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Study of an Inter-Planetary Magnetic Field (IMF) Intensity during Space Weather Disturbances

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Abstract:- This study investigates the intensity of interplanetary magnetic field (IMF) during space weather disturbances and its impact on atmospheric electric currents, which is crucial for understanding space weather. Observations of atmospheric characteristics like conductivity and potential gradient define the Global Electrical Circuit (GEC) connecting the troposphere, ionosphere, and magnetosphere. Utilising data from high-latitude polar regions, where human pollution is minimal, the study assesses various phenomena's effects on atmospheric electricity, employing statistical techniques like the Fourier Transform on Antarctic station data. Results reveal distinct variations in atmospheric electric fields during solar wind-induced geomagnetic storms, influenced by wind speed and local geography. The research emphasises multi-station observations to comprehensively grasp interactions between solar activity, geomagnetic disturbances, and atmospheric electricity. These findings shed light on how changes in the interplanetary magnetic field impact atmospheric electric field intensity, advancing understanding of space weather phenomena.

Keywords: Inter-Planetary Magnetic Field (IMF), space weather disturbances, atmospheric electricity, geomagnetic storms, multi-station observations.

1. INTRODUCTION

Space weather disturbance behaves like a flow of current in an atmospheric electric circuit during adverse or disrupted geomagnetic conditions in the geomagnetic field. Due to this phenomenon, the atmospheric electric currents travel upward, and ionosphere density reaches maximum before the atmospheric electric current flows towards the Earth's surface. Assessment of atmospheric potential is essential for the study of space weather disturbance. Continuous observations of atmospheric electrical characteristics, such as atmospheric conductivity, potential gradient, and electrical field intensity, define the atmosphere's Global Electrical Circuit (GEC). Previous studies suggested that this global electric circuit connects the lower troposphere, ionosphere, and magnetosphere, and atmospheric characteristics are used to assess it. The challenges associated with climate change can be resolved using long-term observations from several sites. Considering the strong record of atmospheric electric data and its observations, the sensitivity of the interactions between atmospheric electrical energy, solar cycles, and atmospheric air quality are insufficient for large-scale studies. Because thunderstorms are unstable, the non-linear influence can be significant throughout the atmospheric electrical systems, but electric charges may be crucial in the electrification of the thunderstorm. Numerous studies have demonstrated that the global electrical system may considerably influence how ionospheric electric field changes influence solar activity. Polar observations are crucial for understanding the Global Electric Circuit (GEC) since they are almost entirely devoid of human pollutants. The radioactivity at the Earth's surface causes the Polar Regions to be covered in ice and most continents to convict. The ice surface has a conductivity of many orders of magnitudes higher than air. The atmospheric electrical tests in Antarctica are useful for understanding the widespread electrical phenomena unique to high latitudes. The global electric circuit uses lower atmosphere generators (often fueled by thunderstorms) and higher atmosphere generators (ionosphere/magnetosphere). The magnetic coordinates of the measuring location determine the impact of this external generator on the surface electric field. Several high-latitude polar zone scientists calculated and documented the atmospheric electrical properties. The influence of the coronal mass ejection and the role of electro-dynamic coupling were seen throughout the local summer by measuring the surface electric field at Maitri station, Antarctica. It resembles a "Carnegie curve," the so-called electric field structure that thunderstorms are said to create. Additionally, it should be emphasised that the typical daily fluctuation is only detectable after averaging many days on certain days. Another problem is that horizontal ionospheric electric fields map down to the Earth's surface while analysing the global electric circuit in the high latitude-polar-cap region. This dawn-to-dusk horizontal potential gap resulting from the solar wind's interaction with the Earth's magnetosphere (V-B) leads to the two-cell convection pattern in the pole region. The E-region of the ionosphere and the solar wind-magnetosphere dynamo can be affected by thunderstorms to the global electric circuit, according to data from the Maitri station on the surface electric field of Antarctica. The cross-polar cap potential significantly impacts the high-latitude region and has spread up to 40 magnetic co-latitudes. Hence, the currents and electric fields produced by the ionospheric wind dynamo are relatively small compared to those of the solar wind magnetosphere dynamo at high latitudes during the solar active period. The enlarged horizontal electric field descends steadily to the lower atmosphere (dawn-dusk potential). The clockwise cell can map the current on the ground and the upward vertical electric field. Researchers would transfer that recorded electric field and atmospheric current to the anti-clockwise convection. The kind of convective cell in magnetic dawn at dusk relies on the station's relative position. Changes brought on by the solar wind can have more immediate consequences on the interplanetary electric field's profound penetration into the mid- and low-latitude ionosphere. The strongest indications of solar wind interactions with the magnetosphere and ionosphere are most obvious in auroral and polar latitudes. In high and polar Arctic and Antarctic regions, surface electric field studies have been conducted often. Still, the magnetospheric/ionospheric contribution to atmospheric electricity at sub-auroral stations has been associated