ISSN 1512-1461

UDC. 555.511.509

WAVES OF OROGRAPHIC ORIGIN IN THE EARTHS ATMOSPHERE AND THEIR ROLE IN SHAPING LOCAL CLIMATE PROCESSES

Khvedelidze Zurab, Zotikishvili Nanuli

Professor of Tbilisi State University, Doctor of Physical and Mathematical Sciences E-mail: zurab.khvedelidze@tsu.ge;
Institute of Hydrometeorology of the Georgian Technical University, senior engineer E-mail: nanu.zoti19@gmail.com

Annotation

The relief of the earth plays an important role in the formation of climatic conditions in the local area. Orographic waves arising under the influence of mountains develop convective movement and increase the probability of lightning clouds. In the presented work, the role of orographic waves was theoretically evaluated for the Kakheti region.The values of the characteristic parameters of the influence of the terrain on the air flow were estimated and the corresponding analysis was carried out. The opinions derived from the theory have been confirmed by the evaluation and distribution of hail in the research region. The distribution of hail and precipitation according to height and the dependence on the direction of the flow of air masses were substantiated.The agreement between the theoretical conclusions and the results observed in operational practice is quite satisfactory.

Keywords: *Orography, dynamics, climate, stream, speed, parameter, layer.*

Introduction

Atmospheric processes in the Earth's atmosphere obey the fundamental laws of physics. All these laws can be given a mathematical form and solved to some approximation using modern computing techniques.

This allows us to study the wave nature of these movements, the main reason of which is the uneven distribution of solar energy on the Earth's surface. Our goal is to model and predict desired processes at different spatial-temporal scales.

Determining, modeling and forecasting the dynamics of the changes in various events taking place in the atmosphere had great theoretical, practical and vital value, has and will continue to have in the future.

Most of the earth's physical-geographical surface - 70% - is a mountainous area. During the flow of the air flow in these areas, it is additionally generated. year orographic waves. They have a number of features, the study of which clarifies the circulation mechanism of air flow and increases the quality of predicting their change.

Since the kinetic energy of atmospheric movements is formed mainly in its lower layers, it is natural to assume that the main part of the wave disturbance experiences conception and development in these layers. At the same time, since the atmosphere is stratified by temperature, density and wind with height, we also have vertical propagation of orographic waves.

In fact, daily atmospheric processes, including the weather in a particular area, in most cases differ sharply from the general background.

This peculiarity is primarily due to the special orography of the ground layer of the earth, the mesoscale radiating surface. Orographic clouds and micro-local clouds are formed weather.The existence of such clouds and waves is confirmed in daily operational data and many satellite images [1.8.9].Even Hemholtz noticed that if two layers of liquid or air with different densities float on top of each other, then the so-called Wave clouds. The mathematical theory of such waves was formulated by academician N. Cochin [1.2].

ISSN 1512-1461

A similar situation occurs in the mountainous area, where orographic waves are reflected and resistance clouds are formed [9]. Such wave clouds propagate along or behind the ridge at the condensing level. The wavelength is about the order of Mtagrekhil, the period of cloud existence is one or two days and nights.

The presence of clouds depends on the wind speed and its duration. Orographic clouds have a relatively small vertical spread – several tens of meters; The strength depends on the physical and geographical conditions of the mountains. These clouds play a major role in the formation of local hail clouds, determining the nature of weather and climate change.

Theoretical statement of the task

Theoretical setting of the task In dozens of scientific works, where the interaction of atmospheric flows with the terrain is considered, the fact that even simple physical models describe the localized terrain waves sufficiently well with steady-equilibrium solutions of Rossby-type equations is indicated [1.2.3]. The obtained results can be extended to specific large mountain ranges, such as the Caucasus, the Rocky Mountains in the USA, the Andes in South America, and others. In order to study the influence of the mountain massif on the movement of the air flow, we should use the Friedman equation for the recorded mountain-hilly area [1.2.3.5.6].

$$\left(\frac{\partial}{\partial t}+u\frac{\partial}{\partial x}+v\frac{\partial}{\partial y}\right)\left(\Delta\Psi+a\Psi_x+b\Psi_y\right)=l\eta\left(a\Psi_x-b\Psi_y\right) \quad (1)$$

Here Ψ is the current function, u and v are the horizontal exponents of the velocity along the coordinate axes ox and oy.

