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# საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

*ტომი 26 , № 2*

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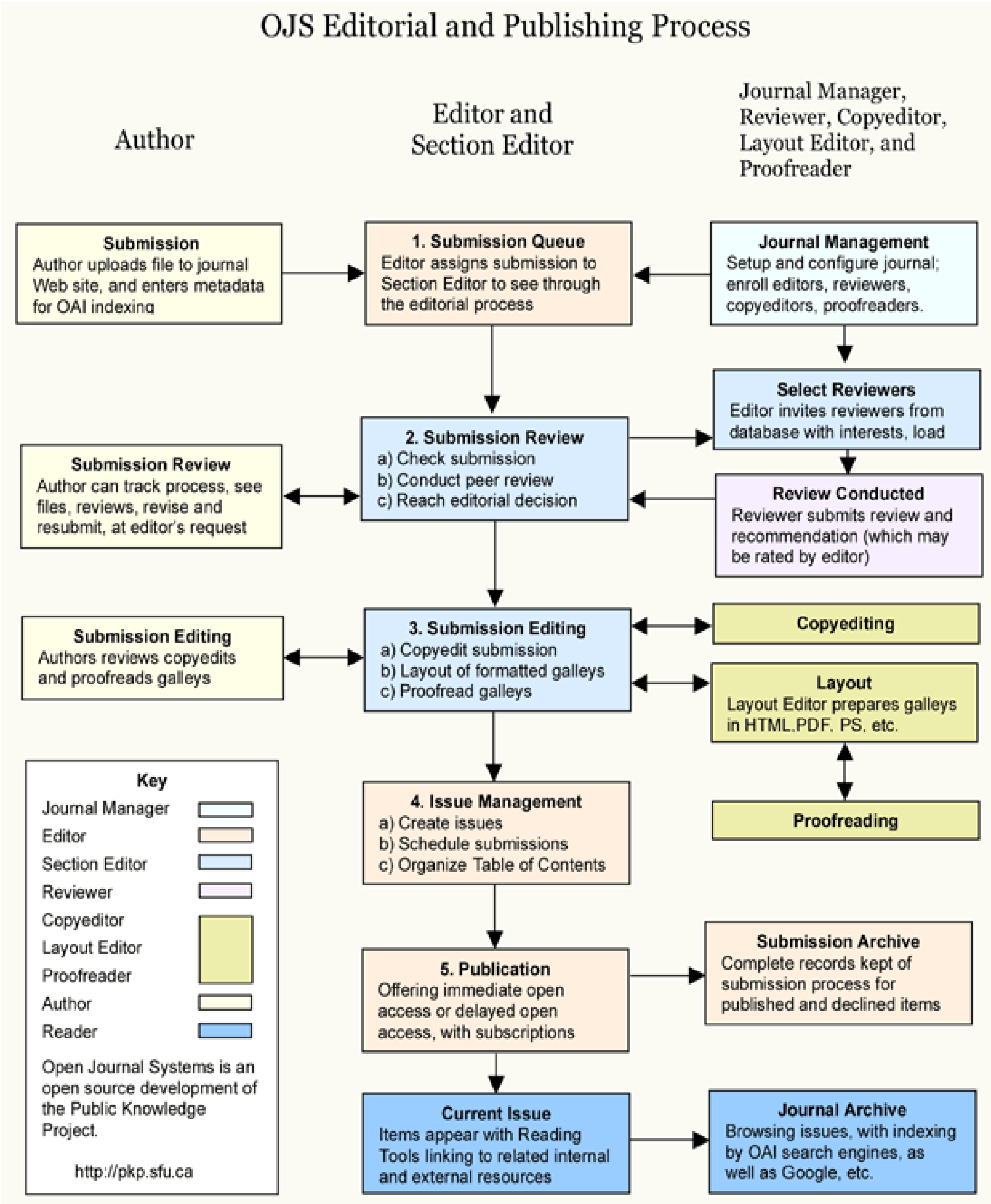

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# Investigation of Ambient Seismic Noise in Different Region of Georgia

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## *ABSTRACT*

*Georgia, like the whole South Caucasus, is a tectonically and structurally complex region. It is one of the active segments of the Alpine-Himalayan belt, therefore it is important to assess the seismic hazard for Georgia. At the regional scale, this assessment is evaluated by applying probabilistic seismic hazard analysis that identifies the annual probability of exceedance of various ground motion levels defined in terms of selected ground motion intensity measures, such as PGA or spectral accelerations (SA) corresponding to various return periods related to possible future earthquake scenarios for a site represented by soil classes A according to EC8, Euro-code 8-EN 1998-1 (1998). At the local scale, seismic hazard assessment is made by analyzing the geological, geomorphological, geotechnical and geophysical characteristics of the site, as it is well established that the incoming seismic motion can change in amplitude, frequency, and duration due the site-specific local characteristics. That is the subject of micro-zonation investigation. Site – specific local characteristics are presented by the following parameters: Dominant frequency, Vs,30 (average shear-wave velocity to a depth of 30 meters) and amplification factor. In this work, we presented results of geophysical survey assessing local site conditions by dominant frequency that allows identification of similar seismic response areas. For this purpose, seismic noise records have been used first time in Georgia.*

***Keywords:*** *Ambient Vibration, Single Station, Ground Motion, Amplification, H/V Method.*

## Introduction

The various impacts of earthquakes on the Earth's surface have brought attention to studying how the ground responds to earthquakes with different magnitudes [1-10]. The amplification of seismic ground motion, caused by site effects, plays a crucial role in the observed destruction during earthquakes. Depending on the site conditions, the earthquake damage can vary across different regions. During the earthquake, soft sediments exhibit noticeable ground motion amplification compared to consolidated rocks. Consequently, buildings situated on these sediments are more prone to damage or complete collapse. This amplification in ground motion is caused by resonance frequency of corresponding sites. Traditional approaches to quantify resonant frequencies have relied on earthquake ground motion recordings of investigation sites. However, the poor data of strong motion in Georgia does not allow us to follow this approach. Availability of seismic noise records has opened up new possibilities for studying ground response characteristics, particularly to estimate dominant frequency of the site [1-10].

The Horizontal to Vertical Spectral Ratio (HVSR or H/V) technique is a widespread approach for site characterization [1-10]. It can be applied by ground motion records caused by earthquakes and ambient noise records. An important advantage of HVSR technique is that it eliminates the influence of the source and provides information on the wave propagation in the environment.

By utilizing seismic noise data, the HVSR technique enables the extraction information about the resonant frequencies of the underlying soil layers. The peaks observed in the HVSR curves correspond to the resonance frequencies, offering insights into the site's dynamic properties [7,9,10]. Knowledge of resonance frequencies of the ground is important when designing structures so that their natural frequency does not coincide with the resonant frequency of the ground.

## Determination of resonant frequencies using seismic noise records

In this work, we concentrated only on the assessment of fundamental frequency. To demonstrate the effectiveness of the proposed methodology, a case study is conducted in a different region of Georgia. Seismic noise data collected from multiple stations are processed, and the HVSR curves are computed. The peaks observed in the HVSR curves are analyzed to determine the resonant frequencies of the underlying soil layers.

We used the TROMINO 3G seismograph (www.tromino.eu ) with an output sampling rate 128 Hz, which are all-in-one instruments expressly designed for tremor measurements and maximum portability (approximately $1dm^3$volume and 1 kg weight). During installation, small holes were dug to accommodate the sensors on the ground whenever possible, usual care was taken in deploying the sensors and ensuring adequate coupling with the soil. Care was taken also at ensuring to avoid placement of sensors directly over utilities or disturbances sources.

Seismic noise was sampled approximately for 30 – 45 minutes at each site and HVSR curves were calculated by averaging the H/V obtained by dividing the signal into overlapping windows of 20s. Each window was detrended, tapered, padded, FFT and smoothed with triangular windows with a width equal to 10% of the central frequency before the Fourier spectra were ratioed, and the Euclidean average was used to combine EW and NS components in the single horizontal (H) spectrum. We consider records only in the range 0.1-20 Hz which is more interesting from an Engineering point of view.

Geophysical measurements were carried out in the area allocated for the construction of hydroelectric power stations in the mountainous regions of West Georgia, at the construction site of multi-apartment residential buildings in the city of Tbilisi, at the construction site of a hotel complex in Batumi, and in the area of the tailing dam in Kazreti.

The recorded time series data is converted to the frequency domain using FFT for all three components. The resonance manifests itself as a local minimum in the vertical velocity component in the frequency domain, such that when a ratio is taken between the averaged horizontal and vertical components of ground velocity, a peak occurs at a particular frequency as shown in Fig. 1 [1, 2]. This resonance frequency is related to the shear wave velocity and thickness of the first layer by the following equation :

$$f_0 = \frac{V_s}{4h} \quad \text{equation (1)}$$

where $f_0$ is a peak resonant frequency (Hz), $V_s$is a shear wave velocity (m/s), h is a thickness of the layer.

$$h = \frac{V_s}{4f_0} \quad \text{equation (2)}$$

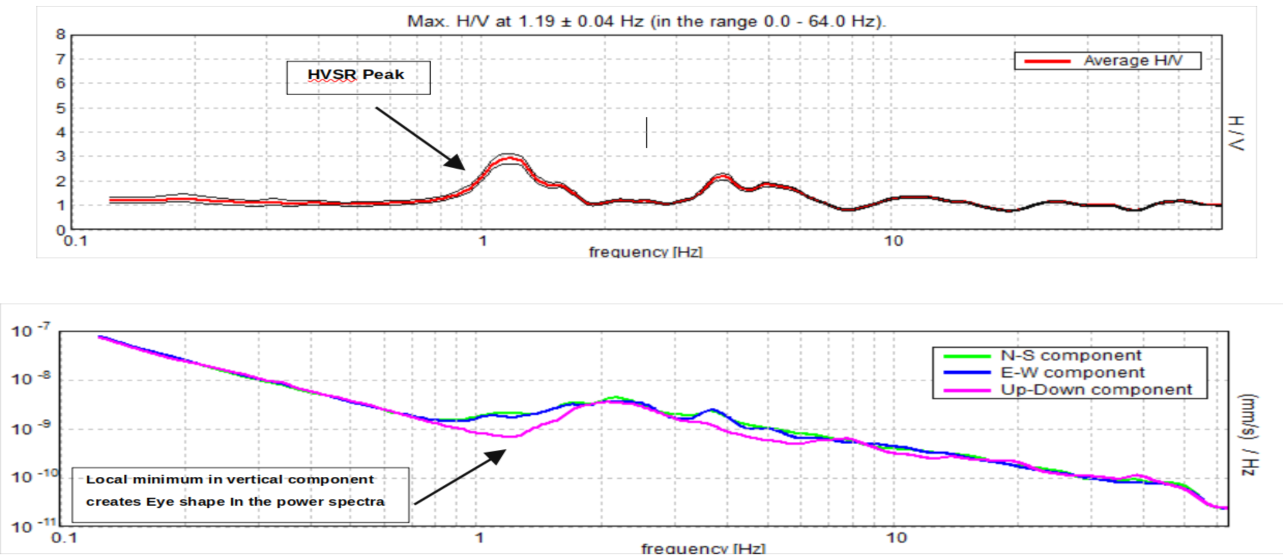



Fig. 1. Record from a Tromino 3G seismometer. HVSR curve in the top panel, and the Fourier spectrum of the three axial components in the bottom panel. Resonance frequency is observed at a peak of 1.19 Hz in the HVSR plot.

When analyzing the spectrum of individual components of Tromino's record, the presence of a one-dimensional (1D) environment can be determined if the horizontal components coincide and a local minimum is observed on the vertical component. In this case, Equations (1) and (2) can be applied as they are valid for a 1D scenario [7] (Fig. 1).

However, if the spectrum of individual components of the Tromino record does not match, indicating a two-dimentional (2D) environment, the relationship between the depth of the sedimentary layer (thickness of the sedimentary layer), resonant frequency and shear wave velocity presented by equation (1) and (2) cannot be used. In such cases, alternative approaches are necessary to calculate the layer thickness and shear wave velocity [7,10].

## Analysis of Ambient Seismic Noise Data

The analysis of the seismic noise measurements revealed that the construction area of Bakhvi 1 HPP headwork is mainly composed of foundations, where the seismic noise records correspond to the rock as HV curve has no peak. This allows us to assess the seismic hazard for the rock in the area. Consequently, the amplification factor in this case is expected to be 1. As for the area of Bakhvi 1 HPP power station, peak was observed here at frequencies in the range of 15-19Hz indicating that the bedrock is quite close to the surface. Fig. 2 presents the distribution of dominant frequency at Bakhvi 1 HPP Power Station. Fig. 3a) b shows examples of HV curves of Bakhvi 1 HPP power station and Headwork.

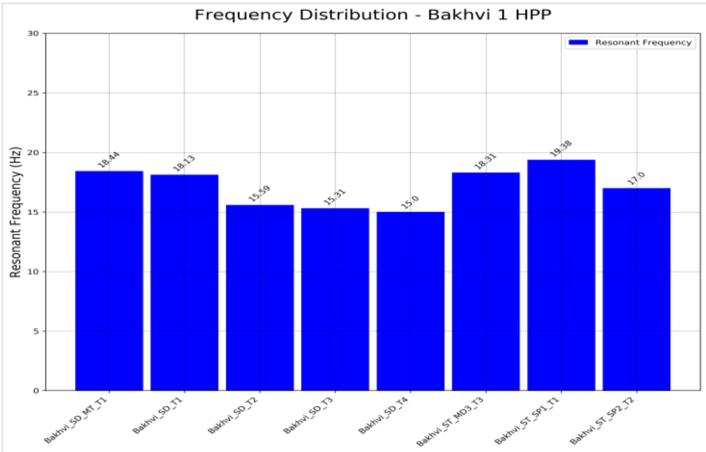



Fig. 2. Frequency Distribution for Bakhvi 1 HPP Power Station.

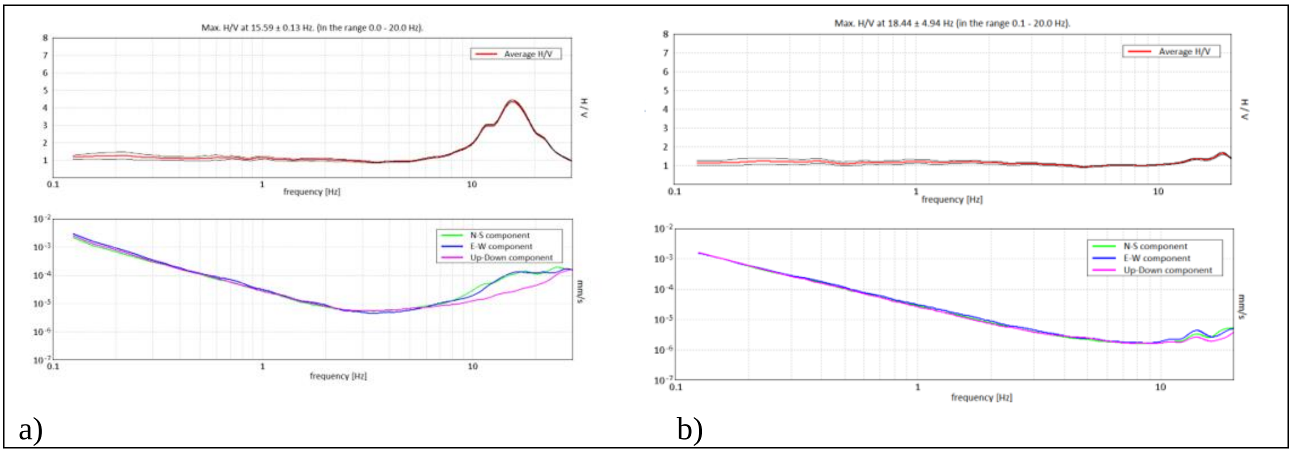
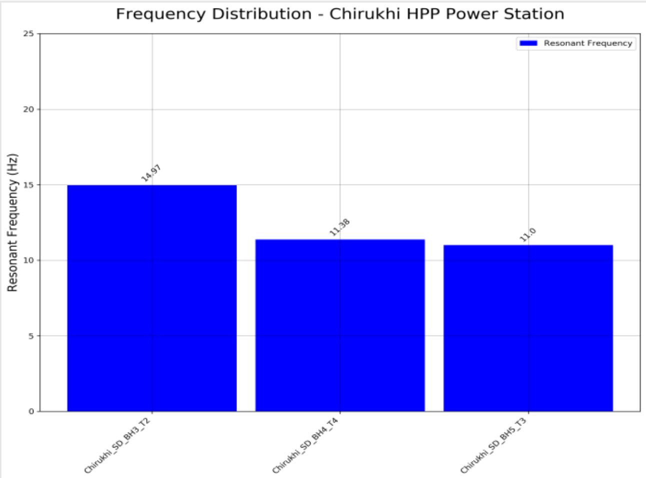


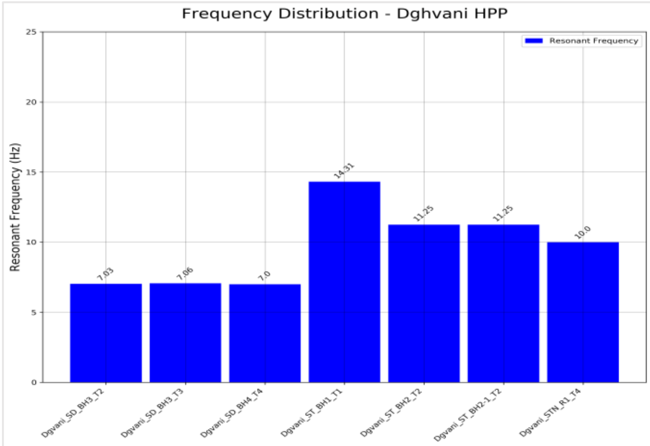

Fig. 3. HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity (in range 0.1-20Hz) of Bakhvi 1HPP a) HPP power station b) HPP Headwork.

Ambient noise measurements were also conducted at the construction sites of Chirukhi HPP and Dghvani HPP. Ambient vibration measurements were taken at a total of 14 points, with 3 points located at Chirukhi HPP power station, 4 points located at Chirukhi HPP headwork, and the remaining 7 points at Dghvani HPP, four of them at headwork and three at power station.

The analysis of the seismic noise measurements revealed that the area of Cirukhi HPP headwork represented by the rock (Fig. 5) and the area of Cirukhi HPP power station characterized by resonance frequencies in the range of 11.0 -15 Hz (Fig. 4 a). Seismic noise records at Dghvani HPP exhibit a mixture of resonance frequencies. The power station of Dghvani HPP shows a similar value of a resonance frequency at 7-7.06 Hz. The headwork of Dghvani HPP, however, is characterized by high resonant frequencies ranging from 10 – 14.31 Hz (Fig. 4b).




a)




b)

Fig. 4. Frequency distribution a) For Chirukhi HPP power station; b) For Dgvani HPP headwork and power station

Fig. 5 a) b)c)d) presents one of the examples of HV curves of seismic noise measurement at Chirukhi HPP and Dgvani HPP sites.

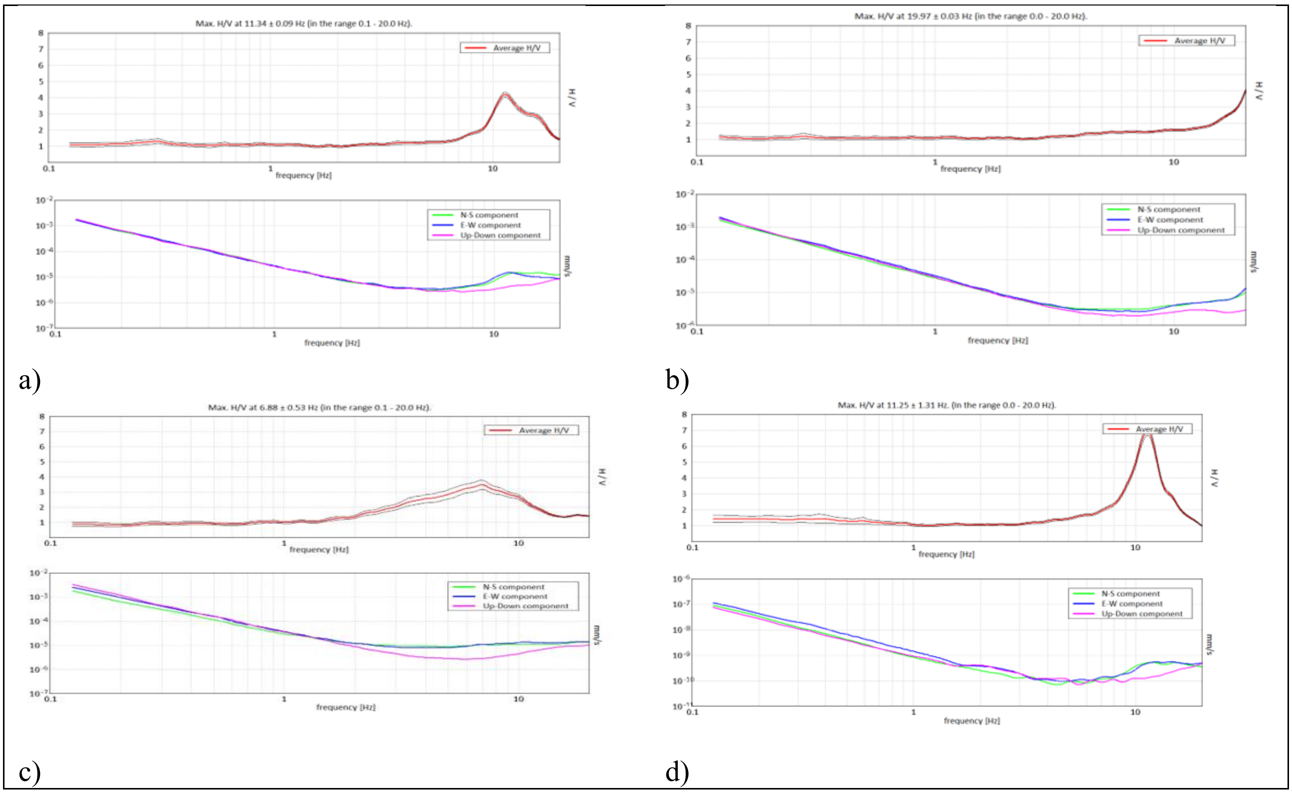



Fig. 5. HVSR curves and Fourier spectrum Frequency-Amplitude curves of N-S, E-W and Up-Down components of the ground velocity a) For Chirukhi HPP power station b) For Chirukhi HPP headwork c) For Dgvani HPP power station d) For Dgvani HPP headwork

Seismic nose measurement records were investigated at the top and bottom of Kazreti Tailing Dam. The analysis of the seismic noise records at the bottom of Kazreti Tailing Dam showed that no peak were observed on the HV curve. Amplitudes across the entire frequency spectrum are less than 2, which means the foundation is rock (Fig. 7b). On the other side peak on the HV curve was observed at a lower frequency at the top of Kazreti Tailing Dam (Fig. 7a) which justifies the homogeneity of the material used to raise the dam. The low value of resonance frequency corresponds to the Height of the tailing Dam which is about 170 m.

