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Dynamics of Atmospheric Microcirculation Processes in Certain Regions of Georgia

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Abstract

There are many microregions on Earth in which the study of developed hydrometeorological processes is important and has great practical value. Such regions include various caverns, highways, open quarry work areas, hydropower plant construction area. A special theoretical approach to study of local events in such areas for their modelling is given in the presented paper. The mathematical basis of this approach is presented; sample examples and calculation procedures are given. The presented materials and obtained results are important for conducting further studies, have practical value and are recommended to be taken into account when carrying out various activities in the local area of similar terrain.

Keywords: Microcirculation processes, wind speed, turbulence flow, atmosphere disturbances, von Karman vortex

Introduction

Atmospheric processes are highly heterogeneous and anisotropic in space and time. The main reason for this is the uneven distribution of energy from the sun to the Earth's surface. In the lower layers of the atmosphere, the heat regime is provided by longwave radiation reflected from the Earth's surface. The heterogeneous surface causes the rays to reflect at different angles, which in turn causes an uneven distribution of the heat field. An uneven heat field causes an uneven distribution of atmospheric pressure to establish so-called permanent "barrier centres". These centres provide air motion mainly from west to east ("leading" flow) (8-12) m/s and other zonal flows. These processes are peculiar everywhere, especially in difficult physical terrain, such as Transcaucasia and Georgia. The wind speed is a three-dimensional vector. The vertical stiffness is small compared to the horizontal stiffness and can only reach 10-20 cm/s or greater under intense convective motion. Such convective movements, however, often occur on uneven, mountainous terrain (Tatishvili et al., 2019a). Therefore, in the mountainous terrain layer, it is not acceptable to have zero divergence of the wind, as is allowed for a straight surface. Experimental measurements of wind vertical velocity are associated with principal difficulties; therefore, it is necessary to evaluate these measurements using theoretical methods (Khvedelidze et al., 2018).

There are several microregions in the territory of Georgia whose climatic conditions sharply differ from the climate, with changes in climatic parameters and impacts on weather conditions in the outer region. Thus, it is necessary to investigate, explain and justify the nature of changes in wind speed, air flow turbulence and climatic parameters on different construction tracks, radiation regimes and environmental pollution assessments for different time intervals. Actions of the mentioned type were ongoing and are still ongoing in Transcaucasia, particularly in Georgia. The Transcaucasia Road, open pit works in the Chiatura and Kaspi regions, and the construction of hydroelectric power stations in various regions. When performing such studies, the spatial change in the turbulent flow of atmospheric air, first in the ground layer, should be studied. It is known that additional orographic turbulent currents and regular oscillatory disturbances are formed in mountainous areas (Khvedelidze et al., 2018). A change in the microrelief of the Earth's surface, even on a small scale, causes local circulation of the air flow. It becomes clear what impact such long-term construction, which we have already mentioned above, will have. It is necessary to analyse the spatial-temporal change mode of meteorological parameters in these regions (Khvedelidze et al., 2023).

There are several microregions in the territory of Georgia whose climatic conditions differ sharply from the climate of the outer region. One of these microregions is the Svaneti Cavern. Zemo Svaneti plays a special role in diverse regions of Georgia. This is due to both its unique nature and centuries-old history, which has added a unique touch to the cultural heritage of this area. Zemo Svaneti is located on the southern slopes of the Central Caucasus. Most of the high peaks of this mountain massif are concentrated in this part of the Caucasus and include those of Shkhara (5203 m above sea level), Tetnuldi (4858 m), Ushba (4700 m), Tikhtingeni (4617 m), and Shkhilda (4368 m) (Khvedelidze, 2018).

The peaks covered with glaciers and permanent snow rise above the villages are scattered on the slopes and terraces, of which the center of the region, the village of Mestia, which is in the hollow region, stands out. The region of Mestia is bordered to the north by the ridge part of the main axial ridge of the Caucasus, which morphologically belongs to the Western Caucasus. This section is covered with a glacial coat. The district is bounded in the northwest by the Kodori ridge, which continues to the Jvari reservoir, and in the southeast, it is bounded mainly by Svaneti and in the southwest direction by the Odishi ridge, which flattens to the southwest.

