.1007/s00704-016-1950-3
[13] Mohammadi B., Gholizadeh M. H., Alijani B. Spatial Distribution of Thermal Stresses in Iran Based on PET and UTCI Indices. Applied Ecology and Environmental Research, 16(5), 2018, pp. 5423-5445.
[14] Zaninovic K., Cegnar T., Matzarakis A. Thermal comfort trends and variability in the Croatian and Slovenian mountains. Meteorologische Zeitschrift, 15(2), 2006, pp. 243–251.
[15] Matzarakis A., Dominik Fröhlich D., Stéphane Bermon S., Adami P.E. Quantifying Thermal Stress for Sport Events—The Case of the Olympic Games 2020 in Tokyo. Atmosphere, 9, 479, pp. 1-13, 2018; doi: 10.3390/atmos9120479; www.mdpi.com/journal/atmosphere.
[16] Mihăilă D., Piticar A., Briciu A. E., Bistricean P. I., Lazurca L. G., Puţuntică A. Changs in bioclimatic indices in the Republic of Moldova (1960–2012): consequences for tourism. Boletín de la Asociación de Geógrafos Españoles, 77, 2018, pp. 521–548. doi: 10.21138/bage.2550
[17] Zare S., Hasheminejad N., Shirvan H.E., Hemmatjo R., Sarebanzadeh K., Ahmadi S. Comparing Universal Thermal Climate Index (UTCI) with selected thermal indices/environmental parameters during 12 months of the year. Weather and Climate Extremes, 19, 2018, pp. 49-57.
[18] Katerusha O., Matzarakis A. Thermal bioclimate and climate tourism analysis for Odessa, Black Sea. Geografiska Annaler: Series A, Physical Geography, 97, 2015, pp. 671–679.
[19] Amiranashvili A., Amiranashvili V., Kartvelishvili L., Nodia Kh., Khurodze T. Influence of Air Effective Temperature and Geomagnetic Storms on the Population of Tbilisi City. Trans. of the Institute of Hydrometeorology, v. No 115, ISSN 1512-0902, Tbilisi, 2008, pp. 434 – 437, (in Russian).
[20] Amiranashvili A., Danelia R., Mirianashvli K., Nodia A., Khazaradze K.,Khurodze T., Chikhladze V. On the Applicability of the Scale of Air Equivalent-Effective Temperature in the Conditions of Tbilisi City.Trans. of M. Nodia Institute of Geophysics, v. LXII, ISSN 1512-1135, Tbilisi, 2010, pp. 216-220, (in Russian).
[21] Amiranashvili A., Mirianashvili K., Fedorova N., Levit V., Fabiana Medeiros Carnaúba, Aliton Oliveira da Silva. Comparative analysis of air equivalent - effective temperature in some cities of Georgia and Brazil, Proc. of Int. Conf. "Environment and Global Warming", Dedicated to the 100$^{th}$ Birthday Anniversary of Academician F. Davitaya, Collected Papers New Series, N 3(82), ISSN 2333-3347, Tbilisi, 2011, pp. 105-110.
[22] Amiranashvili A.G., Chikhladze V.A. Saakashvili N.M., Tabidze M.Sh., Tarkhan-Mouravi I.D. Bioclimatic Characteristics of Recreational Zones – Important Component of the Passport of the Health

