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MODEL OF MAGNETIC DISTURBANCES DURING THE HISTORIC EXTREME MAGNETIC STORM OF 1-2 SEPTEMBER 1859

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Abstract. A calculation of magnetic disturbance for the magnetic storm on September 2, 1859, registered by the Colaba Observatory (India) is presented. It was executed on the base of the model of magnetospheric current systems [Feldstein et al., 2005]. This modeling testified that a temporary feature of the geomagnetic disturbance at the Colaba Observatory consisting of very rapid change of H component of the geomagnetic field during the main phase and the same rapid recovery, is related to temporal dynamics of the tail current system. It includes the rapid movement of the front edge of the plasma layer to the Earth in the main phase of the storm and the subsequent same rapid return it to the tail of the magnetosphere.

1. Introduction

Magnetic storms are the most dramatic and perhaps important component of space weather effecting on the Earth. Super-intense magnetic storms (defined here as those with Dst < -500 nT) appear relatively rarely, however, they have the largest societal and technological relevance. Such storms can cause life-threatening power outages, satellite damage, communication failures and navigational problems. However, the data about such magnetic storms is rather scarce. For example, only one super-intense magnetic storm (with Dst=-640 nT) has been recorded since 1958 (on March 13, 1989), the start of the space-age. Nevertheless, such storms very likely occurred many times in the last 160 years or so when the regular observatory network came into existence. Research on historical geomagnetic storms can help to create a good data base for intense and super-intense magnetic storms. Modern knowledge of interplanetary and solar causes of storms gained from the space-age observations, applicated to super-intense storms data set one can deduce their possible causes and construct a data base for solar ejecta, e.g., frequency of occurrence of extremely large solar flares, evolution of solar ejecta, etc. An other important reason for undertaking such study is to answer some basic questions, namely: i) how many super-intense magnetic storms have occurred in the last 160 years and what were their probable solar and interplanetary causes; ii)what frequency of occurrence of super-intense storms and under what circumstances; iii) is a prediction of a certain number of (say 3) most severe magnetic storm during a solar cycle possible; iv) can the possible damaging effect of supper intense magnetic storms on the modern society be predicted in advance; v) what is the energetics of eruptive phenomena on Sun and Stars, etc.? A partial chronological list of some large magnetic storms occurred during the last 160 years, includes the "Remarkable Magnetic Storms" described in [Tsurutani *et al.* 2003]. One can see that some of the event of September 1-2, 1859 fall under the category of super-intense magnetic storms. From the application of knowledge of interplanetary and solar causes of storms to the super-intense storm, it has been possible to deduce that an exceptionally fast (and intense) magnetic cloud was the interplanetary cause of this geomagnetic storm with a Dst -1760 nT, nearly 3 times as large as that of March 13, 1989 super-intense storm.

In recent times, there has been keen interest in understanding Sun-Earth connection events, such as solar flares, CMEs and concomitant magnetic storms. A geomagnetic storm is characterized by a Main Phase during which the horizontal component of the Earth's low-latitude magnetic field is significantly depressed over a time span of one to a few hours followed by its recovery which may extend over several days. During intense magnetic storms, the auroral activity becomes intense and auroras are not confined to the Auroral Oval only. Rather the Auroras could be seen at the sub-auroral to middle latitude stations. It is now believed that the major cause of solar wind energy transfer to the magnetosphere is magnetic reconnection between interplanetary magnetic field and the Earth's magnetic field. Geomagnetic storms occur when solar wind - magnetosphere coupling becomes intense during the arrival of fast moving (~700 km/s or more) solar ejecta, like CMEs, fast streams from the coronal holes, etc. accompanied by long intervals of intense southward interplanetary magnetic field (IMF) [Tsurutani and Gonzalez, 1997; Klein and Burlaga, 1982] . Such phenomena are named as a "magnetic cloud". As a result, the magnetotail plasma gets injected into the night-side magnetosphere, with energetic protons drifting to the west and electrons drifting to the east, thus, forming a ring of current around the Earth. This current, called the "ring current", produces a diamagnetic decrease in the Earth's magnetic field measured at near-equatorial stations, and is the cause of the main phase of the magnetic storm. The decay of the ring current starts the recovery phase of the storm.

Dessler, Parker and Sckopke [Sckopke, 1966] have shown that the decrease in the equatorial magnetic field strength due to the ring current or Dst (disturbance storm time) index, is directly related to the total energy of the ring current particles, and thus is a good measure of the energetics of the magnetic storm. Though Dst index acts as a proxy for the strength of the ring current, other currents like magnetopause current can contribute to it as well. An empirical relationship between Dst and interplanetary parameters has been derived by [Burton *et al.* 1975].