The Lentekhi municipality is located on the southern slope of the Caucasus range and is one of the most mountainous regions in Georgia. The region is bordered to the southeast and south by the Lechkhumi range, to the west by the Kodori range, and to the north by the main watershed of the Caucasus. The Tskhenistskali River is the main hydrographic unit in the territory of the Lentekhi municipality. It is joined by the Kheledura River and Laskadura River in the town of Lentekhi, after which the Tskhenistsali River flows out of the Kvemo Svaneti cavern. Then, it connects the caverns of Kvemo Svaneti and Tsageri, has a submeridian direction and continues from Lentekhi township to Tsageri at 20 km. The Kvemo Svaneti cavern extends from west to east at 85 km. The area of Lentekhi municipality is 1344 km2. The largest settlement is the village of Lentekhi. There are 61 villages in the municipality (Khvedelidze et al., 2020).

Under quiet atmospheric conditions, in narrow deep canyons, under the influence of a periodically active specific heat source related to solar radiation, a convection boundary layer can form on the slope of the ridge bordering the canyon. As the height in the canyon increases to 200-250 m, the speed of the convection wind increases. After reaching the maximum, its magnitude gradually decreases to such an extent that, at some level, the direction of the wind reverses (inversion). This event should be qualitatively the same in different canyons. It is known that the inversion level, such as the wind speed, increases with increasing atmospheric instability. Under calm, less cloudy conditions, the wind flow on the mountain side, approximately half an hour after sunrise, occurs down the valley (Tatishvili et al., 2019b). When the slope warms up and the specific heat source is activated, the wind blows in the same direction for approximately one hour. After that, the direction of the wind, whose characteristic speed is (1-3) m/s, changes from downwards to upwards.

Methods and Materials

One of the most important contemporary problems from both scientific and industrial-practical points of view is to study the climatic features of local regions against the background of global climate change. The quantitative forecasting of precipitation (QPF) and other meteorological parameters: temperature, wind, pressure and etc on regional scales is still inadequate for many applications such as weather prediction, hydrology, flood and landslide forecasting. For this purpose, it is essential to reproduce precipitation accurately down to the size of small catchment areas. The most applicable is the Weather research and forecasting model (WRF) that is weather numerical forecasting and atmosphere simulation system created as for research as operational application. The model is elaborated USA National Center for Atmosphere Research (NCAR), Mesoscale and Microscale Meteorological Division (MMM), NOAA, NCEP, ESRL, AFWA, Naval Research Laboratory, CAPS, and etc (Ebert et al., 2003). It is used in following fields: real-time numerical forecasting, data assimilation, physical parameterization research, regional climatic simulations and etc. The Dynamical core of the model provides general circulation processes transformation influenced by Caucasus relief and proximity of The Black and Caspian Seas resulting in local weather. The specification of those processes is possible by optimal configuration selection of schemes describing physical processes. Besides ARW provides introduction of higher spatial-temporal resolution horizontal grid that focuses on target sub-region and significantly increases model resolution (from 15km to 5 km.) (Bianco, 2008). The WRF-ARW version 3.1 was running operationally on the NEA cluster during several months with two different model configuration combining different convective and microphysical schemes. All runs were initialized with 25-km NCEP GFS Model GRIB data results from regional NWP do not have the same quality for all areas within the domain. (Kutaladze et al., 2021). The results of model validation are not homogeneous inside domain and are highly dependent on the physical content of the synoptic process and complexity of relief.

Continuous operational data show that the weather in some local regions noticeably differs from that in surrounding areas. This circumstance is mainly related to the shape and the dynamic processes caused by the relief. Therefore, the definition of terrain influence parameters and their analysis are highly pertinent and important. A hydrodynamic approach was used to explain the developed microcirculation processes in the Svaneti cavern. The characteristic parameters of the relief of the region are estimated, and the orographic vertical velocity is calculated. By statistically processing long-term meteorological data, the climatic features of caverns and the nature of air flow dynamics can be determined. The results of the model calculations make it possible to clarify those features.

