Georgian Geographical journal 2022, Vol.2 (1) 45-50

Impact of short-term geomagnetic activity on the variability of meteorological parameters

Marika Tatishvili[1], Nana Bolashvili[2], Ana Palavandishvili[1*]

Abstract

The paper deals with space weather prediction problem. The investigation of the possible effect of powerful magnetospheric storms on the evolving character of meteorological processes in the atmosphere to identify the correlation between magnetospheric disturbances and meteorological variations is presented in the paper. The investigation is preconditioned by the fact that Georgia is prone to hydrometeorological hazards, and it is essential to investigate their causing physical processes. Meteorological effects resulting from fluctuations in the solar wind are poorly represented in weather and climate models. A geomagnetic storm is a significant disturbance of Earth's magnetosphere exchanging energy from the solar wind into Earth's space environment. These storms result from solar wind variations that significantly change the currents, plasmas, and fields in Earth's magnetosphere. Geomagnetic indices measure geomagnetic activity occurring over short periods. 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) has been carried out for the Georgian region using meteorological observation and NASA's Solar Dynamics Observatory and NOAA Space Weather Prediction Centre data. The results show that there exists dependence between meteorological parameters and geomagnetic disturbances.

Keywords: Meteorological parameters, space weather prediction, geo-magnetic index, correlation analysis

Introduction

The NASA Earth Observing System (EOS) program was launched in the early 1990s. EOS is comprised of a series of coordinated polar- -orbiting and mid-inclination satellites for long-term monitoring of the Earth as an integrated system, including observations of the land surface, biosphere, atmosphere, cryosphere and oceans to understand functioning of the Earth as an integrated system[1].

The Earth weather is influenced by several phenomena that occur in near space. Those are Solar EUL Irradiance, Galactic Cosmic Rays, total Electron Content and Solar Cycles. The research of solar cycle influence on weather parameters is presented in the article.

The Sun is the source of the energy that causes the atmosphere's motion 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 a balance between the energy received from the Sun and the energy that the Earth radiates back into Space [1]. This energy is mainly radiated in longwave radiation corresponding to the Earth's mean temperature.

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 transient solar phenomena interacts with the Earth's magnetic environment, it leads to geomagnetic storms. Geomagnetic storms can be characterized by depression in the H component of the geomagnetic field. This depression in the H component of Earth's magnetic field is caused by the Ring Current encircling the Earth westward. Earth's ionosphere responds to varying solar and magnetospheric conditions. During geomagnetic storms due to the compression of Earth's magnetosphere by the 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 ionosphere conductivity and expanding the aurora zone [2]. These intense electric currents are responsible for coupling the high latitude ionosphere with the 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 a cloud of particles ejected from the Sun.

[1] Institute of Hydrometeorology, Georgian technical University, Tbilisi, Georgia, m.tatishvili@gtu.ge
[2] Vakhushti Bagrationi Institute of Geography, Tbilisi, State University, nana.bolashvili@tsu.ge
* Corresponding author: palavandishvili.ana21@gtu.ge

The Sun undergoes a cyclical (~22 years) 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. The Sun reverses the magnetic polarity in the second phase, returning the poles to their 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 arrive 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, blackout, and atmospheric drag on satellite, producing an unplanned change in the orbit and other disturbances in the upper atmosphere.

CMEs are vast clouds of seething gas, charged plasma of low to medium energy particles with the embedded 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 a 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 birthplaces of CMEs are often seen to originate near the site of solar flares [2].

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

A CME can produce the following effects: 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. The magnetospheric storm is a 1–3-day phenomenon spanning all the magnetosphere regions, and it features sharp depressions in the magnetic field. During storms and sub storms, the ionosphere undergoes a rather significant Joule heating with great power of precipitating energetic particles. Enormous 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 response to enhanced anthropogenic activity and increased greenhouse gas (GHG) concentrations, the energy balance of the Earth's atmosphere is altered, affecting its dynamics. Changes can occur in the propagation of atmospheric gravity waves, planetary waves, and tides, which play essential 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 due to mechanisms inherent to the system and 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 the 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 effectively transfers energy from the solar wind into Earth's magnetosphere.

