RESEARCH ARTICLE

The Causes and Effects of Adverse Space Weather

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Abstract: Space climate alludes to profoundly upset conditions on the sun, in the sun powered breeze, magnetosphere, ionosphere, and thermosphere that can influence the exhibition and unwavering quality of room borne and ground-based technological frameworks and can jeopardize human existence and wellbeing. Antagonistic changes in the close Earth space climate can cause interruption of satellite operations, correspondences, route, and electric power circulation frameworks, prompting an assortment of financial misfortunes. This paper talks about a portion of the makes that lead unfriendly space climate. The sources are accepted to be on the sun. The spread of these sources through the interplanetary space is inspected. At last, the collaborations of the interplanetary disturbances with the world's magnetosphere that incorporate bow shock, magnetopause, magnetosphere, and ionosphere are thought of. The case of the June 24-28, 1999 occasion is given to exhibit the sunlight based/interplanetary/magnetosphere between connections. There is no question that the future COS MIC venture will be significant for the investigation of unfriendly space climate.

Keywords: Adverse space weather, Space weather, Solar-terrestrial physics

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1. Introduction

To limit the harm to innovative frameworks that can result from serious geomagnetic aggravations, much consideration has been paid to the expectation of tempests and substorms (Joselyn, 1995). It is trusted that the sun oriented ejections can give a key indicator, and the resulting engendering of the sunlight based created aggravations to 1 AU that produce serious

geomagnetic unsettling influences not really settled. At present the best comprehension of the relationships between sun based emissions and coming about geoeffective sun oriented breeze occasions is measurable (e.g., Joselyn and Mcintosh, 1981; Wilson and Hildner, 1984, 1986; Gosling et al, 1991; Gosling, 1993). For given sunlight based breeze boundaries, for example, the sun based breeze speed V, number thickness N, IMF B and perhaps different boundaries, the geomagnetic storms are displayed by assessment of the geoeffective boundaries Dst and AE (e.g., Burton et al., 1975; Perreault and Akasofu, I 978; Akasofu and Chao, 1980; Sharma et al., 1993; Vassiliadis et al., 1995; Wu and Lundstedt, 1996; Chen et al, 1997).

Then again, the investigation of the sunlight based wellspring of geomagnetic storms has been proceeded for an extensive stretch (Dryer,1982 ;1994; Gosling et al., 1991; Zhao and Hoeksema,1995 ; Hundhansen, 1993). The connection between sun oriented flares and solid attractive tempests has for quite some time been perceived. Transient interplanetary (IP) shock waves have been related with flares (Chao and Lepping, 1974; Hundhausen, 1972). Be that as it may, numerous IP shocks are found no association with flares. Chao (1974) noticed that the affiliations of IP shocks with their flare beginning are not absolutely good. The relationship of a shock wave at 1 AU with a specific flare isn't dependably imaginable. A few shocks can be related with enormous flares while some others can be ascribed uniquely to little ones. Then again, some enormous flares don't create IP shocks close to the earth. Afterward, Tang et al. (1989) showed that there is no relationship between's the flare boundaries and the strength of the IP shock at Earth. The abrupt emission of sun based prominences has likewise been conjured as a wellspring of geomagnetic irritations (Joselyn and Mcintosh, 1981; Wright and McNamara, 1983). Their affiliations are bad (Bravo et al, 1999).

Coronal mass discharges (CMEs) were first seen in the 1970's as changes in coronal structure that happen on a period scale from a couple of moments to a few hours (Gosling, 1975 ; Dryer, 1982; Hundhausen, 1993). Perceptions of CMEs on the Solwind coronagraph on board the P78-l satellite have been contrasted and transient interplanetary shocks saw by the Helios 1 shuttle from 1979 to 1983 by Sheeley et al. (1985). For all intents and purposes each shock ob served by Helios was gone before by a CME saw by Solwind. From that point forward, it has been broadly acknowledged that CMEs are the cylinders, which drive IP shocks ahead. When entering IP space, CMEs are regularly called interplanetary attractive cloud (IMC). A high-thickness area between the previous shock and the limit of the IMC looks like the magnetosheath of the terres preliminary magnetosphere (Bravo et. al., 1999). Subsequently IMCs can be called as an interplanetary magnetosphere. IMCs contain coronal materials, which are considerably less dissipative than impact waves, and consequently can proliferate to an enormous distance in IP space. It is these IMCs, which frequently convey huge southwardIMF, and upgraded force motion because of pressure by the pre surrendered shock, that can produce unfavorable space climate (Gonzalez and Tsurutani, 1987).