We shall focus on the super-intense storm of September 1-2, 1859, which was associated with the Carrington flare that occurred on September 01, 1859. We use ground magnetometer data of the Colaba Observatory (Bombey), India, for the September 1-3, 1859, and our knowledge of interplanetary and solar causes of storms [Feldstein et al., 2005], to identify the probable causes of magnetic disturbance that generate this super storm.

2. Magnetic field calculation for the storm of September, 1859

The magnetogram of the Colaba Observatory for the September 1-3, 1859, are presented in the Figure 1. It shows that the magnitude of the storm sudden commencement (SSC) was about 120 nT. The maximum negative intensity recorded at Colaba was $\Delta H \approx$ -1600 nT, and the duration of the main phase of the storm (corresponding to the plasma injection) was ~ 1-1.5 hours. The location of Colaba (~ 12 LT) was not ideal to detect the maximum magnetic response to the storm. However, based on observation from this one station, one can say that this is now the most intense magnetic storm on record. The authors ([Tsurutani et al., 2003; Li et al., 2006; Siscoe and Cooker, 2006] and references therein) analyzed recorded temporary H component of geomagnetic vector in order to assess the parameters of the interplanetary medium, responsible for generating such a storm. According their evaluation Dst-index reached value of -1760 nT, solar wind speed V $\approx$1500-1700 km/s, the concentration of protons N $\approx$ 1200-1600 cm^-3, Bz IMF $\approx$ -(40-60) nT.

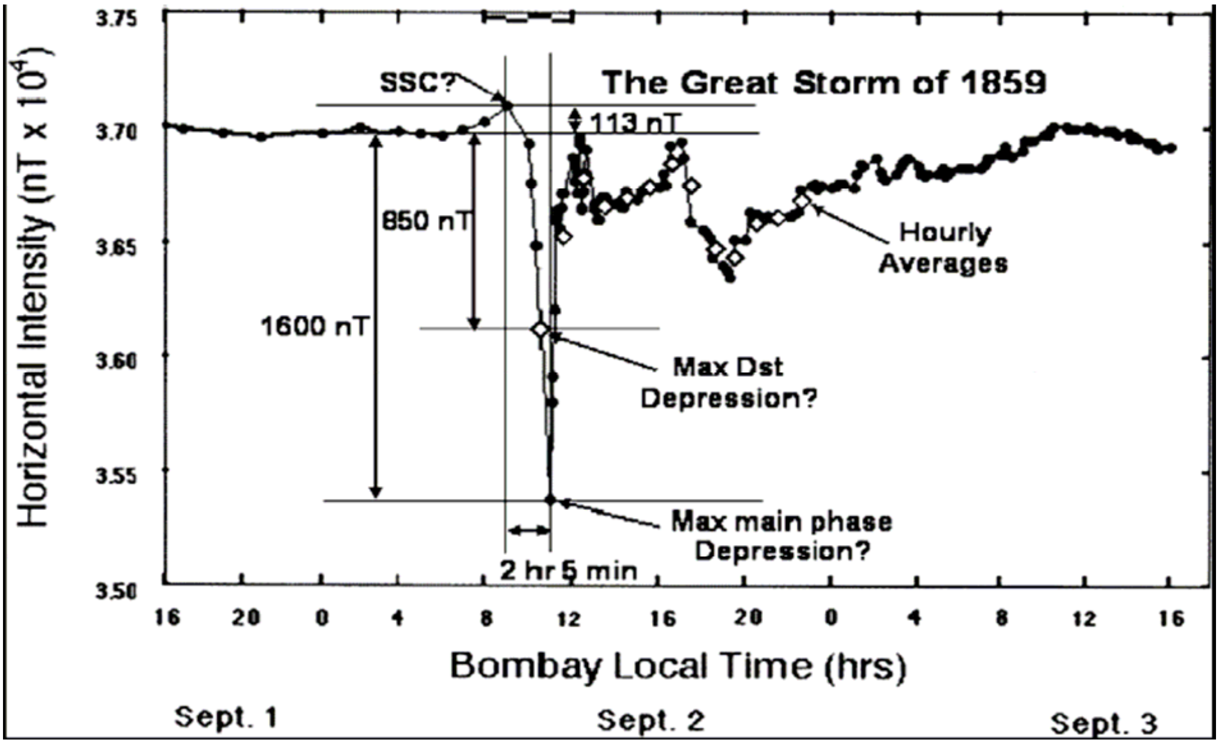

Figure 1. The magnetogram of the Colaba Observatory (Bombey) for September 1-3, 1859.