Fig. 6 shows the distribution of dominant frequency at the top of Kazreti Tailing Dam. Fig. 7a) b) presents one of the examples of HV curves of seismic noise measurements at the top and bottom of Kazreti Tailing Dam correspondingly.

a)

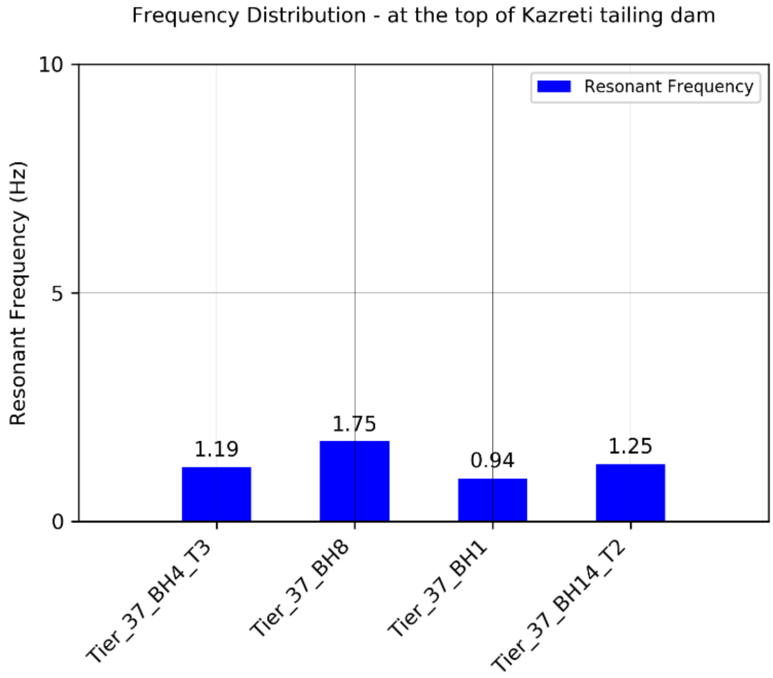
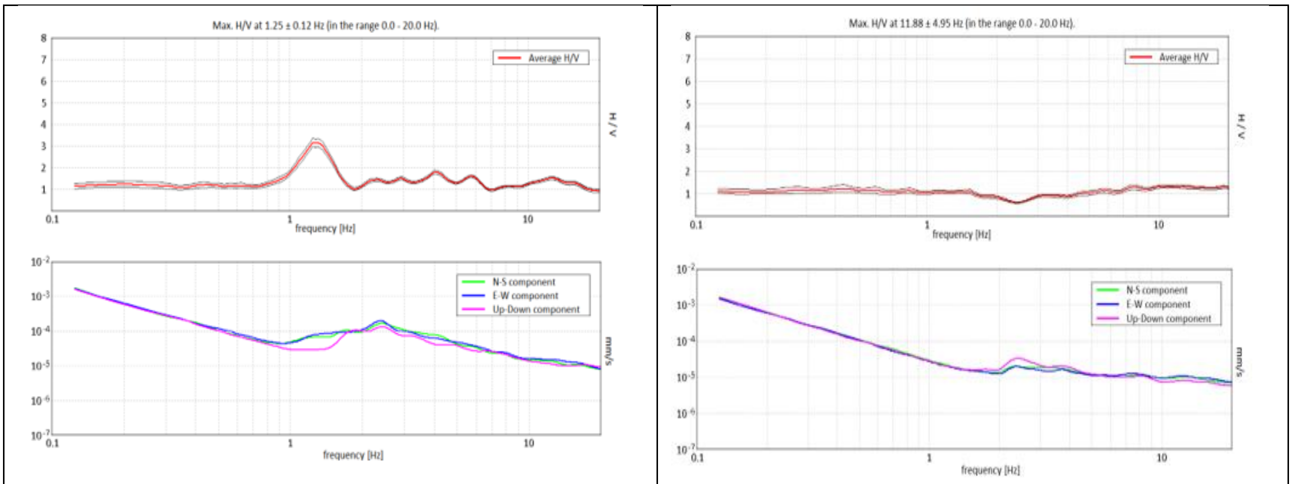


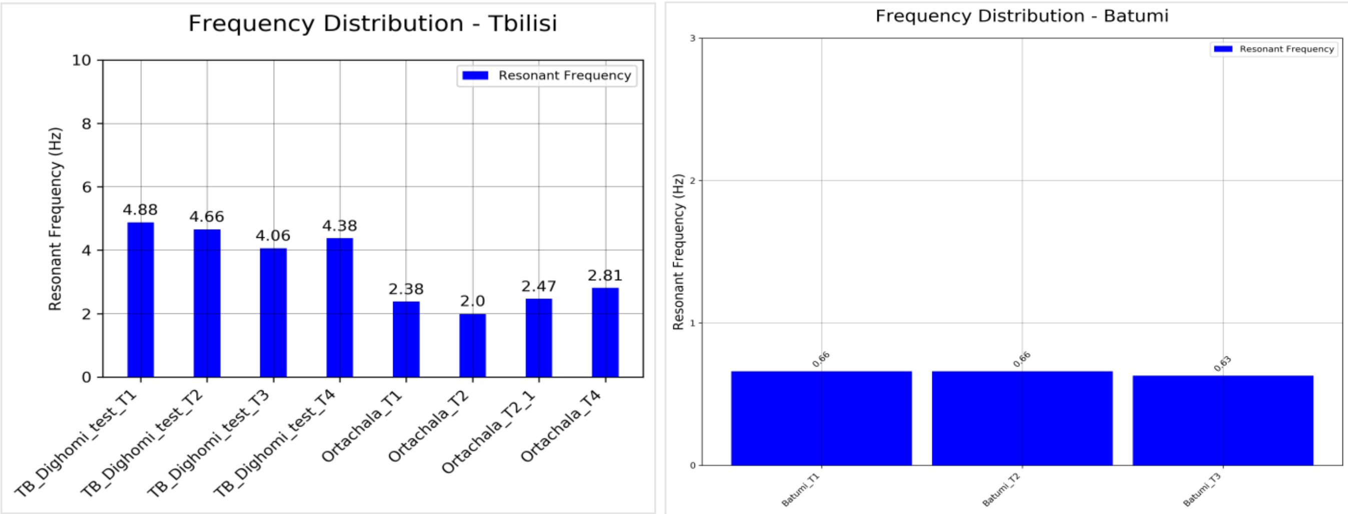

Fig. 6. Frequency Distribution at the top of Kazreti Tailing Dam




| a) | b) |
|---|---|

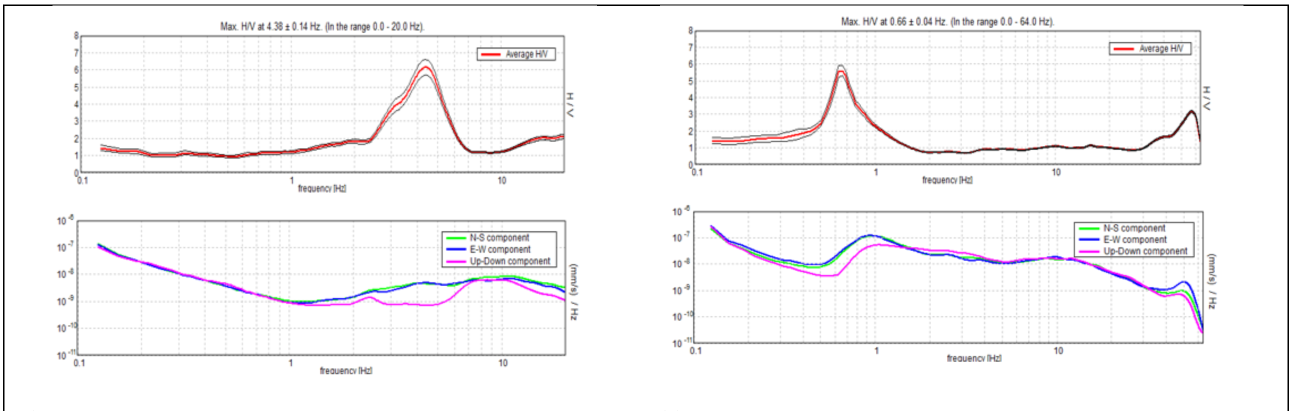
Fig. 7. a) b) HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity at the top and bottom of the Kazreti Tailing Dam correspondingly.

Below are presented the same analyses of seismic records for multi-apartment residential houses in Tbilisi and a hotel complex in Batumi. Fig. 8 a) b) presents the dominant frequency distribution for these sites and Fig. 9 a) b) HVSR curves and Fourier spectrum for investigated sites in Tbilisi and Batumi correspondingly. (Figure 10,11).




a) b)

Fig. 8. Frequency Distribution for a) Tbilisi b) Batumi




a) b)

Fig. 9 HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity (in range 0.1-20Hz) a) Tbilisi b) Batumi.

The conducted studies show that the bedrock of mountainous regions of Georgia comes to the surface because no peak is observed. However, medium frequencies were also observed in the terraced parts of these regions.

In contrast, the Batumi territory exhibited low frequencies (0.6 Hz), which suggests the presence of bedrock at considerable depths, far from the surface. Similarly, the records at the top of Kazreti Tailing Dam displayed low frequencies, indicating the uniformity of the underlying materials used to raise the dam. Seismic surveys conducted at the bottom of the Dam revealed the presence of bedrock. As a result, the mountainous regions of Georgia are characterized by high resonance frequencies, while the plains exhibit low resonance frequencies. The obtained results give us the idea to characterize areas with similar seismic response behavior in the future by collecting information from such cheap measurements as seismic noise. These findings are crucial for assessing local seismic hazards and calculating the seismic hazard of critical infrastructure in relation to ground response.

## Conclusion

Estimation dominant frequency by H/V technique is a widespread method today, though this method is being used for the first time in Georgia. Up to now, equation (1) was used to estimate the dominant frequencies of the ground theoretically when the layer's thickness and matching velocity were known from other seismic data. This approach is not justified in all cases, in particular when the environment is not one-dimensional. Also, when we have several layers, the dominant frequency of the second layer is determined by another approach. [10]

The study of resonance frequencies with seismic noise in different regions of Georgia showed us different values. In particular, the mountainous regions of Georgia are characterized by high resonance frequencies or HV curves without peak, while the plains exhibit low resonance frequencies.

Dominant frequencies are not considered in ground motion prediction equations (GMPE). Site conditions are typically represented by average shear wave velocity (Vs30), which is not enough to study local seismicity. We think that it is important to include the dominant frequency as a separate parameter in GMPE models.

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# გრუნტის თვისებების შესწავლა კრიტიკული ინფრასტრუქტურისთვის

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#### რეზიუმე

საქართველო ისევე როგორც მთლიანად სამხრეთ კავკასია, ერთ-ერთი სეისმურად აქტიური რეგიონია ალპურ-ჰიმალაის სეისმურ სარტყელში. ამიტომ სეისმური საშიშროების შეფასება მნიშვნელოვანია საქართველოსთვის. ნაციონალურ დონეზე სეისმური საშიშროების შეფასება ხდება ალბათური სეისმური საშიშროების მეთოდით, რომელიც განსაზღვრავს გრუნტის სხვადასხვა დონის რხევების წლიური გადაჭარბების ალბათობას. გრუნტის რხევები გამოსახულია რხევის პიკური და სპექტრალური აჩქარებებით. ხოლო შეფასება ხდება გრუნტის A კლასისთვის ევროკოდი 8-EN 1998-1 (1998) მიხედვით.

ლოკალური მასშტაბით, სეისმური საშიშროების დაზუსტება ხდება უბნის გეოლოგიური, გეომორფოლოგიური, გეოტექნიკური და გეოფიზიკური მახასიათებლების მიხედვით, ვინაიდან

ცნობილია, რომ შემომავალი სეისმური რხევები შეიძლება შეიცვალოს ამპლიტუდის, სიხშირისა და დროის ხანგრძლივობის მიხედვით უბნის სპეციფიკური ადგილობრივი მახასიათებლების გამო. ეს საკითხი მიკროდარაიონების მთავარი ამოცანაა.

გრუნტი ხასიათდება შემდეგი სეისმური პარამეტრებით: დომინანტური სიხშირე, Vs30 (განივი ტალღის საშუალო სიჩქარე 30 მეტრის სიღრმეზე) და გაძლიერების ფაქტორი. ამ ნაშრომში წარმოდგენილია გრუნტის კლასიფიკაცია დომინანტური სიხშირით, რომელიც მიღებულია გეოფიზიკური გაზომვებით, კერძოდ სეისმური ხმაურის ჩანაწერებით. გრუნტის მახასიათებელი ეს პარამეტრი მნიშვნელოვანია ლოკალური სეისმურობის დაზუსტებისთვის. ამ მიზნით საქართველოში პირველად იქნა გამოყენებული სეისმური ხმაურის ჩანაწერები.

**საკვანძო სიტყვები:** გარემოს ხმაური, წერტილოვანი სადგური, გრუნტის გადაადგილება, გაძლიერება, H/V ტექნიკა .

# Исследование свойств грунтов для объектов критической инфраструктуры

**Т. Шубладзе, Н. Церетели**

### Резюме

Грузия, как и весь Южный Кавказ, является тектонически и структурно сложным регионом. Она является одним из активных сегментов Альпийско-Гималайского пояса, поэтому важно оценить сейсмическую опасность для Грузии. На региональном уровне это оценивается путем применения вероятностного анализа сейсмической опасности, который определяет годовую вероятность превышения различных уровней землетрясений, определенных по интенсивности движения земли, таких как PGA или спектральные ускорения, соответствующие различным периодам повторяемости землетрясений, связанным с возможными будущими сценариями землетрясений для участка, представленного почвенными классами A в соответствии с EC8, Еврокод 8-EN 1998-1 (1998).

На местном уровне оценка сейсмической опасности осуществляется путем анализа геологических, геоморфологических, геотехнических и геофизических характеристик местности, так как хорошо установлено, что входящее сейсмическое движение может изменяться по амплитуде, частоте и длительности из-за специфических местных характеристик. Это является предметом микрозонального исследования.

Локальные характеристики конкретного участка представлены следующими параметрами: доминирующая частота Vs,30 (средняя скорость поперечной волны до глубины 30 метров) и коэффициент усиления. В этой работе мы представили результаты геофизических исследований, оценивающих местные сейсмические условия по доминирующей частоте для проектирования. С этой целью впервые в Грузии были использованы записи сейсмического шума.

**Ключевые слова:** Вибрация окружающей среды, одна станция, движение грунта, усиление, метод H/V.

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# Regarding the Spontaneous Mechanism of Atmospheric Whirlwind Generation in Narrow Mountain Canyons

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***ABSTRACT***

*In a narrow, rather deep mountain canyons, under certain conditions, an irregular thermal mechanism can be activated, leading to the spontaneous convective movement of the air mass. This effect differs from the well-known phenomenon caused by the diurnal variation of the solar heat flux in large, broad valleys, where the regular diurnal variation in the direction of onshore winds is systematically suppressed. A specific hydrodynamic picture corresponds to spontaneous convection. In particular, there is a change of direction (inversion) in the vertical profile of the horizontal movement of air along the slope of the canyon at a certain height. At that time, Ludwig Prandtl developed the theoretical model through which it is possible to analytically determine the level of velocity inversion compared to the base of the valley. At this height, due to the instability of the velocity profile, the formation of atmospheric vortexes of a certain size is likely. It is natural that the dissolution (dissipation) of such vortexes will affect the temperature field.Therefore, the breakup of whirlwinds is related to the violation of thermodynamic equilibrium, meaning that there will be an impulsive change in the meteorological regime in the local area due to the spontaneous turbulence of air masses in the areas of velocity inversion. The characteristic time of this event will depend on the duration of the temperature field disturbance. It is likely that such a location will become a dangerous opportunity for hang gliding or paragliding enthusiasts. It should be noted that this type of sport has become an important component of tourism in Georgia, particularly in the mountainous regions of the country. Therefore, there is a need to focus on ensuring the safe flight conditions of individual aircraft in narrow valleys. Their formation, among other measures, requires an assessment of the probability of the operation of a thermal mechanism causing stochastic atmospheric disturbances in narrow canyons. This task can be carried out only as a result of a special investigation, based on the monitoring of seasonal and short-term hourly indicators of the mentioned physical event in a specially selected canyon, which can be considered typical for the mountainous regions of Georgia.*

***Key woods:*** *vertical profile, velocity iinversion, turbulence, paragliding, narrow canyons.*

**Introduction.**

The Earth's atmosphere is a global, open thermodynamic system whose functioning is intricately determined by the sun. It comprises from regional and local subsystems, the existence of which is influenced by geographic factors. In mountainous regions, such as the Caucasus, these subsystems are manifested in local atmospheric configurations associated with narrow, relatively deep valleys interspersed between high ridges. While any physical system is only truly isolated in specific cases, the Earth's atmosphere, as a single, closed global system, maintains a continuous interaction with cosmic electromagnetic radiation and cosmic matter. In theory, an isolated system may exist in a thermodynamically unstable but mechanically balanced state for an extended period. Under certain conditions, a portion of the atmosphere in a mountainous region may be found in such a state, adhering to isolation criteria. These subsystems can sometimes be regarded as formations with stable thermodynamic characteristics. However, over time, their physical attributes, including the quantity of atmospheric particles, energy, temperature, and barotropic fields, inevitably undergo fluctuations under the influence of solar radiation.

**A narrow, deep valley can be conceptualized as a channel through which the air mass flows.**

It is known that, under calm atmospheric conditions, during specific periods of the year, both day and night, a disruptive convective movement of the regular air mass can occur along the ridges bordering any valley. For instance, a noteworthy example of such a low atmospheric flow is observed in the section of the Vere River valley from Bethany to Mtkvari River [1]. A suitable physical analogy for this canyon and others with similar orography is the disturbance of the slow laminar motion of the fluid caused by the interaction of relatively high walls in a rectangular channel. In the case of a canyon, as the height increases to 200-250 meters, the wind speed of concern also rises. However, its magnitude, reaching a maximum at a certain height, gradually decreases, leading to the so-called "inversion" level where the wind direction changes in the opposite direction. This effect is qualitatively similar, although potentially quantitatively different, in many narrow valleys. It is noteworthy that a convective effect similar to a spontaneously active disturbing heat source may regularly operate in some wide valleys, such as along the ridges bordering the Alazni River valley [2]. In the first case, the effect is spontaneous, occurring only rarely, while in the second case, it signifies the peculiarity of the action of a regular thermal mechanism, possibly related to the dimensions of the valley and the orography of its surface.

Under normal (calm) less cloudy natural conditions, in both cases, about half an hour after sunset, the wind flow on the mountainside takes place in the lower direction of the valley. In warm conditions, after sunrise, the wind continues to blow in the same direction for about an hour before changing from downslope to upslope. Under calm conditions, the minimum characteristic speed of such wind is (1 - 3) m/s [3]. The inversion of air mass convection speed should qualitatively develop in the same manner for all small mountain rivers. We consider the section of the Iori River valley between the extreme eastern part of the Saguramo-Ialno range and the extreme western end of the Gombor range as a suitable object for further research into this event. The choice of this canyon is due to the contrast in relief over a relatively small area: the highest place (mountain Ialno 1874 m.) and the lowest one River Iori bed at 700-750 m. This canyon overlooks the Iori Plateau, which experiences severe thermal overheating during the summer season. To the north is the Ertso depression, with an average height of 1000-1100 meters. Such a variety of terrain and landscapes determine the complexity of the formation of meteorological elements, making this place interesting for long-term research. Additionally, the Vere River canyon will be utilized for the research, where the inversion of convection speed can also be a frequent occurrence [4]. The mathematical model of this process belongs to the creator of the boundary layer theory L. Prandtl [3].

**Prandtl's model.**

According to Prandtl's model, the non-uniformity of the temperature field in the lower atmosphere is the cause of the inversion effect on the direction of air convection speed by the heat source in narrow canyons. There, this phenomenon is induced by the local orographic feature—the height of the ridges bordering the valley. Usually, the temperature of the surface of the mountain slopes in the canyon varies widely during the day and night, although air convection along the slopes of the valley occurs only under certain conditions.This analytical model is built on the basis of several simplifying assumptions. Specifically, only the developed convective movement in the vertical plane xz is considered (the x-axis is directed along the valley, z-vertically upwards). Due to the small linear scales of convective motion, the Coriolis effect is neglected. The slope of the mountain is inclined to the horizon at a rather small angle α. Directly along the ridge, there is no place for the formation of convection currents because the air mass moving at a low speed does not stop at its surface; the movement is so slow that acceleration can be neglected. Accordingly, the mathematical basis of the model consists of the simplified equations of motion ( the same signs as in [3] are used)

$$\frac{\partial p}{\partial x} = \eta \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}\right), \qquad (1)$$

$$\frac{\partial p}{\partial z} = \eta\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial z^2}\right) - g\rho, \qquad (2)$$

where $p$ is the pressure, $u$ and $w$ are the horizontal and vertical components of the velocity, $\eta$- is the coefficient of turbulent viscosity, and $g$ is the acceleration due to gravity. The temperature in the free atmosphere is assumed to increase linearly with height, and the heating slope introduces a perturbation that is a function of height.

Through ingenious mathematical transformations, in the approximation of a weakly turbulent atmosphere, where the coefficients of temperature transfer and kinematic viscosity can be assumed to be equal to each other, Prandtl demonstrated the relationship of the boundary layer on the canyon slope to the perturbation of the temperature field. In particular, as the temperature $\theta$ in the free atmosphere increases linearly with height, and the surface of the ridge slope introduces a small perturbation $\theta'$ into the temperature field, the keystone equation of the model was obtained

$$\frac{\partial^4 \theta'(n)}{\partial n^4} + \frac{g\beta B \sin^2\propto}{\nu^2}\theta'(n) = 0, \qquad (3)$$

Where $n$- is the height calculated from the slope of the canyon, $\beta$- is the coefficient of temperature expansion of air, $B = const$ - is the vertical temperature gradient, and $\nu$ is the coefficient of kinematic viscosity of air. Due to physical considerations, Prandtl used only one of the solutions of equation (3)

$$\theta' = \theta'_0 \exp\left(-\frac{n}{L}\right)\cos\frac{n}{L}, \qquad (4)$$

which satisfies the following boundary conditions [3]

$$\theta' = \theta'_0, \quad \text{when } n = 0; \quad \theta' = 0, \quad \text{when } n = \infty. \qquad (5)$$

The characteristic in the form of a vertical scale, in (4), represents the height corresponding to the maximum convection speed, which depends on the environmental parameters

$$L = \sqrt[4]{\frac{4\nu^2}{g\beta B \sin^2\propto}} \;. \qquad (6)$$

According to Prandtl, the disturbance of the temperature field along the slope of the canyon leads to the convective movement of the air mass (disturbance), the speed of which is determined by the expression

$$V_1 = \theta'_0\sqrt{\frac{g\beta}{B}} \exp\left(-\frac{n}{L}\right)\sin\frac{n}{L} \;. \qquad (7)$$

The formula (7) image provides a vertical profile of the convective movement speed. An inversion point (level) the speed changes direction (Fig.1). This concept can be envisioned as an abstraction of a tangential-discontinuity surface, where a velocity shift occurs, serving as a prerequisite for the development of Kelvin-Helmholtz or Rayleigh-Taylor hydrodynamic instability in a liquid (gas) medium. Fig.1 displays the vertical profile of convection velocity for a typical set of atmospheric parameters. The velocity profile, in addition to the inversion point, also includes the inflection point ($V_{max}$), where the development of hydrodynamic instability and the generation of atmospheric vortices are also possible.

Therefore, in the Prandtl model, the height of the velocity maximum is $n_m = \frac{L\pi}{4}$. The height of the inversion level corresponding to the first minimum of the trigonometric function ($n_m = \pi L$) are clearly defined. But we contend that the utilization of only one specific solution of equation (3) confines the potential of the Prandtl model as a tool for representing real atmospheric phenomena. Embracing the principle of synergy, the physical depiction becomes more comprehensive when considering the time-varying impact of boundary conditions, a characteristic generally inherent in atmospheric processes. This approach is recognized for enabling substantial quantitative corrections in long-term prognostic meteorological tasks. The variation of boundary conditions is anticipated to be beneficial in modeling short-term local atmospheric processes. For instance, the disturbance of the temperature field in the lower part of the Vere River Canyon, which traverses Tbilisi, is expected to be influenced not only by natural factors but also by anthropogenic pressure [4].

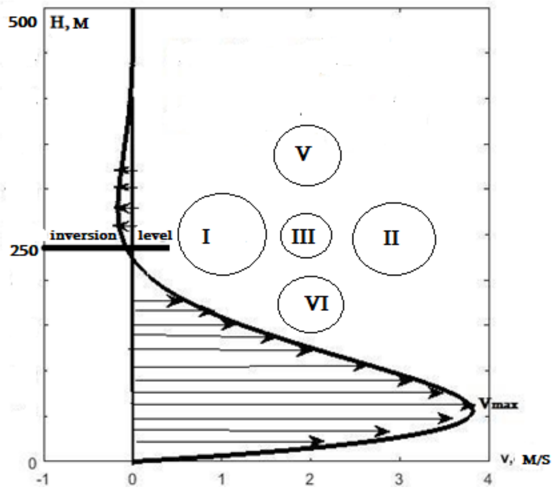

Fig. 1. Convection speed profile and atmospheric vortexes.

Therefore, to account for the urban effect on the local temperature field within the Prandtl model, a different pair of boundary conditions, distinct from (4), was employed

$$\theta' = \theta'_0 \ , \quad \text{when } n = 0 \ ; \qquad \theta' = \infty, \quad \text{when } n = \infty. \qquad (8)$$

These boundary conditions are met by the specific solution of equation (3), which also encompasses the inversion effect, and (4) differs from the image only by the sign of the power of the exponential multiplier

$$\theta' = \theta'_0 \exp\left(\frac{n}{L}\right)\cos\frac{n}{L} \ , \qquad (9)$$

to which the velocity profile also corresponds, differing from the profile in image (7)

$$V_2 = -\theta'_0\sqrt{\frac{g\beta}{B}}\exp\left(\frac{n}{L}\right)\sin\frac{n}{L} \ . \qquad (10)$$

In this case, the velocity inversion event will occur at the height $n_m = \frac{3L\pi}{4}$. Additionally, the vertical profile of convection speed will be different. Naturally, the combination of both solutions results in a change in the level of velocity inversion. However, it should be noted that, since a different model of temperature field change was used to derive equation (1), an apparent contradiction has emerged. In particular, the boundary condition (8) formally allows an unlimited increase in temperature with the increase in height

$$\theta = \theta_0 + Bz + \theta'(n). \qquad (11)$$

Therefore, it is logical to ask: Does a solution to the Prandtl problem have practical value when its asymptotic behavior does not satisfy the condition of the tube disturbance of the temperature field as height increase? It should be considered that the validity of the boundary conditions (8), like (5), is limited to small heights. If this condition is satisfied, the value of the Prandtl model as a mathematical abstraction of a physical process is further enhanced by incorporating another specific solution to equation (3).

**Temperature Field Considerations. Kinematic Model of Atmospheric Wortex.**

The vertical profile of the convection speed exhibits a critical point, enhancing the likelihood of Kelvin-Helmholtz hydrodynamic instability development at the inversion level. This results in the formation of atmospheric eddies, whose decay is associated with Rayleigh-Taylor instability. Consequently, mechanical energy transforms into thermal energy, leading to the disturbance of the temperature field in the inversion area. This factor may contribute to the disturbance of the locally balanced, but unstable, thermodynamic state. During the process of restoration, a change in the meteorological regime in the valley becomes possible, with the characteristic duration depending on the nature of the disturbance of the temperature field. In cases of strong turbulence, this process can be nonlinear, as the disturbance of the temperature field in the area of velocity inversion may trigger the "dynamo-effect," an impulsive strengthening of turbulence. Given that the generation of a chain of eddies should occur in a specific direction within limited space, the structure of the temperature field in the area of velocity inversion is likely to be non-uniform and asymmetric. In the hydrodynamic approximation, this effect can be modeled using the temperature conduction equation [5].