We use the following hydrodynamic equation for a vertical wind velocity compiler (Khvedelidze, 2018):

$$\frac{\partial \Omega}{\partial t} + u\frac{\partial(\Omega + l)}{\partial x} + v\frac{\partial(\Omega + l)}{\partial y} = -lD \qquad (1)$$

For the mountainous territory, the wind velocity vortex in the geostrophic approach may be written as follows (Khvedelidze, 2018):

$$\Omega = \frac{1}{\eta}[\Delta\Psi - (a\Psi_x + b\Psi_y)] \qquad (2)$$

where Ψ is the current function and u and v are the horizontal components of the wind velocity. $\eta = \frac{p_z}{p_0}$- ageostrophic parameter, p_z- pressure at the hill top, p_0- pressure at the bottom, $\Delta -$ Laplacian operator, $a = -\frac{\partial ln\eta}{\partial x}$; $b = -\frac{\partial ln\eta}{\partial y}$; parameters describing the influence of parallel and meridian orography, Ψ_x and Ψ_y current functions derived from the ox and oy axes, D-velocity divergence, and l- Coriolis parameter. From the above equations, we obtain the following equation:

$$\left(\frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y}\right)\left(\Delta\Psi + a\Psi_x + b\Psi_y\right) = l\eta(a\Psi_x - b\Psi_y) \qquad (3)$$

The solution of this equation is a flat wave, and after transformation, the following dependence is obtained:

$$am + bn = 0 \qquad (4)$$

This dependence theoretically confirms the regional problem noticed and recognized in synoptic practice, namely, that atmospheric processes in the Trans Caucasus mainly spread in parallel directions along mountain ridges (Khvedelidze, 2018; Tatishvili, 2017; Tatishvili et al., 2022).

This result is also valid for the local area, where the mountain massif can be approximated in the form of a geometric figure and the appropriate characteristic parameters can be calculated. Thus, the air flow at any selected local polygon is influenced by the up-and-down currents generated by the influence of the terrain, which must be considered. These currents principally determine the nature of local circulation and a number of features in local hollows.

After simple transformations, we obtain the equation for the orographic vertical velocity

$$W_h = \frac{1}{l\eta\rho}(p, \ln\eta)H = \frac{1}{l\eta\rho}\left(\frac{\partial p}{\partial x}b - \frac{\partial p}{\partial y}a\right)H \qquad (4)$$

The identification of a , b and W_k members must be realized for each local region.

Results

The complex topography of the region results in a considerable diversity of climatic zones. Hypsometric heights in the region cover a wide range—from 500 meters on the bank of the Cross Reservoir to 5203 meters on the peak of Shkhara. Accordingly, the climate in Upper Svaneti changes from the humid warm sea climate characteristic of the Colchis Lowland to the humid high mountain climate with permanent snow and glaciers; according to the modern classification, it contains 5 climatic zones. Naturally, all these zones, depending on the local conditions, react in their own way to regional climate change.

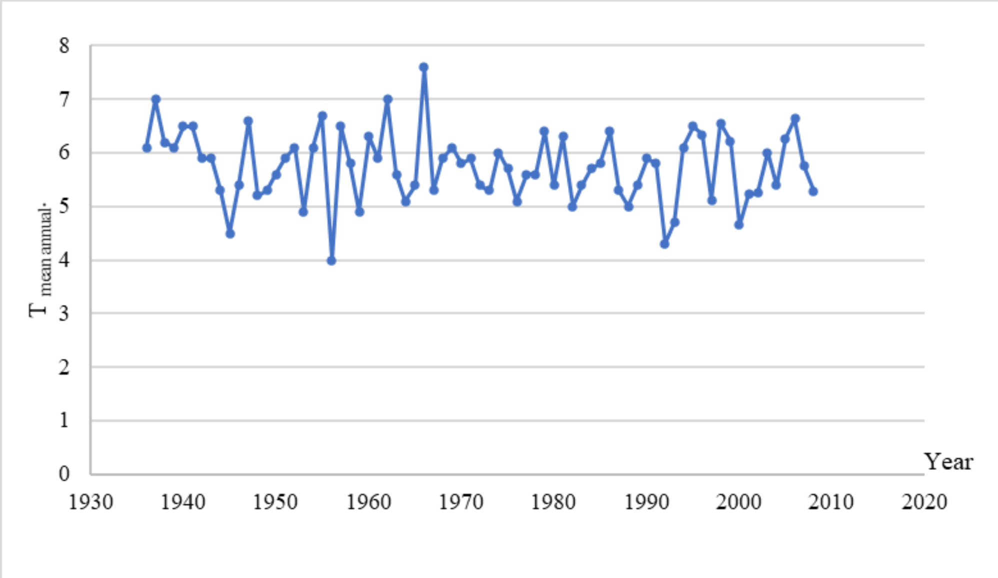

Figure 1. The average annual air temperature according to the Mestia weather station data (1938-2008)

The territory of Zemo Svaneti is characterized by a moderately humid mountain climate. Weather types within the district vary hypsometrically from a moderately humid valley-type climate to a harsh high mountain climate. Atmospheric precipitation is unevenly distributed in the district territory. The average annual amount reaches a maximum in the crown region and a minimum below Mestia in the Enguri River direction and reaches 800-1000 mm per year. The distribution of precipitation is mainly determined by orography.

