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Research Article

A HISTORICAL OVERVIEW OF THE EARTH'S MAGNETISM

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ABSTRACT

This specific paper addresses the historical events that had led in the current scenario, to the development of one of the most important fundamental research areas – Geomagnetism, which might even date back to probably millions of years embedded in the core scientific aspects of even ancient civilizations. On the other hand, the energetic charged particle flux namely the solar wind and its associated magnetic field have their source in the Sun and their interaction with the geo-magnetic field which extends into outer space has its origin inside the earth's core. Needless to say, the contributions of many scientific researchers on the dynamics of upper, middle and lower atmospheres of the earth is indeed remarkable, but certain important aspects require more attention. Hence, the Sun-Earth Connectivity is of utmost importance to Space-weather researchers. Moreover, the Sun-earth connectivity through the geomagnetic storm is a process which is still less understood. Space-weather researchers face huge challenges as the geomagnetic storms turn out to be more dangerous and disastrous at times and hence, the consequences are seen clearly on the ground level and on the space based technological systems. A gradual understanding of the root level causes can lead to solutions with possibly good accuracies which in turn can be helpful in sorting out the various space based and ground based technological anamolies and challenges. The Real-Time Disturbance Storm time index measured for the month of january 2018 is shown below. The decrease in the earth's magnetic field is clearly shown.

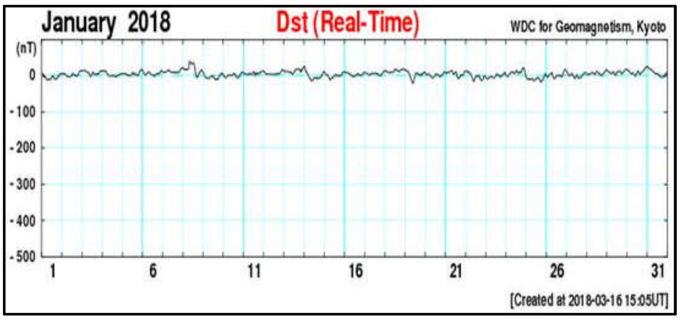

Figure 1 Disturbance storm time index and the variations recorded in the earth's magnetic field in nano-Tesla (nT) for the month of January 2018.

(Courtesy: World Data Centre for Geomagnetism, Kyoto, Japan)

Objective of Research

This paper is the foremost of the series of papers worked out by the author in the Sun-Earth Connection and the various phenomena related. The reason why this research was needed is explained in the consecutive lines. The Space based and ground based technologies encounter huge setbacks and severe disasters in the form of geomagnetic storms, which literally prove fatal to the earth. At least one geomagnetic storm of notable intensity is observed a month by geomagnetic observatories in the form of decrease of the earth's magnetic field by a significant value. This decrease is caused by the highly energetic charged particle flux which enters the earth's magnetosphere and compresses the magnetic field lines. These energetic charged particles penetrate still further into the earth's ionosphere and cause severe disruptions in the GPS communication and navigation systems of the satellites and even disrupt the power grids on the earth. The consequences are still many more and the most important challenges are listed above. Huge power blackouts had been observed as a result of the geomagnetic storms. Hence, the overall process of Sun-Earth interaction needs to be understood in a systematic fashion. The current approach is to try to figure out the solutions to the challenges that occur in that particular zone of the upper atmosphere of the earth, where the effect is maximum observed, say the ionosphere. The author's work can be much useful in triggering some good insights in the areas of space-weather research that connects the Sun and the Earth planet. Moreover, the author strongly feels that, in order to understand the various underlying phenomena and the

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dynamical changes occuring in space, one must carefully work out the root level causes and interactions beginning from the core of the earth to the core of the Sun as all the different space-weather phenomena connecting the Sun and Earth have their origin inside the Sun and Earth respectively. Hence, the author's take on this subject matter is to concretize the understanding of these underlying phenomena by studying the core of the earth to the core of the Sun in-depth and the various space-weather interaction processes. The author takes an approach, where the underlying processes in the core of the earth and Sun are studied in depth and moves on to explain the interaction between the solar wind and the geomagnetic field extended into outer space – which is quite popular as geomagnetic storm. This is indeed a tedious task, given the highly variable and dynamical variations occuring in the core of Earth and the Sun. Hence, this approach is a serious attempt to address these challenging issues step by step.