Resort – Tourist Potential of Georgia. Trans. of the Institute of Hydrometeorology at the Georgian Technical University, vol. 117, ISSN 1512-0902, 2011, pp. 89-92.
[23] Khazaradze K. R. Comparative Analysis of Mean-Daily Value of Air Equivalent-Effective Temperature in Tbilisi and Kojori. Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, v. 20B, 2017, pp. 65–72.
[24] Amiranashvili A., Japaridze N., Kartvelishvili L., Megrelidze L., Khazaradze K. Statistical Characteristics of the Monthly Mean Values of Air Effective Temperature on Missenard in the Autonomous Republic of Adjara and Kakheti (Georgia). Transactions of Mikheil Nodia Institute of Geophysics, ISSN 1512-1135, vol. LXIX, 2018, pp. 118-138, (in Russian).
[25] Abegg B. Klimaanderung und Tourismus. Zurich: Schlussbericht NFP 31. vdf Hochschulverlag AG an der ETH, 1996.
[26] Mieczkowski Z. The Tourism Climate Index: A Method for Evaluating World Climates for Tourism. The Canadian Geographer 29, 1985, pp. 220-233.
[27] Scott D., Mc Boyle G. Using a "Tourism Climate Index" to Examine the Implications of Climate Change for Climate as a Tourism Resource. International Society of Biometeorology, Proceedings of the First International Workshop on Climate, Tourism and Recreation. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/ report.htm, 2001.
[28] De Freitas C. R., Scott D., McBoyle G. A new generation climate index for tourism and recreation. Advances in Tourism Climatology. International Workshop on Climate, Tourism and Recreation, 2004, pp. 19–26.
[29] Matzarakis A., de Freitas C.R. (eds). Proc. of the First Int. Workshop on Climate, Tourism and Recreation. International Society of Biometeorology, Commission on Climate Tourism and Recreation, December 2001.
[30] Matzarakis A., de Freitas C., Scott D. (eds.). Advances in Tourism Climatology. Ber.Meteorol. Inst. Univ. Freiburg Nr. 12, 2004.
[31] Matzarakis A. Climate, thermal comfort and tourism. Climate Change and Tourism-Assessment and Coping Strategies, 2007, pp.139-154.
[32] De Freitas C. R., Scott D., McBoyle G. A second generation climate index for tourism (CIT): specification and verification. International Journal of Biometeorology. 52(5), 2008, pp. 399–407.
[33] Matzarakis A., Rudel E., Zygmuntowski M., Koch E. Bioclimatic Maps for Tourism Purposes. Physics and Chemistry of the Earth 35, 2010, pp. 57–62.
[34] Cengiz T., Akbulak C., Caliskan V., Kelkit A. Climate Comfortable for Tourism: A Case Study of Canakkale. BALWOIS 2008, Ohrid, Republic of Macedonia, 27, May 2008.
[35] Mendez-Lazaro P. A., Terrasa-Soler J. J., Torres-Pena C., Guzman-Gonzalez P., Rodriguez S., Aleman M., Seguinot T. Tourism and Climate Conditions in San Juan, Puerto Rico, 2000-2010. Ecology and Society 19(2), 2014, 11 p., http://dx.doi.org/10.5751/ES-06380-190211
[36] Yan Fang and Jie Yin. National Assessment of Climate Resources for Tourism Seasonality in China Using the Tourism Climate Index. Atmosphere, ISSN 2073-4433, N 6, 2015, pp. 183-194, doi:10.3390/atmos6020183; www.mdpi.com/journal/atmosphere
[37] Robinson D.C. Exploring the Value of Tourism Climate Indices for 18 Locations in South Africa. Dissertation submitted to the Faculty of Science in fulfilment of the requirements for the degree Master of Science, Johannesburg, June 2016, 282 p.
[38] Nhung Thu Nguyen, Bac Hoang. Bioclimatic Resources for Tourism in Tay Nguyen, Vietnam. Ukrainian Geographical Journal, ISSN 1561-4980, № 3, 2016, pp. 33-38, DOI: 10.15407/ugz2016.03.033.
[39] Scott D., Rutty M., Amelung B., Tang M. An Inter-Comparison of the Holiday Climate Index (HCI) and the Tourism Climate Index (TCI) in Europe. Atmosphere 7, 80, 2016, 17 p., doi: 10.3390/atmos7060080www
[40] Dalinkevičiūtė S., Kažys J. Klimatinės paplūdimių turizmo sąlygos Lietuvos jūros krante. Geologija. Geografija, T. 4, Nr. 1, 2018, pp. 1–14, (in Lithuanian), DOI: 10.6001/geol-geogr.v4i1.3719
[41] Farajzadeh H.,Matzarakis A. Quantification of Climate for Tourism in the Northwest of Iran. Iran. Meteorol. Appl., 16, 2009, pp. 545–555, DOI: 10.1002/met.155.
[42] Gandomkar A. Estimation and Analyse of Tourism Climate Index in Semirom Using TCI Model.Journ. of Physical Geography, vol. 3, No 8, Summer 2010, pp. 99 – 110.
[43] Shakoor A. Investigating Biophysics and Bioclimate Effect on the Health of Tourists in Yazd Province Using Tourism Climate Index (TCI). Int. Journ. of the Physical Sciences, vol. 6(28), 9 November, 2011, pp. 6607-6622, DOI: 10.5897/IJPS11.1306