To simplify the mathematical problem, let's consider a stationary atmospheric vortex of cylindrical or spherical shape. In the case of a cylinder, its symmetry axis is collinear with the x-coordinate. Let's examine the intersection of the vortex with the xz plane and utilize the polar coordinate system, where the stationary equation for temperature conduction takes the following form

$$V_r \frac{\partial \overline{T}}{\partial r} + V_\varphi \frac{1}{r}\frac{\partial \overline{T}}{\partial \varphi} = \eta\left[\frac{1}{r^2}\frac{\partial^2 \overline{T}}{\partial \varphi^2} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \overline{T}}{\partial r}\right)\right], \qquad (12)$$

where $\overline{T}$ - is the temperature, $\eta$ -is the temperature conductivity coefficient, $V_r$ ,$V_\varphi$ - are the radial and azimuthal components of velocity.

Assuming that the perturbation of the temperature field depends linearly on the radial coordinate: $\overline{T} = \frac{r}{R_0}T(\varphi) + T_0$, where $T_0$ - is a constant on the vortex boundary: $r=R_0$ for any φ. Such a representation of the search function allows us to use the so-called separation method of variables to solve (12) in the Karman scheme. Since we will observe the cross-section of the unstable vortex with the directed plane of its axis, the following kinematic model of non-uniform rotation is suitable to represent the velocity field [6]

$$V_r = \frac{1}{2}u_0\left(\frac{r}{R_0}\right)(\cos\varphi + \sin\varphi),\; V_\varphi = u_0\left(\frac{r}{R_0}\right)(cos\,\varphi - sin\varphi). \qquad (13)$$

where $u_0$- is the characteristic linear speed of rotation.

Model (13) satisfies the environmental continuity equation and offers a correct scheme for the decomposition of an unstable vortex [6]. Utilizing this model, (12) is transformed into a non-linear equation

$$\frac{d^2T}{d\varphi^2} - \frac{u_0 r^2}{\kappa R_0}(\cos\varphi - \sin\varphi)\frac{dT}{d\varphi} = -\left[1 - \frac{u_0 r^2}{2\kappa R_0}(\cos\varphi + \sin\varphi)\right]T\,. \qquad (14)$$

The equation (14) involves an non dimensional combination: $\delta = \frac{u_0 r^2}{\kappa R_0}$, which, like the parameters Reynolds number and Prandtl number, can be referred to as the criterion of thermohydrodynamic similarity. This implies that, owing to the presence of this characteristic, the solution of equation (14) is universal within certain limits for vortexes with different sizes and speeds.

Equation (14) belongs to the type of second-order differential equations with variable coefficients

$$y'' + f(\varphi)y' + g(\varphi)y = 0\,. \qquad (15)$$

In general, obtaining an analytical solution for equation (15) is challenging due to its non-linear nature, making approximate solutions more feasible. Depending on the nature of the problem, various simplifying assumptions are employed. One such assumption is embodied in the kinematic model (13), allowing the representation of the velocity field without explicitly solving the equation of motion. For instance, in a paper [5] modeling the temperature field in the polar ionosphere, the kinematic model (13) facilitated the use of the Wetzel-Kramer-Brillouin (VKB) method to approximate the solution of equation (14). It is known that equation (15), by introducing a new variable

$$y = z(\varphi) \cdot p(\varphi), \qquad (16)$$

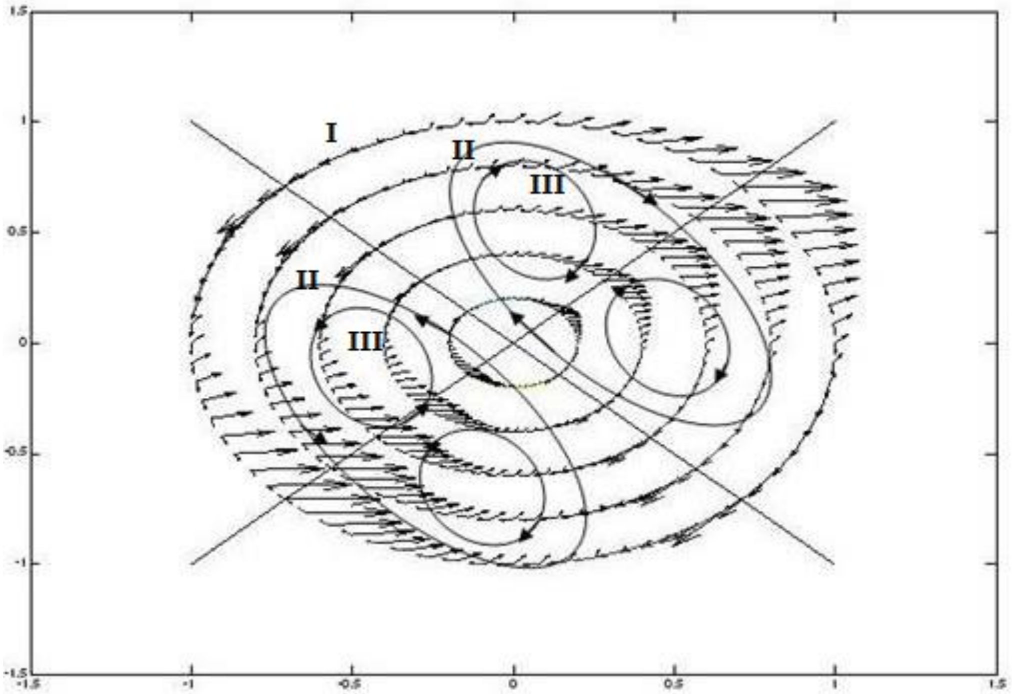


Fig. 2. The dissipation of normalized vortex according to the non-uniform rotation model.

can be transformed into an oscillation equation with a variable coefficient [7]

$$\frac{d^2 z}{d\varphi^2} + h(\varphi) z = 0, \qquad (17)$$

Where $h(\varphi) = \dfrac{P'' + fP' + gP}{P}$,

$$P = e^{-\frac{1}{2}\int f(x)dx}, P' = -\frac{1}{2} f e^{-\frac{1}{2}\int f(x)dx}, P'' = -\frac{1}{2} f' e^{-\frac{1}{2}\int f(x)dx} + \frac{1}{4} f^2 e^{-\frac{1}{2}\int f(x)dx}. \qquad (18)$$

The prime in formulas (18) signifiers the derivative by φ. Particularly in case the equation (14) we will have

$$P = e^{-\frac{1}{2}\int f\varphi d\varphi}, \ f(\varphi) = \delta(\sin\varphi - \cos\varphi), \ h = 1 - \frac{\delta^2}{4}(1 - \sin 2\varphi) - \frac{3\delta}{4}(\cos\varphi + \sin\varphi). \qquad (19)$$

The solution of equation (17) obtained by the VKB method is accurate when $\delta < 1$ and $h > 0$, which does not qualitatively limit the value of the model in terms of its physical significance [7]. However, depending on the boundary conditions of the problem, the approximate analytical solution can take different forms.

Let's estimate the value of the parameter $\delta$, for which we use the maximum characteristic speed of atmospheric convection related to the action of the spontaneous heat source: $V_0$ = (3-5) m/s and the value of the air temperature conductivity coefficient at normal atmospheric temperature $\eta \approx 2.10^{-5}$ $m^2/s$. For example, suppose that the initial size of the atmospheric vortex generated in the area of velocity inversion is: $R_0 \approx$ 10m and the characteristic size of small vortex cells obtained after its decay is: $r \approx 5.10^{-3}$ m. In such a case, we will have: $\delta \approx$/0.4-0.6/, which means that the first criterion for using the VKB method is satisfied. For such values of the parameter $\delta$, in any $\varphi$ case, the second criterion is also satisfied- $h > 0$. Thus, assuming that the initial temperature of the air at the boundary of the atmospheric vortex $T_0$ =const, the approximate analytical solution of equation (14) for the dimensionless temperature: $T' = \bar{T}/T_0$ in general can be represented by the following expression

$$T' = 2\frac{r}{R_0}\left(\frac{e^{-\frac{1}{2}\int f d\varphi}}{h^{1/4}}\cos\left(\int \sqrt{h} d\varphi\right)\right) + 1. \qquad (20)$$

The formula (20) provides a reasonably accurate model representation of the asymmetric temperature field, qualitatively capturing the dissipative nature of the process of disintegration of non-uniform atmospheric vortexes.

## Conclusion

1**.** According to the formula (20), local change of the structure of atmospheric movement should be accompanied by a perturbation of the atmospheric temperature field, the scale of which should depend on the size of the velocity inversion. This observation is crucial for determining the approximate time and thermodynamic conditions of the generation of gyral formations in narrow canyons, with potential implications for the safety of activities like hang gliding or paragliding. To meet this demand, it becomes essential to assess the probability of the development of dangerous atmospheric events characteristic of narrow deep canyons, particularly referring to the convective movement of air caused by the action of an irregular heat source, which can be the reason for the generation of gyral formations.

2. Monitoring conducted under natural conditions demonstrates the effectiveness of the Prandtl model and its modification, theoretically allowing the formation of atmospheric vortexes at the level of convection velocity inversion. The kinematic model of non-uniform rotation provides a qualitative representation of the mechanism of the process of generation and decay of atmospheric vortexes. With its help, the disturbance of the atmospheric temperature field can be modeled using a specific solution of the temperature conduction equation.

3. Beyond theoretical interpretation, there is a natural need to quantify the results of the spontaneous convection effect in the canyons. Long-term monitoring of atmospheric vortexes and temperature fields in a specific canyon, such as the section of the Iori River valley between the extreme eastern part of the Saguramo-Ialno ridge and the extreme western end of the Gombor ridge, is expected to contribute to solving this task.

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# ვიწრო მთიან კანიონებში ატმოსფერული გრიგალების გენერაციის სპონტანურ მექანიზმთან დაკავშირებით

ზ.კერესელიძე, გ.ლომინაძე, ე.სალუქვაძე, ე. ჭანია

## რეზიუმე

ვიწრო, საკმაოდ ღრმა მთის ხეობებში (კანიონებში) გარკვეულ პირობებში შეიძლება ამოქმედდეს არარეგულარული სითბური მექანიზმი, რომელიც გამოიწვევს ჰაერის მასის სპონტანურ კონვექციურ მოძრაობას. ეს ეფექტი განსხვავებულია კარგად ცნობილი ეფექტისაგან, რომელსაც იწვევს მზის სითბური ნაკადის დღეღამური ცვლილება დიდ, ფართო ხეობებში, სადაც სისტემატურად დაიმზირება მიწისპირა ქარების მიმართულების რეგულარული დღეღამური ცვლილება. კერძოდ, კანიონის ფერდის გასწვრივ ჰაერის ჰორიზონტალური გადაადგილების სიჩქარის ვერტიკალურ პროფილში გარკვეულ სიმაღლეზე ადგილი აქვს მიმართულების ცვლილებას (ინვერსია). ლუდვიგ პრანდტლის მიერ აგებული იყო თეორიული მოდელი, რომლის საშუალებით შესაძლებელია ანალიზურად განისაზღვროს სიჩქარის ინვერსიის დონე ხეობის ფუძესთან შედარებით. ამ სიმაღლეზე, სიჩქარის პროფილის არამდგრადობის გამო, სავარაუდოა გარკვეული ზომის ატმოსფერული გრიგალების წარმოქმნა. ბუნებრივია, რომ ასეთი გრიგალების დაშლა (დისიპაცია) გამოიწვევს ტემპერატურული ველის შეშფოთებას. ამიტომ, გრიგალების დაშლა დაკავშირებულია თერმოდინამიკური წონასწორობის დარღვევასთან, რაც თვისობრივად ნიშნავს, რომ ლოკალურ არეში მოხდება მეტეოროლოგიური რეჟიმის იმპულსური ცვლილება, სიჩქარის ინვერსიის ადგილებში ჰაერის მასების სპონტანური ტურბულიზაციის გამო. სავარაუდოა, რომ ასეთი ადგილები სახიფათო შეიძლება გახდეს დელტაპლანით ან პარაპლანით ფრენის მოყვარულთათვის. ამიტომ, არსებობს აუცილებლობა ყურადღება გამახვილდეს ვიწრო კანონებში ინდივიდუალური საფრენი აპარატების უხიფათოდ ფრენის პირობების უზრუნველყოფაზე. ამ ამოცანის განხორციელება შესაძლებელია მხოლოდ სპეციალური გამოკვლევის შედეგად ისეთ კანიონში, რომელიც თავისი მახასიათებლებით ტიპიურად შეიძლება ჩავთვალოთ საქართველოს მთიანი რეგიონებისათვის.

**საკვანძო სიტყვები:** ვერტიკალური პროფილი, სიჩქარის ინვერსია, ტურბულენტობა, პარაპლანერიზმი, ვიწრო კანიონები

# О спонтанном механизме генерации атмосферных вихрей в узких горных ущельях

**З. Кереселидзе, Г. Ломинадзе, Е. Салуквадзе, Э. Чания**

## Резюме

В узких, достаточно глубоких, горных ущельях (каньонах) в определенных условиях может придти в действие нерегулярный тепловой механизм, который может вызвать спонтанную конвекцию воздушных масс. Это явление отличается от хорошо известного эффекта, который считается следствием суточного изменения солнечного теплового потока в больших, широких, ущельях, в которых систематически наблюдаются регулярные изменения направления приземных ветров в течение суток. В частности, вдоль склона ущелья в вертикальном профиле на определенной высоте может иметь место изменение направления горизонтальной составляющей скорости ветра (инверсия). Людвиг Прандтль построил теоретическую модель, при помощи которой можно аналитически определить высоту уровня инверсии относительно основания ущелья. На этой высоте, из-за неустойчивости профиля скорости, существует вероятность возникновения атмосферных вихрей различных размеров. Естественно, что распад этих вихрей (диссипация) будет возмущать температурное поле, с которым будет связано нарушение термодинамической устойчивости. На качественном уровне это означает, что в области инверсии скорости возможно локальное изменение метеорологического режима из–за спонтанной турбулизации воздушных масс. Можно предполагать, что такие места могут стать опасными для любителей полетов на парапланах и дельтапланах. Поэтому, существует необходимость обращения должного внимания на обеспечение условий безопасности полетов на индивидуальных летательных аппаратах в узких ущельях. Реализация такой задачи возможна лишь после специальных исследований в одном из ущельи, характеристики которого можно считать типичными для горных регионов Грузии.

**Ключевые слова:** вертикальный профиль, инверсия скорости, турбулентность, парапланеризм, узкие каньоны.

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# On the Issue of Generation of Hydrodynamic Waves in the Shovi Gorge (Georgia) due to a Collapse on Glacier Tbilisa

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***ABSTRACT***

*The occurrence of a glacial mudflow in the Shovi gorge on August 3, 2023 was caused by a destructive process on the Tbilisa glacier. Based on the existing picture of the spread of the mudflow, it is possible to carry out an analysis regarding the rheological qualities of the water-saturated soil mass that forms its basis. It is also possible to approximately estimate the parameters of various types of hydrodynamic waves, the generation of which was probably possible during the propagation of the debris flow. It seems that such a problem can be satisfactorily solved only in the case of a correct assessment of the values of dimensionless criteria for the flow of debris flow, which are convenient quantitative characteristics that simplify the analysis of the qualitative consequences of applying the principle of hydrodynamic similarity. For example, in the case of approximating the bed of a debris flow with a rectangular channel, you can use the results of well-known analytical solutions obtained under simplifying assumptions that are valid for certain intervals of variation in the Reynolds and Froude similarity numbers. In particular, in the shallow water approximation, in the case of sufficiently large Reynolds numbers, when the fluid flow is highly turbulent, the Froude parameter allows one to fairly correctly simulate changes in the flow regime that occur as a result of the generation of hydrodynamic waves. The negative effects that often accompany the process of propagation of wave disturbances largely depend on the type of these waves. Therefore, in the case of a mudflow in the Shovi gorge, it seems quite realistic, for example, the generation of the so-called rolling hydrodynamic waves, which could well have been among the probable causes that determined the catastrophic scale of the tragic event.*

***Key words:*** *glacier, debris flow, hydrodynamic waves, Reynolds number, Froude number*

## Introduction

A glacial debris flow descending from any glacier can be represented either as a heterogeneous liquid or as a water-containing solid mass moving in a mountain gorge or on a flat area (Fig. 1). The occurrence of a glacial mudflow in the Shovi gorge on August 3, 2023 was caused by a destructive process on the Tbilisa glacier. When analyzing the probable causes of this phenomenon, the lack of sufficient observational data seems obvious. Therefore, it is impossible to unambiguously judge the nature of the processes that took place on this glacier over the past decades and predetermined the catastrophic event, which has tragic consequences. Therefore, at this time, it is only possible to approximately imagine a fairly complete picture of the spread of the mudflow along the gorge of the Bubistskali and Chanchakhi rivers, which are an integral part of the Shovi gorge.

## Glacial flow in Shovi gorge.

In any case, the movement of the glacial flow obeys the laws of hydrodynamics, in particular, the Navier-Stokes equation. Known that, depending on the viscosity properties, the liquid medium may belong to the usual Newtonian, or to the so-called rheological fluid (Bingham fluid). In particular, pure water is a Newtonian fluid, but a debris flow, which is a mixture of water with solid particles and ice fragments, is considered a suspension.

Fig. 1. a) general view of Shovi disaster, b) debris-flow brake area in Shovi valley

Such a medium belongs to the class of viscoplastic (pseudoplastic) Bingham fluid with a characteristic coefficient of plastic viscosity: $\eta \approx /10^9 - 10^{10}/$ Pa.s. Unlike water, Bingham fluid always has an initial shear stress $\tau_0$, which is in the functional dependence $\tau = f(\beta)$ on the deformation rate $\beta = (\frac{\partial \xi}{\partial t})$, where $\xi$ is the magnitude of linear deformation. The nature of this dependence qualitatively changes from nonlinear to linear with increasing parameter β. In this case, pseudoplastic viscosity is transformed into dynamic viscosity, i.e. Bingham fluid acquires the qualities of an ordinary Newtonian fluid. Therefore, for the shear stress the following equation becomes valid:

$$\tau = \tau_0 + \eta\beta. \qquad (1)$$

Among the special qualities of a Bingham fluid that distinguishes it from a Newtonian fluid, one should highlight its ability to maintain a spatial structure after braking on a solid surface. However, the immobile state can only last up to a certain point. It may be disrupted due to the appearance of any factor causing the movement of the viscoplastic medium [1]. In particular, such a factor usually turns out to be an increase in the angle of inclination of the fluid flow channel to the horizon φ. In this case, the shear force of the viscoplastic mass can exceed the force of surface friction with the bottom of the channel. For example, according to information received from direct eyewitnesses of the catastrophic event in Shovi, the mudflow in the lower part of the Shovi gorge acquired sufficient viscoplastic qualities necessary for its braking after collapsing on the glacier Tbilisa for about 20-25 minutes.

It is known that for mathematical modeling of the movement of a liquid medium, certain sets of dimensionless hydrodynamic parameters are used, to estimate the value of which the coefficient of dynamic viscosity of the liquid is the cornerstone characteristic. In an ordinary liquid, the coefficient of dynamic viscosity determines the degree of turbulence of the flow, i.e. its value may vary depending on the flow regime. In the case of a viscoplastic suspension, the dynamic viscosity coefficient is transformed into a plastic viscosity coefficient. Consequently, until a mudflow with suspended solid particles retains the qualities of an ordinary liquid, the distribution of the solid fraction of the mudflow along the channel of movement will largely depend on dynamic viscosity.

**Mudflow with variable rheology.**

The movement of a heterogeneous fluid in a gravity field along an inclined channel approximating a river bed is a physical analogue of the spread of a mudflow along a mountain gorge. The mathematical problem of studying various fluid flows is associated with solving the Navier-Stokes equation. In general, such an operation is impossible. Therefore, simplifying assumptions that are valid for a specific problem are usually used. This method often allows one to obtain a completely correct analytical solution, valid when postulating certain qualities of a moving liquid medium. One of these areas of research is turbulent flows in channels of various geometries and associated hydrodynamic instabilities that generate periodic wave processes. It is known that waves arise in both ordinary and rheological fluids. For example, the flow of liquid of any rheology in channels at sufficiently large angles of inclination of its bottom can become unstable, as a result of which waves of various types can be generated. An important parameter of these waves is their amplitude, i.e. height, which only in some special cases can be determined analytically by solving the well-known Burgers equation [2]. However, for a general idea of the process of propagation of waves similar to those that probably occurred in the mudflow in the Shovi gorge, one can use a more simplified analysis based on the well-known solutions of shallow water equations [3]. In this approximation, in the case of fluid motion in a rectangular channel, after the standard transformation of the Navier-Stokes equations and the continuity of the medium to a dimensionless form, two similarity numbers appear: the Reynolds number and the Froude number. These dimensionless criteria are determined using the hydrodynamic parameters of fluid flow and the linear characteristics of the channel [4]. The Reynolds number determines the flow regime, which for a rapid fluid flow will necessarily be turbulent. In this case, in an ordinary liquid, depending on the value of the Froude number, various waves can be generated. In a viscoplastic medium, which has a different rheology, wave motions can be no less diverse than in an ordinary liquid. For example, in a mixing inhomogeneous fluid, waves arise as a result of the development of instability due to a velocity shift in layers with different densities. A similar effect can also arise due to a restructuring of the flow structure in a rheological fluid, when inhomogeneous layers with large velocity and density gradients appear in it. In any case, the presence of such textures in a liquid medium allows us to simplify the problem of mathematical modelling of waves by introducing a certain small parameter, which is the ratio of the channel depth to the wavelength and serves as a quantitative criterion for the validity of the shallow water approximation. Although such a model significantly simplifies the equations of hydrodynamics, mathematical complications may arise associated with the nonlinearity of waves, the manifestation of which obviously depends on the rheology of the liquid.

At sufficiently large Reynolds numbers, the nonstationary equations of shallow water in a one-dimensional approximation, when moving on an inclined plane with turbulent fluid friction at the bottom of the channel, have the form [5]

$$\frac{\partial}{\partial t}h + \frac{\partial}{\partial x}(hu) = 0,$$

$$\frac{\partial}{\partial t}(hu) + \frac{\partial}{\partial x}\left(hu^2 + \frac{gh^2}{2}\cos\varphi\right) = gh\sin\varphi - C_w\ u^2, \qquad (2)$$

where $h$, $u$ - are the average depth and velocity of the fluid; $g$ - acceleration of free fall force; $\varphi$ – channel inclination angle; $C_w$ - is the friction coefficient, which for simplicity is considered constant. The first equation means the continuity of the medium, the second determines the movement in an inclined channel.

After the standard transition to dimensionless variables and flow parameters, the system of equations (2) takes the form [4]

$$\frac{\partial}{\partial t}h + \frac{\partial}{\partial x}(hu) = 0,$$

$$\frac{\partial}{\partial t}(hu) + \frac{\partial}{\partial x}\left(hu^2 + \frac{h^2}{2}\right) = \alpha h - u^2 \quad , \qquad (3)$$

where $\alpha = tg\varphi/C_w$ — is the only dimensionless parameter that determines the flow. If the movement of a uniform fluid flow in a channel with a normal depth $h_0$ is realized, then the Froude number of such a flow will be determined by the parameter α associated with the Froude number: Fr= $\sqrt{\alpha}$ .