INTRODUCTION

Going back in time, approximately more than 400 years before, a remarkable discovery was made by Robert Norman, a prominent London ship's instrument maker, in which he published a small pamphlet. It is worth noting that small pamphlets initiated a new beginning in the investigation of an age old science of geomagnetism. Norman noticed that a non-magnetic needle, when perfectly balanced did not remain horizontal, when it was magnetized. This sounded a little mysterious and lots of myths circulated around his discovery. He also found that, mounting the needle and giving it the freedom to turn in the vertical plane of the magnetic north, the northward end dipped by about 70 degrees. At the same time, William Gilbert, as a renowned physician to Queen Elizabeth, and a contemporary of Shakespeare, used to spend much of his time on experiments related to static electricity and magnetism. At that time, Gilbert was much against the Psuedo-science and hence, in the process of refuting it, he eventually published his great treatise in Latin (in the year 1600), famous as ***de Magnete,*** in which he reviewed the much earlier writings on these subjects and described his own discoveries. Much before, approximately three hundred years ago, Petrus Peregrinus (1269), observed that the lines of the tangential component of magnetic force converged to two quite opposite points, which he named as magnetic poles. Following this, Gilbert explored the surface field of a spherical lodestone (magnetite) and he traced on it the lines of the tangential component of the magnetic force. William Gilbert, widely considered as the father of the modern geomagnetism, also noted how the tiny magnets dipped at various angles in different "latitudes" relative to these poles. Acknowledging Norman's discovery, Gilbert finally initiated the science of Geomagnetism and wrote

Magnus magnes ipse est globus terrestris

(The earth globe itself is a great magnet)

The compass based directional influence, which is of utmost importance in the present day air and sea based navigation, is one of the oldest known consequences of geomagnetism. This compass based system was used for many centuries until William Gilbert, who was intelligent enough to notice that the cause lies within the earth and not in the heavens, as previously supposed by many people.

The Field – variations and magnetic charts

After Gilbert's great treatise *de magnete* in 1600, the year 1635 witnessed an important breakthrough regarding the main field. This was the year, when Gellibrand showed that the field itself is dynamic and variable and moreover it gradually changes. It was observed that at London, the compass moved steadily westward for approximately 220 years, from 11° E in 1580 to 24° W in the year 1800; the dip also varied, rising to 74 1/2 ° by 1700 and since then gradually decreased to its present value of 66°, which can be considered as minimum. During the last century, the earth's magnetic moment had a decrease by 5 %. The two year period from 1698-1700 was indeed very important as Edmund Halley made the first ocean magnetic survey, in the North and South Atlantic oceans. He embodied his observations in the first oceanic magnetic chart in the year 1701. He also collected many compass based observations done by other mariners and published the world's first magnetic chart in the year 1702. Much later studies of ships' logs have enabled magnetic charts to be drawn, for parts of the globe, for as far back as 1550. These kind of charts are now published by the chief hydrographic offices and revised for every five years. A new world magnetic survey, more complete than any ever before made, will be undertaken internationally as a deferred part of the International Geophysical Year (IGY), during the years 1964-65. Along with this, various other geophysical programs to be undertaken during that period constitute an enterprise called the 'International Quiet Sun year', also known as IQSY. Magnetic observations are made on land, at the sea and by aircrafts, satellites and even rockets. Owing to the gradual and slow secular variation of the earth's magnetic field, the production of these charts is really a never-ending task indeed.

Magnetic disturbances – remarkable contribution by a clock maker

Approximately, two centuries back, an important discovery regarding the transient changes occuring in the earth's magnetic field was made by an eminent London clock maker Graham. This was announced in the year 1722, after a long and continued observations of the small movements of a compass needle. Regular variations on a daily basis were recorded and the additional larger and irregular changes had been superposed. These irregular changes were termed as magnetic disturbances. In this regard, Graham made the first disctinction between geomagnetic quiet or calm and magnetic disturbance (or magnetic activity). When a magnetic disturbance supposedly becomes intense, it is known as a magnetic storm – a brilliant word coined by Humboldt. Interest in geomagnetism increased as many eminent researchers like Celsius of Upsala, Sweden initiated similar studies in the year 1740. In 1741, Celsius and Graham noted an important observation that the magnetic disturbance was often found to be simultaneous at two places. Comparing with the ordinary weather conditions, they concluded that magnetic disturbances are a non local phenomena indeed and are global. In 1741, Celsius had found that auroras can be correlated with magnetic disturbances. In 1770, Wilcke from Sweden observed that the auroral rays lie along the earth's magnetic field lines.