[44] Ramazanipour M., Behzadmoghaddam E. Analysis of Tourism Climate Index of Chaloos City. Int. Journ. of Humanities and Management Sciences (IJHMS), vol. 1, Iss. 5, ISSN 2320-4036; EISSN 2320-4044, 2013, pp. 290-292.
[45] Ghanbari S., Karimi J. The Review of Changes in Tourism Climate Index (TCI) Isfahan (2005-1976). Journ. of Regional Planning, vol. 3, No 12, Winter 2014, pp. 71 – 82.
[46] Hassan E.M., Varshosaz K., Eisakhani N. Analysis and Estimation of Tourism Climatic Index (TCI) and Temperature-Humidity Index (THI) in Dezfoul. 4th Int. Conf. on Environmental, Energy and Biotechnology, vol. 85 of IPCBEE, 2015, pp. 35-39, DOI:10.7763/IPCBEE. 2015. V85. 6
[47] Roshan G., Yousefi R., Fitche J.M. Long-Term Trends in Tourism Climate Index Scores for 40 Stations Across Iran: The Role of Climate Change and Influence on Tourism Sustainability. Int. J. Biometeorol., 2015, DOI 10.1007/s00484-015-1003-0
[48] Nasabpour S., Khosravi H., Heydari Alamdarloo E. National Assessment of Climate Resources for Tourism Seasonality in Iran Using the Tourism Climate Index. Journ. Desert, ISSN: 2008-0875, eISSN: 475-234X, 22-2, 2017, pp. 175-186, http://desert.ut.ac.ir
[49] Toy S., Yilmaz S. Artvin İlindeki İklim Şartlarinin Turizm Ve Rekreasyon Aktiviteleri Acisindan Uygynlugunun Degerlendirilmesi. III Ulusal Karadeniz Ormancılık Kongresi, Cilt: IV Sayfa: pp. 1513-1522, 20-22 May 2010.
[50] Toy S., Yilmaz S. Evaluation of Climatic Characteristics for Tourism and Recreation in Northeast Anatolia (TRA1 NUTS II) Region in the Example of Erzincan City Centre. Journal of Tourism and Gastronomy Studies, ISSN: 2147-8775, vol. 4, iss. 3, 2016, pp. 53-65, DOI: 10.21325/jotags.2016.42.
[51] Rybak O. O., Rybak E. A. Application of Climatic Indices for Evaluation of Regional Differences in Tourist Attractiveness. Nauchnyy zhurnal KubGAU, №121(07), 2016, 24 p., http://ej.kubagro.ru/2016/07/pdf/16.pdf
[52] Amiranashvili A., Matzarakis A., Kartvelishvili L. Tourism Climate Index in Tbilisi. Trans. Of the Institute of Hydrometeorology, vol. 115, ISSN 1512-0902, Tbilisi, 18 – 19 November, 2008, pp. 27 – 30.
[53] Amiranashvili A., Matzarakis A., Kartvelishvili L. Tourism Climate Index in Batumi. “Modern Problems of Using of Health Resort Resources”, Collection of Scientific Works of International Conference, Sairme, Georgia, June 10-13, 2010, ISBN 978-9941-0-2529-7, Tbilisi, 2010, pp. 116-121.
[54] Kartvelishvili L., Matzarakis A., Amiranashvili A., Kutaladze N. Assessment of Touristical-Recreation Potential of Georgia on Background Regional Climate Change. Proc. of IIst Int. Scientific-Practical Conference “Tourism: Economics and Business”, June 4-5, Batumi, Georgia, 2011, pp. 250-252.
[55] Amiranashvili, A., Chargazia, Kh., Matzarakis, A. Comparative Characteristics of the Tourism Climate Index in the South Caucasus Countries Capitals (Baku, Tbilisi, Yerevan). Journal of the Georgian Geophysical Society, Issue (B). Physics of Atmosphere, Ocean, and Space Plasma, v.17b, 2014, pp. 14-25.
[56] Amiranashvili A., Chargazia Kh., Matzarakis A., Kartvelishvili L. Tourism Climate Index in the Coastal and Mountain Locality of Adjara, Georgia. International Scientific Conference “Sustainable Mountain Regions: Make Them Work”. Proceedings, Borovets, Bulgaria, ISBN 978-954-411-220-2, 14-16 May,2015, pp.238-244, http://geography.bg/MountainRegions_Sofia2015
[57] Amiranashvili A. G., Japaridze N. D., Kartvelishvili L. G., Khazaradze R. R. Tourism Climate Index in Telavi (Eastern Georgia). The Questions of Health Resort Managing, Physioteraphy and Rehabilitation, International Collection of Scientific Articles, Vol. I, ISSN 2449-271X, Tbilisi, 2016, pp. 76-81.
[58] Amiranashvili A.G., Japaridze N.D., Kartvelishvili L.G., Khazaradze K.R., Matzarakis A., Povolotskaya N.P., Senik I.A. Tourism Climate Index of in the Some Regions of Georgia And North Caucasus. Journal of the Georgian Geophysical Society, Issue B. Physics of Atmosphere, Ocean and Space Plasma, ISSN: 1512-1127, v. 20B, 2017, pp. 43–64.
[59] Amiranashvili A.G., Japaridze N.D., Kartvelishvili L.G., Khazaradze K.R., Kurdashvili L.R. Tourism Climate Index in Kutaisi (Georgia). International Scientific Conference „Modern Problems of Ecology“, Proceedings, ISSN 1512-1976, v. 6, Kutaisi, Georgia, 21-22 September, 2018, pp. 227-230.
[60] Amiranashvili A.G., Kartvelishvili L.G., Khakhutashvili T.T., Megrelidze L.D. Changeability of the Meteorological Parameters Associated with Some Simple Thermal Indices and Tourism Climate Index in Adjara and Kakheti (Georgia). Journal of the Georgian Geophysical Society, ISSN: 1512-1127, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp. 77-94.
[61] Kobisheva N., Narovlianski G. Climatological processing of the meteorological information, Leningrad, Gidrometeoizdat, 1978, 294 p., (in Russian).

