Journal of the Georgian Geophysical Society, ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 23(2), 2020, pp. 57-63

Impact of Short-Term Geomagnetic Activity on Weather and Climate Formation in Georgian Region

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ABSTRACT

The investigation of possible effect of powerful magnetospheric storms on the evolution character of meteorological processes in the atmosphere aiming to identify correlation between magnetospheric disturbances and meteorological variations is presented in paper. The investigation is preconditioned by the fact, that Georgia is prone to meteorological hazards and it is especially actual to investigate their causing physical processes.

Meteorological effects resulting from fluctuations in the solar wind are poorly represented in weather and climate models. Geomagnetic storm is a major disturbance of Earth's magnetosphere exchanging energy from the solar wind into the space environment surrounding Earth. These storms result from variations in the solar wind that produces major changes in the currents, plasmas, and fields in Earth's magnetosphere.

Geomagnetic indices are measure of geomagnetic activity occurring over short periods of time. They have been constructed to study the response of the Earth's ionosphere and magnetosphere to changes in solar activity. The correlation between geomagnetic storms and meteorological elements (temperature, precipitation, wind) have been carried out for Georgian region using meteorological observation and NASA's Solar Dynamics Observatory and NOAA Space Weather Prediction Center data. The results show that there exist dependence between weather parameters and geo-magnetic disturbances.

Key words: *Natural hydrometeorological disasters, weather forecasting, geo-magnetic index, correlation analysis.*

1. Introduction

The Sun is the source of the energy that causes the motion of the atmosphere and thereby controls weather and climate. Any change in the energy from the Sun received at the surface will affect Earth climate. During stable conditions there has to be the balance between the energy received from the Sun and the energy that the Earth radiates back into the Space. This energy is mainly radiated in the form of long wave radiation corresponding to the mean temperature of the Earth [1].

Solar transients; Solar Flares, Coronal Mass Ejections (CMEs), Solar Energetic Particles (SEPs) are the drivers of the Space Weather Effect in Geo-Space. When the gigantic cloud of plasma released through solar transient phenomena interacts with the Earth's magnetic environment it leads to the geomagnetic storms. Geomagnetic storms can be characterized by depression in the H component of geomagnetic field. This depression in H component of earth's magnetic field is caused by the Ring Current encircling the Earth in a westward direction. Earth's ionosphere responds to varying solar and magnetospheric conditions. During geomagnetic storm due to the compression of earth's magnetosphere by solar wind electric fields have been observed along the geomagnetic field lines to the high latitude ionosphere. Sometimes this electric field penetrates to low latitudes and energetic particles precipitate into the lower thermosphere and below, increasing ionospheric conductivity and expanding the auroral zone [2, 3]. These intense electric currents are responsible for the coupling of high latitude ionosphere with magnetosphere and the enhanced energy input leads to considerable heating of the ionized and neutral gases. There are two types of effects, in time scale, on the Earth produced by solar transients; prompt and delayed. Geomagnetic Storm effects are delayed effects due to cloud of particles ejected from Sun.

The sun undergoes cyclical (~22 year) pattern of magnetic pole reversals observable in the frequency of sunspot activity. This pattern is comprised of two ~11 year solar cycles phases. In the first phase, the sun's magnetic poles reverse polarity. In the second phase, the sun reverses the magnetic polarity again returning the poles back to its original polarity. Solar storm activity is strongly phase dependent. Accordingly Earth magnetic field is influenced by this reverse.

Solar flares are magnetically driven explosions on the surface of the sun. Approximately 8 minutes after solar flare occurs on the surface of the sun, a powerful burst of electromagnetic radiation in the form of X-ray, extreme ultraviolet rays, gamma ray radiation and radio burst arrives at Earth. The ultraviolet rays heat the upper atmosphere which causes the outer atmospheric shell to expand. The x-rays strip electrons from the atom in the ionosphere producing a sudden increase in *total electron content*. Solar flares produce satellite communications interference, radar interference, shortwave radio fades and blackout and atmospheric drag on satellite producing an unplanned change in orbit and other disturbances in upper atmosphere.

