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Impact of Atmosphere Perturbation and Microcirculation on Tbilisi Thermal Regime

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Marika Tatishvili[1,2] *, Nana Bolashvili[2]
Tamaz Karalashvili[2], Nikoloz Suknidze[2]
[1] Institute of Hydrometeorology of Georgian Technical University, Tbilisi, Georgia
[2] TSU, Vakhushti Bagrationi Institute of Geography, Tbilisi, Georgia
* Corresponding author: marika.tatishvili@tsu.ge

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Abstract

This paper investigates the thermal peculiarities of Tbilisi in relation to geomagnetic activity and local microcirculation features. The geographical setting of Tbilisi gives rise to the well-known "Tbilisi Hole" phenomenon, which strongly influences the spatial distribution of air temperature within the city. Geomagnetic storms represent major disturbances of the Earth's magnetosphere that occur when the solar wind interacts with the near-Earth space environment. The strongest storms are typically associated with solar coronal mass ejections (CMEs) and may take several days to reach the Earth. Geomagnetic indices constitute important parameters in weather forecasting methods. In this study, correlations between geomagnetic storms and air temperature in Tbilisi were identified using meteorological observations from the National Environment Agency (NEA) and data from NASA's Solar Dynamics Observatory (SDO) and the NOAA Space Weather Prediction Center. The results indicate that sudden decreases in air temperature occur predominantly on dates associated with geomagnetic storm events. In addition to the influence of geomagnetic activity, a key recommendation for reducing thermal stress in Tbilisi is the expansion of green cover in the city centre and on surrounding slopes. Nature-based solutions represent the most effective approach for achieving this goal and include measures such as green roofs, vertical vegetation, green corridors, and geoparks.

Keywords: Geomagnetic storm, Microcirculation processes, inversion, turbulence flow, atmosphere instabilities

Introduction

Understanding the thermal regime of large cities has become an increasingly important scientific and practical task, particularly in the context of ongoing climate variability, urbanisation, and the growing frequency of extreme weather events. Urban thermal conditions are shaped not only by large-scale atmospheric circulation but also by local factors such as relief, land cover, building density, and anthropogenic heat emissions. In complex topographic settings such as mountain basins and hollows, these influences are further modified by microcirculation processes, temperature inversions, and restricted air exchange, resulting in pronounced spatial and temporal temperature contrasts within relatively small areas.

In recent decades, urban climatology has increasingly focused on the interaction between atmospheric perturbations and local-scale circulation mechanisms. Numerous studies have demonstrated that synoptic-scale disturbances, including changes in atmospheric pressure patterns and variations in solar and geomagnetic activity, can modulate near-surface meteorological conditions, particularly in regions characterised by stable stratification and weak ventilation. In such environments, even short-term atmospheric perturbations may amplify or suppress local thermal anomalies, thereby influencing the intensity and persistence of urban heat accumulation.

The role of microcirculation in shaping urban thermal regimes has been widely recognised, especially in cities located in basins or enclosed relief forms. Local wind systems, slope flows, and valley circulations can either enhance heat removal or promote stagnation, depending on their structure and interaction with background atmospheric conditions. In the case of Tbilisi, the combined effects of the Tbilisi Hollow, surrounding mountain ranges, and the Mtkvari River valley create a highly sensitive climatic system in which small perturbations may lead to measurable thermal responses.

At the same time, growing attention has been paid to the potential influence of atmospheric and space-weather-related factors, including geomagnetic disturbances, on meteorological variables near the Earth's surface. Although the mechanisms linking geomagnetic activity and surface air temperature remain the subject of ongoing debate, empirical studies conducted in different regions suggest that such interactions may be detectable under specific geographical and climatic conditions. Cities characterised by persistent temperature inversions, limited vertical mixing, and strong radiative forcing are considered particularly suitable for investigating these relationships.

Within this broader scientific context, Tbilisi represents a valuable natural laboratory for studying the combined impact of atmospheric perturbations and microcirculation on urban thermal regimes. Its complex relief, frequent inversion conditions, pronounced intra-urban temperature contrasts, and sensitivity to both regional and local atmospheric processes make it especially relevant for integrated climatic analysis. Examining these interactions is not only important for advancing theoretical understanding but also has practical implications for urban planning, public health, and climate adaptation strategies in rapidly warming urban environments.