$\eta=\frac{p_z}{p_o}$ is ageostrophicity parameter, p_z - pressure at mountain height, p_o- standard value of pressure at sea level,, $\Delta\Delta -$ - flat Laplace operator, $a=-\frac{\partial ln\eta}{\partial_x}$ $a=-\frac{\partial ln\eta}{\partial x}$; $b=-\frac{\partial ln\eta}{\partial_y}$ $b=-\frac{\partial ln\eta}{\partial y}$; - Characteristic parameters of the influence of the mountain, respectively in the direction of the parallel and meridian of the earth. Ψ_(x) and Ψ_y are derivatives of the current function with respect to the coordinate axes. The solution of this equation is found in the form of the following flat wave [1.2.5.]:

$$\Psi=\Psi_o e^{i(mx+ny-\sigma t)} \quad (2)$$

Inserting (2) into (1), the neutral-orographic waves and the condition of their existence will be estimated, with the following relationship [1.5.6.].

$$am+bn=0 \ , \quad \text{so} \ \frac{a}{b}=-\frac{n}{m} \quad (3)$$

Here, m and n are wavenumbers. Attitude (3) is a very important result for the mountainous area. Its performance determines the presence of two-dimensional neutral type waves. The ratio of the characteristic length of these waves along the meridian and the parallel is proportional to the average slope of the mountain in the same direction.

Stationary waves will also be observed, for the existence of which the following condition is necessary and sufficient [1.2.5.6.7.8.9.]:

$$\frac{n}{m}=\frac{1}{a}\left(b+\frac{\beta}{l}\right) \quad (4)$$

Comparison of (3) and (4) shows that the β effect does not affect neutral waves, but is essential for stationary type waves. Based on these theoretical results, very important practical conclusions were made:

a) the ratio of wavelengths to the average slope of the terrain is contradictory for neutral and stationary waves;

ISSN 1512-1461

b) The fact recognized in synoptic practice was theoretically substantiated. Most of the atmospheric processes spread over Transcaucasia in the form of zonal flow along the parallel (70% of the processes), meridian invasion from the north practically does not occur, this result is the opposite for the American Rocky Mountain-Helix [1.2.3].

Naturally, the orographic vertical velocity also plays an essential role in the formation of the specified mesoscale motion processes, which is determined by using the orographic Jacobian obtained by us [1–7.]

$$W_h = \frac{1}{l\eta\rho}(p, ln\eta)H = \frac{1}{l\eta\rho}\left(\frac{\partial p}{\partial x}b - \frac{\partial p}{\partial y}a\right)H \qquad (5)$$

where H=1000 m is the height of the ground layer of the atmosphere. Determining and estimating the magnitudes for a specific local region is one of the main goals of scientific research by many specialists. Obviously, these parameters should be evaluated by the orography of the study region.

To do this, we need to know the extent of mountain twist in parallel and meridian directions and the average height of the mountain. If we take the average height of the Main Caucasus
to be 4000 m, the length along the parallel is 1500 km, the width is 120 km, then we will have $a = 0{,}68 \cdot 10^{-6}$1/m; b=6,4$\cdot 10^{-6}$1/m; i.e. =0.1b. Such connection of parameters confirms dependence (3). Namely, that atmospheric processes spread over Transcaucasia mainly by zonal flow along the parallel. Meridian invasion of the stream is possible only in one case out of ten.

It is well known and recognized that the theoretical basis of the change of meteorological elements is based on the possibility of solving the system of equations of hydrothermodynamics [1.2.3.4.5.6]. The solution of the mentioned equations is always performed in a certain approximation. In order to increase the accuracy of forecasting, the influence of various physical factors in the given task is taken into account, and in this way appropriate model schemes for operational practice are constructed [3.8].

