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THE CONNECTION OF GEOMAGNETIC ACTIVITY AND WEATHER FORMATION IN GEORGIAN REGION

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Summary: *Geomagnetic storm is major disturbance of Earth's magnetosphere that occurs when the solar wind enters into the space environment surrounding Earth. The largest storms are associated with solar coronal mass ejections (CME) and take several days to arrive at Earth. Geomagnetic indices are important parameter in weather forecasting methods. The correlation between geomagnetic storms and meteorological elements (temperature, precipitation, wind) have been identified for Georgian region using meteorological observation and NASA's SDO and NOAA Space Weather Prediction Center data.*

Key words: *Coronal mass ejection, Earth magnetic field, Geomagnetic storm, geomagnetic indices.*

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 Earth's surface will therefore affect 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. This energy is mainly radiated in the form of long wave radiation corresponding to the mean temperature of the Earth.

The effects of the radiation and particles that stream out from the Sun would be quite deadly for the inhabitants of Earth if not for two protective features. The first one is Earth's atmosphere, which blocks out the x-rays and most of the ultraviolet radiation. When x-ray or ultraviolet photons encounter the atmosphere they hit molecules and are absorbed, causing the molecules to become *ionized*; photons are re-emitted but at much longer (and less biologically destructive) wavelengths. The second protective mechanism is the Earth's magnetic field. This protects living organisms from the charged particles that reach the planet steadily as part of the solar wind and the much greater bursts that arrive following mass ejections from the Sun. When charged particles encounter a magnetic field, they generally wrap around the field lines. Only when the path of the particle is parallel to the field can it travel without deflection. If the particle has any motion across the field lines it will be deflected into a circular or spiral path by the Lorentz Force. Most charged particles in the solar wind are deflected by the Earth's magnetic field at a location called the Magnetopause, about 10 Earth radii above the Earth on the day side. Inside the Magnetopause, the Earth's magnetic field has the dominant effect on particle motion, and outside, the solar wind's magnetic field has control (www.spaceweather.gov).

Until 1960, Earth's magnetic field, called the geomagnetic field, was thought to be a simple dipole field like that of a bar magnet. We do not yet know the details of what produces the geomagnetic field, except that there must be currents circulating inside Earth, probably associated with the molten core. With the discovery of the solar wind, physicists realized that the magnetic field of Earth is pushed away from the Sun. The solar wind exerts a pressure on Earth's magnetic field which compresses it on the Sun-facing side and stretches it into a very long tail on the side away from the Sun. This complex magnetic envelope is called the magnetosphere .On the Sun-facing side, the solar wind compresses the magnetosphere to a distance of about 10 Earth radii; on the downwind side, the magnetotail stretches for more than 1000 Earth radii. The magnetosphere is filled with tenuous plasmas of different densities and temperatures, which originate from the solar wind and the ionosphere. The ionosphere is the highly charged layer of Earth's atmosphere which is formed by the ionizing effect of solar radiation on atmospheric molecules. This extension of the Sun's magnetic field is called the interplanetary magnetic field and it can join with geomagnetic field lines originating in the polar regions of Earth. This joining of the Sun's and Earth's magnetic fields is called magnetic reconnection, and happens most efficiently when the two fields are anti-parallel. Through reconnection the magnetic fields of Sun and Earth become coupled together Solar wind particles approaching Earth can enter the magnetosphere because of reconnection and then travel along the geomagnetic field lines in a corkscrew path. Positive ions and electrons follow magnetic field lines (in opposite directions) to produce what are called field-aligned currents. The solar wind and the magnetosphere form a vast electrical generator which converts the kinetic energy of solar wind particles into electrical energy. The very complex plasmas and currents in the magnetosphere are not fully understood. Some of the solar wind particles travel back along the magnetotail in currents which make the tail look like it has a giant battery in it. Some particles follow the field lines that converge near the polar regions of the earth and bounce back and forth, trapped in a magnetic mirror. Other particles are injected into the ionosphere and form an oval of light around the polar regions of Earth, called the Auroral ovals. The northern lights are called the Aurora Borealis, while the southern lights are called the Aurora Australis [5].