with these effects. It should be observed that there is little link between the recorded horizontal electric potential and the high latitude of the surface electric field and that the correlations are comparably correlated with the frequency of auroral electrojets. However, there have been no consistent results from earlier research, and the equatorial auroral border station does not employ a comparable method. the delay in time between the electric surface field recorded at the poles and its disappearance during the geomagnetic storms. The fair-weather current, which descends from the ionosphere through the atmosphere in fair-weather zones to the Earth's surface, is a potent ground-based indicator for investigation. This wave of conduction current creates a vertical electric field (EZ), also known as a potential gradient (PG), for regions with weather conditions. In excellent weather, the PG typically has a magnitude of 120 V/m at 1 m above the surface, with the potential to get better with height. Thunderstorms and electrified clouds are the primary generators that drive the world's electric circuit, which transmit charges from cloud tops to the ionosphere. Two secondary generators are more active at medium and high latitudes: ionospheric tides and the solar wind/magnetospheric dynamo. The latter generator is active in polar cap areas where the structure of the magnetosphere and ionosphere is disturbed by the incoming solar plasma through open geomagnetic field lines. This influence is further increased during the geomagnetic storm and sub-storm when the magnetosphere is filled with massive energy. The sub-storm phases (expansion and recovery phases) are often assumed to result from a chain of actions beginning with an enhanced energy coupling into the planet's magnetosphere. The collision of the incoming solar wind plasma with the Earth's magnetic field creates the current systems in the magnetosphere. All electrical fields, generally magnetospheric (VSW B), are created due to the interaction map of the polar cap ionospheric altitude where two-cell electrical field convection patterns between dawn and dusk are formed because of the high electrical conductivity present along and across the magnetic field lines. Significant differences in the ionospheric potential effectively work to diminish the lower atmosphere's electrical conductivity. The magnetospheric generator causes perturbations of around 20% in the current and PG at high latitudes during calm geomagnetic cycles and larger changes during geomagnetically disturbed times. As a result of the intensification of the ionospheric electric field brought on by the development of magnetospheric storms, there is an increase in the amount of energetic particles precipitated into the lower ionosphere. Additionally, it is intended to change the surface electrical field and diminish the ionosphere's conductivity. Coronal mass ejection (CME) and solar energetic particle events have produced short-term space weather phenomena such as particle precipitation, large-scale ionospheric electric field influence on current density, and fair-weather electric field measurements. Significantly increased ground-level atmospheric current density, ground-level ambient current intensity, and ground-level electric atmospheric field during big magnetic sub-storm events all point to a downward shift in the horizontal electric ionospheric field's mapping. However, the effect of solar wind-induced geomagnetic storms on atmospheric electrical parameters at middle and high latitudes has been widely observed. Synchronous measurements of the Space Weather Disturbance, geomagnetic fields, and other geophysical parameters from a network of polar stations across the Arctic regions are restricted. Since the local weather largely governs the electrical fluctuations, it is difficult to observe the effects of geomagnetic sub-storms on the Space Weather Disturbance or current from the network of stations (lat/long). This discrepancy may be attributed to the variety of physical processes involved in geo-effective storms in the near-surface atmosphere. Geomagnetic disturbances from roughly conjugate stations fall within the heading of addressing the sub-storm behaviour of the Northern Hemisphere. Particularly due to sub-storm disturbances, the departure of the space weather disturbance at middle latitudes was investigated, and a related study for significant geoeffective storms was carried out. Recent studies have analysed and validated the variations in the impact of the solar flare/ground level event on the space weather disturbance observed from the mid-to-high-latitude stations. It depends on several factors, including the Sun's and Earth's relative positions, the ionosphere's and atmosphere's state at mid-and high latitudes, and interplanetary space conditions. The amplitude of geomagnetic substorms impacting the atmospheric electrical characteristics will change over time, which is another factor that makes examining several stations exceedingly tiresome. Magnetospheric/ionospheric generators impact the atmosphere's electric field, measured concurrently with the Space Weather Disturbance from high latitudes. It is reasonable to suppose that multi-station experiments frequently measure space weather disturbances. It would result in significant and convincing findings and be able to show how fluctuations in the surface electric field are related. On May 31, 2016, a significant geoeffective storm (Kp = 8) occurred. Three high-altitude stations on the Antarctic plateau measured atmospheric electrical characteristics, and their effects have been examined. The results primarily focus on the latitudinal alterations in the geomagnetic disturbance of the ground-level electric field caused by the solar wind-magnetospheric generator and its impact across closely spaced stations in the polar areas during the substorm. This chapter describes several morphological statistical properties of electric field disturbances connected to space weather activities. However, our work has proven that there is still a wide range of information regarding these observations of space weather disturbances and the impact of geomagnetic field intensity.