One of these basic and important factors is the consideration of the influence of the earth's relief [3.4.5.6] To characterize the change of the geopotential $\phi = gH$ field in a specific local region, let's cite one of the recognized and relatively simple models of the influence of the relief on the air flow, for the barotropic environment. Here g is the acceleration due to gravity, H is the isogibs height of the geopotential. Assume that the physical orographic surface of the Earth is described by the function [1-7].

$$z = Z(x, y)$$

When considering a plane problem, the vertical speed of the air flow at z = 0 is equal to 0, and in our case, at $z = Z(x, y)$ the vertical speed must satisfy the condition of non-penetration of the air flow into the relief, which has the following form [3.4.5]:

$$w(x, y, Z, t) = u(x, y, Z, t)\frac{\partial Z}{\partial x} + v(x, y, Z, t)\frac{\partial Z}{\partial y} \quad , \qquad (6)$$

Integrating the continuity equation from the surface $z = Z(x, y)$ to ∞, provided that $(\rho w)_{z=\infty} = 0$, we get [1,4-8]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{1}{\eta^2}\,(\eta, \phi) \qquad (7)$$

And for horizontal wind speed coefficients we will have [1.2.3.4.5]:

ISSN 1512-1461

$$u=-\frac{1}{l\eta}\frac{\partial\phi}{\partial y};v=\frac{1}{l\eta}\frac{\partial\phi}{\partial x} \qquad (8)$$

Based on dependence (7) and (8), using hydrothermodynamic equations, the following basic prognostic-model ratio corresponding to (1) is obtained by standard approach [1-6]:

$$L\phi+\beta\frac{\partial\phi}{\partial x}=\frac{l}{\eta}(\phi,\eta)-(\phi,\frac{1}{l}\frac{\partial}{\partial x}(\frac{1}{\eta}\frac{\partial\phi}{\partial x})+\frac{1}{\eta}\frac{\partial}{\partial y}(\frac{1}{\eta}\frac{\partial\phi}{\partial y})+l) \quad (9)$$

In (9) $L=\Delta+a\frac{\partial}{\partial x}+b\frac{\partial}{\partial y}$ is a face operator, bracket (A,B) is a well-known Jacobian; Equation (9) differs from the corresponding equation [1.3.6] in the members containing the parameters a and b of the terrain influence and the so-called By adding an orographic $(\phi,\ln\eta)$ Jacobian. Determining and evaluating these values for a specific local region is the main goal of our research. Obviously, for the characterization of climate change, it is important to estimate the numerical value of parameters a, b and w in a separate mountain-hill area and, accordingly, to characterize the dynamics of the air flow.

For example, let's consider the region of Kakheti, in particular the area of the Alazni Valley. In this area, the action of orographic waves is relevant and essential, both in the formation of internal massive and frontal clouds. Clouds of this type are an important active center in the formation and development of hail.

Let's evaluate the orographic parameters of the region [1], to get the size of the region along the Earth's parallel Δx =15.10^4 m, in relation to the meridian $\Delta y = 5.10^4\, m$; The height of the ground layer of the atmosphere H=10^3 m; By the hypsometric table, we calculate the corresponding pressures at the desired points.

Using the formulas given by these data, we determine parameters a, b and vertical speed, we get: w_h=0,89.10^{-2}m/sec, a=0,15.$10^{-6}m$, b=4,1.$10^{-6}m$. Such a small vertical velocity indicates that there is almost no direct updraft in the air flow over the Alazni Valley. Ascending and descending currents are directly along the slopes of the mountain ranges.

In addition, orographic waves in the north-south direction significantly exceed the waves in other directions. This is confirmed by the ratio of a and b parameters a=0.4b b=27.3a. Such influence of mountain-hilliness contributes to the origin and development of clouds of relief lightning nature;

Increases the minimum temperature in winter and the maximum in summer. These considerations are confirmed on the basis of field analysis of meteorological elements of real situations [10].

It was noted that when overcoming the resistance of the air flow in the mountainous regions, the turbulence increases, the convective-rain cloudiness and the possibility of hail formation increase [9]. Obviously, this affects the number of hail days. As the convective movement increases during the summer, the hail increases during the summer, especially in the months of May-June. The analysis of long-term observations [10] has proven that Kakheti and Samtskhe-Javakheti regions are distinguished by the maximum number of hail days, and Guria and Imereti are the least.