The Theory of Magnetism

The theory of magnetism, in general was greatly advanced by the French mathematician Poisson in the year 1824. He defined the magnetic dipole concept, intensity of magnetization and extended the theory of potential, which was developed for electricity and gravitation, to magnetism. In the year 1832, the great German Scientist and mathematician Carl Frederich Gauss showed how to measure the magnetic intensity in absolute units. Gauss, in 1834 had set up the first magnetic observatory at Gottingen, at which all the three magnetic elements could be measured – by eye readings, with the help of mirror and scale; photographic recording did not come into picture until 1847, when it was installed at Greenwich by Airy. Similar magnetic observatories were soon set up at other places, and it was possible to obtain a synoptic picture of the world distribution of the transient magnetic changes. During the International Geophysical year – IGY, there were more than 150 magnetic observatories across the globe.

Sunspots and transient magnetic variations – the connection (The magnetic weather)

In the year 1826, a young German apothecary of Dessau, Samuel Heinrich Schwabe, at the age of thirty-six, was stimulated by a friend, who deeply knew of his astronomical interests, to take up the study of sunspots and their regular observations, which was neglected at that time. Schwabe was indeed a regular and consistent observer; so consistent were his observations that later it was said of him that "The Sun never rose unclouded above the horizon of Dessau without being encountered by Schwabe's imperturbable telescope". After 12 long year years of consistent observations, he published his spot counts in the German *Astronomische Nachrichten* (News). He already saw that they suggested a variation with a period of aboout ten years, but he made this comment only in the year 1843, when he had published a further five years' observations in the same journal. He gave both annual spot counts and annual numbers of spotless days; both showed in inverse ways the cycle of rising and falling activity. Figure 1 shows the sunspot numbers from the year 1750 until the year 2010.

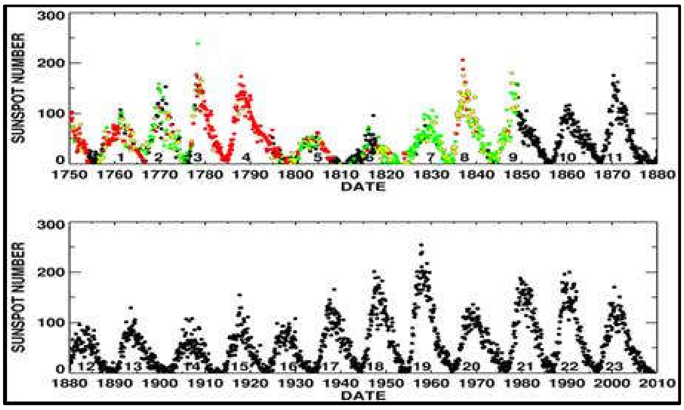

Figure 2 Sunspot numbers shown from the year 1750 - 2010

Meanwhile, Schwabe continued his observations and in the year 1857, when he (Schwabe) was awarded the Gold medal of the Royal Astronomical Society, the President remarked : " Twelve years he spent to satisfy himself, six more years to satisfy and still thirteen more years to convince, mankind" of his discovery; and that thus " the energy of one man has revealed a phenomenon that had eluded the suspicion of astronomers for 200 years". But for some more years, after 1843, this remarkable discovery of the solar or sunspot cycle remained unnoticed a little. In the year 1851, Schwabe's remarkable recognition of the existence of the sunspot cycle was publicized by Humboldt in his famous book *Cosmos*, and within a year Sabine and others announced that the same cycle was shown in the transient magnetic variations as shown in Figure 2.

Hence, it became quite clear that whereas ordinary weather is influenced by the changing geometrical relationships of the earth and Sun, the magnetic weather is influenced by intrinsic changes on the Sun's surface and thereby impacts the geomagnetic field when the solar wind charged particle flux interacts with the earth's magnetosphere.