# კახეთში (საქართველო) ტურიზმის კლიმატური ინდექსის სტატისტიკური მახასიათებლები

ა.ამირანაშვილი, ლ.ქართველიშვილი, ა.მატზარაკისი

### რეზიუმე

ნაშრომში წარმოდგენილია ტურიზმის კლიმატური ინდექსის (TCI) საშუალო თვიური, საშუალო წლიური და საშუალო ნახევარწლიური მნიშვნელობები კახეთის ოთხი პუნქტის (თელავი. დედოფლისწყარო, ყვარელი, და საგარეჯო) 1961÷2010 წ.წ. პერიოდის მიხედვით. კერძოდ, შესწავლილია აღნიშნული ბიოკლიმატური პარამეტრების ცვლილება 1986÷2010 წლებში 1961÷1985 წლებთან შედარებით.

# Статистические характеристики климатического индекса туризма в Кахетии (Грузия)

**А.Г. Амиранашвили, Л. Картвелишвили, А. Матзаракис**

### Резюме

Представлены статистические характеристики среднемесячных, годовых и полугодовых значений климатического индекса туризма (TCI) и его составляющих для четырех пунктов Кахетии (Телави, Дедоплисцкаро, Кварели и Сагареджо) в период с 1961 по 2010 гг. В частности, изучена изменчивость указанных биоклиматических параметров в 1986÷2010 гг. по сравнению с 1961÷1985 гг., а также исследованы тренды значений TCI для выше перечисленных пунктов.