CMEs are vast clouds of seething gas, charged plasma of low to medium energy particles with imbedded magnetic field, blasted into interplanetary space from the Sun. When a CME strikes Earth, the compressed magnetic fields and plasma in their leading edge smash into the geomagnetic field. This produces temporary disturbance of the Earth's magnetosphere called a geomagnetic storm and the equatorial ring of currents, differential gradient and curvature drift of electrons and protons in the Near Earth region. The birthplace of CMEs are often seen to originate near the site of solar flares.

The severity of a geomagnetic storm depends on the orientation of Earth's magnetic field in relation to the solar storm magnetic orientation. If the particle cloud has a southward directed magnetic field it will be severe, while if northward the effects are minimized.

A CME can produce the following affects: electrostatic spacecraft charging, shifting of the Van Allen radiation belt, space track errors, launch trajectory errors, spacecraft payload deployment problems, surveillance radar errors, radio propagation anomalies, compass alignment errors, electrical power blackouts, oil and gas pipeline corrosion, communication landline & equipment damage, electrical shock hazard, electrical fires, heart attacks, strokes, and traffic accidents. Magnetospheric storm is a 1–3 day long phenomenon spanning all the magnetosphere regions, and it features sharp depressions in the magnetic field. During storms and substorms, the ionosphere undergoes rather significant Joule heating with a great power of precipitating energetic particles. Huge energy increases the ionosphere temperature and causes large-scale ion drifts and neutral winds [3].

The Sun continuously provides solar radiation to the Earth, and there is considerable variation in the spectral density. This radiation is sporadically modified by flare events that affect the magnetosphere, thermosphere, and ionosphere. The quasi-steady flow of the solar wind is also modified by coronal mass ejections (CMEs), which accelerate energetic particles and cause geomagnetic storms during subsequent impacts on Earth. Observations have suggested that energetic particle forcing may affect wave propagation, zonal mean temperatures, and zonal winds in the Northern Hemisphere winter stratosphere. However, the mechanisms by which these changes occur are *still not known*. As changes in the Earth's atmosphere occur, whether due to changes in solar forcing or in response to enhanced anthropogenic activity and increased greenhouse gas (GHG) concentrations, the energy balance of the Earth's atmosphere is altered and this affects its dynamics. Changes can occur in the propagation of atmospheric gravity waves, planetary waves, and tides, which play important roles in driving the general circulation of the middle atmosphere. The thermosphere-ionosphere system is known to vary substantially with altitude, latitude, longitude, universal time, season, solar cycle and geomagnetic activity, as a result of mechanisms inherent to the system, as well as a result of space weather. The primary driving mechanism is solar radiation (EUV and UV), but precipitation of charged magnetospheric particles and magnetospheric electric fields also have significant effects on the ionosphere-thermosphere system. The driving processes determine the density, composition, and temperature of the ionized and neutral constituents of the upper atmosphere.

The solar wind conditions that are effective for creating geomagnetic storms are sustained (for several to many hours) periods of high-speed solar wind, and most importantly, a southward directed solar wind magnetic field (opposite the direction of Earth's field) at the dayside of the magnetosphere. This condition is effective for transferring energy from the solar wind into Earth's magnetosphere.

The largest storms that result from these conditions are associated with solar coronal mass ejections (CMEs) where a billion tons or so of plasma from the sun, with its embedded magnetic field, arrives at Earth. CMEs typically take several days to arrive at Earth, but have been observed, for some of the most intense storms, to arrive in as short as 18 hours. Another solar wind disturbance that creates conditions favorable to geomagnetic storms is a high-speed solar wind stream (HSS). HSSs plow into the slower solar wind in front and create co-rotating interaction regions, or CIRs. These regions are often related to geomagnetic storms that while less intense than CME storms, often can deposit more energy in Earth's magnetosphere over a longer interval

2. Data and methods

The study area is Georgian region. The relief of Georgia is mountainous, sharply billowy, where large orographic raisings alternate with intermountain troughs. On the northern part of territory in direction from north-west to south-east Main Caucasus Ridge is stretching, its separate tops are above 5000m. At south part of the territory the South Georgian plateau is stretching. Between Main Caucasus Ridge and south Georgian Plateau the intermountain depression is located, which is presented by lowlands, plains and plateaus.