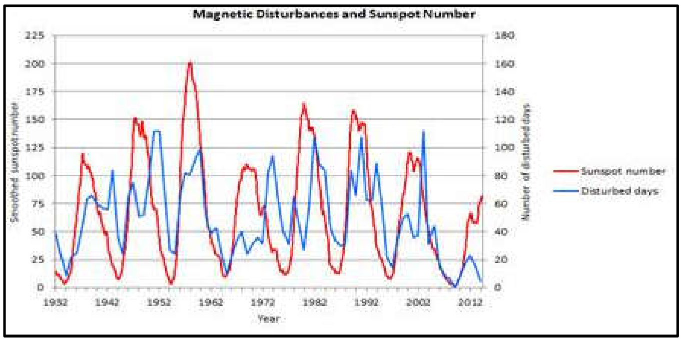

Figure 3 Correlation between sunspot number and magnetic disturbances

Aurora – connection with the earth's magnetic field

In the year 1860, Elias Loomis, professor of natural philosophy at Yale, drew the first diagram of the auroral zone, and pointed out that its oval form, not centered on the geographical pole, somewhat resembles that of the lines of equal magnetic dip – yet another connection between the aurora and the earth's magnetic field. In 1873-74, Hermann Fritz, then professor of Physics at Zurich, published a great auroral catalog, and used it to give a map showing lines – which he called isochasms – of equal frequency of auroral visibility.

The electrically conducting layer, Ionosphere – Events leading to the discovery

By 1880 it had become clear that the small regular daily magnetic changes are found to be greater by 50 percent or more at the sunspot maximum than at sunspot minimum. To the Scottish physicist Balfour Stewart this was a clear pointer to a more accurate source of these variations. In his famous article on Terristrial Magnetism in the 9th (1882) edition of the *Encyclopedia Britannica,* he showed by sound arguments that their cause must be the electric currents flowing in the upper atmosphere, and that the air there must be rendered electrically conducting by the solar activity. This was the first recognition of what is now known as the 'Ionosphere'. Stewart concluded that the electric currents must be induced by dynamo action of airflow across the geomagnetic field. Their own varying field induces secondary currents within the earth. The field of these earth currents modifies the daily magnetic variations observed at the surface of the earth in an appreciable manner. These remarkable studies indeed showed that the upper atmosphere must be more electrically conducting, more inonized during the day time rather than at night , in summer than in winter and mostly at sunspot maximum, rather than at sunspot minimum. Exactly, twenty years later (1902) the existence of the ionosphere was recognized anew by two men independently –

Heaviside and kennelly – from quite different evidence. From Marconi's success in 1901 in sending radio waves from Cornwall to New-found land, they concluded that the waves must be made to follow the curve of the earth by an electrically conducting layer in the upper atmosphere. After another twenty years, radio waves began to prove as a valuable tool for the exploration of the electrically conducting layer – the ionosphere from the ground. Appleton (and others) in England, and Breit and Tuve (and others) in the United States., were the pioneers in such researches, which soon revealed the layered structure of the inosphere – E, F1, F2.

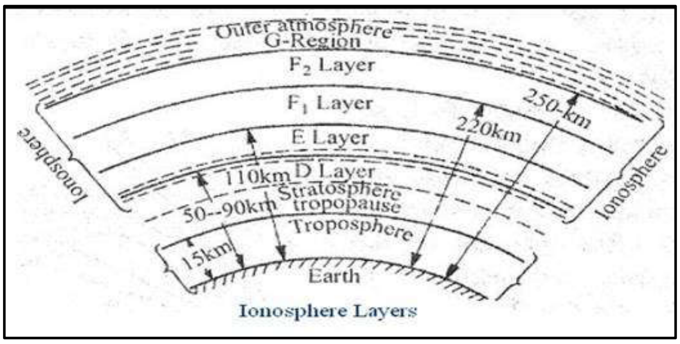

Figure 4 Structured layers of the ionosphere

CONCLUSION

A Brief historical overview had been presented in this paper on Geomagnetism. The way the science of geomagnetism and its development led to the discovery of the ionosphere – the electrically conducting layer in the upper atmosphere of the earth is also shown in this paper. Mostly, the important events that led to the remarkable discoveries about geomagnetic field and ionosphere etc are outlined. Since, geomagnetism and magnetic weather phenomena have a huge impact on the space based and ground based technologies on the earth, it is quite important at this juncture to understand the science of geomagnetism from its initial stages of development. This paper is just an introductory paper in a series of papers by the author on the science of geomagnetism and magnetic weather phenomena. The theoretical connection by means of mathematical equations will be dealt in the coming series of papers on geomagnetism and solar activity.

Limitations and Further Scope

Since, this paper outlines the historical turn of events that led to the remarkable discoveries of geomagnetism, magnetic weather connectivity with solar activity, electrically conducting layer in the earth's upper atmosphere – the ionosphere, the discussion regarding the various limitations can be held a bit a side for the time being and will be further discussed when a rigorous theoretical and mathematical treatment will be perfomed in the coming series of papers on the same subject matter.

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