*Journal of the Georgian Geophysical Society, ISSN: 1512-1127*
*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(2), 2018, pp.113 - 115*

# Memories of Colleagues to the 90 - Anniversary from the Birthday

**Nugzar Ya. Ghlonti**

*Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University,*
*1, M. Alexidze Str., 0160, Tbilisi, Georgia, e-mail: Ghlonti60@yahoo.com*

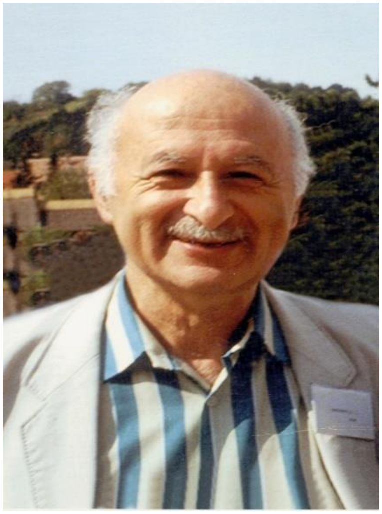
***ABSTRACT***

In connection with the 90th anniversary of the birth of our colleagues who have died, prof. E.A. Jibladze, prof. D.I. Sikharulidze, prof. L.Kh. Shatashvili and acad. dr. A.M. Okudjava, a brief information about their scientific activities is presented.

In 2018, famous Georgian scientists Prof. E.A. Jibladze, Prof. D.I. Sikharulidze, Prof. L.Kh. Shatashvili and Academic Doctor A.M. Okudjava would have turned 90 years old. They have played a major role in the development of Georgian geophysical science in the Caucasus.

Eleonora JIBLADZE (1928-2005) - Doctor of Physics and Mathematics, Professor. In 1950 she graduated from the Faculty of Physics and Mathematics of Tbilisi State University. In 1951-1954 she was a postgraduate student at Institute of Geophysics, Georgian Academy of Sciences. In 1955 she successfully defended her thesis at Institute of Physics of the Earth, Moscow and defended the doctoral thesis in 1977. From 1955 until the end of her life E. Jibladze worked at the Department of Regional Seismology at Institute of Geophysics (she occupied the positions of senior, leading and chief scientist, head of department). At the beginning of her scientific activities she carried out initial processing of seismograms and the compilation of the summary bulletin on the earthquakes in the Caucasus region. The scientific interests of Eleonora Jibladze developed in two directions: a quantitative assessment of seismic hazard and seismotectonic movements. Her works formed the basis for the study of seismic zoning and seismic danger of the Caucasus. She took part in the creation of a new seismic zoning methodology. She is the author of the seismic zoning map of the territory of Georgia, which is a regulatory document in the construction of civil and industrial facilities in our country. Prof. E. Jibladze is an author of about 100 scientific papers, including 6 monographs («Энергия землетрясений, сейсмический режим и сейсмотектоническое движение Кавказа», Metsniereba, 1980, p. 225; «Дманисское землетрясение 2 января 1978 года», January 2. 1978, M. Nauka 1981, p. 173, co-authors: G.I. Murusidze, V.G. Papalashvili, O.D. Gotsadze, et al.; The Seismic Zoning Map of the USSR, scale 1: 1000 000, M., Nauka, 1984, p. 5, co-authors: M.M. Rubinstein, V.G. Papalashvili, I.V. Aivazishvili, O.Sh. Varazanashvili, O.D. Gotsadze, D.I. Sikharulidze; «Параванское землетрясение 13 мая 1986 года», M. Nauka, 1991, p. 128, co-authors: M.S. Ioseliani, O.D. Gotsadze, N.V. Kondorskaya, V.G. Papalashvili, et al.; «Сейсмический режим, сейсмическая опасность и сейсмические движения Кавказа», Institute of Geophysics of Georgian Academy of Sciences,1995, p.113, co-authors: N.K. Butikashvili, N.S. Tsereteli). Six PhD theses have been defended under Prof. E. Jibladze's scientific guidance. She was awarded the Prize of Honour of Georgia.