Tbilisi is located in the eastern part of Georgia, within the Tbilisi Basin, at elevations ranging from 380 to 700 m above sea level. The city's main artery, the Mtkvari River, divides it into two parts—the right and left banks—whose relief differs markedly. The right bank is significantly higher and steeper and is dissected by numerous small rivers and transversely oriented ravines. By contrast, the left bank is relatively flat, although dry ravines, locally referred to as lifeless ravines, are also present. Tbilisi is bordered to the north by the southern foothills of the Saguramo Range, to the east by the north-western section of the Iori Upland, and to the west and south by branches of the Trialeti Range.

The climate of Tbilisi is classified as subtropical semi-arid, with hot summers. The average air temperature in July is +24.4 °C, while the absolute annual maximum reaches 40 °C. Winters are cold, with a mean January temperature of +0.9 °C. The average annual precipitation is approximately 560 mm, with a maximum in spring and a minimum in winter. Northern and north-western winds prevail, although south-eastern winds are also frequent. Due to the city's relatively low geographical latitude, cloud cover is limited, and solar radiation is abundant and prolonged.

July is, on average, the warmest month of the year, with a mean maximum temperature of 29.9 °C. Tbilisi recorded its all-time highest temperature on 4 July 2017, exceeding the previous record by 0.1 °C. The former record had been set on 1 August 2000, when the air temperature reached 40.4 °C (Tatishvili et al., 2025).

A distinctive climatic feature of the Tbilisi Hollow is observed in winter under sunny, calm anticyclonic conditions, when air temperatures on the slopes of Mtatsminda are often 6–9 °C higher than those recorded at the meteorological station located at 459 m above sea level. Cold air descending from the surrounding mountains flows into the Mtkvari River valley, where, due to limited ventilation, it stagnates and further cools.

During winter, Mtatsminda remains warmer throughout the day than the city centre, whereas in summer it is comparatively cooler. At the same time, air humidity increases in the central parts of the city, fog frequently forms (with visibility reduced to 500–700 m), and an aerosol smog layer is almost always present (Khvedelidze et al., 2023). Microcirculation processes contribute to higher air temperatures in the city centre compared to peripheral districts. In both January and July, temperatures in central Tbilisi are 0.6–2 °C higher than those recorded in Digomi and Samgori. Wind speeds in the city centre are also lower (2.2 m/s in January and 2.1 m/s in July) than in the outer districts, such as Digomi (3.7 m/s and 5.2 m/s) and the airport area (5.4 m/s and 7.2 m/s).

Vertical air mixing in Tbilisi is weak (Tatishvili et al., 2024), and air movement is largely limited to slope winds. As a result, strong temperature inversion layers frequently develop, leading to the accumulation of dust and other pollutants and, consequently, to increased air pollution. Under these conditions, the intensity of long-wave radiation increases, while ultraviolet radiation decreases. Ultraviolet rays become concentrated in the near-surface layer, contributing to elevated levels of ground-level ozone, which has adverse effects on living organisms (Khvedelidze et al.).

Another important climatic characteristic of Tbilisi is the long-term persistence of an aerosol cloud during morning hours, clearly visible from the surrounding hills. This phenomenon is associated with temperature inversion, the effects of which vary depending on cloud cover, precipitation, and mist formation. The inversion layer forms a stable "cap" over the city that inhibits ventilation. Within the Tbilisi Hollow, a persistent upward airflow of relief origin develops; due to closed circulation patterns, this airflow does not dissipate over the surrounding mountains but instead changes direction and returns to the urban area.

Methods and Materials

Numerous studies have been devoted to the investigation of meteorological parameters in Tbilisi. Among the most recent are the works of Amiranashvili et al. (2023, 2024) and Aliyev et al. (2025), in which these parameters—particularly air temperature—are discussed in detail.

To conduct the present research, ground-based air temperature data from meteorological stations for the period 2014–2018 were used, together with satellite-based data obtained from NASA (NOAA Space Weather Prediction Center, n.d.; Sunspot Watch, n.d.; NASA Solar Dynamics Observatory, n.d.; NASA Earthdata, n.d.) and data provided by the NOAA Space Weather Prediction Centre.

Solar flares, coronal mass ejections (CMEs), and solar energetic particles (SEPs) are the primary drivers of space weather effects in geospace. Solar activity can be quantified using several indices or combinations of indices, including the sunspot number (WN) and the solar radio flux at 10.7 cm (F10.7), which reflect variations in the Sun's electromagnetic output. In addition, parameters such as the interplanetary magnetic field strength (B) and solar wind speed (v) at the Earth's orbit are used to characterise solar wind properties.