During the IMC section, the world's bow shock and magnetopause will be compacted considerably. Regularly the magnetopause is pushed to the geosynchronous circle (Shue et al., 1998). The places of the bow shock can likewise change in huge plentifulness at brief time frame stretches (Wu et. al. 2000, to be distributed). Under such associations among theIMCs and the Earth's magnetosphere, lively sunlight based and magnetospheric charge particles (Baker et al., 1990), geomagnetic storms and magnetospheric substorms are additionally started. Unfavorable space climate is connected with their event. Inside the magnetosphere, high-scope convection design and the related electrodynamic boundaries are changed under an immediate consequence of sun powered breeze/magnetosphere/ionosphere communications (Richmond et al., 1998). Field-adjusted flows and Alfven waves are additionally created (Ma and Lee, 1999). It is guessed that the entire ionosphere including the tropical abnormality areas will be affected by antagonistic space climate. In this paper, we will give the case of the June 24-29,1999 occasion to show a progression of associations beginning from sun oriented surface and finishing on the ground. On the sun powered side, we utilize the information from SOHO's EIT and LASCO coronagraph information to distinguish the sun based occasion. The source surface attractive field information are gotten from Wilcox Observatory of Stanford University (Zhao and Hoeksema, 1995). A kinematic code (Hakamada and Akasofu, 1982) is utilized to work out the engendering from the source surface to 1 AU. Interplanetary attractive field and plasma information of WIND and Geotail are utilized as the upstream information boundaries for forecasts of the positions and states of the world's bow shock and magnetopause. The IZMEM model (Papitashvili et al., 1999) is utilized to compute the field-adjusted flows in the polar area. Future estimations will utilize a more modern AMIE code (Richmond and Kamide, 1988) for this reason.

It is accepted that the plan we exhibit is a helpful one not just for understanding the material science of the couplings between various locales of the sun oriented earth-bound climate yet in addition potentially for space climate forecast.

2. The Solar Source

The relation between solar flares, transient IP shocks and strong geomagnetic storms has long been recognized (Dryer, 1984). Therefore, solar flares were considered as the most likely solar cause for geomagnetic storms. However, more recent observations on board satellites

from coronal and near-surface solar event measurements suggest that the source of the storms is coronal mass ejections (Sheeley et al; Harrison, 1994; Webb and Hundhausen, 1987). Recently Brave et al (1999) found the percentage of solar associations of interplanetary magnetic clouds (IMCs) are 51 % for Ha. flare, 21% for filament eruption, 7% for both of the previous two and 15% for neither of them. From all those studies, it is practically reas0nable to assume the solar source is the CMEs for space weather studies. In order to identify a solar source and use it for prediction purpose, we use a kinematic code. This code was designed by Hakamada and Akasofu (1982) and modified by Akasofu and Fry (1986) and Sun et al. (1985). This method combines the magnetic field frozen-in property and some observational property of the solar wind to construct a 3-D solar wind model. It is useful for the study of large structures in the solar wind particularly the large disturbances generated by IMCs.

3. Interplanetary Source

Because of the rotation of the Sun, the solar wind and the disturbance entering the inter planetary space will interact with the ambient solar wind originating from different longitudes on the solar surface. This interaction can create additional source for geomagnetic storms. Since the direct cause for storms is a large southward IMF Bz , we look for processes that can generate such a component.

A CME in general is composed of a bright loop, a dark region and a filament or prominence close to the Sun (Hundhausen, 1993, Tsurutani and Gonzalez, 1997; Tsurutani et al, 1999). When entering IP space, the material of the CME is called a driven gas (Bame et al., 1979; Hirshberg et al, 1970). Occasionally, magnetic fields of the given gas have the form of a magnetic cloud or giant flux rope (Burlaga et al, 1987; Klein and Burlaga, 1982). This flux rope will have a Bz component. When the material carrying the magnetic cloud has a speed greater than the ambient solar wind by more than the ambient fast wave speed, fast shock wave will form. This MHD fast shock can compress the upstream magnetic field substantially. If a moderate southward Bz already exists upstream, a large southward Bz will be generated. When it reaches the magnetosphere, a large storm will be initiated. Fast MHD shock can generate the storm efficiently.