In the shallow water approximation, the Froude number makes it possible to classify hydrodynamic waves, the generation of which is possible at sufficiently large Reynolds numbers, when the flow is highly turbulent. In particular, in the case of approximating a debris flow bed with a rectangular channel, one can use the results of well-known analytical and numerical solutions obtained for certain types of hydrodynamic waves. To do this, let us estimate the characteristic intervals of change in the values of the indicated hydrodynamic similarity numbers: Reynolds number Re=$\frac{u_0 d}{\eta}$, where $u_0$ is the characteristic velocity value, $d$ is the channel width, $\eta$- is the kinematic viscosity coefficient; Froude number Fr=$\frac{u_0}{\sqrt{g h_{0 \cos\varphi}}}$, where $h_0$ – is the normal (characteristic) channel depth. It has been proven that the flow in the channel becomes unstable at Fr > 2 ($\alpha$ > 4). For example, the characteristic speed of the mudflow and the parameters of the Shovi gorge: $u_0$= /10-20/ms$^{-1}$ ,d= /40-60/m, $h_0$ =/8-10/m, $\alpha$=5$^0$. For water containing an admixture of solid particles, η≈/1-10/10$^{-6}$ m$^2$s$^{-1}$. Consequently, we will have characteristic intervals of change in the indicated dimensionless parameters of hydrodynamic similarity: Re≈/4-12/ 10$^7$ and Fr≈/1-2.2/. The large Reynolds number means that the degree of turbulation of the flow in the main part of the Shovi gorge was critically high. It is also likely that the local value of the Froude number in some places of the gorge could go beyond the characteristic interval, for example, due to a change in the depth of the flow or a decrease in its speed. There is also no doubt that at times the mudflow changed its rheological properties under the influence of various factors that actively influenced the movement of the medium. This effect could probably be especially noticeable in the last, widest section of the gorge, where the viscous plastic nature of the mudflow was fully appeared. In this place, the distribution of the mudflow mass was completely similar to the movement of a viscous plastic medium with a low (≈20%) water content. Particularly interesting is the question of the nature of wave motions, the spectrum of which can be represented by the results of some solutions to the shallow water equations, as well as by data from laboratory experiments [4]. In this case, the Froude number is obviously the parameter that serves as a quantitative criterion that distinguishes between different types of long hydrodynamic waves, the generation of which is possible in the shallow water approximation [13]. Thus it is obvious that the generation of waves of various types is directly dependent on the value of the Froude number. Let us consider this issue in more detail, for which we can use the following classification:

1) $0.3 \leq Fr \leq 0.5$. This range of Froude number values for the case of a mudflow propagating along the Shovi gorge is unlikely. It is more typical for a channel of finite depth, along the bottom of which a liquid flows with a higher density than in the surface layer. It is known that with such a flow structure in a non-uniform fluid, can be generated so-called gravitational (density) waves;
2) $0.9 < Fr < 1.1$. According to the Kadomtsev-Petviashvili equation, for such Froude numbers, when the influence of factors of linear dispersion, nonlinearity and spatial effects is balanced, the generation of solitons (solitary waves) is possible. The probability of the existence of such a balance necessary for the emergence of solitons, as well as the conditions necessary for the generation of gravitational waves, is probably quite low. However, despite the stringency of the condition, it is impossible to completely exclude the possibility of the propagation of solitons and, especially, gravitational waves during a catastrophic phenomenon in the Shovi gorge;
3) $Fr \leq 2$. For such Froude numbers, according to the shallow water equations, as a result of the effect of turbulent friction between the mudflow mass and the bottom of the channel is possible generation so-called linear rolling waves. For waves of this type, the critical value is Fr=2, which determines the threshold for the development of linear instability and a noticeable increase in the wave amplitude;
4) $Fr > 2$. At a sufficiently large Fr, a nonlinear stage of increasing flow instability develops in the liquid. This case corresponds to a certain critical depth of the channel in which the hydrodynamic pattern of a turbulent flow arises. In highly turbulized liquids, so-called depression waves, as well as rolling waves with hydraulic jumps, which contribute to a change in flow regime from supercritical to subcritical;

5) 2 < Fr < 6. In a turbulent flow, a modulation effect of traveling packets of nonlinear rolling waves, averaged within certain spatial and temporal scales, may occur. Such a specific wave effect in the Shovi gorge could arise in those places where there was a sharp increase in the value of the local Froude number.

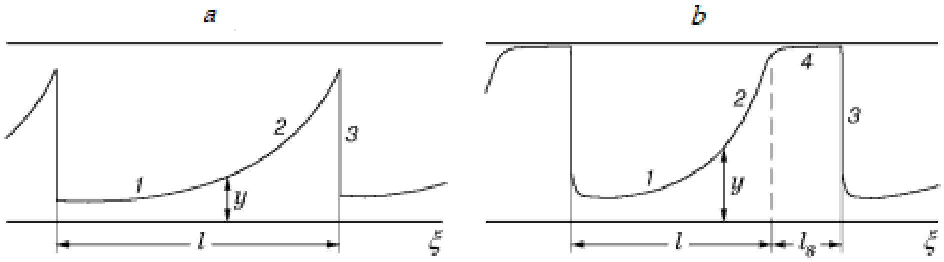


Fig.2. rolling waves

It is obvious that among the considered waves of various types, from the point of view of reconstructing the picture of the propagation of the mudflow in the Shovi gorge, rolling waves are of the greatest interest. In [4], the solution to the system of equations (3), depending on the variable $\xi = x - Dt$ ($D$ - wave speed), is considered. A feature of such wave solutions is the presence of a smooth section of the wave trajectory, indicating the transition between subcritical flow and supercritical flow (sections 2, 1 in Fig. 2a). This site is determined relative to the coordinate system moving at wave speed $D$ and indicates the presence of a hydraulic jump (section 3 in Fig. 2a), which converts the supercritical flow into a subcritical one. Therefore, an important parameter characterizing rolling waves is their critical depth y, at which the determinant of the system of equations (3): $\Delta = h - (u - D)^2$, becomes zero. Hence, when $h = y$, $u = u_c$ when the condition is

$$\Delta_c = y - (u_c - D)^2 = 0 \qquad (4)$$

the equations of stationary waves take the form

$$h(u - D) = y(u_c - D),$$

$$\frac{\partial}{\partial \xi}\left(h(u-D)^2 + \frac{h^2}{2}\right) = \alpha h - u^2 = F. \qquad (5)$$

Of physical interest are waves propagating to the right ($D > u > 0$). In the vicinity of the critical depth, the determinant ($\Delta$) changes sign ( site 4 on Fig. 2,b). A necessary condition for the existence of a continuous solution to the second of equations (5) is that the right-hand side vanishes at $h = y$

$$\alpha y = u^2 \qquad (6)$$

Due to condition (4), (6) as well as the condition $D > u_c$, the following expressions are valid

$$u_c = \sqrt{\alpha y} \quad , \quad D = y^{1/2}\left(1 + \sqrt{\alpha}\right), \quad u = D - y^{3/2}/h = y^{1/2}\left(1 + \sqrt{\alpha} - 1/z\right. \quad , \qquad (7)$$

From expression (5) it follows that the value $\frac{\partial h}{\partial \xi}$ is a function of the variable z, where $z = h/y$.

$$\frac{\partial h}{\partial \xi} = \frac{F}{\Delta} = (\alpha z^2 - (1 + 2\sqrt{\alpha} - {}^{1}/_{z}) + 1)/(z^2 + z + 1)\,. \qquad (8)$$

Thus, in a coordinate system moving with speed *D*, the flow downstream from the critical point should be supercritical ($\Delta < 0$), and upstream - subcritical ($\Delta > 0$). This requirement follows from the stability conditions of a hydraulic jump that transforms a supercritical flow into a subcritical one.

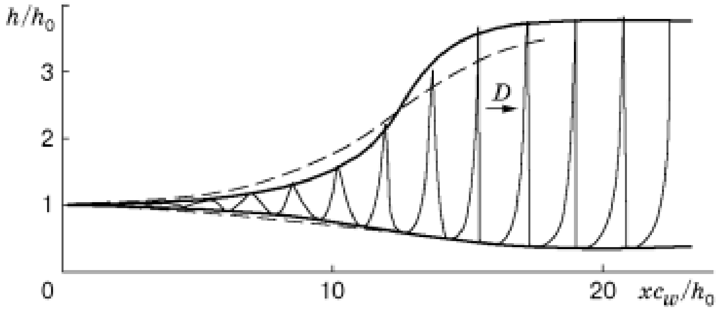


Fig.3. results of numerical calculations on the evolution of a rolling wave packet

As an example of what can happen to a wave packet as the Froude number increases, we can use the result of numerical simulation. Figure 3 corresponds to the theoretical picture of the evolution of a packet of modulated rolling waves when Fr=5. According to a computer experiment, the generation of waves in a flow of inhomogeneous fluid occurred as a result of a nonlinear increase in small disturbances, the initial amplitude of which was ≈1% of the normal channel depth $h_0$. The maximum amplitudes that were recorded in the corresponding laboratory experiment turned out to be significantly less than the theoretical ones [4]. Nevertheless, the qualitative nature of the growth in the amplitude of the wave packet, which initially had an exponential character, was confirmed. However, after the traveling wave passed a certain distance, the increase in amplitude stopped. It turned out that for a developed turbulent flow the average values of the minimum depths satisfy the inequality: $\frac{xC_w}{h_0} \leq 10$. It is believed that Small disturbances grow exponentially along the channel until the wave parameters reach the boundary of the hyperbolicity region of the system of shallow water equations, after which the growth of the wave amplitude stops and the flow becomes quasiperiodic. The thick lines show the distribution of the average values of the maximum and minimum wave depths along the channel over many periods. Note that the average values of the minimum wave depth in a developed flow, determined in a laboratory experiment and as a result of non-stationary numerical calculations, are in good agreement. At that time, the corresponding experimental values of the maximum amplitude turned out to be significantly less than the analytically determined theoretical amplitudes. Therefore, it was concluded that equations (1) do not convey the true structure of waves during their breaking, i.e. in case of hydraulic jumps.

**Conclusion**

Thus, during the propagation of the mudflow in the gorge of the Bubistskali and Chanchakhi rivers, which are an integral part of the Shovi gorge, hydrodynamic waves of various types could exist. In the range of values of the Froude hydrodynamic similarity number corresponding to the mudflow bed in the Shovi Gorge, the generation of traveling rolling waves, the height of which could reach several meters, should be considered most likely. The appearance of solitary waves (solitons), as well as the so-called gravitational waves were unlikely, but the possibility of their generation in places where local conditions were suitable cannot be ruled out. In the lower, widest section of the Shovi gorge, in the so-called zone cottages, the movement of the mudflow mass was hydrodynamically similar to the movement of the ice mudflow in the gorge of the Genaldon River, which occurred after the collapse on the Kolka glacier in 2002 [6]. In particular, despite the huge difference in the initial volumes of glacial mudflows that descended from the Tbilisa and Kolka glaciers, the thickness of viscous plastic sediments in the last flat areas of their distribution, taking into account the difference in covered areas, turned out to be comparable. Obviously, this is due to the same type of braking of the viscoplastic debris flow at the stage of its final stop, which is also indicated by a decrease in wave amplitudes within /1-3/ m (Fig.1b)

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# მყინვარ თბილისაზე ჩამოქცევის გამო შოვის ხეობაში (საქართველო) ჰიდროდინამიკური ტალღების წარმოქმნის საკითხთან დაკავშირებით

## ზ. კერესელიძე, ნ. ვარამაშვილი

### რეზიუმე

2023 წლის 3 აგვისტოს შოვის ხეობაში მყინვარული ღვარცოფის გაჩენა თბილისის მყინვარზე მომხდარმა დამანგრეველმა პროცესმა გამოიწვია. ღვარცოფის გავრცელების არსებული სურათიდან გამომდინარე, შესაძლებელია ანალიზი ჩატარდეს მის საფუძველის, წყალით გაჯერებული ნიადაგის მასის, რეოლოგიურ თვისებებთან დაკავშირებით. ასევე შესაძლებელია დაახლოებით შეფასდეს სხვადასხვა ტიპის ჰიდროდინამიკური ტალღების პარამეტრები, რომელთა წარმოქმნა, სავარაუდოდ, შესაძლებელი იყო ღვარცოფული ნაკადის გავრცელების დროს. როგორც ჩანს, ასეთი პრობლემა დამაკმაყოფილებლად შეიძლება გადაწყდეს მხოლოდ ღვარცოფული ნაკადის უგანზომილებიანი კრიტერიუმების მნიშვნელობების სწორი შეფასების შემთხვევაში, რაც მოსახერხებელი რაოდენობრივი მახასიათებლებია, რომლებიც ამარტივებს მსგავსების პრინციპის გამოყენების ხარისხობრივი შედეგების ანალიზს. ჰიდროდინამიკური მსგავსება. მაგალითად, ღვარცოფული ნაკადის კალაპოტის მართკუთხა არხით აპროქსიმაციის შემთხვევაში, შეიძლება გამოყენებული იქნას ცნობილი ანალიტიკური ამოხსნების შედეგები, რომლებიც მიღებულია გამარტივებული დაშვებებით, რომლებიც მოქმედებს რეინოლდსის და ფრუდის მსგავსების რიცხვების ცვალებადობის გარკვეული ინტერვალებისთვის. კერძოდ, მეჩხერი წყლის მიახლოებისას, საკმარისად დიდი რეინოლდსის რიცხვების შემთხვევაში, როდესაც სითხის ნაკადი ძალზე ტურბულენტურია, ფრუდის პარამეტრი საშუალებას იძლევა საკმაოდ სწორად მოახდინოს დინების რეჟიმის ცვლილებების სიმულაცია, რაც ხდება ჰიდროდინამიკიური ტალღების წარმოქმნის შედეგად. უარყოფითი ეფექტები, რომლებიც ხშირად თან ახლავს ტალღური შეშფოთებების გავრცელების პროცესს, დიდწილად დამოკიდებულია ამ ტალღების ტიპებზე. ამიტომ შოვის ხეობაში ღვარცოფის შემთხვევაში საკმაოდ რეალისტურად ჩანს, მაგალითად, ე.წ. მგორავი ჰიდროდინამიკური ტალღები,

რომლებიც შეიძლება იყოს იმ სავარაუდო მიზეზთა შორის, რომლებმაც განსაზღვრეს ტრაგიკული მოვლენის კატასტროფული მასშტაბები.
**საკვანძო სიტყვები:** ყინვარი, ღვარცოფი, ჰიდროდინამიკური ტალღები, რეინოლდსის ნომერი, ფრუდის ნომერი.

# К вопросу о возникновении гидродинамических волн в ущелье Шови (Грузия) в результате обвала ледника Тбилиса

**З. Кереселидзе, Н. Варамашвили**

**Резюме**

Возникновение гляциальной сели в ушелье Шови 3.08.2023 года было вызвано разрушительным процессом на леднике Тбилиса. По имеющейся картине распространения селя, можно провести анализ относительно реологических качеств водонасыщенной грунтовой массы, составляющей его основу. Можно также приблизительно оценить параметры различных типов гидродинамических волн, генерация которых вероятно была возможна в процессе распространения селевого потока. Представляется, что такая задача может быть удовлетворительно решена только в случае корректной оценки величин безразмерных критериев течения селевой массы, являющихся удобными количественными характеристиками, упрощающими анализ качественных следствий применения принципа гидродинамического подобия. Например, в случае аппроксимации русла селевого потока прямоугольным каналом, можно воспользоваться результатами известных аналитических решений, полученнннных при упрощающих допущениях, справедливых для определенных интервалов изменения чисел подобия Рейнольдса и Фруда. В частности, в приближении мелкой воды, в случае достаточно больших чисел Рейнольдса, когда поток жидкости является сильно турбулентным, параметр Фруда позволяет достаточно корректно моделировать изменения режима течения, происходящие в следствие генерации гидродинамических волн. От типа этих волн в значительной степени зависят негативные эффекты, часто сопровождающие процесс распространения волновых возмущений. Поэтому, в случае селевого потока в ушелии Шови, вполне реальной представляется, например, генерация т.н. катящихся гидродинамических волн, которые вполне могли оказаться среди вероятных причин, определивших катастрофические масштабы трагического события.

**Ключевые слова:** ледник, селевой поток, гидродинамические волны, число Рейнольдса, число Фруда.

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# The Geography of Risks of Breakthrough of Glacial Lakes and Valleys

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***ABSTRACT***

*Against the background of climate warming, various natural events are frequent. One of them is floods, which occur when drowned lakes that are damaged by many factors break through. Such events are common during the advance and retreat of glaciers. The resulting dammed lakes differ from each other in their strength, duration, character and other properties. The result of floods has mostly a negative impact on the surrounding area in the glacier valley. There are examples of both processes in Georgia, and their results are always negative, so their study and some kind of systematization is necessary to properly manage the expected natural event to avoid the catastrophic consequences of overflowing floods.*

***Key words:*** *Dam floods, breakthrough, glacier, drowned lake, dammed lake, mudflow.*

## Introduction

Many catastrophic events related to climate warming (including in Georgia [1-4]) have become more frequent in the modern world. All of them are sensitive and by their nature represent a threat to the surrounding area as well as to the inhabitants. One of the catastrophic events in the background of climate warming is the action of glaciers, which has been going on for years in the mountainous part of Georgia. Glaciers are characterized by pulsations, during which they periodically advance or retreat. In both cases, the process is noteworthy because of their action, it is possible to create dammed lakes and their sudden breakthrough. Also important are the depressions and breakthroughs on the negative forms on the glaciers, or in the depressions under the tongue. In both cases, defining the perspectives of avoiding the consequences of expected floods is important for the sustainable development of the mountainous part of the country.

## Materials and methods

The data are searched and marked according to the multi-year materials, which are given both in the studies of the Institute of Hydrometeorology and in the National Environment Agency. The data of dammed lakes and their morphometric parameters in the individual studies of the authors refer to the breakthrough of dammed lakes and the occurrence of marginal waterfalls. Also, to analyze such processes in the world.

## Results

The active reduction of glaciers in the world started in 2006 and continues to this day. In any case, the process of their retreat and advance is dangerous for the breakthrough of glacial dammed lakes. Almost all mountainous countries in the world have similar processes. Their active and modern management is available to most developed countries, because the state structures are actively involved in the implementation of budgetary protection mechanisms. A similar type of engineering is not achievable in developing countries.

Such countries are India, Pakistan, Andean countries. Losses are also recorded in the Cordillera and Alps. The process of melting, which is taking place on the glaciers today, causes the quantitative increase of the glacial lakes. However, it should also be noted that if the warming continues, there will be no more glaciers, which will reduce the risks of events related to frozen lakes in mountainous regions. However, the disappearance of glaciers represents a separate ecological disaster. [5,6] As for Georgia, disasters arising from the breakthrough of glacial lakes have always occurred over the years. Moreover, according to the risks of this disaster, our country ranks 26th in the world (Fig. 1) [5]

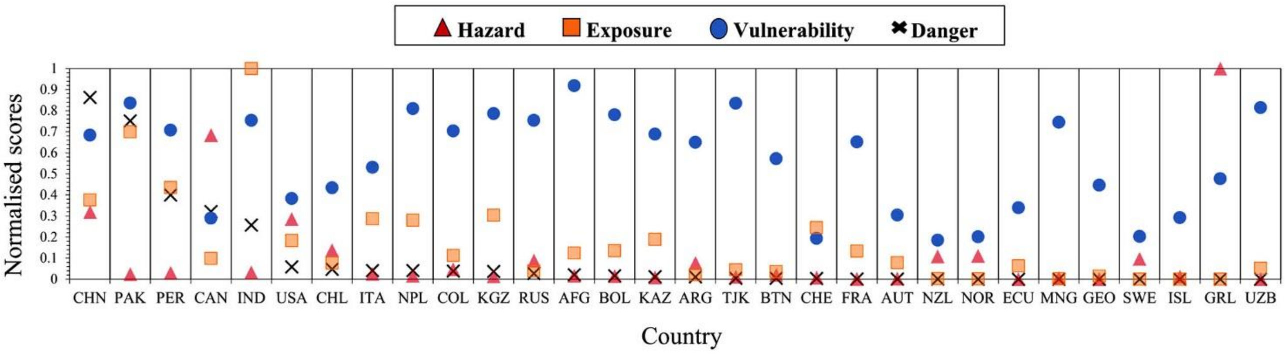


Fig. 1. Final normalised scores of GLOF lake conditions ('hazard'), exposure, vulnerability, and danger for each country, rdered from highest danger score (left) to lowest (right).

Such examples in history are known under the name of "Kazbeg fall". In the glaciation area of the glacier, pulsation occurred on the Devdorak glacier in 1776, 1785, 1808, 1817, 1832, 1842 and 1854. The glacier advanced catastrophically by 3-5 km. The valley was covered with ice, moraines and gravel. Numerous ice crevasses and subglacial voids appeared. Water accumulated, strengthening the condition of the advancing glacier. There were cases when the process of melting of ice dams lagged the accumulation of water. Water collected in negative landforms; Ice dams were breached due to heavy subsidence, which was followed by waterfalls. The strongest catastrophic flood occurred on August 20, 1832. The rapid waterfall (40-50 m/s) brought down the 15 million m3 volume of debris. who seized the river. Tergi in Dariali valley, village Below Gveleti, 2 km long, 90-100 m thick. The river stopped for 4 hours. pattern flow. Dagubda water: volume 20-25 million m3, depth 80-90 m, the breakthrough of which was followed by a catastrophic flood. During the last policing on Dedvdorak, the same processes were repeated in 2017.

An example from the past is also the glacial bath from the Kazbegi glaciation. Here, at the beginning of June 1909, on the left side of the glacier, Mt. Bagna (4048 m) was cut off by a huge southern slope, which fell in the form of a rock-avalanche at an altitude of 3550-3560 m above the glacial bath, occupying its entire 350-400 m wide surface [7-9]. The 1.82 km long tongue was actually cut off. The stability of the ice bath was broken. A network of fissures of various lengths, depths and widths, intra-ice and sub-ice voids appeared; As a result of the accumulation of water, many small open and closed lakes appeared. On June 6, 1909, the dams were breached as a result of the flooding, which was followed by a glacial flood. river In the Chkheri valley, the village suffered a lot of damage. To Gerget, the military road was cut off. After 2 hours, the dam broke, and the stream of water came down in the form of a waterfall.

An example of the retreat of the glacier is also the natural event that occurred on Mna in 1953, which occurred on the moraine lake of the same name located on the tongue of the glacier. The main factor was atmospheric precipitation (127 mm). during which the glacial dam could not withstand the water; broke through and caused a dam flood. river Mnaskhevi was covered with a 4-5-meter-high embankment of debris from the flood.

Unfortunately, on August 3, 2023, Md. A natural disaster also occurred in Bubisskali valley. When a rock-avalanche broke off to the west of the Buba glacier, which collided with the glacier. According to the research of the National Environmental Agency of the LSI, the rock-avalanche caused the collapse of a certain part of it, which caused the overflow of subglacial water masses, after which the generated flow began to move at a high speed in the bed of the valley (Fig. 2, 3).

Fig. 2. Buba Glacier and the birthplace of a rock avalanche
Fig. 3. Glacial mudflow in Buba river valley, near Chanchakh river

The dynamic rocky material and part of the glacial mass transformed into a glacial mudflow flood bordering the waterfall in the upper part of the valley. The high-speed flow in the bed, in the middle and lower part of the valley, caused the base of the slopes to be washed away, activating coastal landslides. Unfortunately, 33 people who were in the Shovi resort lost their lives in the disaster. (Fig. 4)

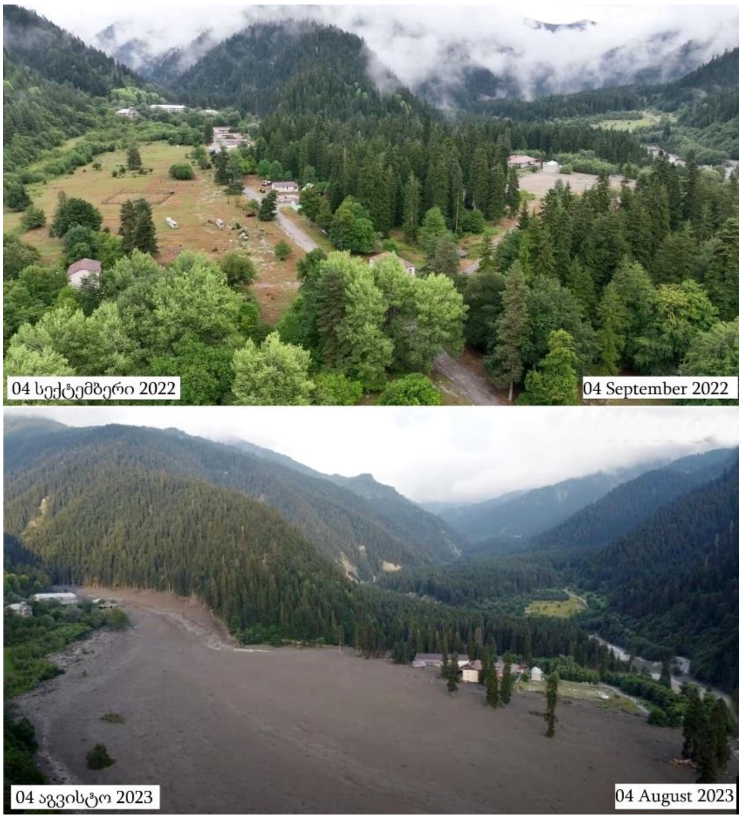


Fig. 4. The photo shows the Shovi resort before the disaster in 2022 and after August 3, 2023.

Based on these examples, when glaciers move back and forth, they leave behind the debris they brought, so-called end moraines. (Fig. 5) Negative landforms also appear, where water collects and forms morainic lakes. That's why it's important to control them. Lakes on glaciers were studied according to cartographic and remote sensing. Studies have shown that they are widespread in the nival-glacial zone of the Western Caucasus, occupying insignificant areas (from 100 to 10,000 $m^2$), depth (from 0.5 to 10 m) [10-12].

Fig. 5. A glacial lake on a glacial moraine, southern slope of the mountain Mkinvartsveri (2023)

They are placed at the end of the glacier tongue or directly in the glacier. Their variability is different from year to year, as the retreat and melting of glaciers, as well as atmospheric precipitations change their condition. Therefore, each of them is notable for its morphometric properties. which include: (Table 1)

Table 1. Morphometric Characteristics of Glacial Dammed Lakes

| Ordinal Number | Short description of the lakes location | Height of location (in meters) | Height of lake (in meters) | Area (A) | | Principal Morphometric Parameters and Coefficient | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | The lenght of the lake (in meters) | Watershed basin | Development Coefficient of Watershed basin $K=F/f$ | Development Coefficient of Shoreline Length $c=0,28\ l/\sqrt{f}$ | Streching $C_1=l/\acute{B}= L^2/f$ | Compactness $C_2=\acute{B}/B$ |

As a result of such processes, the lakes that arise and do not form are potentially dangerous objects for the territory and the population in the mountainous area.