The geomagnetic activity index Kp has been continuously calculated since 1932 by the Helmholtz Centre Potsdam (GFZ). The Kp index is one of the most widely used geomagnetic indices and is designed to represent the level of geomagnetic disturbance on a global scale over three-hour intervals in Universal Time. To facilitate averaging, Kp values are converted from their quasi-logarithmic scale into a near-linear scale expressed in nanotesla, yielding the three-hourly ap index. The daily Ap index is then calculated as the average of the eight three-hour ap values.

Two main methodological approaches were applied in this study: (1) analysis of microcirculation processes using wind velocity equations, and (2) correlation analysis between meteorological parameters and geomagnetic activity.

Results

The wind velocity is a three-dimensional vector. Vertical component is much smaller compared to horizontal motion and can only be (10-20) sm/sec or more in intense convective motion. Such convective motions, however, often occur on bumpy, mountainous terrain. Therefore, in the mountainous terrain it is not acceptable to have wind zero divergence as allowed for a smooth surface. Experimental measurements of wind vertical velocity are associated with principal difficulties and therefore their evaluation using theoretical methods is necessary.

It is assumed that origin of wind velocity is conditioned only by surface friction and relief; it is defined from integration of continuity equation:

$$W = -\int_0^H \left(\frac{du}{dx} + \frac{dv}{dy}\right) dz \qquad (1)$$

The air flows are affected by upwind –downwind currents rising from relief considering of which is essential on any selected local polygon. Those currents define local circulations and peculiarities. After transformations the equation (1) obtains the following type:

$$W = \frac{1}{lp}\left[rot_z\tau + \frac{1}{\eta}(pln\eta)H\right] \qquad (2)$$

The obtained equation is differing from already existing ones by the last member that reflects orographic loading [2].

$$W_0 = \frac{1}{l\rho\eta}(p, \ln\eta)H \qquad (3)$$

where H s atmosphere layer altitude and W0 reflects upwind flow velocity rising from orographic factor. After calculations W0 amounts 8,7sm/sec. that indicates that orographic factor is important. This fact is revealed on the formation of local wind in Mtkvari River gorge. In Mtkvari River gorge wind transfers in gradient wind and their directions coincide. Thus, we got one wind flow in the gorge that is much stronger than in other river basins (e.g. Rioni River). Such event is usually observed every day and is of orographic nature. We can use this factor to explain so called “Tbilisi Hollow” phenomena.

The calculated vertical orographic velocity calculated is about 12.64 sm/s. Air masses mainly move in only one direction along the Mtkvari gorge.

In Tbilisi Hollow, the origin of the closed mountain-valley circulation occurs, which is enhanced by the low vertical velocity (maximum two dozen cm/s). Obviously, such dynamics of the air flow

substantiates all the climatic features mentioned above in it. Since there is a constant upward current of relief origin, which, due to the closed circulation, does not disappear above the mountain, but changes direction and returns to the city

Discussions

The air masses generally move only in one direction - across the Mtkvari gorge (h = 4.12m). In the cavern there rises congested circulation that is enhanced by the deficiency of vertical velocity (max. 20sm/sec). Such flow dynamic justifies all the climate "phenomenal" peculiarities (Tatishvili, et.al. 2019).

The above discussed is one reason of Tbilisi thermal regime. Another process that affects temperature distribution is geomagnetic activity.

During a geomagnetic storm the high-latitude currents which occur in the ionosphere change rapidly, in response to changes in the solar wind. These currents produce their own magnetic fields which combine with Earth’s magnetic field. At ground level, the result is a changing magnetic field which induces currents in any conductors that are present.

The Sun-Earth environment has variables, which are changing on regular basis due to starbursts. These variables are the Kp, proton flux and E-flux. Sudden changes in these parameters may abruptly influence the environment of the Earth. If an E-flux hike is responsible for global warming, then an E- flux lowering may lead to snowfall, thunderstorms and erratic rainfall. The effect of earth directed CME would not only trigger the earthquake, but affect the whole environment of the Earth, including the destruction of ozone layers leading to climate change (Tatishvili, et.al. 2021).