2. DATA ANALYSIS

When no or little evidence of a climatic disturbance has been found, the activity of space weather disturbances during interplanetary magnetic fields is explored. Space Weather Disturbance observations were made in Antarctica at a ground-based station, and data was collected from www.glocaem.wordpress.com. Regarding space weather disturbance activity, the interplanetary magnetic field was measured on May 31, 2016. A chosen day's electric field intensity pattern exhibits comparable statistical patterns representing precise measurements. In contrast to the study of disrupted interplanetary magnetic field circumstances, the minimum and maximum variations of the space weather disturbance have been standardised to give a knowledge of the behaviour of the disturbance in normal weather situations. The IMF data, accessible at polar stations for this atmospheric investigation, may have been specifically selected for May 2016 due to Space Weather Disturbance.

This chapter's issue statement focuses on studying the distorted airfield under the influence of the inter-magnetic field. As it is obvious that a certain day is taken into account, the atmospheric state for May 31, 2016, is selected to study its consequences.

3. STATISTICAL TECHNIQUES

The Fourier Transform is a mathematical procedure that converts a signal's domain (or x-axis) from time to frequency. The latter is very helpful for breaking down a signal of several pure frequencies. The Fourier Transform may be used for more than only digital signal processing. In reality, the Fourier Transform helps quicken convolutional neural network training. Remember how a convolutional layer applies a kernel to a specific area of an image and multiplies all of the data there bit-wise. The square root of the variance is used to calculate the standard deviation, a statistic that expresses how widely distributed a dataset is in terms of its mean. Calculating each data point's departure from the mean may determine the standard deviation as the square root of variance. The bigger the deviation within the data collection, the more the data points deviate from the mean; hence, the higher the standard deviation, the more dispersed the data. A dataset's dispersion from its mean is measured by standard deviation. It is determined as the variance's square root. In scientific studies, standard deviation is frequently used to gauge an event's relative riskiness.

4. RESULTS ANALYSIS

The study analyses the interplanetary magnetic field (IMF) intensity and its impact on space weather conditions. The research focuses on understanding the behaviour of the atmospheric electric field strength during selected periods of geomagnetic disturbances. While the study successfully depicts the space weather conditions using IMF parameters, it acknowledges the limitation of not considering various environmental factors such as wind speed, precipitation, and rain affecting the electric field. The analysis reveals significant variations in the potential gradient (PG) data collected at polar stations during geomagnetic substorms.