Based on the given wave theory, the orientation of mountains and hills with respect to the prevailing air flow plays a big role. For example, according to [10] in the Rock region, which is 1800 m. At altitude, the recurrence of hail is 1.8 days per year, while in Telavi, located at 562 m, it is 2.7 days. Hail-dangerous clouds mostly form and move along the Gombor ridge, which is filled with warm moist air masses in the ground layer.

This causes and strengthens the conception and development of hail. According to the material cited in [10], hail processes from the study region are most active in Telavi and Gurjaani regions, where the average number of hail days per year exceeds three. Today in Sagarejo and Sighnaghi districts it is (2.1-2.5), while in Lagodekhi it is less than 1.5. see Table 1.

ISSN 1512-1461

Table 1.

Meteorological Station	height z.d. (m).	hail days quantity (in years)	Average intensity of hail (in points)	Average precipitation per year (mm)
Sighnaghi	795	2.1	2.3	811
Telavi	568	3.0	2.0	776
Lagodekhi	435	1.5	1.7	975
Gurjaani	415	2.3	2.5	783
Sagarejo	802	3.1	2.2	865
Alazani	290	-	-	804

Thus, the distribution of the number of hail days largely depends on the physical-geographical conditions of the area, especially the orography and altitude. Analysis of the observed data [10] reveals that the number of hail days in the southeast of Georgia increases linearly from 2000 m. to the height, it is maximum at 2500 m, and decreases above.

Precipitation, which is unevenly distributed, is subject to the same change. Its quantity increases according to the height and territorially (800-1000) mm. varies between, see table N1 - derived from operational practice. The material presented here corresponds well with and explains the theoretical approach presented in the presented article.

Conclusions:

1. In the territory of Kakheti, the flow of the air flow from the northwest to the east will be predominantly observed (b=27.3a); The direct vertical movement of the stream is small. Mainly updrafts of air are along ridges.
2. The influence of orography strengthens convection currents and increases the probability of formation and development of clouds containing hail.
3. Theoretically, updrafts and terrain influence should develop at (1000-1500) m height, and then the influence decreases. Indeed, by analyzing the multi-year data of hail in Kakheti, the number of days with hail and precipitation increases linearly by 2000 m. to a height, and then decreases.
4. The given theory well explains the role of orographic waves influence on the hail of the study region. Theoretically justifies the events that are observed in operational practice.

Literature:

[1].Khvedelidze Z. "Dynamics of regional microcirculation atmospheric processes in the mountainous area" GTU Institute of Hydrometeorology Publishing House, monograph. Tbilisi. 2018 p. 105.

[2]. Khvedelidze Z. "Dynamic Meteorology",TSU Publishing house, Tbilisi, 2002, p. 535

[3]. Khvedelidze Z. "Wave motion in the lower layers of the atmosphere and the problem of pollution" Textbook, TSU Publishing House, Tbilisi, 1991. p. 200.

[4]. Khvedelidze Z. "Brief Scientific Reference" – a helpful guide. GTU Institute of Hydrometeorology Publishing House, Tbilisi. 2021 p. 90.

ISSN 1512-1461

[5]. Khvedelidze Z. “Study of atmospheric movements in the Coriolis force field in the presence of mountains” Proceedings of the USSR Academy of Sciences. F. and from. 18 №3 1982 p. 227-235.
[6]. Khvedelidze Z., Zotikishvili. N. "Study of the dynamics of the turbulent flow of air in the ground layer of the atmosphere during the change of microrelief" gesj "Physics" (http//gesj. Internet-academy. Org.ge/physic/; ISSN 06363.2021. No. 1(25). pp. 42-51.
[7]. Khvedelidze Z., Tatishvili M., Zotikishvili. N, Samkharadze I. "The role of mountain-valley terrain in the study of local air flow circulation" gesj "Physics" (http//gesj. Internet-academy. Org.ge/physic/; 2018, N 1(19) p. 21-31.
[8]. Khvedelidze Z. Synoptic meteorology (short course) TSU Tbilisi. 1998 p. 80.
[9]. Khvedelidze Z. Physics of clouds – a course of lectures, TSU Publishing House. Tbilisi 1987 p.115.
[10]. Pipia M. "Climatology of Hail in Eastern Georgia"Dissertation for the academic degree of Doctor of Geography. Telavi 2016 page 114.

Article received 2023-10-11