The effect of Earth directed Coronal Mass Ejections (CME) from the Sun reveals a significant impact on the atmosphere and geosphere. It has been observed that there is a close relationship between Kp values (Planetary Indices) and particle flux (Electron flux and Proton Flux) with the CME. The response of the magnetosphere to interplanetary shocks or pressure pulses can result in sudden injections of energetic particles into the inner magnetosphere

In order to identify connection between geomagnetic activity and synoptic and circulation processes 2015-17 warm period (III-IX months) various synoptic and geomagnetic indices daily data (Sunspot Watch, n.d.) have been studied for Georgian conditions.

Table 1. Geomagnetic activity indices and meteorological elements daily data for 2015-17 warm period in Georgia

Geostorms		Insignificant cloudiness (700 hpa)		Showers. Thunderstorm	
Geomagn. index	Geomagn storm type	Number of events	Circulation processes	Number of events	Circulation processes
K4	Active	10	South-west wave	20	South-east wave South-west wave High pressure area High pressure area (1 event)
K5	Minor storm	25	South-west wave	10	South-east wave South-west wave
K6	Moderate storm	23	High pressure area (8 event)	8	South-east wave South-west wave
K7	Strong storm	4	High pressure area (3 event)	3	South-west wave
K8	Severe storm	1	High pressure area	-	

It is ascertained that during all magnetic storms south-west or south-east wave processes have been formed and strong storms create high pressure areas. Depending on the synoptic situation wave processes leads the formation of thunderstorm and heavy showers. In addition, through geomagnetic storms the direction of circulation processes may drastically be changed.

The obtained NEA ground and space observation data are used for correlation analysis. The obtained results depict that temperature sudden decreases occur mainly on those dates when geo storm happens despite season of the The obtained NEA ground and space observation data are used for correlation analysis. The obtained results depict that temperature sudden decreases occur mainly on those dates when geo storm happens despite season of the year (Fig 1-8).

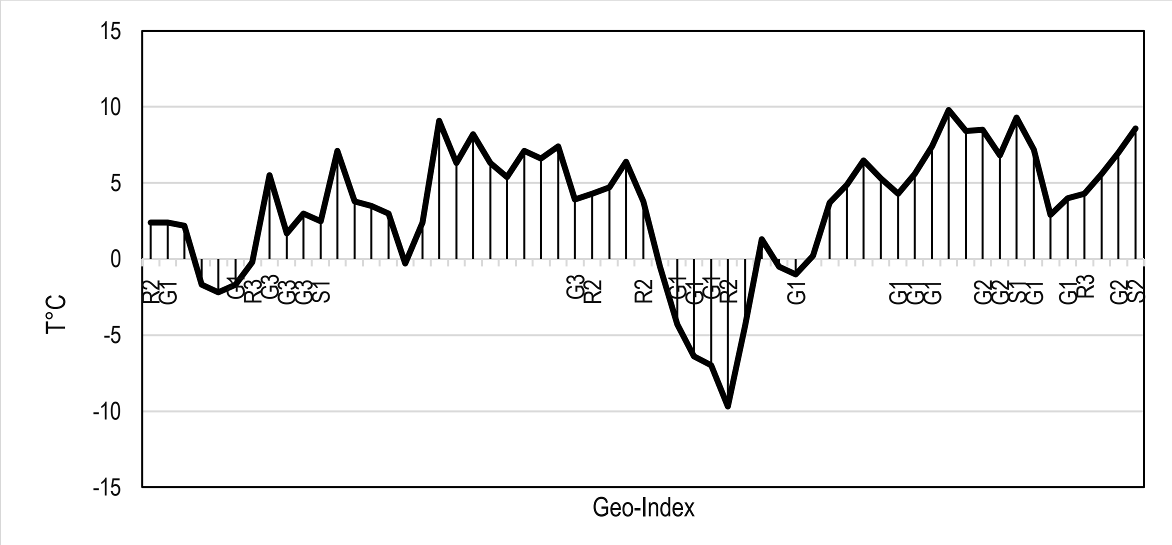

Figure.1. Correlation of temperature and kp geo index for 2014 (January and February)