David SIKHARULIDZE (1928-2011) - Doctor of Physical and Mathematical Sciences, Professor. In 1950 he graduated from the Faculty of Physics and Mathematics of Tbilisi State University. Since 1950 he worked at the Department of Seismology of Institute of Geophysics, Georgian Academy of Sciences. In 1960 he defended his candidate thesis and in 1979 defended the doctoral dissertation at Institute of Physics of the Earth, in Moscow. From 1970 to 2005 he headed the Department of Physics of Earthquake Foci at Institute of Geophysics. Prof. D.I. Sikharulidze laid the foundations, worked out and developed methods for surface seismic waves, with the help of which the radial and lateral heterogeneous structure of the earth's crust and upper mantle is studied, which is a completely new direction in seismology. In his doctoral thesis Prof. D.I. Sikharulidze studied horizontal heterogeneities in the crust and upper mantle based on the study of reflected and refracted surface waves. Prof. D.I. Sikharulidze is an author of over 100 scientific papers, including four monographs. («Дисперсия волн Лява для трехслойной модели Земли», Metsniereba, 1969, p. 223, co-author: N.P. Tutberidze; «Строение Земли по поверхностным волнам», Metsniereba, 1978, p. 242s; «Строение, напряженно-деформированное состояние и условия сейсмичности литосферы Малого Кавказа», Metsniereba, 1983, p. 123, co-authors: N.P. Tutberidze, A.Kh. Bagramyan, P.O. Jijeishvili, B.Ts. Yeremyan, N.A. Nibladze, R.L. Shavishvili ; «Поверхностные волны в обратных задачах сейсмологии», Yerevan, Academy of Sciences of Armenia, 1987, p. 222, co-authors: N.P. Tutberidze, A.Kh. Bagramyan, P.V. Manjgaladze, T.Sh. Gegechkori, A.M. Avetisyan, T.N. Gogoladze, T.M. Gevondyan, M.B. Mkrtchyan). About ten PhD theses have been defended under his leadership. Prof. D.I. Sikharulidze was awarded the Prize of Honour of Georgia.



Luli SHATASHVILI (1928-2000) - Doctor of Physical and Mathematical Sciences, Professor. In 1952 he graduated with honours from the Department of Physics of Tbilisi State University having specialized in Physics. In 1952-1956 he worked at the Cosmic Ray Station at the Hydrometeorological Service, which in 1956 was transferred to Institute of Geophysics of the Georgian Academy of Sciences. From 1956 till his last days, Professor L.Kh. Shatashvili worked at Institute of Geophysics, occupied the positions of the Head of the Laboratory of High Energy Cosmic Rays, the Head of the department of Cosmic Rays. At the Institute he completed his postgraduate course. In 1962 he defended his candidate thesis and in 1977 defended the doctoral dissertation.

Professor L.Kh. Shatashvili was a prominent specialist in the field of Interplanetary Space and Physics of Cosmic Rays. He is the author of the fundamental work on the theory of quasi-periodic variations in the intensity of cosmic rays, which led to the awareness of the dominant role of the asymmetric solar wind in the formation of 27-day variations of charged particles of cosmic radiation. Professor L.Kh. Shatashvili's works on the 27-day variations are recognized as classical works and have been included in all known monographs. He is an author of about 200 scientific papers, including 4 monographs («Квазипериодические вариации космических лучей», Metsniereba, 1974, p. 126, co-author: M.V. Alania; «Квазипериодические вариации интенсивности и анизотропии космических лучей», Metsniereba, 1981, p. 131, co-author: B. D. Naskidashvili; «Квазипериодические вариации космических лучей и солнечно-земные явления», Metsniereba, 1991, p. 96, co-authors: N.A. Nachkebia, O.G. Rogava). Prof. L.Kh. Shatashvili was awarded the Prize of Honour of Georgia, was a member of many problem councils of the Academy of Sciences of Russia, a member of the US Geographical Society.