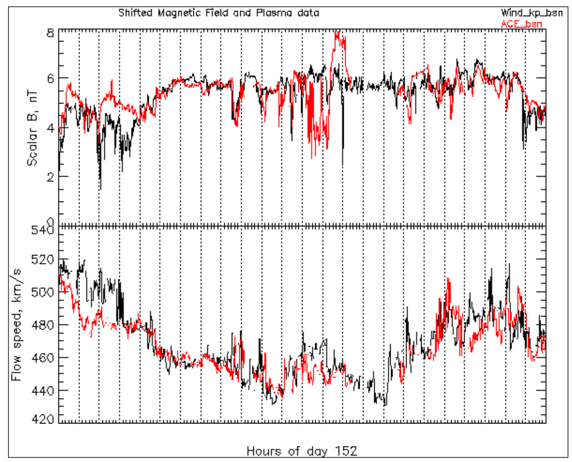

Figure 1. Interplanetary Magnetic Field (IMF) on 2016/05/31

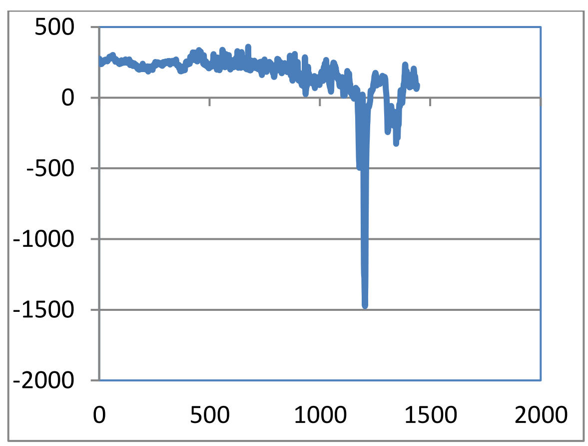

Figure 2. Potential Gradient (PG) on 2016/05/31

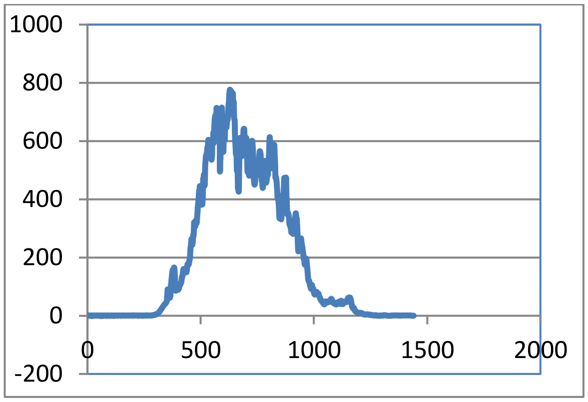

Figure 3. Standard Deviation of Electric Field Intensity

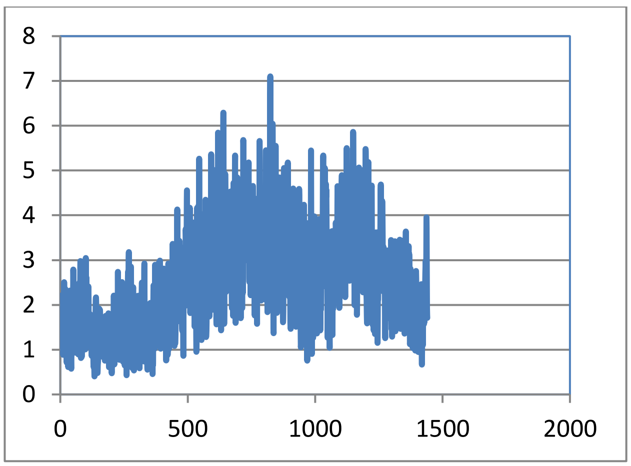

Fig 4 Fast Fourier analysis of Electric Field Intensity

Using statistical techniques like the Fast Fourier Transform (FFT), the study identifies fluctuations in the horizontal section of the Earth's magnetic field correlated with variations in PG. The research identifies distinct intervals during geomagnetic disturbances, characterised by fluctuations in the electric field intensity, particularly in response to solar wind-induced geomagnetic storms. Additionally, the study examines the impact of geomagnetic disturbances on the observed space weather disturbance from high-latitude stations. Despite some contradictory results, likely due to complex physical processes and site selection, the research underscores the necessity of a comprehensive network of observatories to understand the underlying mechanisms fully. A result shows the space weather condition using the IMF parameters and depicts the ambient electric field strength of the selected day. This research does not address how different environmental factors, such as wind speed, precipitation, and pouring rain, affect the electric field. Figure 1 displays the average PG variance data collected at the poles. Additionally, it is feasible to reduce the horizontal section of the Earth's magnetic field and break the impact of a geomagnetic substorm on PG during the first 20 minutes between 04:20 and 8:20 UT. Using a statistical technique like FFT, it was possible to detect that the horizontal section of the signal fluctuated significantly up to 150 nT and was associated with PG variations observed in Figure 2. The incidence of variations stands out more from the experimental measurements. The second phase, which runs from the start of the substorm until 11:30 UT, shows a little departure of PG and a dramatic increase in amplitude. It occurs simultaneously as abrupt geomagnetic field oscillations ('H). According to the DFM data, the substorm began at about 08:24 UT. As seen in the standard deviation graph in Figure 3, a contemporary response was detected on the PG as a tiny departure around 08:25 UT. The IMF significantly impacts PG in the later phases since PG intensity coincides with the IMF's expansionary period. According to the results of this investigation, the PG shift occurred between 09:00 and 09:40 UT, with the magnetic disturbances increasing from 09:15 to 09:20 UT. Additionally, the PG recovered after 11:00 UT and then increased positively. A shift in the vertical magnetic field at around 10:15 UT can be linked to the subsequent difference in PG.