Complex orographic conditions and influence of the black Sea preconditioned the formation of great variety of climate and landscapes. Here exist most of Earths climatic types, from marine wet subtropical climate of west Georgia and steppe continental climate of east Georgia up to eternal snow and glaciers of high mountain zone of Great Caucasus, and also approximately 40% of observed landscapes. Thus those climatic zones condition formation of different dangerous hydrometeorological phenomena, namely: hailstone, heavy showers, flooding, thunderstorm, draughts, sea storms [4].

Georgia is prone to all types of natural hazards. The risk resulting from geohazards such earthquakes, landslides and meteorological hazards is considerably high; risk from hydrologic hazard as flash-floods also is significant.

The natural hydrometeorological disasters number for 1961-2010 years period is presented in Table1.

Table 1. Natural hydrometeorological events number for 1961-2010 period in Georgia

Period	Floods	Heavy showers >=30mm	Hailstone	Draughts	Strong winds >=30m/sec	Avalanche	Big snow
1961-1970	20	3	6	3	4	6	7
1971-1980	17	16	35	5	8	9	6
1981-1990	25	18	39	1	12	9	8
1991-2000	15	7	6	7	5	18	5
2001-2010	32	52	44	5	20	25	9

The natural disasters in Georgia have to be considered as the standing negative factor for the sustainable development of the state. The importance of aroused problems from abovesaid hazards stimulates the active investigation of reasons and physical processes involved in.

Since *NASA* launched Earth Observing System (*EOS*) program coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans []. *EOS* enables the improved understanding of the Earth as an integrated system. Considering large amount of information from satellites it became possible to revised atmosphere processes suggesting new approaches and hypothesis.

The aim is to investigate possible effect of magnetospheric storms on the evolution character of meteorological processes in the atmosphere, to study the correlation between magnetospheric disturbances and meteorological background variations. The Sun, together with the Earth's motion along its orbit, govern changes in the solar–terrestrial environment on time scales ranging from minutes to glacial cycles. Changes in Earth's climate have been the focal point of recent research in the solar–terrestrial physics (STP), and a special emphasis has been placed on the coupling between the troposphere (below 10–15 km altitude), middle atmosphere (10–100 km altitude), and near- Earth Geo-space (mesosphere, thermosphere, ionosphere, and magnetosphere), and solar activity.

The Kp index is probably the most widely used of all magnetic indices. It is intended to express the degree of "geomagnetic activity," or disturbance for the whole Earth, for intervals of three hours in Universal Time [5,6].

Time sequences of circulation patterns and parameters of solar activity are also subject of investigations. Intrusions into Atlantic and Europe were observed nearby geomagnetic-disturbance days. It was found that increasing of geomagnetic activity lead to the change of meridional flow into the zonal one of the atmospheric circulation in the mid-latitudes on the Northern Hemisphere (Bucha, 1988, 1991). It was also depicted that short-term and long-term changes in solar activity, the geomagnetic field and weather demonstrate very similar quasi-periodic variations

Total Electron Content (or TEC) is an important descriptive quantity for the ionosphere of the Earth. TEC is the total number of free electrons integrated between two points, along a tube of one meter squared cross section, i.e., the electron columnar number density. Affected by solar activity, Total Electron Content (TEC) describes the total number of free electrons present within one square meter between two points (i.e. between the receiver and satellite involved in measuring TEC). These maps are also used to monitor ionospheric weather, and to nowcast ionospheric storms that often occur responding to activities in solar wind and Earth's magnetosphere as well as thermosphere. The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere. The TEC will therefore depend on local time, latitude, longitude, season, geomagnetic conditions, solar cycle and activity, and troposphere conditions. TEC consideration in precipitation formation may be important.