Interplanetary shock waves can be grouped into two types. The first type consists of corotating shocks, which are generated by interactions of solar wind streams. The lifetime of these streams may be longer or shorter than one solar rotation period. Hence, the corotating shocks do not necessarily have a recurrence tendency of 27 days (a solar rotational period). The second type consists of transient shocks generated by IMCs. Non-linear large amplitude waves can steepen into fast shocks (Chao, 1973). Both these two types of shocks can amplify the ambient southward Bz to produce the interplanetary cause for geomagnetic storms. Nu

merical and empirical models have been proposed for this generation mechanism.

The compressed region between the driver gas and the shock wave can be called the sheath region, which is generated in interplanetary space. In principle, the strength and the direction of this Bz can be predicted when the undisturbed source surface magnetic fields and solar wind speeds are known (Wu and Dryer, 1996). Large amplitude Alfven waves and turbulence when compressed by the shocks may also be the source for storms when large Bz' s are present. Tsurutani and Gonzalez (1997) have listed six types of possibilities of how large southward Bz are created: (1) shocked southward fields (Tsurutani et al., 1988), (2) bending of the heliospheric current sheets(HCS) (Tsurutani et al., 1984), (3) amplification of Alfven waves and turbulence (Tsurutani et al., 1995), (4) draped magnetic fields in the sheath region (Midgley and Davis, 1963; Zwan and Wolf, 1976; McComas et al., 1989), (5) equinoctial By effect (Russell and McPherron, 1973) and (6) fast stream-HCS interactions (Odstrcil and Pizzo, 1999). It is hoped that kinematic simulation can account for some of the above listed possibili ties.

4. Magnetospheric Effects

The supersonic solar wind impinges on the Earth' s magnetosphere generating the magnetopause (MP) and bow shock (BS). Both MP and BS are never been found to disappear. During the recently observations by the ISTP satellites WIND, ACE, Geotail and IMP-8 on May 11, 1999, the number density of solar wind had dropped to below 1 per cubic cm for more than half a day. Both BS and MP have been found to cross some of these satellites at large distances from the Earth. On the other hand, under some extreme solar wind conditions when the high solar wind speed, number density and large southward Bz prevail, the MP and BS can be pushed much closer to the Earth. Sometimes the MP moves inside the geosynchronous orbit and some orbiting satellites may enter the magnetosheath and be exposed to the solar wind and fields. Some vulnerable satellites will have difficulties in coping with highly variable fluctuations of the fields and energetic solar wind particles. Thus, forecasts of those geosynchronous MP crossings are very important to the safety of geosynchronous satellites.

The locations of the MP are not only important for modeling the magnetosphere but also essential in space weather forecasts. Models for the size and shape of the MP are plenty (Fairfield, 1971; Formisano et al., 1979; Petrinec and Russell, 1993,1996; Roelof and Sibeck, 1993; Shue et al.,1997, 1998). Only a few of them can be used for predictions. Shue et al. (2000) first compare two models (Petrinec and Russell, 1996; Shue et al., 1998) to test the capability of predictions of geosynchronous MP crossings by GOI;:Ss satellite using seven years of data. Yang et al. (2000) improve the prediction of Shue et al. (2000) by using a new model derived from a carefully selected database of MP crossings.

The models for the Earth's BS are also important for space weather studies (e.g., Fairfield, 1971; Formisano, 1979; Slavin and Holzer, 1981; Farris and Russell, 1994; Cairns et al., 1995; Cairns and Lyon, 1995; Peredo et al., 1995; Bennett et al., 1997; Wu et al., 2000). Recently,

Chao et al. (2000) have selected a database of BS crossings from Geotail using only the multiple crossing events with quiet upstream conditions. The satellite WIND is used as a monitor to obtain the upstream parameters Dp, Bz, f3 and Mms, which are the solar wind dynamic pressure, IMF Bz, plasma beta and magnetosonic Mach number respectively. A model for the size and shape of the BS is thus derived. This model is able to predict the IMC induced BS crossings very accurately. As an example, the 26 Geotail's BS crossings, which are induced by the October 18-20, 1995 IMC event, are correctly predicted by this model except one. Solar wind disturbance induced BS and MP crossings for a selected event will be demonstrated in the next section.