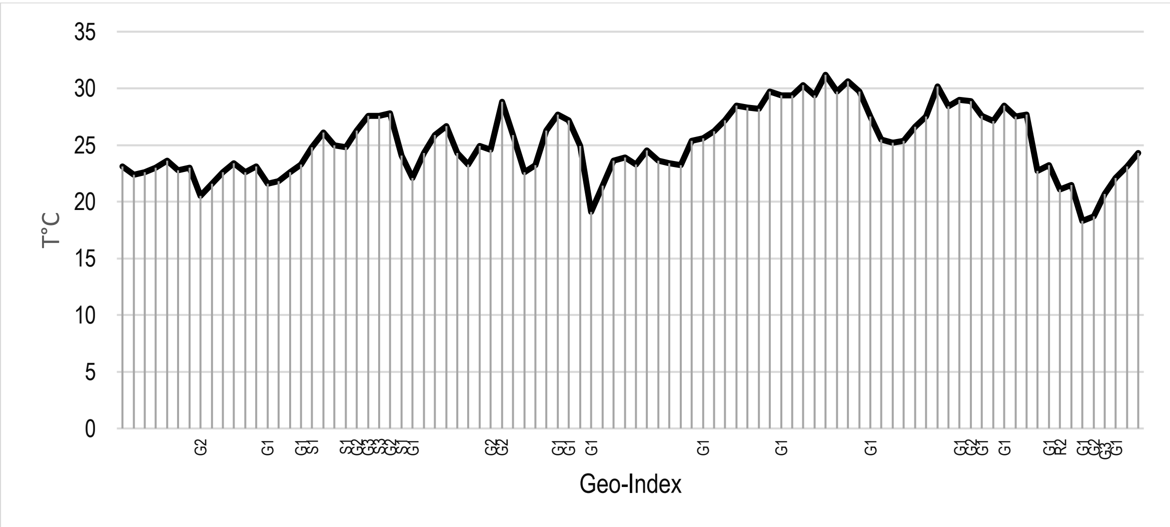

Figure.2. Correlation of temperature and kp geo index for 2015 (June-August)

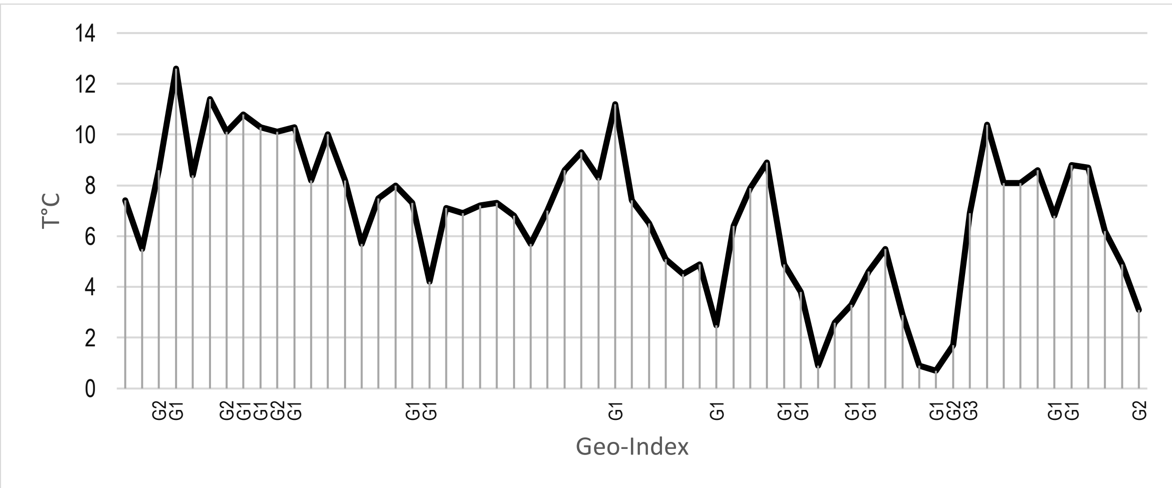

Figure.3. Correlation of temperature and kp geo index for 2015 (November-December)