Archil OKUDJAVA (1928-2008) - Academic Doctor of Physical and Mathematical Sciences. In 1949 he graduated from the Faculty of Physics and Mathematics of Tbilisi State University having specialized in Theoretical Physics. From 1950 he worked at Institute of Geophysics at the Department of Physics of Atmosphere. Since 1971 he headed the Laboratory of Modelling of Atmospheric Processes. In 1969 he successfully defended his thesis for the degree of Candidate of Physical and Mathematical Sciences. A.M. Okudjava is a leading specialist in the study of atmospheric phenomena. A.M. Okudjava’s works are devoted to laboratory modelling of microphysical and electrical processes occurring in convective clouds during their natural development and artificial effect on them. (Monograph: «Гетерогенная нуклеация льда», Metsniereba, 1984, p. 140, co-authors: T.G. Gzirishvili, A.I. Kartsivadze). A.M. Okudjava has a great merit in the creation of one of the significant laboratory complexes at Institute of Geophysics - the Thermal Chamber and its equipment, measuring devices. A.M. Okudjava is an author of many scientific works and three inventions. He was awarded a silver medal of the USSR Exhibition of Economic Achievements for participation in the development of scientific research area in the field of Physics of Clouds.

## კოლეგების ხსოვნისადმი დაბადებიდან 90 წლის თავთან დაკავშირებით


**ნ.ღლონტი**



**რეზიუმე**

წარმოდგენილია მოკლე ინფორმაცია აწ გარდაცვლილი ჩვენი კოლეგების პროფესორ ე. ჯიბლაძის, პროფესორ დ. სიხარულიძის, პროფესორ ლ. შათაშვილის და აკადმიური დოქტორის ა.ოკუჯავას სამეცნიერო მოღვაწეობის შესახებ მათი დაბადებიდან 90 წლის თავთან დაკავშირებით


## Памяти коллег к 90-летию со дня рождения


**Н.Я. Глонти**



**Резюме**

В связи с 90-летием со дня рождения ушедших из жизни наших коллег проф. Э.А. Джибладзе, проф. В.И. Сихарулидзе, проф. Л.Х. Шаташвили и академического доктора А.М. Окуджава, представлена краткая информация об их научной деятельности.

# Information for contributors

Papers intended for the Journal should be submitted in two copies to the Editor-in-Chief. Papers from countries that have a member on the Editorial Board should normally be submitted through that member. The address will be found on the inside front cover.

1. Papers should be written in the concise form. Occasionally long papers, particularly those of a review nature (not exceeding 16 printed pages), will be accepted. Short reports should be written in the most concise form not exceeding 6 printed pages. It is desirable to submit a copy of paper on a diskette.
2. A brief, concise abstract in English is required at the beginning of all papers in Russian and in Georgian at the end of them.
3. Line drawings should include all relevant details. All lettering, graph lines and points on graphs should be sufficiently large and bold to permit reproduction when the diagram has been reduced to a size suitable for inclusion in the Journal.
4. Each figure must be provided with an adequate caption.
5. Figure Captions and table headings should be provided on a separate sheet.
6. Page should be 2.0 x 2.0 cm. Large or long tables should be typed on continuing sheets.
7. References should be given in the standard form to be found in this Journal.
8. All copy (including tables, references and figure captions) must be double spaced with wide margins, and all pages must be numbered consecutively.
9. Both System of units in GGS and SI are permitted in manuscript
10. Each manuscript should include the components, which should be presented in the order following as follows:
    Title, name, affiliation and complete postal address of each author and dateline.
    The text should be divided into sections, each with a separate heading or numbered consecutively.
    Acknowledgements. Appendix. Reference.
11. The editors will supply the date of receipt of the manuscript.

CONTENTS - სარჩევი

# საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

## მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

*ტომი 21 , № 2*

ჟურნალი იბეჭდება საქართველოს გეოფიზიკური საზოგადოების პრეზიდიუმის დადგენილების საფუძველზე

ტირაჟი 50 ცალი

# JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

***Physics of Solid Earth, Atmosphere, Ocean and Space Plasma***

***Vol. 21, № 2***

Printed by the decision of the Georgian Geophysical Society Board

Circulation 50 copies

# ЖУРНАЛ ГРУЗИНСКОГО ГЕОФИЗИЧЕСКОГО ОБЩЕСТВА

**Физика Твердой Земли, Атмосферы, Океана и Космической Плазмы**

***Том 21, № 2***

Журнал печатается по постановлению президиума Грузинского геофизического общества

Тираж 50 экз

**Tbilisi-თბილისი-Тбилиси**
**2018**