It has been demonstrated in many studies that the large-scale ionospheric convection at high latitudes is primarily controlled by IMF B and solar wind dynamic pressure outside the magnetosphere. The couplings of solar-wind/ magnetosphere/ ionosphere determine the pat terns of high-latitude convection and related electrodynamic parameters in the ionosphere. Models of inner magnetospheric convection require knowledge of the electric potential distribution around the polar cap boundary. Similarly, models of thermospheric dynamics need to know the plasma convection at high latitudes in order to model correctly the effects of ion drag and Joule heating. A model is designed for this kind of study, called AMIE (The Assimilative Mapping of Ionospheric Electrodynamics), which is used to synthesize collections of diverse data relating to high-latitude ionospheric electrodynamics into coherent patterns of conductivities, electric fields and currents, and related parameters (Richmond, 1992; Richmond et al., 1998). At present, A MIE is a specification model rather than a forecast model, although its mathematical structure could allow inclusion of time as an additional dimension, which would permit temporal extrapolation. Nonetheless, this specification model can be used to help initialize forecast models of thermospheric winds and composition, ionospheric electron density, and inner-magnetospheric particle populations. Another recent model designed for the study of ionospheric convection patterns is the IZMEM model (The IZMIRAN Electrodynamic Model). Both models can deduce the field-aligned current system in the polar cap. For a satellite at a typical altitude of 800 km the toroidal component of ionospheric current produces a relatively weak magnetic perturbation. By contrast, the field-aligned current system can produce relatively strong magnetic perturbations at satellite altitudes (Richmond and Kamide, 1988). A field-aligned current system calculated from the IZMEM model for the period June 24-29 is given in the next section. An origin of the field-aligned currents has been proposed by (Ma and Lee, 1999). They have carried out a three-dimensional compressible MHD simulation to study the generation of field-aligned currents and Alfven waves by magnetic reconnection. The results indicate that the presence of IMF By leads to a shift of the reversal site between the downward and upward field-aligned currents that may contribute to the ob served region 1 field-aligned currents near noon in the polar ionosphere. This result can be incorporated into the AMIE model to study solar-wind/ magnetosphere coupling.

5. The June 24-29, 1999 Event

In this section, we present observations and analyses of a solar disturbance and the associated IP disturbances that lasted for a little over two days and were observed at 1 AU by ISTP satellites. Such disturbances interact with Earth's bow shock and magnetopause causing their positions and shape to change. The interactions may also influence the polar as well as the equatorial ionosphere. The IPEI payload on ROCSAT-1 observes "bubbles" in the equatorial region of the ionosphere during the passage of this disturbance.

(1) Identification of solar source

A review of possible solar activities, which can be related to the interplanetary disturbance observed at lAU from 0200 UT of June 26 to 0300 UT of June 28, shows that two flares and one filament eruption (DSF) occurred at 1818 (N22E37),June 22, 0649(N23E42), June 23, and 1051 UT (N33E09), June 24, respectively, are the possible sources for the event. The observations provided by the LASCO and EIT on board SOHO also reveal solar disturbances at 1400 UT, June 24. LASCO and EIT show a CME and a region of flare activity, respectively, at this time. This solar disturbance will be assumed as our solar source for this event.

(2) Interplanetary propagation

These disturbances and solar wind will start from the source surface. The source surface of the magnetic field measurement is obtained from Wilcox Observatory of Stanford University. One Carrington Rotation (no. 1951) of the Solar Magnetic Field Synoptic Chart is shown where the projections of the locations of the Earth and the origin of the disturbances are indicated by a"*" and "0" respectively. With this information, the kinematic code is used to calculate the propagation of disturbances in 3-dimension interplanetary space. Solar wind is assumed to have a radial propagation from the source surface at 2.5 R0 from the Sun. The magnitude of the solar wind speed is assumed to be proportional to the magnetic field strength. With the frozen-in condition assumed, the magnetic fields are carried to IP space. Without any disturbance on the source surface, the magnetic fields are assumed to be in the radial directions. When there is a disturbance added on the source surface with intensities of the velocities decreasing from the center of the source following a Gaussian distribution, the magnetic field will be stretched such that a non-radial component will be generated. This will be the source for Bz component. Outward field is indicated by dash curves and inward field by solid curves. Compression and rarefaction of field lines can be easily noticed from the curves. The simulation starts on

1818 UT, June 22 when the first disturbance is initiated. The circle is the position of the Earth. The first plot shows the IP magnetic fields projected on the ecliptic plane at 0000 UT, June 24. The second one is for OOOOUT, June 25 when all the disturbances have already left the Sun. One can find that the first disturbance reaches 1 AU in late June 25. The kinematic code maps the source surface magnetic field structures in interplanetary space where the sectors of inward and outward magnetic fields are clearly seen. Fast and slow streams originating from different polarities of the solar surface can form the sector structures and interaction regions. Therefore, this code is also good for prediction of the arrival of corotation shocks due to fast- and slow- stream interactions. We would like to point out the discontinuity of field lines at longitude 0°or 360°. It is not real. We use is not taken simultaneously. Since we are interested in the region far from this longitude, our results are not affected by this discontinuity. The simulated disturbance as seen at the Earth's position where the solar wind radial velocity V, number density N, IMF B and its latitude 8 and longitude cI> are respectively shown from top to bottom. The disturbance arrives at the Earth in late June 25 and is so strongly compressed in its frontal part that a shock is formed at the leading edge. The whole event lasts until in early June 28. Smflll northward and then a little southward IMF Bz is observed inside the compressed sheath region