The most significant 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 to arrive in as short as 18 hours for some of the most intense storms. Another solar wind disturbance that creates conditions favourable to geomagnetic storms is a high-speed solar wind stream (HSS). HSSs plough 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, can deposit more energy in Earth's magnetosphere over a longer interval.

Methods and Materials

To understand variability character of meteorological parameters such as temperature, pressure, wind speed and precipitation the impact of short-term geo-magnetic activity on those characters is investigated in presented aticle.

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

Complex orographic conditions and the influence of the Black Sea preconditioned the formation of a great variety of climates and landscapes. Here exist most of Earth's 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 approximately 40% of observed landscapes. Thus, those climatic zones condition formation of different dangerous hydrometeorological phenomena, namely: hailstone, heavy showers, flooding, thunderstorm, draughts, and sea storms [5].

The aim is to investigate the possible effect of magnetospheric storms on the evolving character of meteorological processes in the atmosphere, to study the correlation between magnetospheric disturbances and meteorological background variations. The Sun and 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 solar-terrestrial physics (STP), and a particular 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.

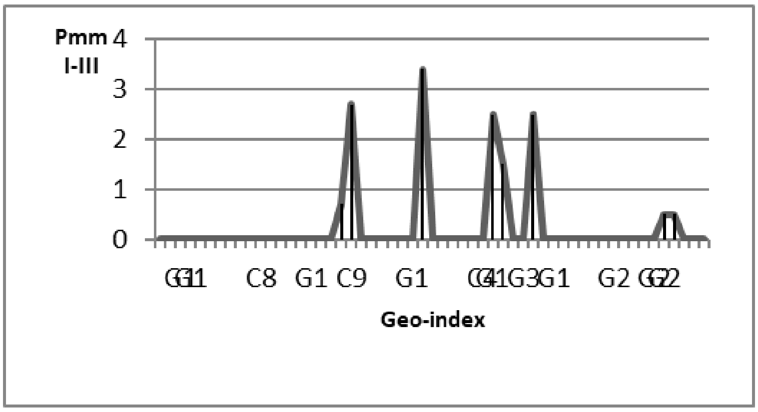
The Kp index is probably the most widely used of all magnetic indices. It is intended to express the degree of "geomagnetic activity," or disturbance for the whole Earth, for intervals of three hours in Universal Time [6].

Time sequences of circulation patterns and solar activity parameters are also subject to investigations. Intrusions into the Atlantic and Europe were observed nearby geomagnetic-disturbance days. It was found that increasing geomagnetic activity leads to the change of meridional flow into the zonal one of the atmospheric circulations in the mid-latitudes on the Northern Hemisphere. 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

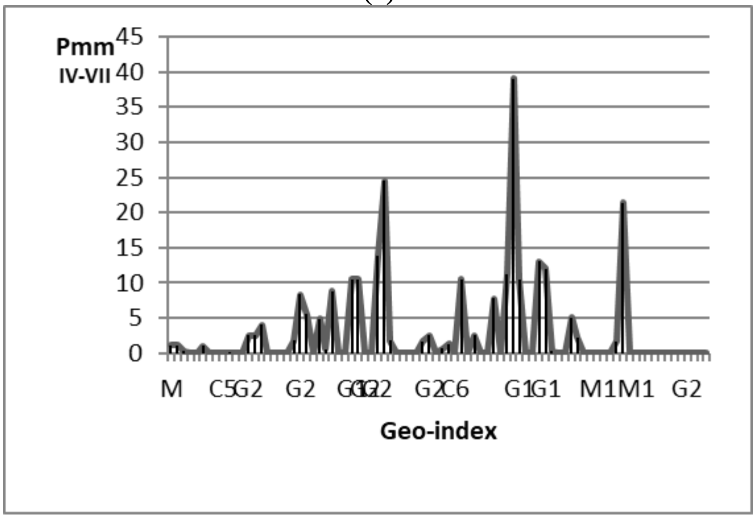
To establish the influence of geomagnetic activity on the formation of weather pattern geomagnetic indices achieved from the following open sources [6,7,8, 9,10] and meteorological observation database for 2014-18 have been analysed. The meteorological database was extracted from the Georgian National Environmental Agency archive. The 4 locations were chosen: Tbilisi (Kartli Region), Batumi- Adjara Region, Telavi-Kakheti Region and the last one in high mountain zone-Mta-Sabueti. The results showed that constantly weather patterns change: increased wind velocity; temperature change (decrease); precipitation amount increase follows the geomagnetic activity. The Tbilisi data is used to present dependence of precipitation, temperature and wind speed on geo-magnetic kp index.