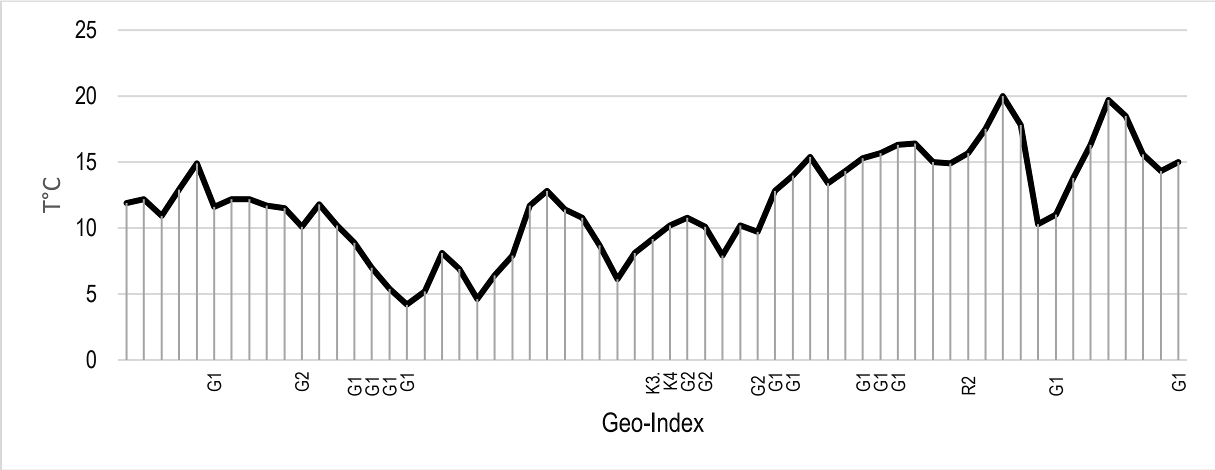

Figure.4. Correlation of temperature and kp geo index for 2016 (March-April).

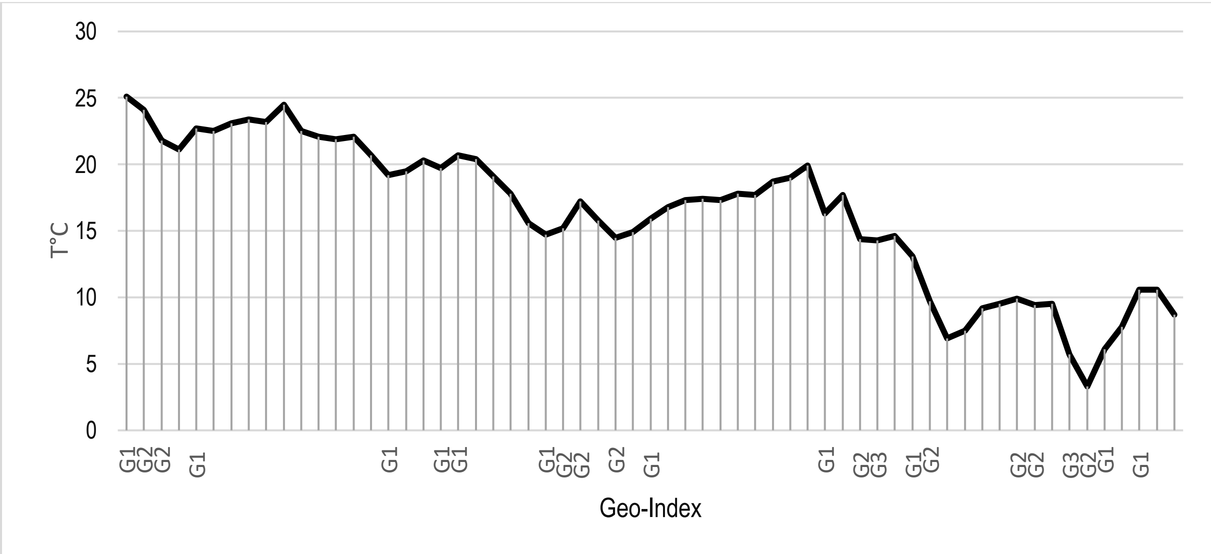

Figure.5 Correlation of temperature and kp geo index for 2016 (September-October)