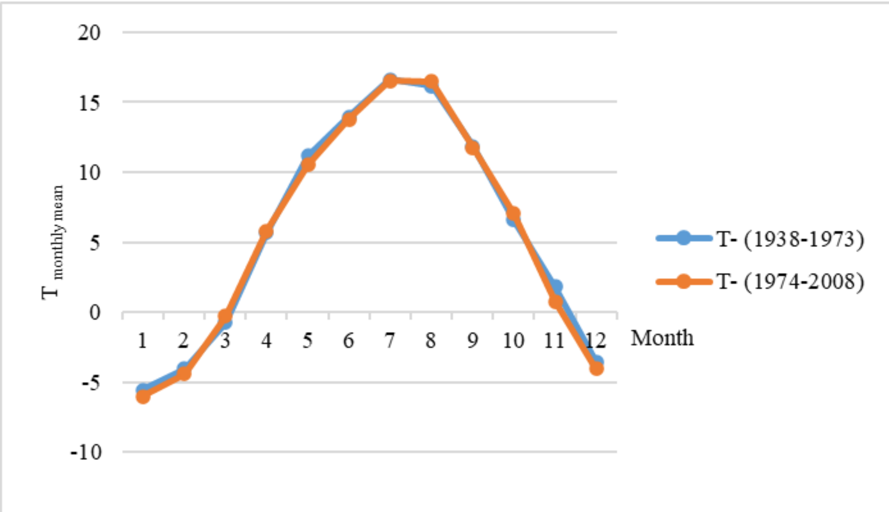

Figure 2. Distribution of the monthly mean air temperature according to the Mestia weather station data (yellow, 1974-2008; blue, 1938-1973)

The significant part reflecting the climate of Upper Svaneti (the middle zone) has been characterized by the Mestia weather station, which is located at an elevation of 1,441 m. Mestia has a humid climate with cold winters and long, cool summers. Based on observations from 1936-1960, the average annual temperature of this area is 5.7°C, and the average temperature of the coldest month (January) is -6.0°C. The average temperature of the hottest month (July) is 16.4°C, the absolute minimum is -350°C, and the absolute maximum is 35°C. The sum of the active temperatures (more than 10°C) is 2,039 degrees, the average annual relative humidity of the air is 75%, the annual precipitation sum is 918 mm, and the maximum of the monthly sum usually occurs in the month of October and reaches 95 mm, while the minimum occurs in February (61 mm). The average annual wind speed is equal to 1.1 m/s. North and southwest winds prevailed in the surrounding area.

According to the Mestia weather station data, the average air temperature for the coldest month (January) in 1938-2008 was -5.7°C, and that for the hottest month (June) was 16.6°C. For the course of the average annual temperature according to the last 10 years of data (after 1999), the average annual temperature reached its maximum of 6.6°C in 2006.

To determine the temperature dynamics, we divided the given period into two (35-year) parts: 1938-1973 and 1974-2008. The distribution of average monthly air temperatures for both periods is given in Fig. 2.

According to the data from the last 35 years, an increase in the monthly mean temperature is observed in March (0.10°C), August (0.30°C) and October (0.40°C). For other months, the average monthly temperature is either constant or decreasing.

According to the Mestia weather station data, the average air temperature in 1938-2008 for the coldest month (January) was -5.7°C. The hottest month (June) is 16.60°C in temperature. For the mean annual temperature, according to the last 10 years of data, it reached its maximum in 2006 (6.6°C).