The third interval, from 11:30 to 13:45 UT, exhibits an increase in the electric field, which a spike may follow in wind speed or local effect. In order to process the local weather impact on the observed Space Weather Disturbance at the poles, the time series of the AWS channels are examined. In order to evaluate the weather, meteorological factors have been monitored during the whole observation period. Wind direction determines the strong fluctuations in the PG, which are discovered towards the conclusion of the second period. a disrupted geomagnetic perturbation's effect on the observations of space weather disturbance made from high-latitude stations. However, the results are contradictory; this may be because of the intricate physical processes behind the mechanisms and the selection of the measuring site. In the end, it is believed that a network of numerous station observations will only be feasible if a comprehensive knowledge of the physical mechanism can be achieved. The equator edge of the auroral zone is where the observatories used for this investigation are located. The research suggests that each interval's magnetic field fluctuation and corresponding impacts on space weather disturbance are distinct. The variance in PG indicates that local impacts were nonexistent over the observation period. The space weather disturbance may be disturbed by local dominating elements such as orography, the current weather, and the height of the stations above sea level. Daily variations in thunderstorms' electric field accompany the PG's geomagnetic disturbances. These results compare the normalised PG values to the high-latitude station's daily mean average value on May 31, 2016. The daily average curve of PG at stations is used to calculate the departure of PG from its background field, the so-called electric field. Since the magnetic field readings from the other two observatories indicate relatively small changes, the IMF activity during the first interval is extremely ambiguous. It appears to be limited to the pole. Additionally, the station's PG is fluctuating. Compared to past times, the short-term/small-scale magnetic change on PG is negligible and can be difficult to differentiate from other local impacts. Because of this, it is challenging to say whether the initial interval of the response has any discernible impact on the PG. Electric-magnetic measurements contain the IMF signature linked to the observed PG variations. Generally, a southerly shift of the IMF-BZ is typically linked to the commencement of IMF and is directly tied to the improvement. From high latitude to sub-auroral latitude, the subsiding impact of mapping a large-scale horizontal ionospheric electric field to the lower atmosphere may differ. The station's position concerning the foci of the convection cells affects how the ionospheric electric field and PG interact. Ionospheric electric potential (horizontal electric field) and current patterns across high latitudes comprise two main parts during an IMF. The first is a result of patterns of magnetospheric convection. At the same time, the second is a result of a westward electrojet in a dark region linked to a three-dimensional substorm current circuit. These two elements were recognised as a characteristic of the interaction between the solar wind, magnetosphere, and ionosphere.

5. CONCLUSIONS

The conclusion of the study highlights the significant impact of Interplanetary Magnetic Field (IMF) activity on geomagnetic disturbances, particularly observed at ground-level stations. The first interval of the study revealed substantial IMF activity only at stations, correlating strongly with notable changes in Potential Gradient (PG) as reported by various observatories. While middle-latitude stations might exhibit weaker responses, fluctuations in magnetic field and PG data remain evident. The study suggests that IMF and magnetic latitude influence PG amplitude variance, with increased PG during IMF expansion phases due to the downward mapping of ionospheric horizontal electric fields. These fluctuations significantly affect space weather disturbances observed at high-latitude stations. Despite challenges in comprehensively understanding atmospheric electricity at single observation points, the data convincingly support the notion that PG changes during geomagnetic disturbances. For the first time, the research illustrates how the dawn-dusk convection cell affects PG from near-magnetic poles to middle latitudes, with successful downward mapping of ionospheric electric fields. A more reliable dataset was constructed using data from three high-latitude sites, offering insights into the relationship between solar wind changes and surface electric fields. The study indicates that Earth's electric field strength fluctuates throughout the day under space weather circumstances, potentially exacerbating space weather disturbances. Although IMF variations show limited relationships with PG variants, the localised electric field nature around certain stations is inferred from the dataset. The research establishes that localised electric field fluctuations range between 1.11 and 0.0932 kV/m under high IMF production. These findings align with similar studies, providing a basis for future research. Despite constant space weather circumstances, variations in electric field intensity demonstrate anticipated benefits, underscoring the importance of understanding and monitoring these phenomena for broader scientific insights and practical applications.

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