## Conclusion

Determination of mitigating aspects of the occurrence of natural hazards and natural hydrometeorological events is one of the important aspects for the state stability of the country. Especially when worldwide efforts are being made to eliminate climate warming. At the 28th UN Climate Change Conference in November 2023, the main issue at the world leaders' summit was global warming, which was held in Dubai, United Arab Emirates. Where the involvement of all states was noted to find new alternative solutions to climate problems in order to protect the natural and public environment. Therefore, it is important to manage hydro-meteorological events, to know the disasters that happened in the territory of our country, both in the past and in the modern period. We need to do their statistics, data recording, methods, forecasting and analysis. It is necessary to perform works that include:

1. Complete study of climatic recorders (materials of the day, month, year);

2. In the event of recurrence of floods, determining their inundation areas, zoning them on geo-informational and general geographic maps, as well as planning and drawing up risk assessment maps;
3. Monitoring, such as expeditionary monitoring on existing hydrological channels, in potentially dangerous valleys, which is possible by organizing a hydrological checkpoint;
4. Control of melting in the glacier tongue and ablation-accumulation zone. In addition, monitoring of the depressions, grottoes, doors, cirques and so-called In the area of glacial lakes.
5. Warning of the population;
6. Design implementation of existing hydro-engineering structures in potentially dangerous areas, including drainage devices, which will periodically empty the glacial lake during the melting of water.
7. An early warning system that determines the critical limit of glacier and river levels; Radar measurements along the glacial valley and its adjacent areas.

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# მყინვარებზე არსებული დაგუბებული ტბებისა და ხეობების გარღვევის რისკების გეოგრაფია

ს. გორგიჯანიძე,  გ. ჯინჭარაძე. მ. სილაგაძე, ი. ჭინჭარაული

**რეზიუმე**

კლიმატური დათბობის ფონზე ხშირია სხვადასხვა სტიქიური მოვლენები. ერთერთი მათგანი არის ნაზღვლევი წყალმოვარდნები, რომელთაც ადგილი აქვთ მრავალი ფაქტორის მიერ დაგუბებული ტბების გარღვევის შემთხვევაში. ასეთი მოვლენები ხშირია მყინვარების წინ წამოსვლისა და უკან დახევის დროს. წარმოშობილი დაგუბებული ტბები ერთმანეთისაგან განსხვავდებიან თავიანთი სიძლიერით, ხანგრძლივობით, ხასიათით და სხვა თვისებებით. წყალმოვარდნების შედეგი კი უმეტესად უარყოფითად აისახება მყინვარის ხეობაში მიმდებარე ტერიტორიაზე. საქართველოში ორივე პროცესის მაგალითები არსებეოს და შედეგებიც მუდამ უარყოფითია, ამიტომ მათი შესწავალ და ერთგავრი სისტემაზიაცია აუცილებელია, რადგან მოსალოდნელი სტუიქიური მოვლენა სწორად ვამრთოთ, რათა თავდიან ავიცილოთ ნაზღვლევი წყალმოვარდნების კატასტროფული შედეგები.

**საკვანძო სიტყვები:** ნაზღვლევი წყალმოვარდნა, გარღვევა, დაგუბებული ტბა, მყინვარი, ღვარცოფი

# География рисков прорыва ледниковых озер и долин

**С. Горгиджанидзе, Г. Джинчарадзе, М. Силагадзе, И. Чинчараули**

**Резюме**

На фоне климатического потепления часто происходят разные стихийные явления. Завальные паводки, которые имеют место из-за переполнения озер вследствии различных факторов. Такие явления являются частыми во время движения ледников взад и вперед. Возникшие бассейны озер отличаются друг от друга мощностью, продолжительностью и другими характерными свойствами. Следствия завальных паводков отрицательно влияют на прилегающие территории ледниковых ущелий. В Грузии налицо примеры этих процессов и результаты всегда отрицательные. Поэтому, их изучение и систематизация являются обязательными для того, чтобы правильно управлять стихийным бедствием и избежать следствия завальных паводков.

**Ключевые слова:** Завальные паводки, прорыв, ледник, запруженное озеро.

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# Comparative Analysis of Earth's Climate and Solar and Geomagnetic Activities

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***ABSTRACT***

*This paper investigates the intricate relationship between solar activity and Earth's climate and geomagnetic activity, utilizing data spanning from 1974 to 2021. Analyzing monthly averaged measures such as Wolf number, total solar irradiance (TSI), global ocean temperature anomalies (GOTA), and Ap index of geomagnetic disturbances, we employ various methods including linear correlation analysis, recurrence quantification analysis (RQA), and cross wavelet transform (XWT). The study reveals a periodically varying correlation between TSI and GOTA with periodicity of approximately 12 years, emphasizing the intricate interplay between solar activity and climate. The recurrence plots and RQA unveil periodicity and phase transition after 1995. XWT also show multifrequency transient event ocurring in 1996. Collectively these findings suggest that the transient event might be related to the phase transition around this time period in the studied system.*

***Key words:*** *Sun-Earth connections, solar activity, ocean temperature, Wolf number, RQA, correlation analysis, cross wavelet analysis.*

## Introduction

Solar activity plays a pivotal role in governing various phenomena associated with space weather. The intricate processes occurring on the sun not only influence space weather dynamics but also exert a significant impact on Earth's climate. This is why the study of solar activity and Sun-Earth interactions is important. Previous results were obtained in the paper [1] and the present article is an extension of the initial research.

The characterization of solar activity relies on indices designed to quantify its various facets. One such index is wolf number [2] which is related to number of sunspots on the visible surface of the Sun by the formula $R=k(10G+N)$ where N is the number of sunspots, G is the number of sunspot groups and k is correction coefficient. Its dynamic range spans from 0 to 450 within a 24-hour period.

There also exists another solar activity index called total solar irradiance (TSI) [3], which is the flux of solar electromagnetic radiation measured at 1 A.U. (Astronomical Unit) distance and integrated over all wavelengths [4,5]. In SI units TSI is measured in $Wm^{-2}$.

The Ap index [6] is a daily measure for magnetic activity of Earth's magnetic field. It is derived from K-index, integer ranging from 0 to 9 that describes disturbance in the horizontal component of the magnetic field. Ap is calculated by converting three-hour K-values into a simpler scale called the a-index, and then averaging eight of these a-values for the day. The Ap index, as an averaged planetary A-index, provides a helpful picture of geomagnetic conditions.

We also use global ocean temperature anomalies (GOTA) [7] as climate data. All given datasets are plotted in figure 1.

The study [8] employed wavelet coherence analysis to reveal an in-phase resonance oscillation between TSI and sunspot number (SSN), with SSN identified as a primary driver for TSI's periodic variation. Additionally, intermittent resonance periodicity was observed in the 2–6 month band during the maximum time of solar cycles, indicating a more complex and unsteady relationship.

Wavelet coherence analysis was also used to explore the relationship between TSI and the atlantic multidecadal oscillation (AMO) [9]. The results reveal significant coherence between TSI and AMO, providing insights into the long-term variations of surface temperature and their connection to solar activity cycles. The paper emphasizes the importance of understanding this coherence for improved comprehension of recent climate changes and enhancing long-term forecasting.

**Analysis methods**

From the group of statistical tools, we use linear correlation analysis, which determines the time dependance of correlation coefficient between two time series within a window of fixed length sliding forward in time. Correlation coefficient varies from -1 to 1. This analysis was performed on pairs of time series: 1) TSI and temperature and 2) TSI and wolf number.

Recurrence quantification analysis (RQA) is used to study complexity of a system. Along with the construction of the recurrent diagram quantitative measurements are evaluated: recurrence rate (RR), determinism (DET) and entropy (ENTR) [10].

Cross wavelet transform (XWT) introduced in [11] is an extension of the continuous wavelet transform applied to two different time series simultaneously. It allows the exploration of common power and phase relationships between the two series in the time-frequency space. The XWT helps identify whether specific features in one time series are consistently related to features in another series, providing insights into potential causal relationships or shared influences. Wavelet coherence (WTC) also introduced in [11] is a measure that quantifies the degree of coherence or correlation between two time series across different scales (frequencies) and times. It is derived from the XWT. While XWT reveals areas of common power, WTC provides a more refined analysis by indicating not only the presence of common power but also the consistency or phase locking of this power over time. WTC is particularly useful for uncovering locally phase-locked behavior between the two time series, indicating whether their oscillatory patterns are synchronized or correlated at specific frequencies and time intervals.

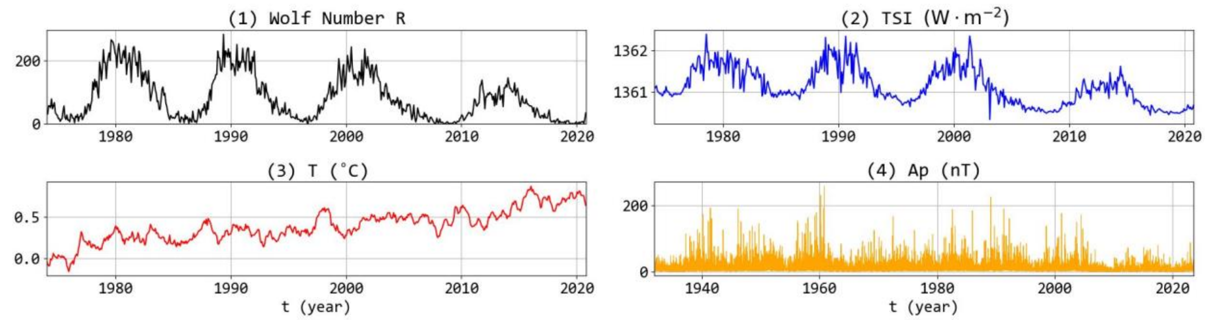


Fig. 1. (1) wolf number, (2) TSI, (3) GOTA, all averaged monthly and (4) daily Ap index.

**Results**

Linear correlation analysis of Fig. 4(2) reveals a periodically varying correlation between TSI and GOTA, accompanied by a linearly decreasing trend. The observed period oscillation in correlation spans approximately 12 years, while the trend slope registers at around -0.01 years$^{-1}$.

Fig. 4(4) shows strong correlation of above 0.6 between TSI and wolf number. Furthermore, in 1983 correlation starts to increase to levels above 0.75. Around this time, the 11-year solar activity begins to enter a new minimum. Recurrence diagram of TSI and wolf number in Fig. 2(1,2) shows that they both have periodic and noisy components. After about 2000 years, the black areas on both recurrence diagrams become larger, which is related to the beginning of the activity minima [12].

The DET for monthly Wolf number is close to 1. Evolution of TSI's DET shows that TSI is more deterministic during solar activity minima. we can conclude this if we observe DET in Fig. 2(4). Its value is lower during 1980-1990 and increases after 2000. From recurrence plot in Fig. 2(2) one can see that periodicity in the system is regular from time range of 1974 – 1995 and then also from 2005 – 2020, however these two time ranges do not appear to produce regular recurrence patterns with each other (bottom right and top left quarters of the plot). Together with this, white narrow and short vertical lines around year 1996 in the bottom left quarter of the plot indicate that some sort of phase transition has occured roughly around 1996.

Cross wavelet analysis shows that wolf number and TSI are coherent in different time regions and on different time scales. Especially, the modes with a period of about 11 years have the longest coherence. In addition, for the given time range of 1974 – 2021, phase difference between the modes of the 11-year period is constant and not equal to 0. Arrow orientation in figures 4 indicates phase difference. This means that there is a delay between the main periodic activity of the Sun and its radiation measured on Earth. There are less time intervals and scales of coherence for TSI and GOTA. they are given in Fig. 3(2).

In all coherence plots in Fig. 3 except Fig. 3(2) pronounced horizontal line with period of 3.2 years starting from 1970 and ending at 1994 can be seen. Furthermore multifrequency oscillations are observed during the end of this time range, especially on Fig. 3(1), indicating transient behavior, which is close to the phase transition point seen on the recurrence plot Fig. 2(2).

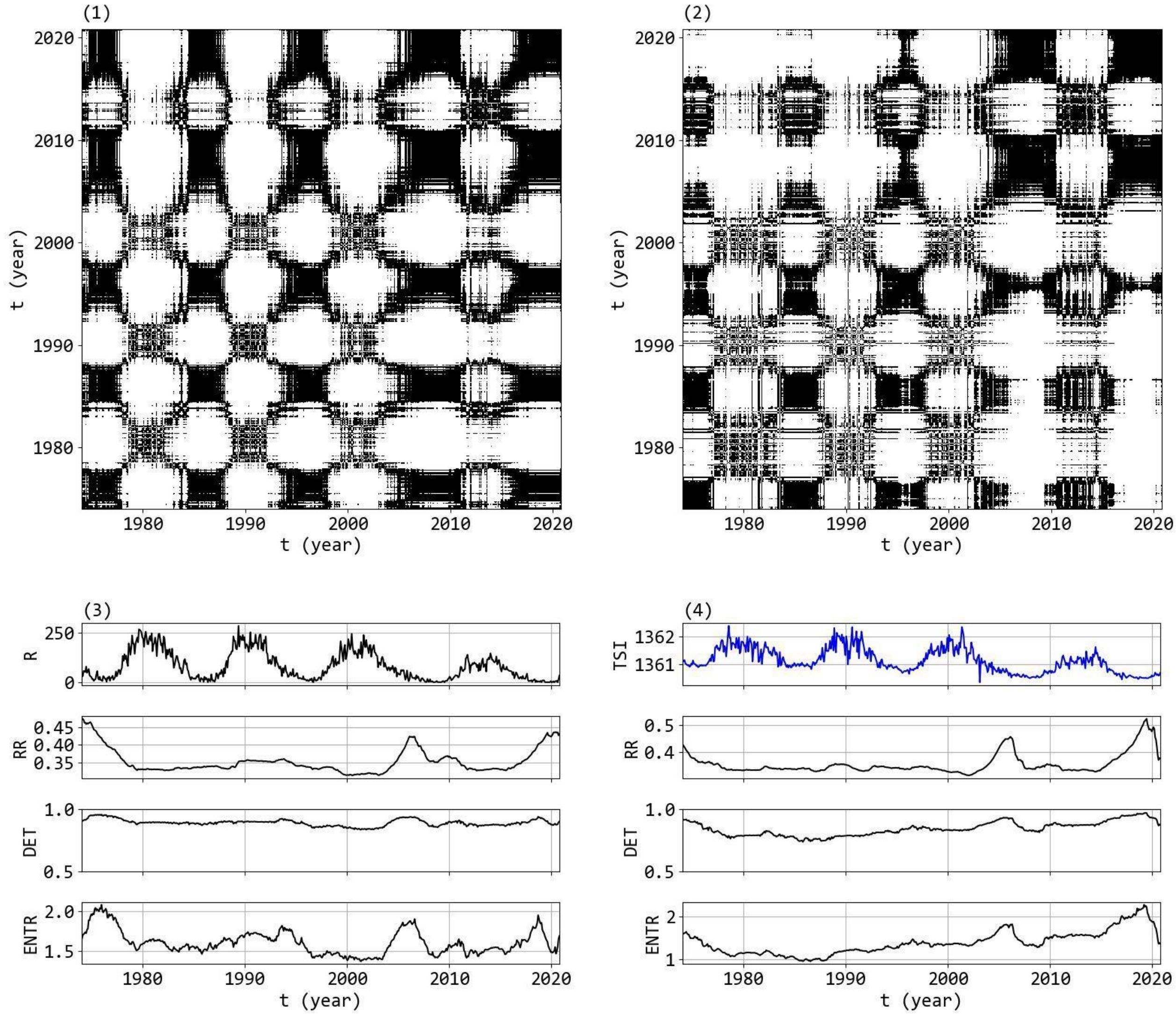


Fig 2. (1) - (2) Recurrence diagrams of wolf number and TSI. (3) - (4) Dynamics of RQA measures generated from (1)-(2). The window size is 10 years.

## Conclusions

Correlation analysis of solar activity and Earth temperature data shows that correlation between them changes with a period of about 12 years and also decreases linearly. For the given time period (1974-2021) correlation between TSI and wolf number is positive and increases after 1983. RQA of wolf number and TSI shows that the determinism of wolf number is close to 1 and the determinism of TSI starts to increase after 1990. TSI and wolf number are characterized by high coherence and their main 11-year activity modes has constant nonzero phase difference.

The recurrence plots unveils a regular periodicity in the system during the time spans of 1974–1995 and 2005–2020. However, intriguingly, these two periods do not exhibit regular recurrence patterns with each other. With further features on the recurrence plot for 1996 this suggests a phase transition occurring during that time. Coherence plots reveal a pronounced horizontal line with a 3.2-year period, extending from 1970 to 1994. Towards the end of this timeframe, multifrequency oscillations indicate transient behavior closely aligned with the observed phase transition in the recurrence plot. These findings collectively suggest that some sort of transient event cause a phase transition in the studied system.

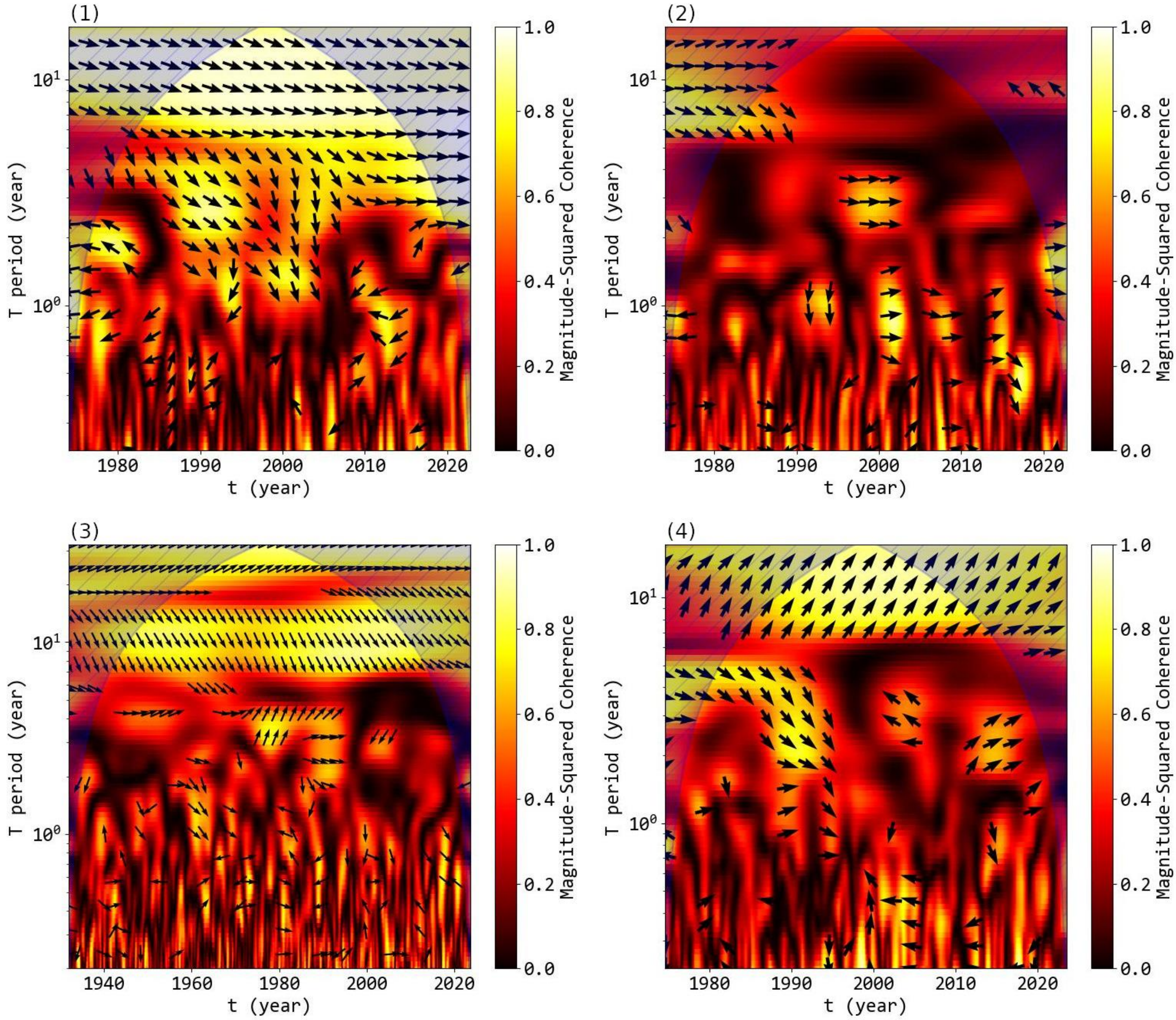


Fig. 3. (1) Wavelet coherence between wolf number and TSI, (2) TSI and GOTA, (3) Wolf number and Ap index and (4) TSI and Ap index.

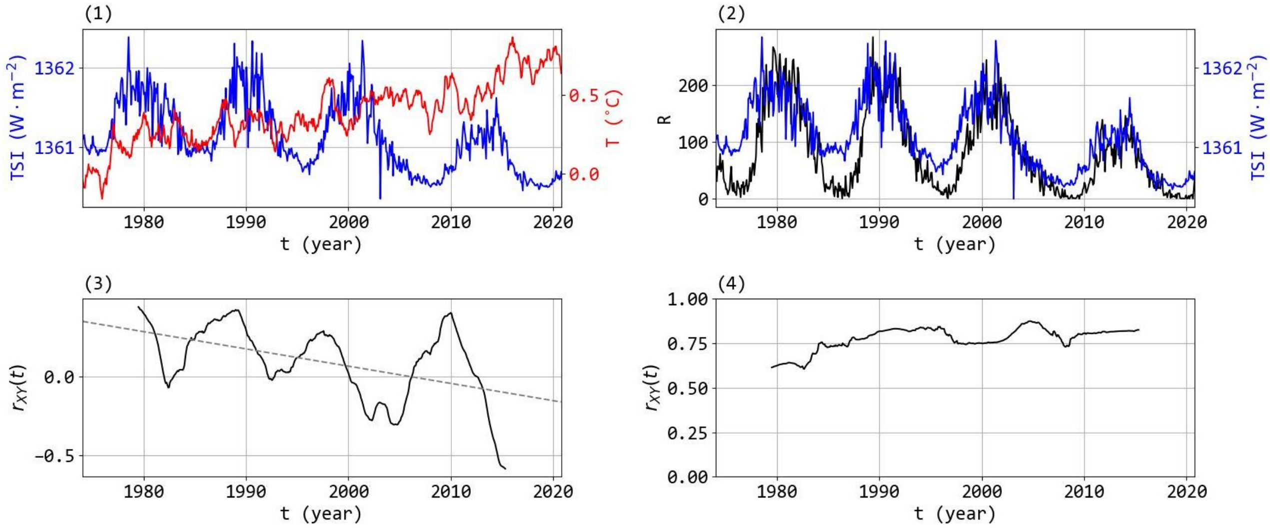


Fig. 4. (1) Monthly data of TSI and GOTA. (2) Monthly data of wolf number and TSI. (3) Evolution of correlation between TSI and temperature and its linear trend (dashed gray line). The window size is 11 years. (4) Evolution of correlation between wolf number and TSI. The window size is 11 years.

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# დედამიწის კლიმატის, მზისა და გეომაგნიტური აქტივობების შედარებითი ანალიზი

ლ. ბურდილაძე, ა. ღურჭუმელია, ო. ხარშილაძე

## რეზიუმე

ამ ნაშრომში გამოკვლეულია მზის აქტივობას, დედამიწის კლიმატსა და გეომაგნიტურ აქტივობას შორის რთული კავშირი 1974 წლიდან 2021 წლამდე არსებული მონაცემების გამოყენებით. გაანალიზებულია თვიური საშვალო მაჩვენებლები, როგორებიცაა ვოლფის რიცხვი, მზის მუდმივა (TSI), ოკეანის გლობალური ტემპერატურის ანომალიები (GOTA) და Ap ინდექსი გეომაგნიტური შეშფოთებებისთვის. გამოყენებულია სხვადასხვა მეთოდები, მათ შორის წრფივი კორელაციური ანალიზი, რეკურენტული რაოდენობრივი ანალიზი (RQA) და კროს-ვეივლეტ გარდაქმნა (XWT). კვლევა ავლენს პერიოდულად ცვალებად კორელაციას TSI-სა და GOTA-ს შორის დაახლოებით 12 წლის პერიოდულობით, რაც ხაზს უსვამს მზის აქტივობასა და კლიმატს შორის რთულ დინამიურ კავშირს. რეკურენტობის გრაფიკმა და RQA-მ გამოავლინა პერიოდულობა და ფაზური გადასვლა 1995 წლის შემდეგ. XWT ასევე აჩვენებს მრავალსიხშირულ ტრანზიენტულ მოვლენას, რომელიც მოხდა 1996 წელს. ერთობლივად ეს დაკვირვებები იძლევა ვარაუდის საფუძველს, რომ შესწავლილ სისტემაში ტრანზიენტული მოვლენა შესაძლოა დაკავშირებული იყოს ფაზურ გადასვლასთან ამ პერიოდის განმავლობაში.

**საკვანძო სიტყვები:** მზე-დედამიწის კავშირი, მზის აქტივობა, ოკეანის ტემპერატურა, ვოლფის რიცხვი, RQA, კორელაციური ანალიზი, კროს-ვეივლეტ ანალიზი.