Results and Discussion

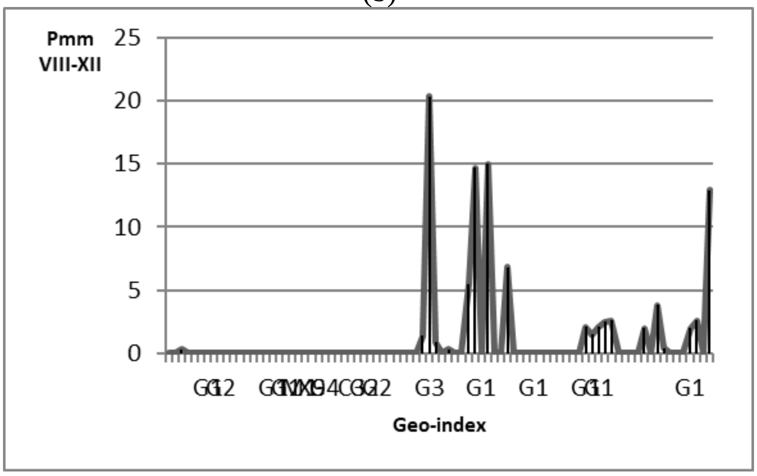
To identify the connection between geomagnetic activity and meteorological processes, 2014-17 period precipitation, wind, temperature observation data and geomagnetic kp index daily data have been used for Georgian conditions. The charts below show the correlation between meteorological parameters and geomagnetic activity expressed in planetary kp index.



(a)



(b)



(c)

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

The analysis has been conducted for current, pre and aftershock 3 and 5 days. For meteorological parameters current day is crucial, and a 3,5-day time-lapse is reliable for circulation processes. It is ascertained that during all magnetic storms, southwest or southeast wave processes have been formed, and strong storms create high-pressure areas. Depending on the synoptic situation, wave processes lead to thunderstorms and heavy showers. In addition, the direction of circulation processes may drastically change through geomagnetic storms.

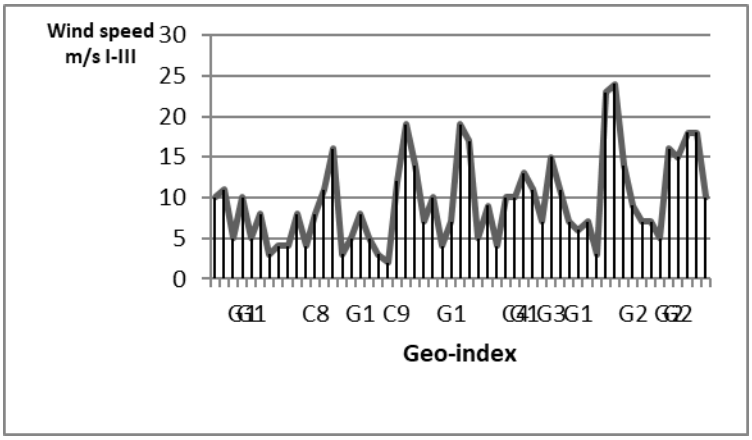


Figure 2. Wind speed and geo-index (kp) correlation for Tbilisi point in 2017 (I-III)

The Vere River tragedy on 13 June 2015 clearly shows how meteorological disasters triggered geo-hazard. On this day, flash-flood on the Vere River flooded part of Tbilisi city, destroyed buildings, infrastructure, Zoo, many Zoo habitats, and 18 casualties. After analysing satellite data and the synoptical situation, what happened became clear. During several days from 9 to 14 June, 2 MEV, high energy electrons penetrate the atmosphere (NOAA/SWPC, Boulder, Co, USA. spaceweatherlive.com; Earthdata.nasa.gov). The abundant electrons create stable clusters in the lower atmosphere resisting precipitation infall. After they became so massive that they could not resist gravitation, a significant amount of rainwater fell out from clouds, causing flooding [11].