Analysis of the extreme storms that occurred in the absence of data about the parameters of the interplanetary medium, executed on the basis of modern models of geomagnetic activity indices and model parameters of the magnetosphere, can not be correct. This is due to the fact that all these models have been established on the basis of statistical processing of data sets that are practically have not so large amplitude of the velocity and density of the solar wind, as well as the vector components of IMF as described above. Therefore, such high-amplitude parameters of the interplanetary medium from revaluation, based on correlation models of indices Dst, AE (AU, AL) may differ significantly from those parameters, which were in reality.

In the analysis of magnetic disturbances recorded by observers in Colaba, considerable interest is not only the amplitude of geomagnetic disturbances, but also the physical nature of the form of temporary changes in the magnetic component H. It does not contain commonly observed in the magnetic storms characteristic temporal course of field's recovery associated with the decay of the ring current particles. In this storm the field changes during the main phase and during the recovery phase, nearly the same. Such unusual dynamics of geomagnetic disturbances at low-latitude observatory is explained as a consequence possible a very large amplitude of the dynamic pressure of solar wind during all the storm including the recovery phase [Li et al., 2006].

We offer another explanation for the unusual form of the magnetic storm following from our model Dst variation [Feldstein et al., 2005]. It supposes that the magnetospheric tail current system gives a significant contribute to the magnetic field variation during large storms. This form is a consequence of the significant displacement of the plasma layer in the Earth's magnetosphere. The front edge of the plasma layer relocates at a distance of 2-3 R_E from the Earth's center, then the same rapidly returns to a distance of ~ 10 R_E.

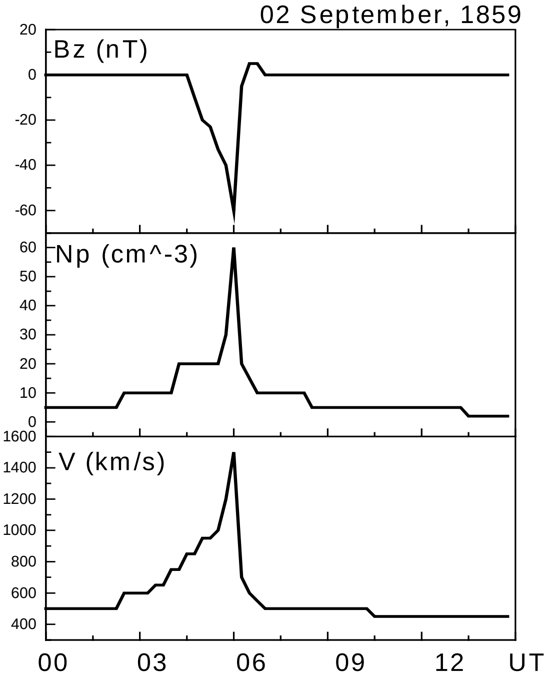

Figure 2. The solar wind parameters used for calculation of the input parameters of storm field modeling.

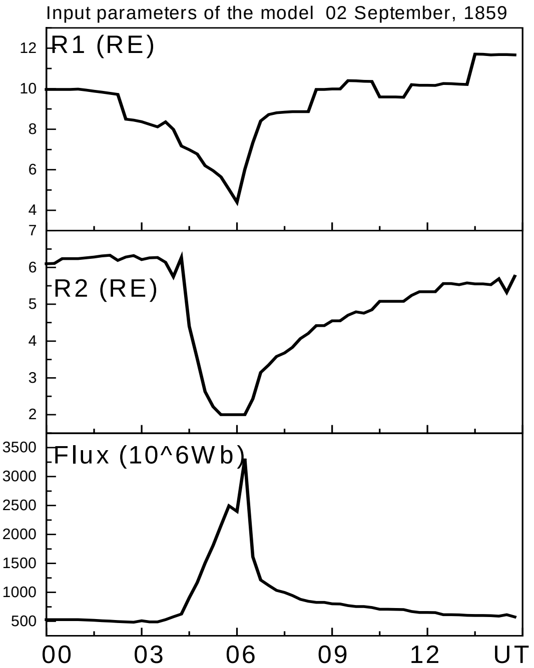

Figure 3. The input parameters for the modeling of the magnetic storm field in September 2, 1859.