To establish influence of geomagnetic activity on the formation of weather pattern geomagnetic indices achieve [6,8] and meteorological observation database for 2014-18 have been analyzed. The 4 location were chosen namely: Tbilisi- (Kartli Region), Batumi- Adjara Region, Telavi-Kakheti Region and last one in high mountain zone-Mta-Sabueti. The results showed that always weather pattern change: increase wind velocity; temperature change (decrease); precipitation amount increase follows geomagnetic activity. Here Tbilisi data is used.

3. Results and discussion

To identify connection between geomagnetic activity and meteorological processes 2014-17 period precipitation, wind, temperature observation data and geomagnetic indices daily data (http://SunSpotWatch.com) have been studied for Georgian conditions. Below presented charts show the correlation between meteorological parameters with geo-magnetic activity expressed in indices.

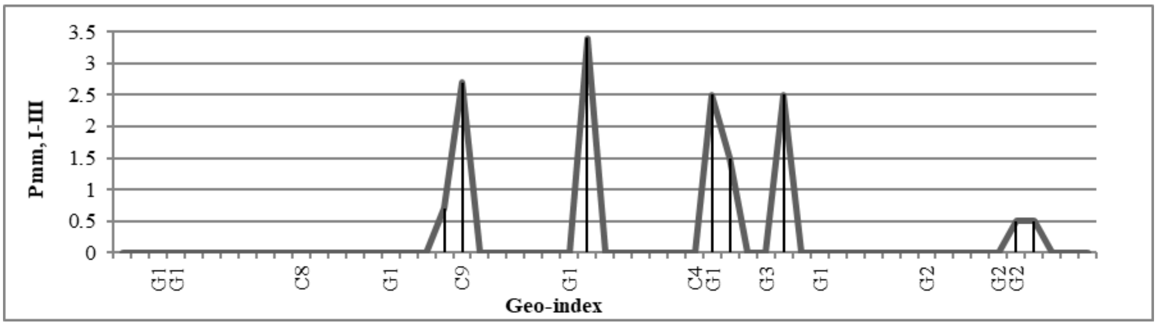

Fig.1a

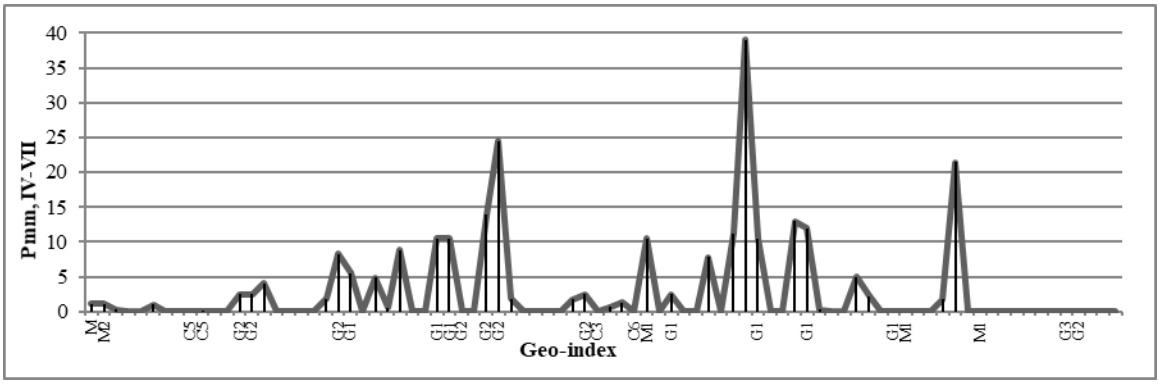

Fig.1 b

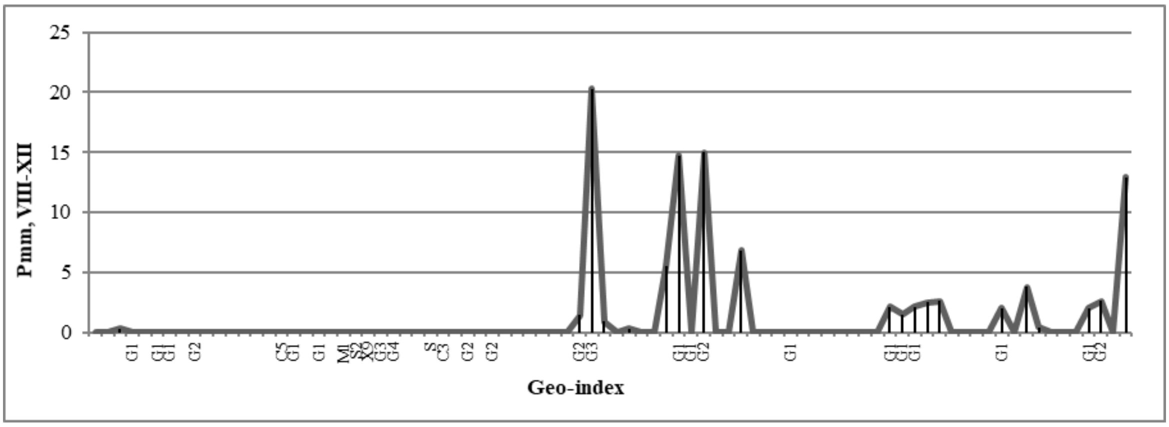

Fig.1 c

Fig.1 (a,b,c). Precipitation and geo-index correlation for Tbilisi point in 2017.

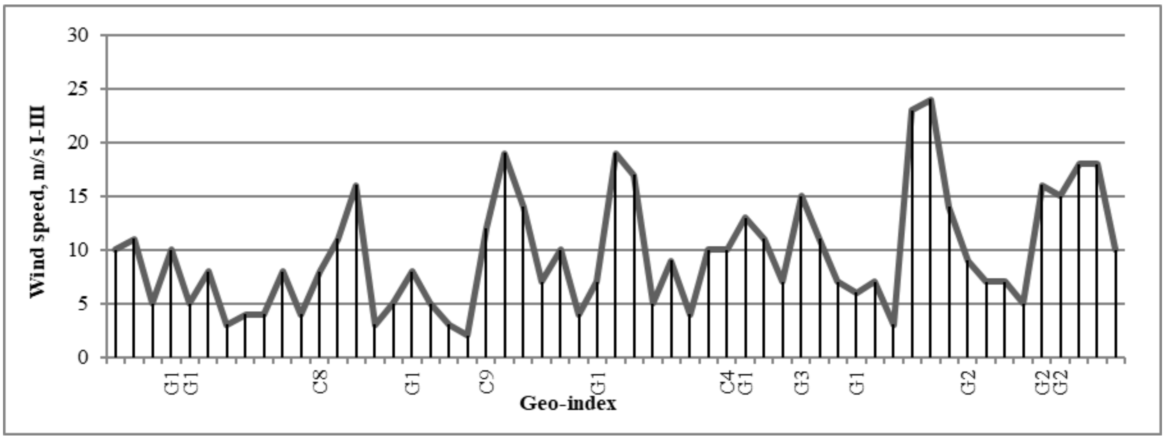

Fig.2. Wind speed and geo-index correlation for Tbilisi point in 2017 (I-III).

The analysis has been conducted for current, pre and aftershock 3 and 5 days. For meteorological parameters current day is crucial and 3-5 day time lapse is reliable for circulation processes. 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 Vere River tragedy in 13 June, 2015 is clear evidence of how meteorological disaster 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 analyzing 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 [7,8]. The abundant amounts of electrons create stable clusters in lower atmosphere resisting precipitation in fall. After they became so massive that couldn't resist gravitation the great amount of rain water has been fallen out from clouds, causing flooding [9,10].

It is not fully clear the physical mechanism of this correlation and the issue needs further investigation applying quantum filed theory that is more suitable for description of photon-photon or photon-charged particle interaction as during geomagnetic activity great amount of charged particles and photons penetrate atmosphere.

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 r^4 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 [12].

4. Conclusion

From analyzing 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 are the result of increasing atmosphere electricity and thunderstorm activity, that are produced by high energy charged particles intrusion into upper atmosphere [11].

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.