# Сравнительный анализ климата Земли, солнечной и геомагнитной активности

Л. Бурдиладзе, А. Гурчумелия, О. Харшиладзе

## Резюме

В этой статье исследованы сложные взаимосвязи между солнечной активностью, климатом и геомагнитной активностью Земли, с использованием данных за период с 1974 по 2021 гг. Мы анализируем такие среднемесячные показатели, как число Вольфа, полное солнечное облучение (TSI), глобальные аномалии температуры океана (GOTA) и Ap индекс геомагнитных возмущений, используя различный методы, в том числе, линейный корреляционный анализ, количественный рекуррентный анализ (RQA) и кросс-вейвлет-преобразование (XWT). Исследование выявило периодически меняющуюся корреляцию между TSI и GOTA с периодичностью примерно 12 лет, подчеркивая динамическое взаимодействие между солнечной активностью и климатом. Графики рекуррентности и RQA раскрывают периодичность и фазовый переход после 1995 года. XWT также показывает многочастотное переходное событие, произошедшее в 1996 году. В совокупности эти результаты позволяют предположить, что переходное событие может быть связано с фазовым переходом примерно в этот период времени в изучаемой системе.

**Ключевые слова:** солнечно-земные связи, солнечная активность, температура океана, число Вольфа, RQA, корреляционный анализ, кросс-вейвлет анализ.

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# Intensification of a Tropical Cyclone During Landfall: A Critical Forecasting Challenge

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***ABSTRACT***

*Not very rare in reality, socially very dangerous rapid intensification (RI) of tropical cyclone (TC) during landfall remains actually an unpredictable phenomenon. Attempts to identify the presence of such a critical forecasting problem have so far been unsuccessful. In the work, the problem is again considered within the framework of the alternative so-called Equilibrium Translation Model (ETM). The basis for the consideration is TC Ian (2022), the unique parameters of which make it possible to refine and strengthen the previously obtained results. The new findings are further supported by analysis of the parameters of TC Charley (2004) who committed landfall in the same region. Potential of so-called Alignment number (An) is once again demonstrated to be an effective hazard identifier.*

***Key words:*** *tropical cyclone, rapid intensification, landfall, equilibrium translation, Alignment number.*

## Introduction

Judging by the practice of forecasting the TC development, existing theoretical and numerical models do not even allow for the existence in nature of the phenomenon of the TC intensification during landfall: forecasts based on them practically never predict such a development [1].

In general, there is indeed at least one strong factor aimed at reducing the TC intensity during landfall. This is a fairly rapid decrease in the area of the sea surface underlying a TC with a decrease in seawater heat inflow serving as "fuel" for the cyclonic motion. Existing models seem to give to this factor an absolutely dominant role.

At the same time, during landfall, not only simple but even the TC RI is in fact not at all a rare natural phenomenon.

According to [1], among 38 powerful (fourth and fifth intensity categories) TCs that made landfall around the world in 2004–2013, more than a third (16 TCs) rapidly intensified during landfall with the most severe consequences (among them, TCs Charley (2004), Felix (2007), Haiyan (2013)).

However, regular forecasts in no case predicted the TC intensification during landfall.

A similar rigid standard of not predicting the phenomenon was also maintained in subsequent years, including, for example, the landfall of TC Ian in southwest Florida in 2022 [2]. By the way, all this is happening even against a trend towards improving the prognosis of cases of TC RI in areas of the open sea (not related to the landfall stage) [3-4].

The very existence of the TC RI phenomenon during landfall fundamentally calls into question the adequacy of existing theoretical and numerical models. Overcoming resulting deadlock long ago required identification of the problem by separating it from the general class of RI, which was not done. No steps were taken for a general analysis of individual cases of the TC RI during landfall. Despite being based on extensive field data, the first generalization of the critical forecasting problem [1] remained outside the attention of researchers of tropical cyclogenesis (not a single citation).

In important reviews published later [3-5], the problem of forecasting the TC RI during landfall is not even mentioned. In a slightly different aspect, only work concerning the possible multiplication of this phenomenon with global warming [6] addresses the problem (more details below).

At the same time, the above seemingly fundamental contradictions find a logical resolution within the framework of the ETM [7-12], which considers a TC as a giant natural heat engine, the mechanical output power of which depends on two parameters - heat inflow and heat conversion efficiency. By the way, the latter can vary widely regardless of the former.

Below, the problem is again considered within the framework of the ETM, using as a new base TC Ian (2022), rapidly intensified during landfall in southwest Florida [2, 13].

The unique parameters of Ian make it possible to refine and strengthen the previously obtained results. The new findings are further supported by analysis of the parameters of the similar landfall of TC Charley (2004) in the same southwest Florida. A much more reliable determination of the critical value of the An ($An_{cr}$) corresponding to RI has been achieved. This was also facilitated by new, more accurate TCHP maps [14].

**Equilibrium Translation Model: concept and promotion strategy**

The long-term inability to correctly predict the TC RI, reflecting the need to overcome the lack of understanding of the thermohydrodynamics of decisive interactions in the system sea-cyclone-atmosphere has attracted the author's attention since the 2000s [3-4].

At the first stage of a purely qualitative analysis, the conclusion was made that, in a TC, an internal thermal drive arises, directed towards an increase in the sea surface temperature (SST). Next, the presence of a negative feedback between the internal thermal drive and TH translation speed was established, which made it possible to introduce the TC equilibrium translation concept.

Next, the key assumption was made that equilibrium translation mode is the basis of the RI phenomenon. In other words, it was assumed that when the main TC drive, large-scale environmental wind and the TC internal thermal drive are in certain conformity, this huge natural heat engine becomes most efficient in converting sea water heat into wind energy, resulting in the RI.

The validity of the ETM can be assessed by the adequacy of its final product - the dimensionless similarity number, named by the author Alignment number – ***An*** (Dr. Gvelesiani suggested calling this parameter the Shekriladz*e* number [15]).

***An*** is equal to the ratio of the total amount of TCHP contained under the sea surface, "processed" by a TC per unit time, to the heat transferred during the same time from the sea surface to the TC - a factor that determines the establishment of equilibrium translation (if we wanted to use a physically more logical reciprocal, we would have to deal with fractional quantities that are inconveniently small for the similarity number).

The basic equation for the An can be written as follows [7-12]:

$$An = \frac{Q \cdot \delta S_{sc}}{A_{34} \cdot q}, \qquad (1)$$

where $\boldsymbol{A_{34}}$ is an area inside tangent wind velocity 34 knots (corresponding to the TC outer boundary, as assumed in regular forecast advisories) ($m^2$); $\boldsymbol{q}$ is integral heat flux (sensitive and latent) from the sea surface to a TC averaged inside $\boldsymbol{A_{34}}$ ($w / m^2$); $\boldsymbol{Q}$ is tropical cyclone heat potential (TCHP) averaged inside $\boldsymbol{A_{34}}$ ($J / m^2$); $\boldsymbol{\delta S_c}$ is increment of the cooled sea surface (cooled sea surface remaining behind a TC during unit time) ($m^2 / s$).

Here, the role of the tangential wind speed field is reflected by the parameter ***q*,** determined by a three-zone heat transfer model [12] taking in account the wind speed distribution specified in the regular forecast advisory. The combined effect of the environmental wind and internal driving force is reflected by the parameter $\boldsymbol{\delta S_c}$. Based on comparison with available field data, the main conclusion was made that the TC equilibrium translation, accompanied by the RI, always must occur at a constant, critical value of the alignment number $\boldsymbol{An_{cr} = const}$.

The prospect arose to overcome the historical impasse in forecasting the TC intensity and, most importantly, the TC RI. In addition, the ETM has shown the potential to provide a basis for analysis of a number of other important aspects of tropical cyclogenesis, including the TC unusual trajectories, the formation of secondary eyewalls, and the impact of global warming.

It became clear that the results obtained could only make sense if, after a thorough re-verification, they became the basis for a virtually complete restructuring of large-scale studies of tropical cyclogenesis. It was also clear that achieving widespread interest in a field of research new to the author of the study was also not an easy task.

To this end, a strategy was adopted to highlight the identification, for the first time in almost a hundred years of research, of the similarity number characterizing the TC development, and to reinforce the significance of the latter as much as possible by demonstrating the correlation of its critical value with RIs in an ever-increasing number of real TCs.

Of course, optimism was built on the general recognition of the TC RI forecasting as the most important unsolved problem in the field.

As for other aspects of tropical cyclogenesis, it was decided not to focus on them at all, since they could only be supported by qualitative considerations.

Simultaneously, there was hope that when reading the publications, colleagues themselves would reveal the multidimensionality of the ETM. Moreover, some of these possibilities were practically lying on the surface.

First of all, this concerned the almost obvious projection of the model onto the phenomenon of so-called unusual trajectories, the second most important unsolved problem of tropical cyclogenesis after the RI forecasting.

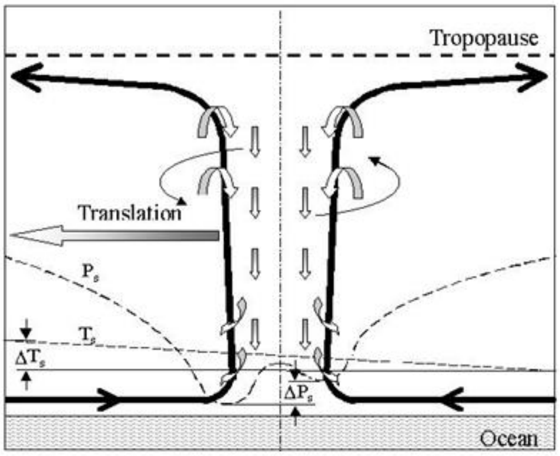


Fig. 1. Scheme of internal thermal drive.

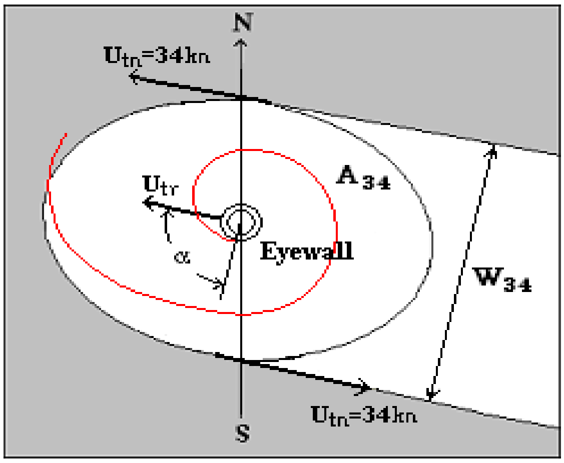


Fig. 2. The occurrence of TH lateral movement.

Internal thermal drive (Fig. 1) is formed by a transverse gradient of static pressure on the eyewall cloud, which, in turn, arises due to the presence of a difference in the temperature of the air sucked into the wall around its circumference. In general, the internal drive direction depends on the point at which the warmest air hits the wall, which may not coincide with the frontal point of the eyeall (Fig. 2).

In our publications, without any explanation, the condition $\boldsymbol{\alpha = 0}$ is automatically accepted as one of the conditions for the implementation of equilibrium translation. Such a situation could have caused serious criticism of the model, but, unfortunately, even this did not happen.

The fact is that an attempt at such criticism, even with the simplest qualitative reasoning, would reveal the rich consequences of the internal thermal drive concept itself.

For example, with reasonable assumption of a strong excess of external drive over internal one in most regimes of the TC translation, in the presence at the initial moment of a non-zero value of angle $\boldsymbol{\alpha}$ one would reveal the TC self-organized evolution to equilibrium translation (movement to $\boldsymbol{\alpha = 0}$).

Indeed, using the example of Fig. 2 it is easy to notice that the additional movement of the eyewall at a relatively low speed to the left, with subsequent deformation of the field of spiral flows, will be constantly directed towards a reduction in angle $\boldsymbol{\alpha}$.

The situation will change dramatically if there is a temporary, but sufficiently long-term decline in wind speed or complete calm. Internal drive will become the leading force, the direction of which will depend on the distribution of TCHP along the TC perimeter (in our studies the TCHP filed was assumed to be roughly uniform).

In such a situation, any movement of the TC can occur, from zigzag to marking time.

Projection can be continued onto another important phenomenon – the formation of the TC secondary eyewall, if we keep in mind the possible occurrence of internal instability in a TC, when the regional wind speed recovers and internal drive begins to quickly change direction and amplitude.

Further progress, of course, requires detailed analysis. However, the very fact that the occurrence of both of the above phenomena is much more likely with existence, in a TC, of an additional drive of variable direction and amplitude, should not raise much doubt.

Returning to the main line of the strategy, it should be noted that its implementation to a certain extent goes beyond the author's capabilities.

The fact is that accurate and reliable establishment of the An value by Eq. (1) for a given situation is only possible by the relevant research and monitoring centers that are able to determine with high accuracy all of necessary parameters, including the most difficult to determine δSc.

Unfortunately, such work has not yet been done.

As if assuming such a risk, in order to at least approximately verify the ETM, from the very beginning another equation was introduced [3-4], definable using solely publicly available information, such as regular forecast advisories and daily TCHP maps:

$$An = \frac{Q \cdot U_{bb}}{R_{ef} \cdot q} \tag{2}$$

where $U_{bb}$ is the TC rear boundary center translation speed; $R_{ef} = 2A_{34} / \pi W_{34}$ is effective radius of TH (in the case of circular TH it is equal to the radius), $W_{34}$ is the transverse size of $A_{34}$.

In Eq. (2) the role of the $\delta S_c / A_{34}$ ratio is reflected by the ratio $U_{max} / R_{ef}$, while $U_{bb}$, $A_{34}$, $W_{34}$ and $R_{ef}$ are determined by the data from relevant forecast advisories [2] using the methods [12 ].

Based on Eq. (2), a number of studies [1, 7-12, 16-17] were conducted analyzing the life cycles of numerous real TCs by constructing curves of the correlation of the maximum tangential wind speed ($U_{max}$) and ***An*** over time. The high repeatability of the correlation between ***Umax*** and $An_{cr}$ over a sufficiently large number of TCs, with a spread of $An_{cr} = 35 \pm 20\%$, allowed us to conclude that the ETM has fundamental potential in terms of understanding and describing the TC development.

Of course, the cases with the TC RI during landfall were also involved, e.g., TC Charley that made devastating landfall in the same southwest Florida in 2004 [16].

However, similar results could not shake the wall of total ignorance of the model and the similarity number, combined with a difficult to explain persistent avoidance of identification of the real critical forecasting challenge - the problem of forecasting the TC RI at landfall.

Regarding the latter, one episode is also remarkable.

In 2017, study [6] was published, which focuses on an assessment of the potential impact of global warming on the incidence of the *RI* before landfall. The conclusion was made about potential significant increase in this important parameter when global warming.

As the review of the article showed, the validity of this conclusion raises serious doubts.

The fact is that the conclusion was based on the results of simulation future events using exactly the above-mentioned numerical models, based on which forecasts have never predicted the real not so rare manifestations of the phenomenon [1].

The article does not say anything about the existing negative experience in using these models in forecasting practice. Conclusions [1] are not only not refuted, but not even mentioned.

The possibility of a very useful public examination of an important problem arose.

To this end, in the same 2017, the author addressed the Bulletin of the American Meteorological Society with a “letter to the editor” with a detailed consideration and criticism of the article, of course, involving the *ETM-An*. The letter ended with a paragraph:

“In general, the above circumstances, together with the unsuccessful experience of using the modern numerical models in real forecasting practice, create serious doubts regarding the validity of the conclusion about significant increase in the incidence of *TH* rapidly intensifying before landfall when global warming.”

Ultimately, we were faced with a shocking precedent for the suppression of scientific debate: the letter was rejected by the journal based on reviewer conclusions. Another attempt to bring a critical problem out of the silence zone failed. Serious signs of a strong position in the area of non-scientific corporate interests have emerged.

**TCs Ian (2022) and Charley (2004): two landfalls with rapid intensification**

The main object of consideration is TC Ian (September 23 – 30, 2022), which made successive landfalls in Cuba, southwest Florida, and South Carolina [1]. It became one of the costliest hurricanes in the history of observations with the lion's share of damage in Florida. Ian's landfall in Florida was accompanied by the RI, once again highlighting the still unresolved problem with predicting the parameters of such development.

TC Ian's RI during landfall is characterized by a unique set of parameters recorded in regular forecast advisories. They made it possible to refine the method for determining the An. Examination of TC Charley (2004) using a refined method allows to reinforce the previous findings.

Ian moved in a straight line at five distances between points corresponding to successive forecast advisories, of which two distances until approaching the shore. For the first four of these distances, including the start of landfall, it moved at a constant speed. The TC constant external dimensions are recorded in three consecutive forecast advisories, the intermediate of which (advisory number 22, 0900 UTC 09/28/2022) we link to the start of landfall (here we assume that landfall begins with the transition to land of 10 ÷ 15% of the $A_{34}$ area).

Since in such an "ideal" case the increment of the cooled sea surface is equal to the product of the TC transverse size (***W***) by the TC center translation speed (***U***$_{tr}$), then Eq. can be transformed to the following form:

$$An = \frac{Q \cdot W \cdot U_{tr}}{A_{34} \cdot q}, \qquad (3)$$

Although Eq. 1 is strictly applicable only to the above section of the Ian's translation, to a certain approximation, it can also be applied to the life cycles of Ian and Charley as a whole, as was done in this study. ***U***$_{tr}$ is taken directly from the relevant forecast advisory, ***W***, the transverse size of ***A***$_{34}$, is determined based on interpolations between corresponding pairs of radii of the TC recorded in the same advisory. ***Q*** is determined from the TCHP map for the previous day [14].

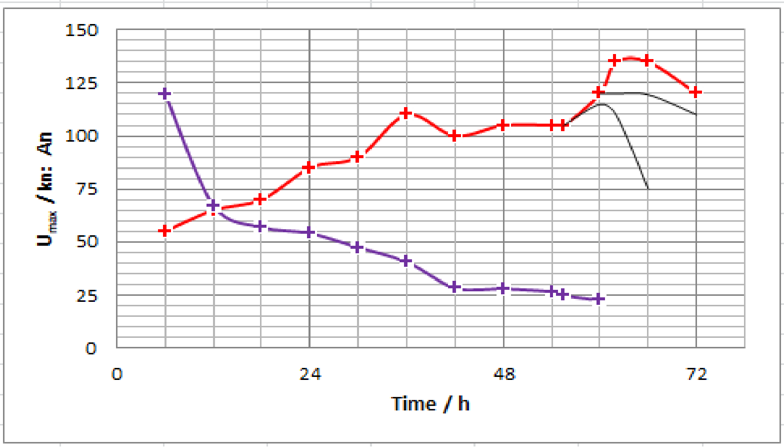


Fig. 3. Time course *of* ***U***$_{max}$ (red crosses) and *An* (purple crosses) before and during landfall of TC Ian (2022) in southwest Florida and regular forecasts (black curves).

The correlation between $\boldsymbol{U_{max}}$ and *An* before and during Ian's landfall can be traced by Fig. 3.

The data covers a segment of Ian's life cycle from the northern coast of Cuba to Southwest Florida. The main interest, of course, is the landfall stage, which began around the 60$^{th}$ hour (here we assume that landfall begins with the transition to land of 10 ÷ 15% of the $A_{34}$ area.). Time 0 in Fig. 3 corresponds to 21:00 UTC 09/25/2022.

The curves are constructed based on discrete points, each of which corresponds to a specific forecast advisory issued at a given point in time. The standard time step for issuing the advisory is 6 hours, however, during the landfall they were issued more often, which is reflected in Fig. 3.

Ultimately, any An value corresponds to a specific advisory, and all parameters used are among the parameters available at that time to the compilers of the corresponding advisory. In other words, when compiling any forecast advisory, there was a theoretical possibility of judging the situation also by the current value of An.

The situation presented in the graph is quite meaningful.

At 04:30 on September 28, 2022, the regular forecast advisory correctly predicted the RI starting on the open sea, which is consistent with the conclusion made in the review [3-4] about the presence of progress in this part.

Further, apparently, in the numerical models the taboo embedded in them on allowing the TC intensification during the Landfall period worked reliably. At the 60$^{th}$ hour, at the conditios of real intensification, its cessation with a further decline in intensity was predicted.

In contrast, the An predicted both the onset of the RI and its continuation. The absolute values of $An_{cr}$ will be discussed in more detail below.

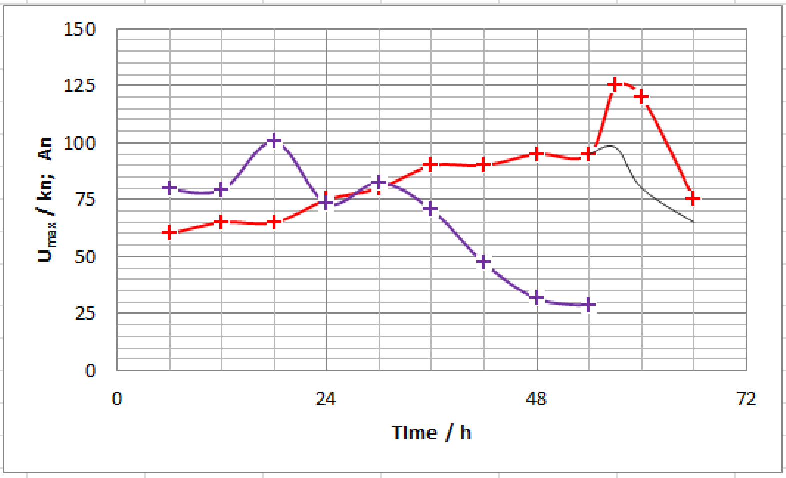


Fig. 4. Time course *of* $\boldsymbol{U_{max}}$ (red crosses) and *An* (purple crosses) before and during landfall of TC Charley (2004) in southwest Florida and regular forecast (black curve).

Ian's famous predecessor, T.S. Charlie, made a devastating landfall accompanied by RI in roughly the same area of Florida in 2004. The correlation between $\boldsymbol{U_{max}}$ and An before and during Charley's landfall (according to Eq. 3) is presented in Fig. 4.

Forecasters, also based on numerical models, also predicted a decrease in TC intensity with the onset of landfall, although at that time there were quite compelling circumstances for this: Charley itself was not at all at the RI stage and there was not so warm water ahead, with TCHP 2 - 3 times less than in Ian's case (striking evidence of the powerfulness of the RI's mechanism).

The difference between the $An_{cr}$ values for the Charley case obtained from Eq. 2 [16] (***$An_{cr}$ = 35***) and in this work by Eq. 3 (***$An_{cr}$ = 29***), cast doubt on the equality of similar values for Ian published in the report [17] and obtained in this work (***$An_{cr}$ = 23*** in both cases). A re-check revealed a calculation error when preparing the report [17]; in fact, for Ian they are 35 and 23, respectively.

Based on the above arguments, preference in terms of accuracy can be given to that obtained in this work (***$An_{cr}$ = 23***), although this is only an intermediate result.

Ultimately, the sought critical value must be identified by the relevant research and monitoring centers which can do this using the basic Eq. (1) with much greater accuracy (by the way, in this case another absolute value of ***$An_{cr}$*** can be identified, without changing anything in principle, remaining the same for different TCs).

In general, the results of the work this time more accurately confirmed the previous conclusion about the fundamental potential of the ETM in terms of predicting the TC development.

## Conclusion

Not very rare in reality, but the most socially dangerous cases of a TC landfall with simultaneous RI have actually never been predicted correctly. However, attempts to convince the relevant scientific community to identify the existence of such a critical forecasting challenge still remain unsuccessful.

In parallel, over the course of two decades, the same community consistently ignored the model and similarity number formed a framework that claimed to comprehensively reflect the features of the TC development, including its rapid intensification.

This work continues to move toward overcoming these barriers.

Still working within the same framework of the ETM, previously made conclusions about the potential of the Alignment number to be an effective hazard identifier are confirmed here with comparatively high accuracy through the analysis of the unique landfall parameters of TCs Ian (2022) and Charley (2024).

Due to the use of approximate equations in all studies, all obtained results require re-checking and refinement by the relevant research and monitoring centers using Eq. (1).

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# ტროპიკული ციკლონის გაძლიერება ხმელეთზე გადასვლისას: კრიტიკული გამოწვევა პროგნოზირების სფეროში

ი. შეყრილაძე

### რეზიუმე

ტროპიკული ციკლონის არც თუ ისე იშვიათი, სოციალურად ძალზე საშიში სწრაფი გაძლიერება ხმელეთზე გადასვლისას პრაქტიკულად არაპროგნოზირებად მოვლენად რჩება. სიტუაციის პრობლემური ხასიათის იდენტიფიცირების მცდელობები ამ დრომდე წარუმატებელი იყო. ნაშრომში პრობლემა კვლავ განიხილება ალტერნატიული, ე.წ. წონასწორული ტრანსლაციის მოდელის ფარგლებში. განხილვის საფუძველია ტროპიკული ციკლონი იანი (2022), რომლის უნიკალური პარამეტრები ადრე მიღებული შედეგების დაზუსტებისა და დახვეწის საშუალებას იძლევა. ახალი დასკვნები მხარდაჭერილია ტროპიკული ციკლონის ჩარლის (2004) ხმელეთზე მსგავსად გადასვლის პარამეტრების ანალიზით. კიდევ ერთხელ არის დემონსტრირებული ე.წ. თანადობის რიცხვის პოტენციალი, როგორც საფრთხის ეფექტური იდენტიფიკატორისა.

