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Impact of solar coronal mass ejections (CME) on formation of Earth climate and weather pattern

Marika Tatishvil, Irine Mkurnalidze, Inga Samkharadze,Nunu Tsintsadze
Institute of Hydrometeorology of Georgian Technical University, Tbilisi, Georgia
marika.tatishvili@yahoo.com

Abstract— Earth Observation System (EOS) program is designed to examine the role of Earth-Sun connection in wide-scale global processes in order to determine the function of the Earth as a single system. One of global climate change reason is caused due to emissions of greenhouse gases like carbon dioxide into the atmosphere. The real drivers of climate are the Sun's insulation (light and heat), its magnetic flux, and the relative position and orientation of the Earth to the Sun.

The variations in the Sun's magnetic flux control the amount of cosmic rays enter the atmosphere. Cosmic rays produce ionizations and the ions form nuclei for cloud formation. Cloud cover has a great effect on global temperature, but this area is still poorly understood and not addressed in climate models. Meteorological effects resulting from fluctuations in the solar wind are presently poorly represented in weather and climate models. Geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of 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. The largest storms that result from these conditions are associated with solar coronal mass ejections (CME) where a billion tons of plasma from the sun, with its embedded magnetic field, arrives at Earth. CME typically take several days to arrive at Earth,

Geomagnetic indices are important parameter in weather forecasting methods. The development of the global circulation processes are depending on their capacity in, and then the emergence of the local weather. Applying Earth's magnetosphere model is conducted the continuous observation on the magnetic field and the expected geomagnetic storms have to be predicted what is important in weather formation on the earth

The correlation between geomagnetic storms and meteorological elements (temperature, precipitation, wind) have been determined 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 income radiation. New approaches have been suggested to explain observation results.

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

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 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.

From historical and geological records we know that the Earth's climate has always been changing. Sometimes such changes have been relatively abrupt and have apparently had large sociological effects. It is therefore natural that our society is interested in future climate changes and in particular is concerned about a possible influence on climate of society itself. This concern is associated with the effect of the increasing amount of greenhouse gases, in particular CO_2, which is due to human activities related to the burning of fossil fuel [1].

The determination of the natural climate variability is therefore of decisive importance for a credible estimation of the man-made signal and hence for possible political decisions regarding initiatives to mitigate the effects of the increased amount of greenhouse gases. The climate variations prior to the industrial era may thus be strongly influenced by variations in solar activity. After the start of the industrial era and the associated increasing concentration of greenhouse gases in the atmosphere we are faced with at least two simultaneously operating mechanisms, both possibly contributing to the observed global warming of about 0.5° since 1890. Because of the significant economic aspects associated with possible political interventions based on estimated effects on society of emissions of greenhouse gases, there is a considerable interest in a precise evaluation of future climate changes. If the reported correlations between solar activity variations and climate changes are indeed associated with a physical mechanism that could be understood and predicted, this would probably mean a major reduction of the uncertainty associated with the natural climate oscillations [2].

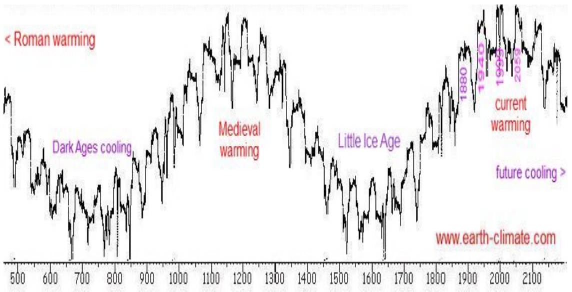

Fig.1. Earth climate variation during centuries

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 [4]..

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 taillook 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].

Data and methods

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. Currents as high as one million amperes are common and the total power produced in this giant generator can be as much as 3 x 1012 watts! 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.

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 [7].

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. Under these conditions, the effects of solar mass ejections are much less significant. In order to know what is going to happen on Earth we must know not only what happened on the Sun but also the nature of the magnetic fields that are carried along with the solar wind. Solar forecasters are interested in placing a satellite between the Sun and Earth so that the nature of the solar wind can be observed before it arrives. Until such a satellite can be deployed, forecasting will remain difficult

The second area of work is that of constructing a model for the Solar-Terrestrial environment. In addition to the complexities of MHD[6,9,10], the problem is difficult because there are three different domains involved, which all couple together. The first domain is that of the Sun; to simply construct a mathematical model of the Sun is far beyond us at the present time. There are still many mysteries about what is going on inside the Sun, what triggers flares and even why sunspots form. The second domain is the interplanetary medium, once thought of as empty space. This space is filled with the solar wind plasma, which is not fully understood. The third domain is the geomagnetosphere, with its many regions and currents. The magnetotail, extending for millions of kilometers out from Earth, has been difficult to study directly and remains poorly understood. We are not close to having a model for any one of these domains by itself, yet the final complication comes from the fact that these three domains are not at all separate. A change in one of these domains can have major consequences on the surface of Earth; we hope one day to have a comprehensive model for the entire solar-terrestrial environment but this is certainly a problem for physicists of the future.