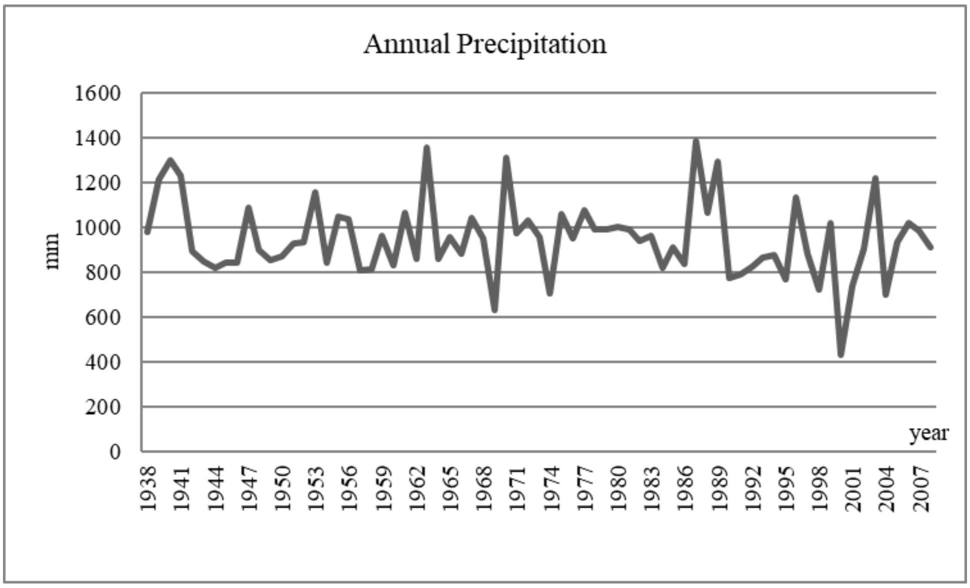

Figure 3. Distribution of the annual precipitation sum for the Mestia weather station (1938-2008)

Discussions

The peculiarities of the Mestia cavern in the Svaneti region are particularly interesting. This hollow occupies a significant area in the altitude zone of 1000-2000 meters. The cavern is characterized by cold winters and long cool summers. If for model calculations we conditionally assume that the hollow occupies (50/50) the area of a square kilometre, then the following values are obtained for the orographic parameters: a=7, 2.10-4 1/m, b=10-4 1/m; that is, a=7,2b. These parameters are inversely proportional to the wavelength of the invading air masses. Therefore, the wind in the cavern mostly blows (in the landward layer) from the west in a direction parallel to the main ridge. The orographic vertical velocity is small. The intruding air mass is surrounded by mountains covered with high glaciers on three sides; due to the low vertical speed, mass flow cannot occur over these mountains. The air stream is reflected from the mountains (a law of momentum constancy) and remains in the hole for a long enough time. This is the reason for the climatic peculiarity of Svaneti, which has a cold winter and long cool summer. From the given reasoning, the received theoretical modelling result substantiates the climatic specialness that is observed in caverns.

Conclusion

The existence of hollows over terrain significantly complicates weather prediction (Tatishvili et al., 2020; Tatishvili, 2017). The latent heating in a large complex of deep moist convection often produces a cyclonic vortex. These vortices can then initiate additional convection the next day. As a result, they represent a complex forecast challenge: for a numerical model forecast to make an accurate "day 2" forecast, it must make a correct prediction of the location and timing of the convection on day 1 (which is itself difficult); it must represent the vertical structure of latent heating that leads to the development of the cyclonic vortex; it must correctly capture the evolution of the vortex; and it must determine whether the lifting associated with that vortex will initiate convection again. When steady wind flows around an isolated obstacle, such as a mountain or a mountainous island, atmospheric vortex streets (AVSs) can be generated on the leeward side of the obstacle under favourable meteorological conditions. The AVS pattern exhibits a double row of counterrotating vortex pairs shedding alternately and resembles the classic von Karman vortex street; these types of vortex streets have significant weather and climate implications. Atmospheric vortex streets may modulate cloud and wind patterns over downstream regions and are an additional reason for forecasting uncertainty. To avoid all these complications together with numerical weather predictions, another model must be run: the microscale model, which depicts local atmospheric disturbance (Tatishvili et al., 2022.) This coupling became essential, as Georgia is a country with great tourism potential, including winter sport tourism. Detailed information on the wind stream velocity can aid in safe paragliding sport and rescue missions. Additionally, research outcomes may be important for early warning systems.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

M.T., Z.K. and I.S. conceived of the presented idea. I.S., N.Z., and N.N. performed the analytic calculations. M.T. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research and analysis of the manuscript.

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