Since the early 1900's scientists have suspected that both the auroras and the variations in the Earth's magnetic field must be caused by some kind of currents which flow in the upper atmosphere. Today we know that there are many currents which flow in the magnetosphere caused by the very complicated interplay between the solar wind and Earth's magnetic field. Although these currents are only partially understood at present, the one that has been studied most extensively is the Birkeland current, which is associated with the auroras. When the solar wind encounters the Earth's magnetic field about 50,000 km above Earth, an electromotive force (EMF) of about 100,000 volts is generated. This applied EMF is distributed throughout the magnetosphere and Earth's upper atmosphere, much as the voltage from a electric utility generator is distributed around a power grid. A portion of the solar-wind-generated EMF, perhaps 10,000 volts, accelerates electrons down magnetic field lines into the ionosphere at altitudes of about 100 km. These electrons first travel horizontally and then back up to the upper atmosphere to form a closed circuit. Although this circuit has many similarities to a simple circuit with wires and a battery, it is also very complex since it occurs in three-dimensional space and varies wildly in time as the solar-wind intensity changes. It is the high-speed electrons near the bottom of this current loop which collide with molecules and atoms of the atmosphere that produce the auroras. The strongest Auroral emission comes from altitudes of about 100 km. As with any simple circuit, energy is dissipated as the electrons flow around the loop. Some of this energy shows up as the light of the auroras, but most of it becomes thermal energy—heating the atmosphere. Another important result of the Birkeland current is that, like any current loop, it produces a magnetic field. This field extends down to the Earth's surface where it adds to the geomagnetic field, causing it to fluctuate. These fluctuations in magnetic field can then induce currents in the Earth's surface, or in conductors like power lines or pipelines. All of this is determined by the behavior of the solar wind reaching Earth, which in turn is determined by the events taking place on the Sun. It also means that many of our electronic systems on Earth may become disrupted or even damaged. Our sun produces high-energy solar cosmic rays (protons and ions) in Solar Proton Events (SPEs). These particles generally have energies in the range of 10 MeV to 100 MeV [4]. Very energetic SPE events are also capable of generating near-relativistic protons in the order of 20 GeV.4 Table 3 gives the arrival time of the protons based on energy level after the solar flare first becomes visible on the Earth. In general, SPEs take from hour to minutes to reach Earth depending on their energy. High-energy protons in

SPEs produce ultraviolet auroras, invisible to the human eye, when they collide with Earth's atmosphere. These reactions produce NOx byproducts that eventually settle on the planet's surface. The nitrates from large SPEs are detectable in the ice cores. The observations show that a massive SPE can also produce a short-lived major magnetic spike on Earth. Protons in SPEs and CMEs have energy spectrums ranging from around 10 KeV to above 20 GeV. However, solar events producing protons with energies above 1 GeV are rare. Due to geomagnetic shielding solar energetic particles with energies less than 100 MeV can only reach the Earth's atmosphere over Polar Regions where they lose their energy in collision with atoms in the atmosphere creating a cosmic ray shower of particles. If the particles have energies greater than 500 MeV, the cosmic ray shower can penetrate to the planet's surface

The complex coupling of the solar wind and the geomagnetic field produces many effects near Earth. Earth is embedded in the outer atmosphere of the Sun and therefore is affected by events which occur in the surface layers and coronal regions of the Sun. Terrestrial effects are the result of three general types of conditions on the Sun: eruptive flares, disappearing filaments and coronal holes facing Earth [5].

Mid-latitude coronal holes (usually occurring during the phase of solar activity following solar maximum) are sources of high-speed solar wind streams, which buffet Earth in synchronism with the 27-day solar rotation. Previously the cause of these recurring geomagnetic storms was unknown, so the regions were called M-regions, M for mysterious. Non-recurrent major storms and large geomagnetic storms are almost always associated with coronal mass ejections (CMEs) and with the shock waves associated with CMEs.

Several centuries ago, the disruptive effects of the Sun were totally unnoticed by humans. But as technology developed that utilized currents, conductors, and eventually electromagnetic waves, the disruptive effects of the Sun became evident. Early telegraph systems in the 1800s were subject to mysterious currents that seemed to be generated spontaneously.