It is not fully clear the physical mechanism of this correlation and the issue needs further investigation applying quantum field theory that is more suitable for description of photon-photon or photon-charged particle interaction as during geomagnetic activity significant number of charged particles and photons to penetrate atmosphere [12, 13].

Most water properties are preconditioned because 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 [14, 15,16]. 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 numbers, their interaction increases [14].

Conclusion

This correlation became obvious from analysing historical meteorological observations and geomagnetic activity records. This activity has driven many dangerous hydrometeorological events (flood, landslide) over Georgian territory due to the intensification of precipitation. Even hail processes intensification results from increasing atmosphere electricity and thunderstorm activity, produced by high energy charged particles intrusion into the upper atmosphere.

These kinds of studies are essential in understanding Earth magnetism and the Sun-Earth environment. It may be assumed that only existing numerical weather models are insufficient, and magnetic models must be enhanced to make forecasting more precise.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.T. data processing, paper preparation, N. B. data processing, paper preparation, A. P. literature analysis.

References

[1] spaceweatherlive.com

[2] SOLAR PHYSICS AND TERRESTRIAL EFFECTS. Space Environment Center. 2012

[3] Toshitaka Tsuda, Marianna Shepherd and Nat Gopalswamy. Advancing the understanding of the Sun–Earth interaction—the Climate and Weather of the Sun–Earth System (CAWSES) II program. Progress in Earth and Planetary Science (2015) 2:28 DOI 10.1186/s40645-015-0059-0

[4] M.Tatishvili, N.Bolashvili, I.Mkurnalidze. Climate and causes of its variability. //Transactions of Institute of Hydrometeorology, Tbilisi, Georgia, 2013, v. 119, pp. 38-43.

[5] M.Tatishvili, E.Elizbarashvili, R. Meskhia, Sh.Elizbarashvili.Natural hydrometeorological disasters, their causes and prevention measures . The Macrotheme Review. A multidisciplinary journal of global macro trends, 148-154,A Macrotheme Capital Management, LLC Academic Publication, Volume 2, Issue 1, Winter 2013 (January). ISSN 1848-4735, France

[6] www.spaceweather.gov

[7] sdo.gsfc.nasa.gov

[8] http://SunSpotWatch.com

[9] Earthdata.nasa.gov

[10] http://SunSpotWatch.com

[11] Tatishvili M., Mkurnalidze I., Samkharadze I., Tsintsadze N. Impact of solar coronal mass ejections (CME) on formation of Earth climate and weather pattern. International Scientific Journal. Journal of Environmental Science. v.7. issue 1. pp1-5. 2018. ISBN -13:978-1721539185

[12] Tatishvili M., Khvedelidze Z., Mkurnalidze I., Samkharadze I., Kokosadze Kh. THE CONNECTION OF GEOMAGNETIC ACTIVITY AND WEATHER FORMATION IN GEORGIAN REGION. International Scientific Conference „Modern Problems of Ecology" Proceedings, ISSN 1512-1976, v. 6, Kutaisi, Georgia. 2018

[13] Tatishvili M. Developing Weather Forecasting System in Georgia. Ecology & Environmental Sciences 2 (7) DOI:10.15406/mojes. 2017.02.00046.

[14] Tatishvili M. Energy Transformation in Clouds According Quantum Principles. // International Scientific Journal. Journal of Environmental Science. vol 3. ISBN- 13: 978-1499721980; ISBN -10: 1499721986, Vienna, Austria 2014. pp. 7-9.

[15] Tatishvili M. ON THE WATER QUANTUM PROPERTIES IN METEOROLOGY International Scientific Conference „Natural Disasters in the 21st Century:Monitoring, Prevention, Mitigation" Proceedings, ISBN 978-9941-491-52-8, Tbilisi, Georgia, December 20-22, 2021

[16] Tatishvili M. On Some Considerations of Cloud Particles and Photons Interaction Journal of the Georgian Geophysical Society, *e*-ISSN: *2667*-9973, *p-ISSN*: *1512-1127*Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(2*)*, 2021