**საკვანძო სიტყვები:** ტროპიკული ციკლონი, სწრაფი გაძლიერება, ხმელეთზე გადასვლა, წონასწორული ტრანსლაცია, თანადობის რიცხვი.

# Усиление тропического циклона во времяв ыхода на сушу: критический вызов прогнозирования


## И. Шекриладзе



### Резюме

Не столь редкое, социально весьма опасное быстрое усиление тропического циклона во время выхода на сушу остается практически непредсказуемым явлением. Попытки идентифицировать проблемный характер ситуации пока не увенчались успехом. В работе проблема вновь рассматривается в рамках альтернативной, так называемой модели равновесной трансляции (МРТ). Основным объектом рассмотрения является тропичекий циклон Иан (2022), уникальные параметры которого позволяют уточнить и усилить полученные ранее результаты. Новые результаты подтверждаются анализом параметров аналогичного выхода на берег тропического циклонф Чарли (2004). Еще раз продемонстрирован потенциал так называемого числа выравнивания как эффективного идентификатора опасности.



**Ключевые слова:** тропический циклон, быстрая интенсификация, выход на сушу, равновесное перемещение, число вырвнивания.

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# PM2.5 and PM10 in the Atmosphere of Kutaisi City

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***ABSTRACT***

*Based on the atmospheric air monitoring data and using experimental measurements there has been assessed concentrations of micro aerosols (PM2.5 and PM10) and features of their time change in the atmosphere of Kutaisi city and its adjacent territories. There have been determined the numbers of days and observation, when their average daily concentrations exceed the respective maximum permissible concentrations. Micro aerosols surface distribution pattern has been built up according to experimental measurements data. Zones of high and low concentrations have been established.*

***Keywords:*** atmosphere, pollution, micro aerosols, concentration, monitoring, PM.

## Introduction

At the modern stage of social development, under conditions of intensive growth of industry and mobility great importance is attached to protection of atmospheric air purity. This problem is very important in the viewpoint of human health protection, as far as human health is vulnerable to the quality of purity of environment [1-4]. According to the World Health Organization data, in 2016 7.6% of population mortality was caused by atmospheric air pollution [5]. Therefore, study of environment contamination, elaboration of measures focused on its mitigation is a critical mission aimed to protection of ecology and social health. This problem is especially topical for large cities, which are characterized with a great number of pollution sources, diversity of ingredients and high level of contamination.

PM2.5 and PM10 are ranked among main polluting agents of the atmosphere. Due to their small sizes, they easily penetrate human cardio-vascular system, have a strong negative influence on health and cause diseases, which often end up with a lethal outcome [6-8]. Presense of PM2.5 and PM10 in the atmospheric air is stipulated by industrial, agrarian and transport emissions. At the same time, a sharp increase of PM2.5 and PM10 concentrations for several days in the atmosphere of Georgia is mainly caused by synoptic processes, namely large-scale transfer of dust from Sahara and Middle Asia deserts [9].

Monitoring of atmospheric air pollution with PM2.5 and PM10 in Georgian cities has been started in 2017. Routine observations have been made in Tbilisi, Rustavi, Kutaisi and Batumi. Some results of this monitoring have been analyzed in the works [9-21]. Summarized results of studies of air pollution in Kutaisi and its surroundings by particulate matter PM2.5 and PM10 are presented below.

Kutaisi is ranked second among large cities of Georgia. Its population surpasses 147 thousand people. Once a large industrial city, today Kutaisi is an administrative and cultural-recreational center of the Imereti region. Resort city Tskaltubo and many historic monuments, including Gelati monastery complex – a monument of UNESCO cultural heritage, Bagrati Cathedral, Palace of Geguti, Martvili and Motsameta monasteries, as well as touristic attractions – Sataplia and Prometheus caves, Kinchkhi, Martvili, Baldi canyons etc. are located in the city and its surroundings.

Kutaisi is a big transport hub as well. Imereti section of the Great Silk Road passes there and an airport of international importance is located nearby. Hundred of cars move back and forth on its narrow streets. Motor transport traffic is especially intensive in summer and autumn seasons. In its turn, industrial enterprises are presented in relatively less quantity. They are mainly limited by construction, asphalt-concrete and some repair or transport facilities. Socioeconomic function, physical-geographical location, climate and infrastructure of the city determine the necessity of study of ecological situation in Kutaisi.

Proceeding from socioeconomic function of Kutaisi city, study of time change and spatial distribution of PM2.5 and PM10 in its air is a crucial task. The presented article is devoted to the mentioned problem.

Routine observations over PM2.5 and PM10 concentrations in the atmosphere of Kutaisi have been started in 2018 and still proceed at one surveillance station only. This observation point is located at the intersection of L. Asatiani Street and I. Chavchavadze Avenue, at the crossroad with very loaded vehicle traffic (98, L. Asatiani Str.). Observations are carried out by the National Environmental Agency within atmospheric air pollution monitoring plan.

**Research method.** Data of the Kutaisi monitoring network of the National Environmental Agency and results of experimental measurements conducted by authors are used for assessment of PM2.5 and PM10 concentrations in the atmosphere of Kutaisi city. Experimental measurements were carried out in May and July using the mobile apparatus "Aeroqual Series 500". Concentrations for monitoring network are obtained through one-hour averaging of measured values, while for experimental measurements – via 10-minute averaging.

**Research results.** In Table 1 there are given the values of microparticles average annual concentrations and number (N) of exceedances of average daily concentrations over 24-hour average maximum permissible concentrations (MPC), which are obtained on the basis of routine measurements conducted in 2018-2020 at the station of air quality monitoring network [9]. It is seen from Table 1 that in the mentioned years the average annual PM2.5 concentration is less than MPC (25 $\mu g/m^3$), is minimal in 2020 and maximal in 2019. The qualitatively similar distribution is received for PM10, as well. Its average annual concentration is less than MPC (50 $\mu g/m^3/m^3$), is minimal in 2020 ($\mu g/m^3$) and maximal in 2019 (49 $\mu g/m^3$). Therefore, 2019 year is characterized by maximal exceedances over MPC – 115 observations.

Table 1. Average annual concentration of PM2.5 and PM10 and number (N) of average daily concentration exceedances over MPC

| year | 2018 | 2919 | 2020 |
|---|---|---|---|
| PM2.5 ( $\mu g/m^3$) | 16 | 18 | 14 |
| PM10 ( $\mu g/m^3$) | 40 | 49 | 30 |
| N | 68 | 115 | 25 |

In Table 2 there are given the values of average monthly concentrations of microparticles in March-May 2020 and number of exceedances (M) of PM10 average hourly concentrations over MPC.

Table 2. Average monthly concentration of PM2.5 and PM10 and number (M) of PM10 average hourly concentrations exceedances over MPC

| Month | March | April | May |
|---|---|---|---|
| PM2.5 ($\mu g/m^3$) | 12 | 15 | 9 |
| PM10 ($\mu g/m^3$) | 22 | 38 | 20 |
| M | 34 | 176 | 7 |

It is seen from Table 2 that in the period under review average monthly concentrations of microparticles in Kutaisi city atmosphere don't surpass the respective average daily MPCs. Average monthly concentration of PM2.5 is maximal in April and minimal in May. In case of PM10 we have a qualitatively similar distribution. Its average monthly concentration is relatively high in April (38 $\mu g/m^3$). The number of observations, during which the average hourly concentration of PM10 exceeded average daily concentration, was high in April, as well.

In Fig. 1 there are shown the diagrams of micro aerosols average daily concentration change in April-May 2022 measured at air quality monitoring station.

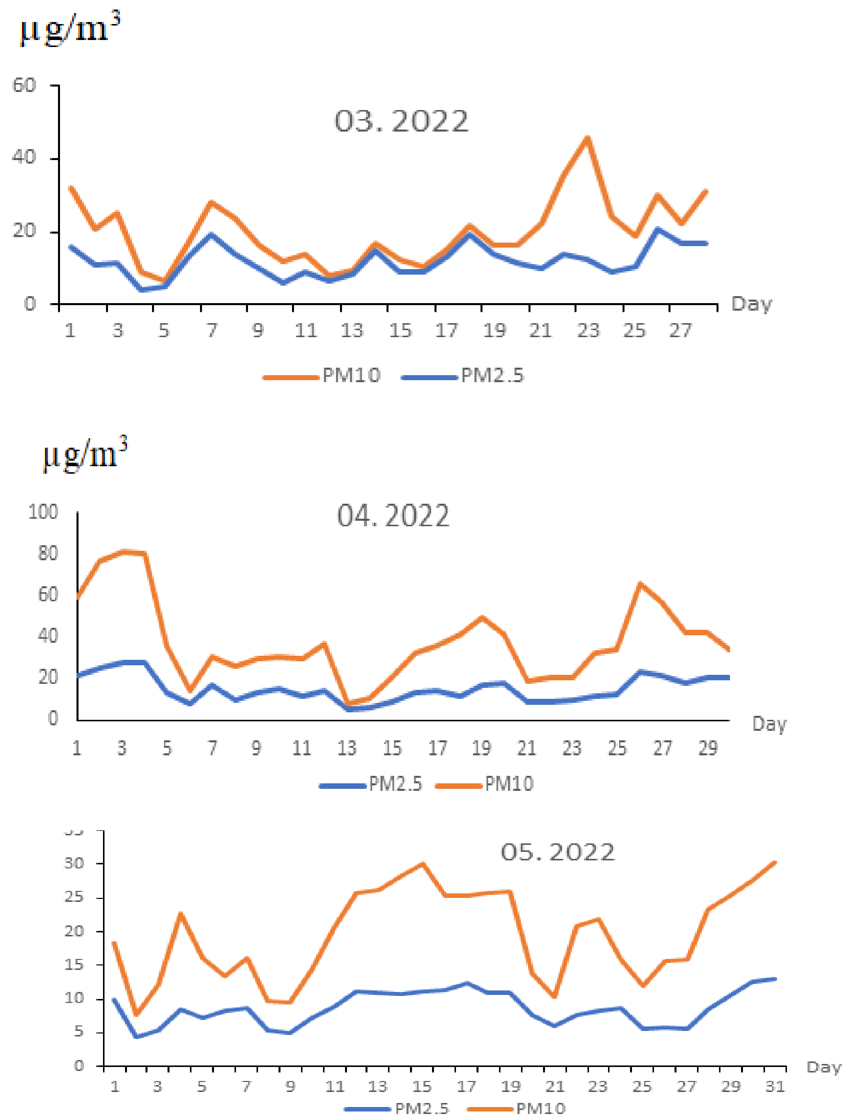


Fig. 1. Values of average daily concentrations of PM2.5 and PM10 in March, April and May 2022 at atmospheric air quality monitoring station

As is seen from Fig. 1, changes of PM2.5 and PM10 average daily concentrations are qualitatively similar. Their local maximum values are observed 3-4 times a month. PM10 concentration always exceeds the respective index of PM2,5 (Fig. 1) and PM10/ PM2.5 ratio is within a range of 0-3.8 (Fig. 2). It is relatively high in April, while in March and May it changes almost in one and the same interval.

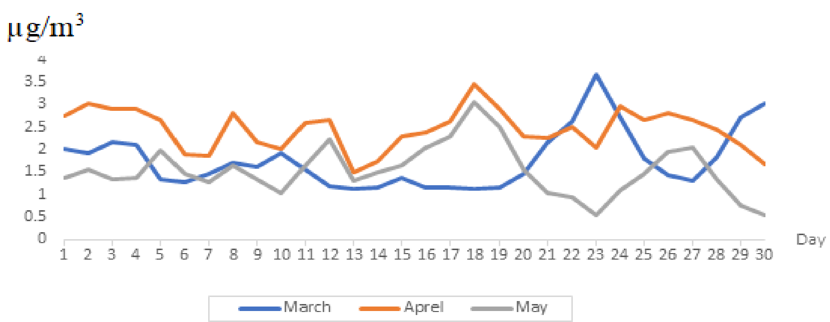


Fig. 2. Ratio of PM10/PM2,5 concentrations in March, April and May, 2022

In May and July, 2023 experimental measurements at the territory of Kutaisi city and its surroundings were carried out under conditions of windless and warm weather at 1.5 m height from the underlying surface.

In Fig. 3 there are shown column diagrams of PM10 and PM2,5 concentrations in the atmospheric air of Kutaisi city and its surroundings. It is seen from Fig. 3 that values of PM10 and PM2,5 concentrations in the observation points are not proportional to each other. In spring and summer PM10 concentrations vary within a range of 8,4-132,5 $\mu g/m^3$, while in case of PM2.5 – 4,6-25,1 $\mu g/m^3$.

Extremely high PM10 concentration (2,6 MPC) is registered at the territory adjacent to the Avtomshenebeli Street. High concentrations (more than MPC) are fixed in the city center (Green bazaar, Rustaveli Bridge), in the middle part of Tabukashvili Street, and at the intersection of Kutaisi by-pass road and Tabukashvili Street.

Territorial distribution of PM2,5 differs from that of PM10: high concentrations (20-25 $\mu g/m^3$) are registered on Gamarjveba Square, in the beginning of Kutaisi-Tskaltubo road and on the Avtomshenebeli Street. In the central part of the city PM2,5 concentrations are within a range of 5-10 $\mu g/m^3$.

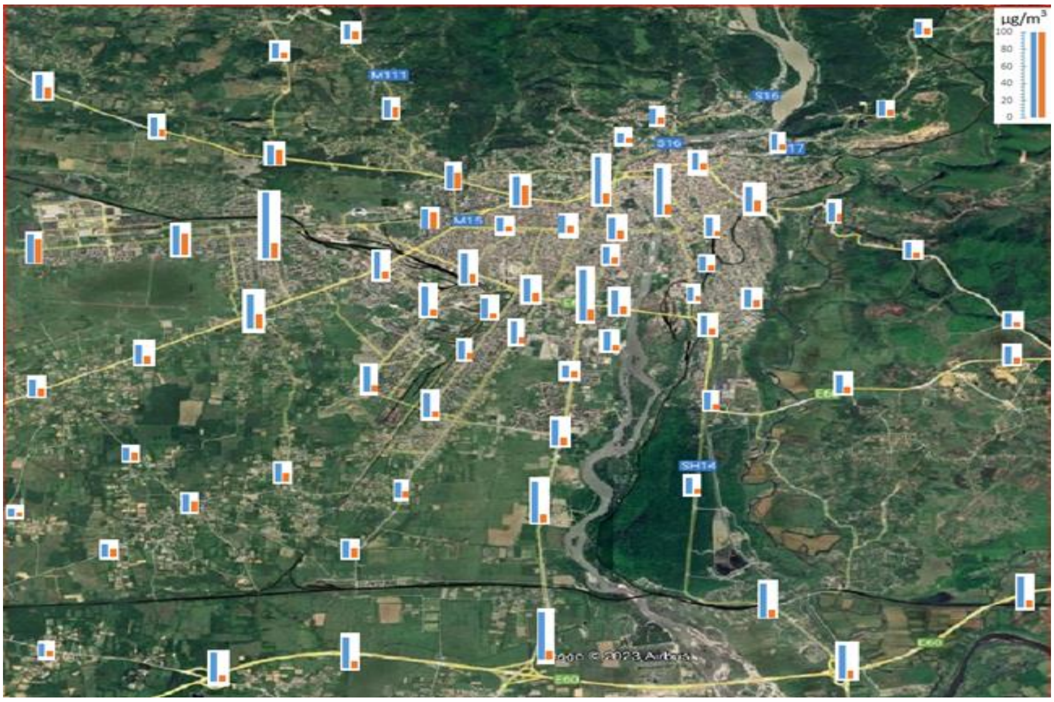


Fig. 3. Values of PM10 and PM2,5 concentrations in Kutaisi city and its surroundings (dark blue – PM10, rose – PM2,5)

PM2,5 and PM10 concentrations were measured in populated localities adjacent to Kutaisi city, as well. The values of their concentrations were as follows: Kvitiri Village – 6 - 12 $\mu g/m^3$; Partskhanakevi Village – 4,6 - 8,4 $\mu g/m^3$; Geguti Village – 6,2 - 13,9 $\mu g/m^3$; Khoni district – 8- 16 $\mu g/m^3$; Martvili District – 19 - 23 $\mu g/m^3$ (in foggy weather).

**Conclusions**

Time change of PM2,5 and PM10 concentrations in the atmospheric air of Kutaisi city is analyzed using the data of National Environmental Agency monitoring network. Concentrations are measured in the observation point, which is located at the territory with intensive vehicle traffic – 988, Asatiani Str. Average annual concentration for 2018-2020 and average monthly concentrations for March-May, 2022 are determined. The number of days, when PM10 average hourly concentration exceeds average daily concentrations is established.

Values of PM2,5 and PM10 concentrations in May and July, 2023 are determined in the atmosphere of Kutaisi city and its surroundings and the map of column diagrams for concentration spatial distribution is plotted. The values of maximum and minimum concentrations of micro aerosols, concentration change ranges and areas of relatively heavy and mild contamination of atmospheric air are established.

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## PM2.5 და PM10 ქ. ქუთაისის ატმოსფეროში

### ა. სურმავა, ვ. კუხალაშვილი, ნ. გიგაური, ლ. ინწკირველი

**რეზიუმე**

ატმოსფერული ჰაერის მონიტორინგის მონაცემებზე დაყრდნობით და ექსპერიმენტული გაზომვებით შეფასებულია ქ. ქუთაისსა და მის მიმდებარე ტერიტორიაზე ატმოსფეროში მიკროაეროზოლების (PM2.5 და PM10) კონცენტრაციები და მათი დროში ცვლილების თავისებურება. განსაზღვრულია დღეთა და დაკვირვებათა რაოდენობები, როცა მათი საშუალო დღიური შემცველობა აჭარბებს შესაბამის ზღვრულად დასაშვებ კონცენტრაციებს. ექსპერიმენტული გაზომვების მონაცემებით აგებულია მიკროაეროზოლების ზედაპირული განაწილების სურათი. დადგენილია მაღალი და დაბალი კონცენტრაციების ზონები.

**საკვანძო სიტყვები:** ატმოსფერო, დაბინძურება, მიკრო აეროზოლები, კონცენტრაცია, მონიტორინგი, PM.

## PM2.5 и PM10 в атмосфере г. Кутаиси

### А. Сурмава, В. Кухалашвили, Н. Гигаури, Л. Инцкирвели

**Резюме**

На основе данных мониторинга атмосферного воздуха и экспериментальных измерений в атмосфере г. Кутаиси и его окрестностей оценены концентрации микроаэрозолей (PM2,5 и PM10) и особенности их изменения с течением времени. Определены количество дней и период наблюдений, когда их среднесуточное содержание превышает значения соответствующих предельно допустимых концентраций. На основе данных экспериментальных измерений построена картина поверхностного распределения микроаэрозолей. Установлены зоны повышенных и пониженных концентраций.

**Ключевые слова:** атмосфера, загрязнение, микроаэрозоли, концентрация, мониторинг, PM.

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# Results of a Study on the Impact of Surface Ozone Concentration on the Spread of COVID-19 in Tbilisi

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***ABSTRACT***

*The results of a study of the influence of diurnal values of surface ozone concentration (SOC) on the infection positivity rate with coronavirus COVID-19 (IR) of the population of Tbilisi from October 8, 2020 to May 31, 2021 are presented. It was found that IR values are inversely correlated with SOC. For example, at ozone concentrations from 0 to 20 mcg/m$^3$ values of COVID-19 Infection Rate on average was 18.5 %, whereas with SOC values from 80 to 100 mcg/m$^3$ – only 2.3%. Connection daily values of IR with SOC has an inverse linear form. IR = -0.2307·SOC + 20.543 for individual cases; IR = -0.2113·SOC + 19.756 for averaged values of IR in different ranges of SOC values.*

***Key Words:*** *surface ozone concentration, COVID-19, infection positive rate.*

## Introduction

Four years have passed since the outbreak of the new coronavirus (COVID-19) in China, which was recognized on March 11, 2020 as a pandemic due to its rapid spread in the World [1]. During this period of time, despite the measures taken (including vaccination), several strains of this virus appeared. The overall level of morbidity and mortality is currently declining significantly, although in many countries of the world it remains quite high.

According to [2] globally, the number of new cases increased by 52% during the 28-day period of 20 November to 17 December 2023 as compared to the previous 28-day period, with over 850 000 new cases reported. The number of new deaths decreased by 8% as compared to the previous 28-day period, with over 3000 new fatalities reported. As of 17 December 2023, over 772 million confirmed cases and nearly seven million deaths have been reported globally.

During the period from 13 November to 10 December 2023, over 118 000 new COVID-19 hospitalizations and over 1600 new intensive care unit (ICU) admissions have been recorded with an overall increase of 23% and 51% respectively amongst the countries reporting consistently within the current and past reporting periods.

As of 18 December 2023, JN.1, a sub-lineage of BA.2.86 Omicron variant has been designated a separate variant of interest (VOI) apart from its parent lineage BA.2.86 due to its rapid increase in prevalence in recent weeks. Globally, EG.5 remains to be the most reported VOI.

Regarding Georgia, from February 27, 2020 to September 30, 2022 in this country 1785137 new cases of COVID-19 infection were registered; died - 16912 people. Due to the sharp decline in coronavirus infection in Georgia after September 30, 2022, official statistics on COVID-19 are not published [3].

Researchers and specialists in various fields of sciences from all over the world, together with epidemiologists and doctors, have engaged in intensive research into this unprecedented phenomenon (including in Georgia [3-11]), providing them with all possible assistance. In particular, in our early work [10] it was noted that in 2021, work on statistical analysis, forecasting, systematization of forecasts, spatio-temporal modeling of the spread of the new coronavirus, etc. is actively continuing. Similar work continues in 2022 [11-14]. Our latest work [15] presents the results of a statistical analysis of daily, total by day of the week and monthly data on officially registered deaths from the new coronavirus COVID-19 in the countries of the South Caucasus (Armenia, Azerbaijan, Georgia). from March 12, 2020 to May 31, 2022 are presented.

A significant number of papers are devoted to studies of the influence of various meteorological factors (included surface ozone) on the COVID-19 pandemic [15-31].

In our last papers [23,24] results of a study of the influence of diurnal values of separate components of simple thermal indices (temperature and air relative humidity, wind speed) on the infection positivity rate with coronavirus COVID-19 (IR) of the population of Tbilisi from September 1, 2020 to May 31, 2021 are presented. It was found that IR values are inversely correlated with air temperature and wind speed, and positively correlated with air relative humidity. The effect of four different thermal indices (air effective temperature and Wet-Bulb-Globe-Temperature) on the IR values averaged over the scale ranges of their categories was studied. It has been found that an increase of the air effective temperature leads to a decrease of the IR values. In the latter case, the level of significance of the relationship between thermal indices and IR values is much higher than in the case of the relationship between IR and separate components of these indices. In work [24] results of a study of the influence of diurnal values of Angstrom Fire Index (AFI, temperature and air relative humidity combination) on the infection positivity rate with coronavirus COVID-19 (IR) of the population of Tbilisi over the same period of time are presented. It was found that an increase in AFI values (reduction of fire danger) leads to an increase in IR. Thus, with the “Low” fire danger category, the IR value averaged 11.5%, and with the “Extreme” category - 3.5%. The relationship between the AFI and IR values has the form of a second power polynomial. Thus, AFI also manifests itself as a bioclimatic indicator. In the future, it is planned to compare AFI values with various indicators of human health.

As for the effect of ground-level ozone concentration on the spread of Covid-19, research data is ambiguous. For example, in papers [26,27] note a direct connection between the concentration of ground-level ozone and the spread of the covid-19 virus. In the works [28-31] note the presence of a feedback between ozone and the spread of the Covid-19 viral infection.

In the work [30] shown, that as of September 10, 2020, over 70,000 cases and over 2,000 deaths have been recorded in Poland. Of the many factors contributing to the level of transmission of the virus, the weather appears to be significant. In this work authors analyze the impact of weather factors such as temperature, relative humidity, wind speed and ground level ozone concentration on the number of COVID-19 cases in Warsaw, Poland. The obtained results show an inverse correlation between ground level ozone concentration and the daily number of COVID-19 cases.

The results of [28] show that in four major metropolitan areas in Italy during a strict lockdown because of COVID-19 pandemic implemented by the Italian government, COVID-19 pandemic–related infections are slowed down by higher tropospheric ozone concentrations and eased by the atmospheric particulate. Authors quantitatively assessed that higher levels of tropospheric ozone, already proven effective against viruses and microbial contaminants, play a role in flagging COVID-19 pandemic transmission.

In study [31] examined the relationship between new daily cases, ground-level ozone, temperature, relative humidity, and wind speed. Temperature was found to have the strongest correlation with new cases, an inverse correlation. Ozone did have a significant inverse correlation with cases, but is highly autocorrelated with temperature. The author believes that would require much more in-depth analysis techniques- and more data- to tease out a definitive connection.

We also continue to conduct similar studies. The results of a study of the influence of diurnal values of Surface Ozone Concentration on the infection positivity rate with coronavirus COVID-19 of the population of Tbilisi from October 8, 2020 to May 31, 2021 are presented below.

**Material and methods**

Data of Agency on the Environment of Georgia about the daily mean Surface Ozone Concentration (SOC, mcg/m$^3$) for three point of Tbilisi (Kazbegi av., Tsereteli av. and Varketili) during October 8, 2020 to May 31, 2021 were used in the work [32; https://air.gov.ge/en/reports_page]. For the same days, data of National Center for Disease Control and Public Health of Georgia about infection positivity rate with coronavirus COVID-19 (IR) of the population of Tbilisi were used (IR = Confirmed Coronavirus Cases/Test Number, %).