When an intense surge of solar wind reaches Earth, there are many changes which occur in the magnetosphere. The day side of the magnetosphere is compressed closer to the surface of Earth and the geomagnetic field fluctuates wildly. This type of event is generally called a geomagnetic storm. 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.

When a mass of plasma is ejected from the Sun, the plasma travels outward in the solar wind. These plasma bursts have their own magnetic fields which are carried along with the plasma. How these fields are oriented when they arrive at Earth determines whether magnetic reconnection will occur. When the direction of the solar wind field is opposite the direction of Earth's field, magnetic reconnection occurs, and the geomagnetosphere essentially becomes a part of the solar magnetic field. In this condition, Earth is much more prone to the effects of the solar wind. Solar wind particles can enter the magnetosphere more easily, and those already within the magnetosphere are energized. Changes in solar wind magnetic fields cause wild fluctuations in the magnetospheric fields. In response to these fluctuations, in accordance with Lenz's Law, massive currents flow throughout the magnetosphere. It is these high altitude currents that induce voltages at ground level. If the magnetic field of the solar wind is in the same direction as the Earth's field, then magnetic reconnection does not occur and the magnetosphere is much more separated and protected from the solar wind [6]. 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.

The effect of Earth directed Coronal Mass Ejections (CME) from the Sun reveals a sensational 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. Solar active regions usually reach kilogauss values in their magnetic field. When the earth directed CME glances along the magnetic shield, local disturbances in the atmosphere of the Earth have been noticed. Cyclic changes of the general atmosphere circulation are of prime interest as are the transformation and recurrence of circulation forms, which characterize planetary wave dynamics. The changes of the atmospheric pressure in geomagnetically and electronically excited cases (including the solar activity effect) in comparison to the variations in geomagnetically and electronically quiet cases.

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 (http://SunSpotWatch.com) 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 NOAA Space Environment Services Center (SESC) in Boulder is one of the world centers that make forecasts of solar and geomagnetic activity. Daily predictions are issued for the likelihood of solar flares, proton flares, x-ray events and magnetic storms. Longer-range forecasts are also made so that the launches of manned spaceflights can be planned with more safety. The SESC is a worldwide nerve center for about 1400 data streams, including x-ray and particle flux data from the GOES satellites, H_ images and magnetograms from observatories around the world, measurements of the geomagnetic field at many locations, and 10.7-cm radio levels from several radio telescopes. Each day the features of the solar disk are mapped by hand so that the evolution of active regions, coronal holes, filaments, and neutral lines may be carefully studied. Forecasters attempt to consider all of this information when making their daily forecasts of solar effects on Earth [7]. At the present time, these forecasts are not very reliable; major flares are sometimes not forecast and predictions that are made often do not come true. Even though forecasters have a large amount of data to work with, the physics of the Sun, the magnetosphere, and the interplanetary medium is not well understood. At the present time, many partial mathematical models have been developed, but there is no comprehensive model of the Solar-Terrestrial environment.

In most cases, the ability to predict the behavior of nature comes from a mathematical model. For example, the motion of an object falling in a gravitational field can be modeled using the mathematical expression $v = g \_ t$. Earth weather forecasters have been trying for the last 30 years to construct a mathematical model of the global weather using the very complex equations of fluid dynamics to describe the circulation of the oceans and atmosphere. Even with the best supercomputers to run these models, it has proven impossible to precisely model Earth weather. Modeling the solar-terrestrial environment is vastly more complex. The physics necessary to do this includes not only fluid dynamics but also Maxwell's equations. This combination is known as magnetohydrodynamics (MHD) [8], and at the present time the equations of MHD cannot be completely solved analytically. Numerical solutions exist which involve the use of a computer in a "trial and error" fashion. Numerical solutions, however, can give incorrect results and at best are an approximation. There is some suspicion that we have not yet developed the physics necessary to fully understand the Sun, where strong magnetic fields are erupting and plasmas swirl at ultra-high temperatures. The issue needs further investigation applying quantum filed theory that is more suitable for description of photon-photon or photon-charged particle interaction [9]. It may be assumed that for weather forecasting the only existed numerical weather models aren't sufficient and they have to be enhanced by electromagnetic models to make forecasting more precise.

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