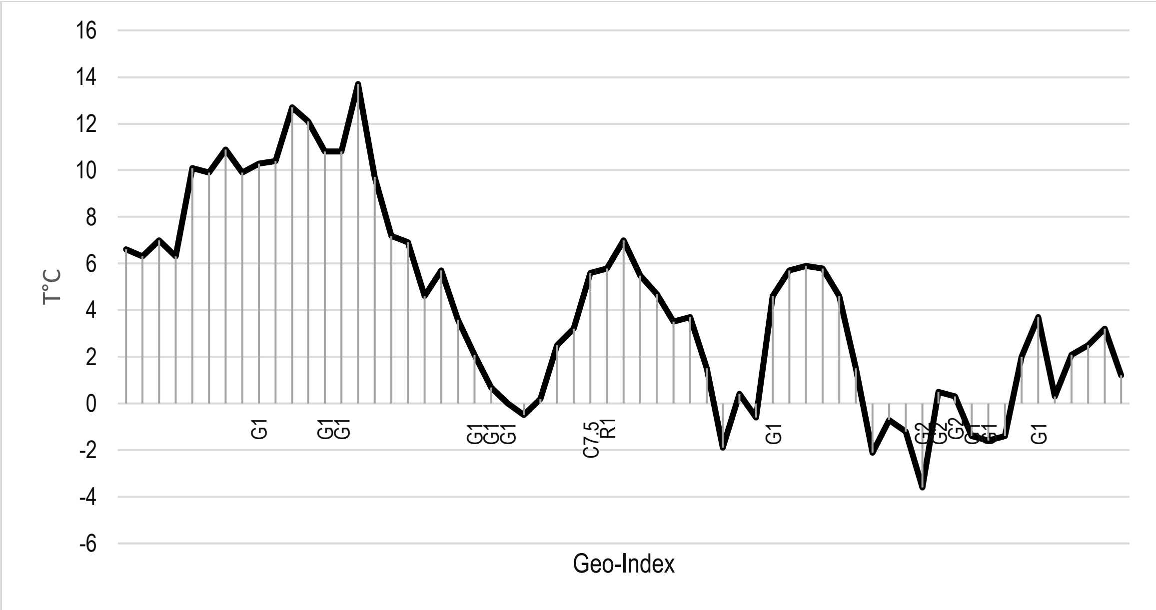

Figure.6. Correlation of temperature and kp geo index for 2016 (November-December).

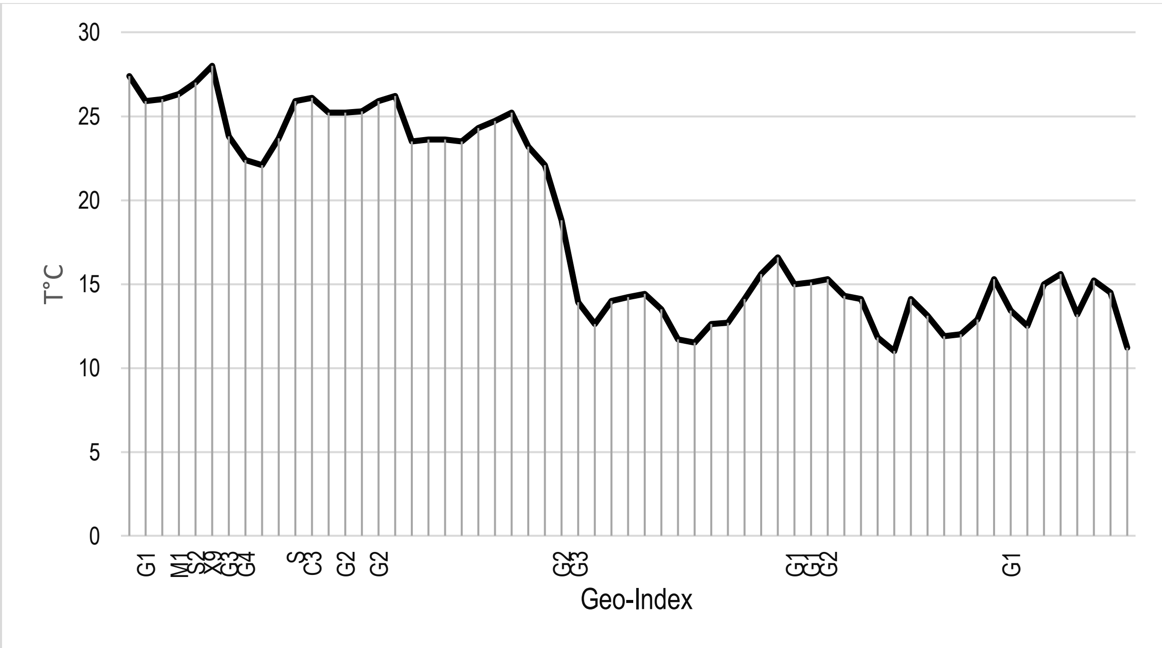

Figure.7. Correlation of temperature and kp geo index for 2017 (September-October).