The paper compares the mean daily values of SOC with the IR values. Data analysis was carried out using standard methods of mathematical statistics [33].

The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; St Dev - standard deviation; $\sigma_m$ – standard error; $C_V$ = 100·St Dev/Mean – coefficient of variation, %; $R^2$ – coefficient of determination; R – coefficient of linear correlation; α – level of significance.

The degree of correlation was determined in accordance with [33]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

**Results and discussion**

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

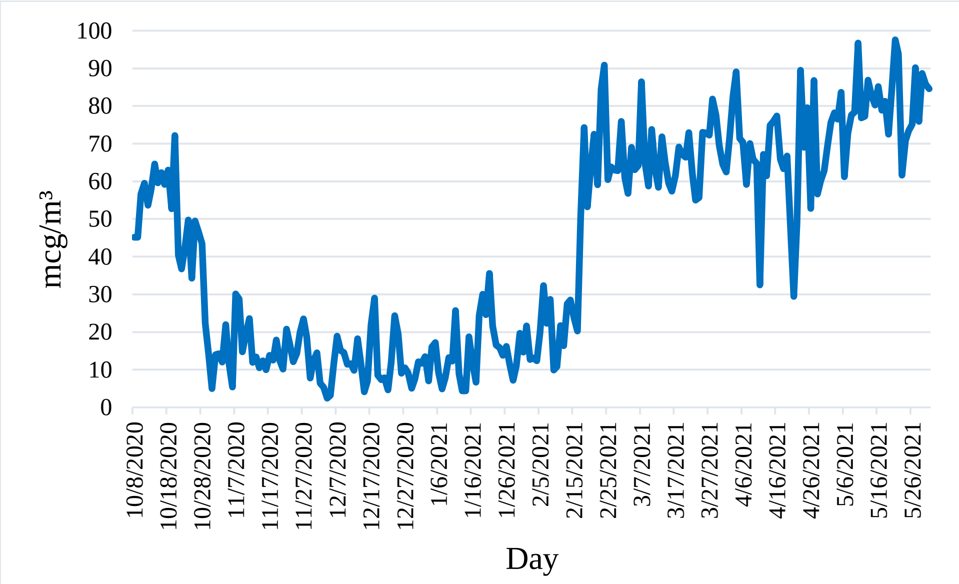


Fig. 1. Time-series of SOC in Tbilisi from October 8, 2020 to May 31, 2021.

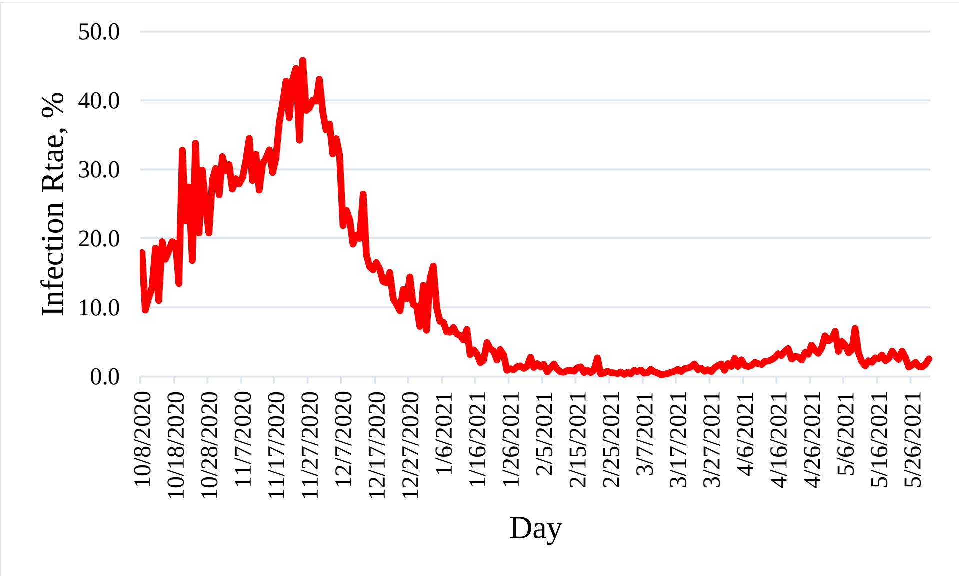


Fig. 2. Time-series of IR in Tbilisi from October 8, 2020 to May 31, 2021.

In Fig. 1-2 time-series of SOC and IR in Tbilisi from October 8, 2020 to May 31, 2021 are presented.

In Table 1 statistical characteristics of daily values of SOC and IR in Tbilisi for the time period under study are presented.

Table 1. Statistical characteristics daily values of SOC and IR in Tbilisi.

| Variable | Mean | Max | Min | St Dev | $\sigma_m$ | $C_v$, % | Count |
|---|---|---|---|---|---|---|---|
| SOC | 42.6 | 97.6 | 2.4 | 28.5 | 1.9 | 66.9 | 236 |
| IR | 10.7 | 45.8 | 0.2 | 12.6 | 0.8 | 117.7 | |

In particular, as follows from Fig. 1-2 and Table 1, the range of variability of the studied parameters is as follows: SOC – from 2.4 to 97.6 mcg/m$^3$; IR – from 0.2 to 45.8 %. Mean value of SOC is 42.6±1.9 mcg/m$^3$ and IR – 10.7±0.8 %.

Connection daily values of IR with SOC has an inverse linear form. For individual cases IR = -0.2307·SOC + 20.543 (R=0.52, α<0.005, moderate correlation).

In Fig. 3 data about values of COVID-19 Infection Rate under different surface ozone concentration is presented. In Table 2 statistical characteristics of daily values of SOC and IR in Tbilisi in different ranges of SOC values are presented.

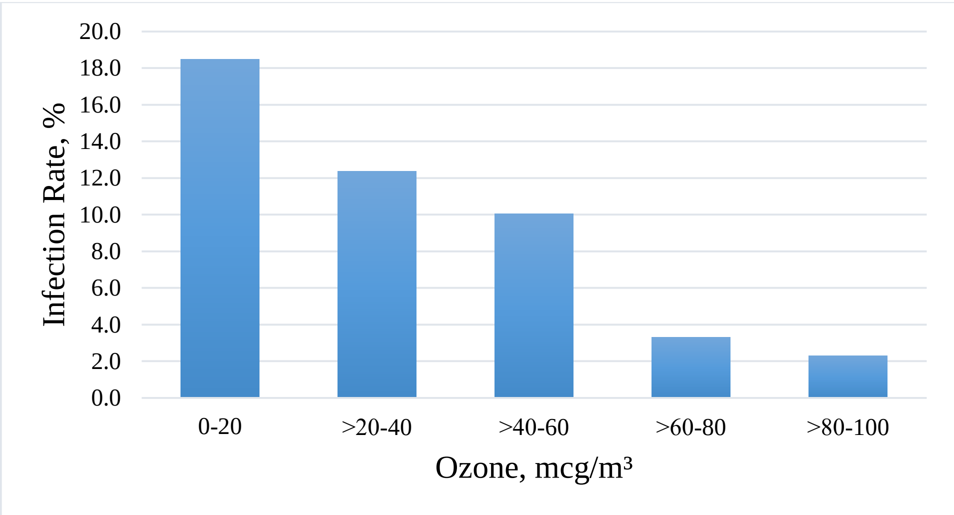


Fig. 3. Values of COVID-19 Infection Rate under different surface ozone concentration.

Table 2. Statistical characteristics of daily values of SOC and IR in Tbilisi in different ranges of SOC values.

| SOC | Variable | Mean | Max | Min | St Dev | $\sigma_m$ | $C_v$ (%) | Count |
|---|---|---|---|---|---|---|---|---|
| 0-20 | SOC | 11.7 | 19.9 | 2.4 | 4.4 | 0.5 | 37.6 | 86 |
| | IR | 18.5 | 45.8 | 0.7 | 14.0 | 1.5 | 75.9 | |
| >20-40 | SOC | 26.5 | 36.8 | 20.3 | 4.7 | 0.9 | 17.9 | 29 |
| | IR | 12.4 | 43.1 | 0.6 | 13.7 | 2.6 | 110.6 | |
| >40-60 | SOC | 53.1 | 59.6 | 40.4 | 5.8 | 1.1 | 10.9 | 30 |
| | IR | 10.0 | 33.8 | 0.2 | 10.0 | 1.9 | 100.1 | |
| >60-80 | SOC | 69.2 | 79.6 | 60.1 | 5.8 | 0.7 | 8.4 | 69 |
| | IR | 3.3 | 32.8 | 0.3 | 5.2 | 0.6 | 157.5 | |
| >80-100 | SOC | 86.9 | 97.6 | 80.2 | 4.7 | 1.0 | 5.4 | 22 |
| | IR | 2.3 | 5.1 | 0.4 | 1.1 | 0.2 | 48.7 | |

For example, at ozone concentrations from 0 to 20 mcg/m$^3$ values of COVID-19 Infection Rate on average was 18.5 %, whereas with SOC values from 80 to 100 mcg/m$^3$ – only 2.3% (Fig. 3, Table 2).

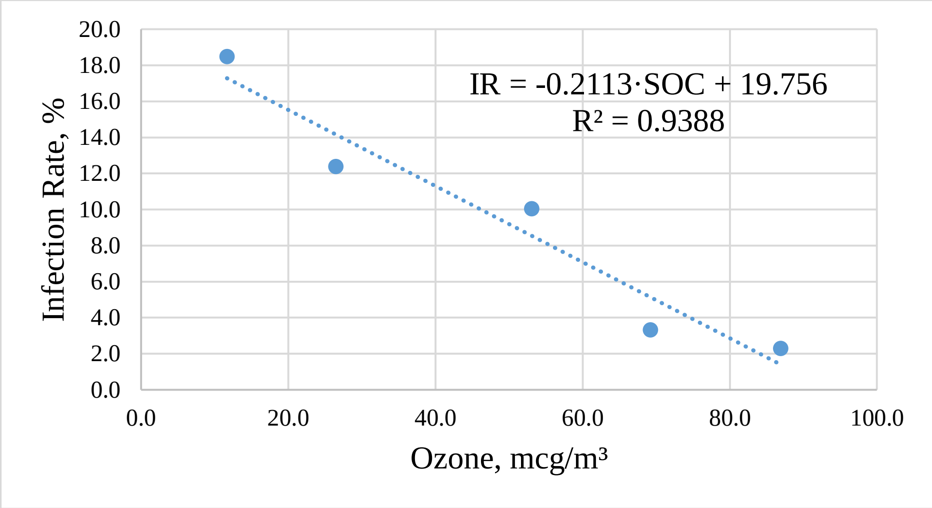


Fig. 4. Linear correlation between daily values of COVID-19 Infection Rate and Surface Ozone Concentration in Tbilisi from October 8, 2020 to May 31, 2021 ($\alpha<0.005$, very high correlation).

Connection daily values of IR with SOC for averaged values of IR in different ranges of SOC values in Fig. 4 is presented. Same as for individual cases, this connection has an inverse linear form, but with a much higher level of correlation (very high correlation).

Thus it has been found that an increase of the Surface Ozone Concentration leads to a decrease of the IR values (both for individual and averaged values of the studied parameters). In the latter case, the level of significance of the relationship SOC and IR values is much higher than for the individual cases. The reason for this (as in for thermal indexes [23-25]) may be that often with a small number of tests, overestimated IR values obtained (testing is carried out only for visitors with coronavirus symptoms. When data are averaged these shortcomings are smoothed out. Accordingly, the above results were obtained.

## Conclusion

The spread of COVID-19 in Tbilisi, as in other parts of the world, significantly depends on both individual meteorological factors and their complexes (thermal indicators), and the level of air pollution (including ozone concentration). As many researchers note, this dependence is often ambiguous and in many cases is determined by local climatic and other specific conditions, the type of virus, etc. In the future, we will continue this research both for Tbilisi and for other regions of Georgia.

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# თბილისში COVID-19-ის გავრცელებაზე მიწისპირა ოზონის კონცენტაციის გავლენის კვლევის შედეგები

ა. ამირანაშვილი, ნ. ჯაფარიძე, ჯ. ხარჩილავა, კ. ხაზარაძე, ა. რევიშვილი

## რეზიუმე

წარმოდგენილია მიწისქვეშა ოზონის კონცენტრაციის (SOC) დღიური მნიშვნელობების ქალაქ თბილისის მოსახლეობის კორონავირუსით ინფიცირების დადებითობის მაჩვენებელზე COVID-19 (IR) კვლევის შედეგები 2020 წლის 8 ოქტომბრიდან 2021 წლის 31 მაისამდე. აღმოჩნდა, რომ IR მნიშვნელობები საპირისპირო კორელაციაშია SOC-თან. მაგალითად, ოზონის კონცენტრაციებისთვის 0-დან 20 მკგ/მ$^3$-მდე, COVID-19 ინფექციის პოზიტიურობის მაჩვენებელი საშუალოდ შეადგენდა 18.5%-ს, ხოლო SOC-ის მნიშვნელობებისთვის 80-დან 100 მკგ/მ$^3$-მდე იყო მხოლოდ 2.3%. ყოველდღიურ IR მნიშვნელობებსა და SOC-ის შორის ურთიერთობას აქვს შებრუნებული წრფივი ფორმა. IR = -0,2307·SOC + 20.543 ინდივიდუალური შემთხვევებისთვის; IR = -0,2113·SOC + 19.756 - საშუალო IR მნიშვნელობებისთვის SOC-ის მნიშვნელობების სხვადასხვა დიაპაზონში.

**საკვანძო სიტყვები:** მიწისპირა ოზონის კონცენტრაცია, COVID-19, დადებითობის მაჩვენებელი.

# Результаты исследования влияния концентрации приземного озона на распространение COVID-19 в Тбилиси

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## Резюме

Представлены результаты исследования влияния суточных значений концентрации приземного озона (SOC) на показатель положительности инфицирования коронавирусом COVID-19 (IR) населения города Тбилиси за период с 8 октября 2020 года по 31 мая 2021 года. Было обнаружено, что значения IR обратно коррелируют с SOC. Например, при концентрациях озона от 0 до 20 мкг/м$^3$ показатель положительности инфицирования коронавирусом COVID-19 в среднем составлял 18.5 %, тогда как при значениях SOC от 80 до 100 мкг/м$^3$ – всего 2.3%. Связь суточных значений IR с SOC имеет обратную линейную форму. IR = -0.2307·SOC + 20.543 для отдельных случаев; IR = -0.2113·SOC + 19.756 для усредненных значений IR в разных диапазонах значений SOC.

**Ключевые слова**: концентрация приземного озона, COVID-19, показатель положительности.

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***Chronicle***

# International Scientific Conference "Geophysical Processes in the Earth and its Envelopes"

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***ABSTRACT***

*Information about the international scientific conference "Geophysical Processes in the Earth and its Envelopes" Dedicated to 90-th Anniversary of Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, which was held on November 16-17, 2023 at Ivane Javakhishvili Tbilisi State University is presented.*
***Key words:*** *geophysical processes, Earth and its envelopes, natural disasters, earth ecology, mitigation.*

## Introduction

On November 16-17, 2023, Ivane Javakhishvili Tbilisi State University hosted the International Scientific Conference "Geophysical Processes in the Earth and its Envelopes" Dedicated to 90-th Anniversary of Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University.
The conference was attended by about 200 researchers from 38 organizations from 9 countries (Georgia; Armenia; Slovenia; Hungary, Belarus; Austria; Ukraine; Italy; Chechen Republic, Republic of North Ossetia - Alanya, Russia).
The objectives of the conference were the presentation of the results of research in the field of geophysical processes in the Earth and its envelopes at the plenary session (oral\stand\video). Also, presentation of reports selected by the scientific committee and their discussion at plenary, sectional sessions and in poster form.
The target group was Georgian and foreign scientific, educational, governmental and non-governmental organizations, which have direct contact with the theme of the conference (universities, research institutes, educational organizations, structures of emergency situations, etc.).
The conference participants were given certificates.
The collection of conference materials and all of its separate articles is available on the website of the National Scientific Library: http://dspace.gela.org.ge/handle/123456789/10378

## Goal of the Conference

- Discovering the potential of scientists in the field of geophysical processes in the Earth and its envelopes;
- Establishing and strengthening ties between different generations of scientists;
- Defining the prospects for the development of scientific research;
- Identify opportunities for improving the scientific-educational field of secondary and higher education institutions in relation to the issues of the conference;
- Strengthening international scientific cooperation on conference topics;
- To acquaint the world scientific community, governmental structures, other interested organizations and individuals with the current state of the problems related to the fields of geophysical processes in the Earth and its envelopes.

## Conference Organizers

The conference was organized by the Mikheil Nodia Institute of Geophysics of the Tbilisi State University.

## Conference Supporting Organizations

The supporting organization of the conference was the Georgian Geophysical Association.

## Scientific Committee and Editorial Board

**Tamaz Chelidze:** Academician, Chairman of the Scientific Committee, Editor-in-Chief; **Nodar Varamashvili, Jemal Kiria:** Co-Chairmans of the Scientific Committee - TSU, M. Nodia Institute of Geophysics, Georgia; **Nana Bolashvili**: Co-Chairman of the Scientific Committee – TSU, Vakhushti Bagrationi Institute of Geography, Georgia; **Tengiz Tsintsadze:** Co-Chairman of the Scientific Committee – GTU, Institute of Hydrometeorology, Georgia; **Avtandil Amiranashvili** (Deputy Editor-in-Chief), **Nugzar Ghlonti, George Melikadze** - TSU, M. Nodia Institute of Geophysics, Georgia; **Liana Kartvelishvili** - National Environmental Agency, Georgia; **Marika Tatishvili** - GTU, Institute of Hydrometeorology, Georgia; **Magda Davitashvili** – I. Gogebashvili Telavi State University, Georgia; **Ketevan Khazaradze** - Georgian State Teaching University of Physical Education and Sport, Georgia; **Nino Japaridze** - Tbilisi State Medical University, Georgia; **Laura Rustioni, Gianluca Pappaccogli** - University of Salento, Italy; **Janja Vaupotič** – Jožef Stefan Institute, Slovenia; **István Fórizs** - Institute for Geological and Geochemical Research, Hungary; **Sergey Stankevich** – Scientific Centre for Aerospace Research of the Earth, National Academy of Sciences of Ukraine, Ukraine; **Sergey Nazaretyan** - Regional Survey for Seismic Protection, Ministry of Internal Affairs of the Republic of Armenia, Armenia.

## Organizing Committee

**Mikheil Pipia:** Chairman of Organizing Committee; **Manana Nikolaishvili** – Deputy Chairman of Organizing Committee; **Sophiko Matiashvili, Zamira Arziani, Ekaterine Mepharidze, Dimitri Amilakhvari, Dimitri Tepnadze, Levan Laliashvili** – TSU, M. Nodia Institute of Geophysics, Georgia; **Nino Taniashvili** - Georgian Geophysical Association, Georgia; **Nazibrola Beglarashvili,** - GTU, Institute of Hydrometeorology, Georgia; **Inga Janelidze** – Georgian Technical University, Georgia.

**Conference Themes – All problems of the** geophysical processes in the Earth and its envelopes.

### Expected Results

- Promoting historical and modern achievements in the field of geophysical processes in the Earth and its envelopes;
- To acquaint the world community with the current state of the problems related to the science of the Earth;
- Enhance international cooperation for the scientific and practical application of modern achievements related to the conference;
- Assess the social and economic risks associated with the conference topics and identify opportunities for joint action to prevent these risks;
- Identify opportunities to improve the scientific-educational base of secondary and higher education institutions in the field of Earth Sciences.

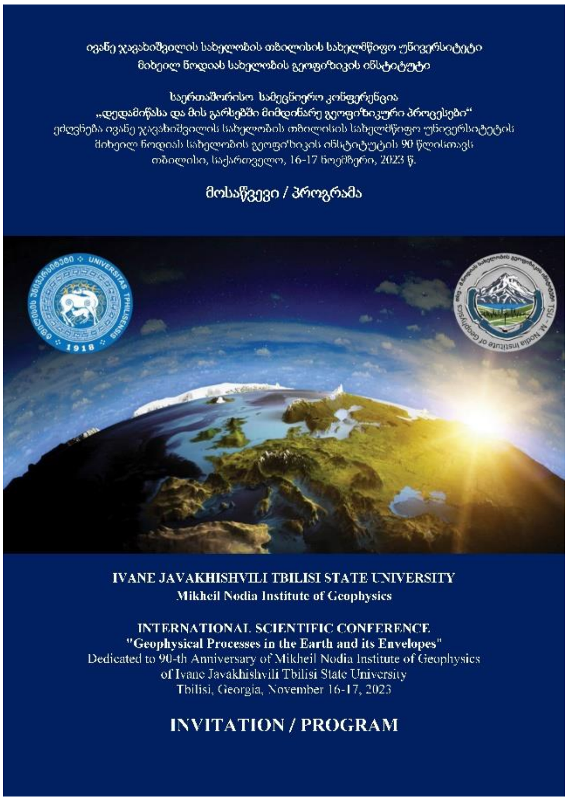
The conference was opened by the deputy rector of Ivane Javakhishvili Tbilisi State University Nino Gvenetadze, chairman of the scientific committee academician Tamaz Chelidze and co-chairman of the scientific committee, director of Mikheil Nodia Institute of Geophysics, TSU, Nodar Varamashvili. Speakers made a general overview about the modern problems of geophysical processes in the Earth and its envelopes and wished the conference participants fruitful work.

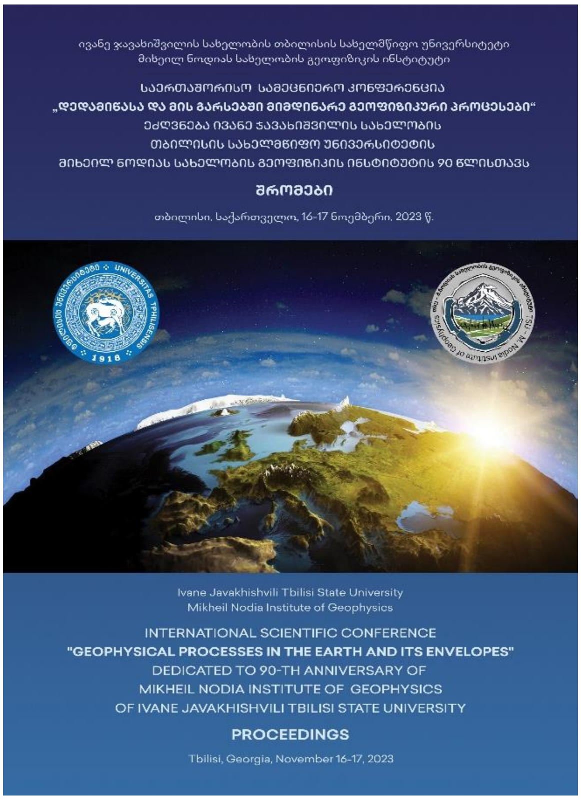
A total of 86 oral and poster presentations were considered at the conference. 84 reports published (see References). Two reports, at the request of the authors, will be published in another editions (Kordzakhia G. , Shengelia L., Tvauri G., Dzadzamia M., Guliashvili G. - Comparison of Comparison of Satellite Remote Sensing and Field Ground Observation Data for the Large Glaciers Retreat Study in Georgia; Gorgijanidze S. – The Geography of Risks of Breakthrough of Glacial Lakes and Valleys).

The proceedings of this conference as a whole, as well as its individual works, are published and posted on the portal of the Institute of Geophysics, which are included in the international electronic library data base DSpace, indexed in Google Scholar and Publish or Perish.

According to the results of the conference, a decision was made, in which the achievements and gaps in the directions of geophysical processes in the Earth and its envelopes are discussed. Future meetings have been planned.

## Photos from Conference





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0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8
Ice Thickness [km]
-1.0 0.0 1.0 2.0 3.0
Topography [km]


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## საერთაშორისო სამეცნიერო კონფერენცია „დედამიწასა და მის გარსებში მიმდინარე გეოფიზიკური პროცესები“

### ნ. ვარამაშვილი, მ. ფიფია

**რეზიუმე**

წარმოდგენილია ინფორმაცია ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტის მიხეილ ნოდიას სახელობის გეოფიზიკის ინსტიტუტის 90 წლის იუბილესადმი მიძღვნილი საერთაშორისო სამეცნიერო კონფერენციის „დედამიწასა და მის გარსებში მიმდინარე გეოფიზიკური პროცესები“ შესახებ, რომელიც ჩატარდა 2023 წლის 16-17 ნოემბერს ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტში.

**საკვანძო სიტყვები:** გეოფიზიკური პროცესები, დედამიწა და მისი გარსები, ბუნებრივი კატასტროფები, დედამიწის ეკოლოგია, შერბილება.

## Международная научная конференция “Геофизические процессы в Земле и ее оболочках“

### Н.Д. Варамашвили, М.Г. Пипиа

**Резюме**

Представлена информация о международной научной конференции “Геофизические процессы в Земле и ее оболочках“, посвященной 90-летию Института геофизики имени Михаила Нодиа Тбилисского государственного университета имени Иване Джавахишвили, которая прошла 16-17 ноября 2023 года в Тбилисском государственном университете имени Иване Джавахишвили.

**Ключевые слова:** геофизические процессы, Земля и ее оболочки, стихийные бедствия, экология Земли, смягчение последствий.

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

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