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მოკლევადიანი გეომაგნიტური აქტივობის გავლენა ამინდისა და კლიმატის ფორმირებაზე საქართველოს რეგიონში

მ. ტატიშვილი, ა. ფალავანდიშვილი

რეზიუმე

სტატიაში წარმოდგენილია ძლიერი მაგნიტოსფეროს ქარიშხლების შესაძლო გავლენის კვლევა ატმოსფეროში მეტეოროლოგიური პროცესების ევოლუციაზე, მაგნიტოსფეროს შეშფოთებებსა და მეტეოროლოგიურ ვარიაციებს შორის კორელაციის გამოსავლენად. კვლევა მნიშვნელოვანია

იმის გამო, რომ საქართველოში ხშირია საშიში მეტეოროლოგიური მოვლენები და განსაკუთრებით მნიშვნელოვანია მათ გამომწვევი ფიზიკური პროცესების შესწავლა.
მეტეოროლოგიური ეფექტები, რომლებიც გამოწვეულია მზის ქარის ვარიაციებით, ცუდად არის წარმოდგენილი ამინდისა და კლიმატის მოდელებში. გეომაგნიტური ქარიშხალი არის დედამიწის მაგნიტოსფეროს იძულებითი გარღვევა, მზის ქარიდან ენერგიის გაცვლა დედამიწის გარშემო არსებულ გეო-გარემოში. ეს ქარიშხლები წარმოიქმნება მზის ქარის ცვლილებების შედეგად, რაც იწვევს დედამიწის მაგნიტოსფეროში მიმდინარე დინებების, პლაზმისა და ველების მნიშვნელოვან ცვლილებებს.
გეომაგნიტური ინდექსები არის გეომაგნიტური აქტივობის საზომი, რომელიც ხდება დროის მოკლე მონაკვეთში. ისინი შეიქმნა დედამიწის იონოსფეროსა და მაგნიტოსფეროს რეაქციის შესასწავლად მზის აქტივობის ცვლილებებზე. გეომაგნიტურ შტორმებსა და მეტეოროლოგიურ ელემენტებს შორის კორელაცია ჩატარდა საქართველოს რეგიონისთვის მეტეოროლოგიური დაკვირვების მონაცემებისა და NASA–ს მზის დინამიკის ობსერვატორიისა (Solar Dynamics Observatory) და NOAA– ს კოსმოსური ამინდის პროგნოზირების ცენტრის მონაცემების გამოყენებით. შედეგები აჩვენებს, რომ არსებობს კავშირი ამინდის პარამეტრებსა და გეომაგნიტურ შეშფოთებებს შორის.

Влияние кратковременной геомагнитной активности на погоду и климатообразование в Грузинском регионе

М.Р. Татишвили, А.М. Палавандишвили

Резюме

Представлено исследование возможного влияния мощных магнитосферных бурь на характер эволюции метеорологических процессов в атмосфере с целью выявления корреляции между магнитосферными возмущениями и метеорологическими вариациями. Исследование обусловлено тем фактом, что Грузия подвержена опасным метеорологическим явлениям и особенно актуально исследовать вызывающие их физические процессы.
Метеорологические эффекты, возникающие в результате колебаний солнечного ветра, плохо представлены в моделях погоды и климата. Геомагнитная буря - это сильное нарушение магнитосферы Земли, обменивающееся энергией солнечного ветра с космической средой, окружающей Землю. Эти бури возникают в результате изменений солнечного ветра, которые вызывают серьезные изменения токов, плазмы и полей в магнитосфере Земли.
Геомагнитные индексы являются мерой геомагнитной активности, происходящей за короткие периоды времени. Они были созданы для изучения реакции ионосферы и магнитосферы Земли на изменения солнечной активности. Корреляция между геомагнитными бурями и метеорологическими элементами (температура, осадки, ветер) была проведена для региона Грузии с использованием данных метеорологических наблюдений и данных обсерватории солнечной динамики (Solar Dynamics Observatory) NASA и Центра прогнозирования космической погоды NOAA. Результаты показывают, что существует зависимость между погодными параметрами и геомагнитными возмущениями.