Figure 2 shows the model values of Bz IMF [nT], the concentration of protons N_p [cm^-3] and solar wind speed V [km/s] of solar wind used for our calculation of the input parameters for the modeling of the storm disturbance for 1-3 September, 1859. These parameters are presented in the Figure 3. They are: R_1 – the distance to the subsolar point of the magnetosphere, in the R_E; R_2 - the distance from the Earth's edge of the plasma layer in the tail; flux – the magnetic flux in the tail of the Earth's magnetosphere, in Wb. The input parameters were used to calculate the contributions of three main magnetospheric current systems to the modeled magnetic storm. The result of calculation is presented in the Figure 4. It consists the magnetic disturbances produced on the Earth's surface by the current system of the Earth's magnetotail DT, by the magnetopause current DCF, and by the ring current DR. The summary magnetic disturbance is shown by thick line. One can see that without taking into account of the magnetospheric tail current (for accepted parameters of the solar wind) contribution DCF significantly reduces the magnetic disturbance due to the ring current on the Earth's surface, in that way, decreasing the total depression of the field. Taking into account the contribution of the tail current to the total decreasing of the geomagnetic field reduces the model disturbance to the form similar that as was observed at the Colaba Observatory – the very rapid (≈1-2 hours) change of H component of the geomagnetic field during the main phase and the same rapid recovery up to prestorm level. The proposed model in contrast to [Li et al, 2006] lets not include very large concentrations of solar wind protons (≈1500 cm^-3) near the Earth's orbit for long time for explanation of the observed picture of the disturbance.

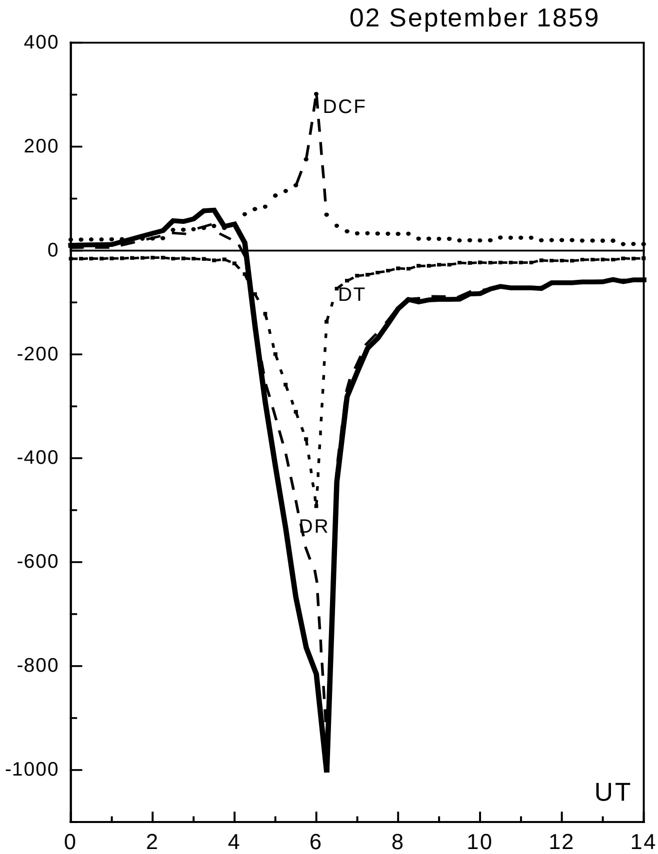

Figure 4. The model magnetic disturbance calculated for 2 September, 1859: the magnetic disturbances due to the ring current DR, the magnetospheric tail current DT, the magnetopause current DCF, and the summary model magnetic field (thick line) on the Earth's surface (location of Colaba).

3. Conclusions

A possible explanation for the unusual form of the magnetic perturbations of the super-intense magnetic storm, registered at the Colaba observatory (India) on 2 September, 1859, was considered. Based on the model of magnetospheric current systems [Feldstein et al., 2005], a calculation of model magnetic disturbance was carried out. It has shown that a temporary feature of H component of the geomagnetic field at the Colaba observatory consisting of very rapid change field in the main phase of the storm and the same swift recovery, is related to temporal dynamics of the intensity of the tail current system of the magnetosphere. Observed form of the storm of 2 September,1859, is explained by rapid movement of the front edge of the plasma layer of the Earth to the Earth, right to a distance of ≈2-3 R_E, in the main phase of the storm, and the subsequent same rapid return it to the magnetospheric tail to a distance ≈7-8 R_E.

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