6. Discussion and Summary

Research in solar-terrestrial physics has been conducted for many years. Only in the last few years have serious efforts been given to applying the findings for space weather prediction. Since we still have many problems in each of the areas: the Sun, the interplanetary space and the magnetosphere as well as their couplings, the predictions we have attempted are very preliminary. Nevertheless, the scheme we outline above can offer useful results for space weather study.

On the solar side, the causes for adverse space weather need to be identified. Through many years of study, the space physics community generally considers CMEs the most important cause, as compared to other solar activities, such as flares, filament eruptions, and coronal holes. These solar activities and the CME might be interrelated and the physics of their relationship is still not very clear. Therefore, for practical purposes, we take CMEs as the basis for the space weather prediction.

The ability to predict a CME release from the solar corona is still a long way off. The direct way to find the source is to observe the eruption of CMEs. The early satellites, like Skylab, SMM, and the recent SOHO can measure the CMEs seen only at the limb. The CMEs propagating earthward are observed as halo CMEs by SOHO. It is difficult to observe the head-on type CMEs. Hence, we take the next most likely source, a filament eruption as our disturbance. Once the source is selected, we have to describe how such a disturbance propagates from the solar corona to the vicinity of the Earth.

Numerical simulations have been the most common practice for the propagation of solar interplanetary disturbances. Because of the non-uniform nature of the solar corona and inter planetary space, it is not easy to simulate such phenomena in 3-dimensional space with all the inhomogeneities included. It is generally believed that the MHD simulations can give a fairly good description of the propagation and interactions of all the three MHD wave modes. One would expect that the various types of discontinuities such as the fast, slow, intermediate shocks, rotational and tangential discontinuities, could be generated in such simulations. Without including the effect of the rotation of the Sun and the general non-uniform coronal back ground, Wu et al. (1 999) simulate the famous January sun-earth connection event. A large amount of super-computer time is needed for just one such single simulation. On the other hand, we use a simple kinematic model, which cannot account for the interactions of the MHD wave modes but can describe the supersonic flows evolving in interplanetary space. The boundaries between the flare (or CMEs) ejecta and the ambient solar wind in general represent the fast shock surfaces . The effects of solar rotation and the non-uniform surface-magnetic field are included in a crude way in this simulation. By incorporating multi-satellite observations, it is possible to derive the shape and size of the interplanetary disturbances. The ex ample of the June 24-28, 1 999 event demonstrates the usefulness of this kinematic model. This kind of simulation can be performed even on a personal computer. Because it is ease to use and efficient, we hope to develop its capability for space weather prediction.

The BS and MP are the most important boundaries of the Earth 's magnetosphere. They protect us from the direct damage by the solar wind and some energetic particles. The prediction of the positions and shape of the BS and MP is very essential for space weather prediction. But, before a good prediction for the detailrd structures of the solar wind made from the solar source is available, predictions of changes of the locations and shape of BS and MP mainly rely on the upstream observations of the magnetosphere. Fortunately, the ISTP satellites, particularly the WIND and ACE are very useful for such purposes. Our models for the BS and MP respectively have demonstrated very accurate predictions for many events and hope they will be implemented for space weather prediction in the near future.

The responses inside the Earth 's magnetosphere due to the solar and interplanetary disturbances are under very active study particularly for space weather studies. The energy transfer function c needs further study so that the magnetosphere response can be more accurately calculated. The field-aligned currents due to interplanetary Alfven waves and rotational discontinuities need to be incorporated in the ionospheric circulation models such as the AMIE, IZMEN and .others. The global distribution of ionospheric election density and the polar region field-aligned currents obtained from the COSMIC project would provide valuable data for the study of ionospheric response to the adverse space weather.

In summary, we have demonstrated a scheme for modeling solar disturbances, which propagate through the interplanetary space and interact with the Earth 's magnetosphere causing changes of the BS, MP and the polar and equatorial ionospheres . Comparison with observations in these regions shows this prediction scheme warrents further development.

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