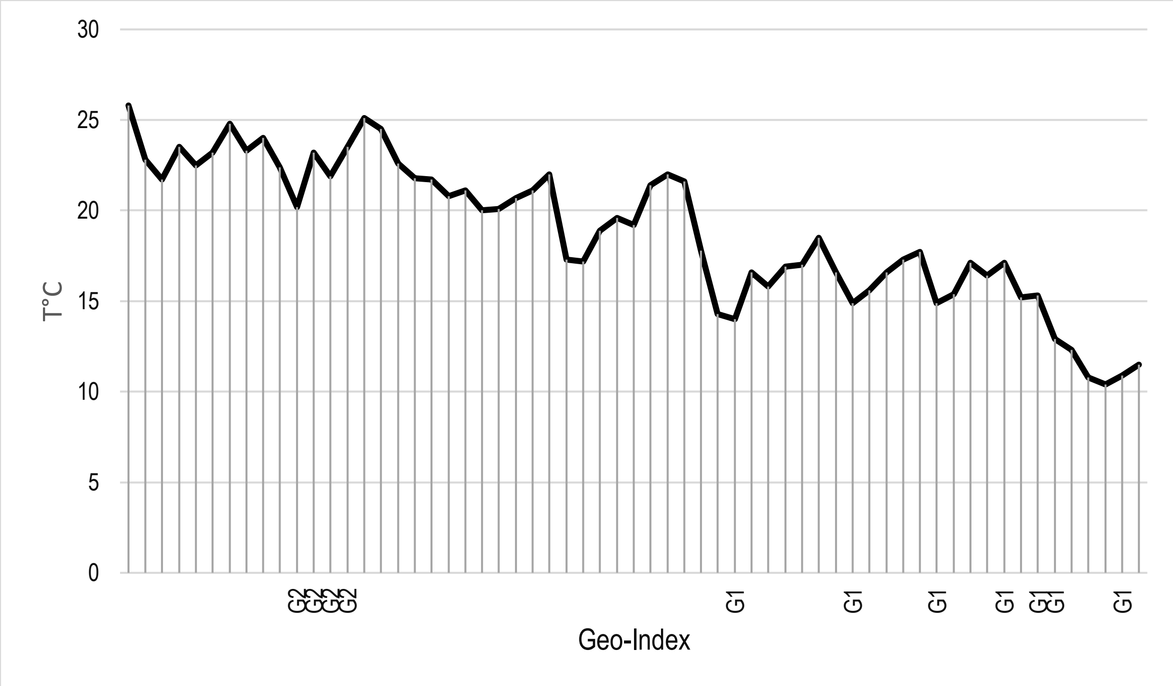

Figure.8. Correlation of temperature and kp geo index for 2018 (September-October)

Conclusion

The Vere River tragedy on 13 June 2015 is clear evidence of how upper atmosphere activity triggered geo-hazard. On this day, flash-flood on Vere River flooded part of Tbilisi city, destroyed buildings, infrastructure, Zoo, many Zoo habitats and 18 humans were dead. After analysing satellite data and synoptical situation it became clear what happened. During several days from 9 to 14 June 2 MEV high energy electrons penetrate atmosphere. The abundant amounts of electrons create stable clusters in lower atmosphere resisting precipitation infall. After they became so massive that couldn't resist gravitation the great amount of rainwater has been fallen out from clouds, causing flooding. The most of water properties are preconditioned by the fact that three component atoms aren't placed on one line. Negative charge prevailed on oxygen atoms part and positive on hydrogen. Thus, water molecule is electrically polarized. Among atoms and molecules acts force that always has attractive character. It is intermolecular dispersive or Van-Deer-Vaalse force. It is only one of the expressions of electromagnetic force. It acts among electrically neutral systems such as dipole or quadruple. In dipoles force reduces by r4 inverse proportional and in quadruple by r-6. It is not temperature dependent and its nature is quantum. By increasing dipole number their interaction increases (Tatishvili et.al. 2022)

1From analysing of historical records of meteorological observations and geomagnetic activity this correlation became more obvious. Many dangerous hydrometeorological event (flood, landslide) occurred over Georgian territory has driven by this activity, as the result of intensification of precipitation amount. Even hail processes intensification is the result of increasing atmosphere electricity and thunderstorm activity, that are produced by high energy charged particles intrusion into upper atmosphere.

These kinds of studies are essential in understanding of Earth magnetism and the Sun-Earth environment. It may be assumed that for weather forecasting the only existed numerical weather models aren't sufficient and they have to be enhanced by magnetic models to make forecasting more precise.

The main recommendation on how to make Tbilisi city cooler except the geomagnetic storm is to increase green cover in city centre and hill slopes. The best way for this action is Nature Based Solutions that include many possibilities such as green roofs, vertical vegetation, green troops, geo-parks.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

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

ORCID iD

Marika Tatishvili https://orcid.org/0000-0003-3327-2208
Nana Bolashvili https://orcid.org/0000-0001-9854-2614

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