The NOAA Space Environment Services Center (SESC) in Boulder is one of the world centers that makes 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. 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), 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. Certainly it is impossible to simulate these conditions in experiments on Earth.

The abundance of good correlations between solar activity and climate parameters indicates a physical link. Solar activity variations have traditionally been associated with the sunspot number although it is well known that solar activity may not be described by a single number. In particular it has been difficult to find a good representation of the long-term variations of solar activity. That solar cycle relationships cannot just be extrapolated to represent long-term behavior is demonstrated by the relative variations of the sunspot number and the geomagnetic activity index, aa. Although aa is an index specifically associated with the fluctuations in the terrestrial magnetic field, it does represent the result of the continuous interaction between the geomagnetic field and the solar wind, and hence some form of solar activity.

Discussion

In order to understand influence of geomagnetic activity on the formation of weather pattern geomagnetic indices achieve [4,8] and meteorological observation database for 2014-17 have been analyzed. The 3 location were chosen namely: Tbilisi- (Kartli Region), Batumi-Ajara Region and Telavi-Kakheti Region. The results showed that always weather pattern change: increase wind velocity; temperature change (decrease); precipitation amount increase follows geomagnetic activity.

Table.1. Correlation of meteorological parameters with geomagnetic activity in Tbilisi, Georgia for June, 2015

Day 2015	Pres. mm	Av. temper. (^{0}C).	Max. wind veloc. (m/s)	Rel. hum. %	Precip. mm.	Geo-magn. indices
08.06.	728	21	9	67	0.7 in 12 h. Thunders.	G2 – Moderate Geomagnetic, K 6 expected
10.06.	721	23	18	67	**2.0** in 12 h. Thunder(s)	G1 (Minor)
12.06.	723	23	10	70	Thunder.	Geomagnetic K 4 expected
14.06.	723	22	12	63	Shower(s)	Geomagnetic K 4 expected. G1 – Minor.
15.06.	721	22	10	64	**0**.3 in 12 h.	Geomagnetic K 4 expected. G1 (Minor).
16.06.	719	23	10	65	0.3 in 12 h	Geomagnetic K 4 expected. G1 Minor
17.06.	718	24	10	61	0.3 in 12 h Rain.	Geomagnetic K 4 expected. G1 - Minor
18.06.	718	25	9	62	-	S1 - Minor
19.06.	719	25	8	60	Rain shower(s),	Category G1
20.06.	718	19	10	70	0.6 in 12 h Shower(s).	Category G1

In addition 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.

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 [11]. But 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.

References

1. M.Tatishvili, N.Bolashvili, I.Mkurnalidze. Climate and causes of its variability. Transactions of Institute of Hydrometeorology, v. 119, 2013. pp. 38-43.
2. Advancing the understanding of the Sun–Earth interaction—the Climate and Weather of the Sun–Earth System (CAWSES) II program. Toshitaka Tsuda, Marianna Shepherd and Nat Gopalswamy.Progress in Earth and Planetary Science (2015) 2:28 DOI 10.1186/s40645-015-0059-0.
3. SOLAR PHYSICS AND TERRESTRIAL EFFECTS. Space Environment Center. 2012 .
4. www.spaceweather.gov
5. Electrodynamical Coupling of Earth's Atmosphere and Ionosphere: An Overview A. K. Singh,1 Devendraa Siingh,2 R. P. Singh,3 and SandhyaMishra**1**Hindawi Publishing Corporation
International Journal of Geophysics Volume 2011
6. SOLAR PHYSICS AND TERRESTRIAL EFFECTS. Space Environment Center. 2012
7. Lightingmaps.org. Blitzortung.org
8. http://SunSpotWatch.com

9 The World Magnetic Model. Chulliat, A., S. Macmillan, P. Alken, C. Beggan, M. Nair, B. Hamilton, . Woods, V. Ridley, S. Maus and A. Thomson, 2015,

10. The US/UK World Magnetic Model for 2015-2020: Technical Report, National Geophysical Data Center, NOAA National Centers for Environmental Information. NOAA. 2017.

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