Disturbance in the Ionosphere and Radiation Blackout Due to Coronal Mass Ejections

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Abstract

We have investigated the effect of coronal mass ejections on the ion density of ionosphere, which have in turn the effect on the high frequency radio waves transmitted from the earth's surface. Although the low frequency radio waves are widely for the communication but there high frequency are equally responsible for long range communication. We have seen the effects of high intense coronal mass ejections from 2022 to 2024 on the disruption of ion concentration in the ionosphere. The severe radiation blackout on May 2024 was also been analyzed by looking into the changes in ion densities during day time and night time.

Introduction

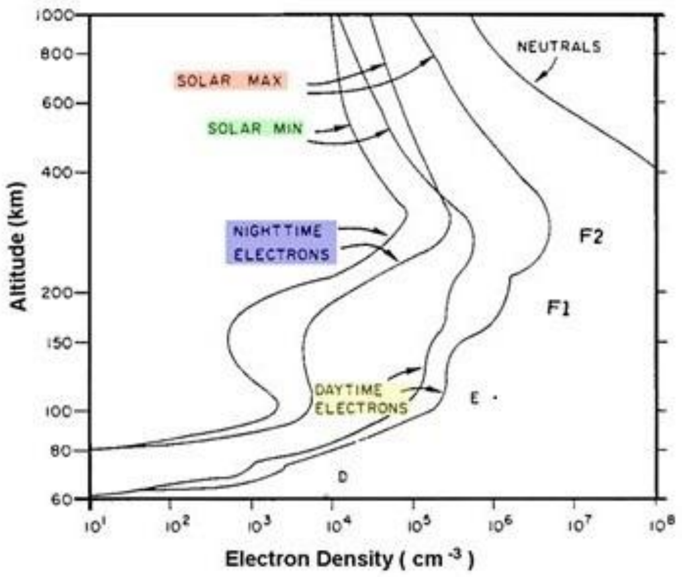
the use of long electrical conductors in the communication was first started when a telegraph was invented. This is probably the first man made system being affected by magnetic disturbance. These magnetic could be from any of the celestial bodies. But the magnetic disturbances from the sun in the form of coronal mass ejections or solar flares have very intensive effects. This sometimes leads to radiation blackouts.

The Sun emits electromagnetic radiation that spans a continuum of wavelengths from radio, through microwave, infrared, visible, ultraviolet X-ray and beyond. Ultraviolet radiation interacts with the upper atmosphere to form an ionized layer known as the ionosphere. Radio waves interact with the ionosphere in a variety of ways depending on their frequencies. For frequencies below about 30 MHz, the ionosphere can act as a reflector, and this property permits very long-distance radio communications around the world. At higher frequencies, above 30 MHz, radio signals usually pass through the ionosphere.

Range (Hz)	Wavelength (meters)	Band Name
3 Hz - 30 Hz	100,000 - 10,000 km	Extremely Low Frequency (ELF)
30 Hz - 300 Hz	10,000 - 1,000 km	Super Low Frequency (SLF)
300 Hz - 3 kHz	1,000 - 100 km	Ultra Low Frequency (ULF)
3 kHz - 30 kHz	100 - 10 km	Very Low Frequency (VLF)
30 kHz - 300 kHz	10 - 1 km	Low Frequency (LF)
300 kHz - 3 MHz	1,000 - 100 meters	Medium Frequency (MF)
3 MHz - 30 MHz	100 - 10 meters	High Frequency (HF)
30 MHz - 300 MHz	10 - 1 meter	Very High Frequency (VHF)
300 MHz - 3 GHz	1 - 0.1 meter	Ultra High Frequency (UHF)
3 GHz - 30 GHz	0.1 - 10 cm	Super High Frequency (SHF)
30 GHz - 300 GHz	10 - 1 mm	Extremely High Frequency (EHF)
300 GHz - 3 THz	1 mm - 0.1 mm	Terahertz (THz)
3 THz - 30 THz	0.1 mm - 0.01 mm	Submillimeter Wave
30 THz - 300 THz	0.01 mm - 0.001 mm	Infrared (IR)

Table 1 …… range of frequencies of the radio waves

Reflection from the ionosphere



Plot 1 Electron density as function as altitude during day and night

The ionosphere is one of the layers of earth's atmosphere that is characterized by a high concentration of ionized particles (electrons and ions). In the reflection of electromagnetic waves these ionized particles play a crucial role. It is because of this reflection, the long range communication has become possible, especially in the high-frequency (HF) radio bands. Depending on the concentration of those charged particles the ions ionosphere have got various layers. These layers are at different altitudes from the surface of earth. How due to various effect the concentration of particles may vary from time to time in those layers. The ionosphere is critical for radio propagation, particularly for long-distance communication. Here is an overview of the different layers of the ionosphere:

1.D-Layer: This layer ranges from altitude: 50 to 90 km (31 to 56 miles) with having low Electron Density compared to other layers. This leyer has a weaker Ionization: Primarily ionized by ultraviolet (UV) light from the Sun. Function: The D-layer is the lowest layer of the ionosphere, and it plays a significant role in absorbing radio waves, especially at lower frequencies. This layer have very high absorption coefficient

2. E-Layer range from altitude 90 to 150 km (56 to 93 miles) with Electron Density: Moderate compared to other layers. This ionization of this layer is also due to ultraviolet radiation, though it has a higher electron density than the D-layer. This layer is the responsible for most the reflections in the mid frequency range of radio waves with some greater strength during the day than during the night.

. 3. F-Layer ranges from Altitude 150 to 600 km (93 to 373 miles) having very high electon density than the above two layers. The high frequency radio waves are being reflected from here. This layer is further divided into two layers F1 and F2 with respect their altitudes and prominence during day and night. The F-layer is critical for skywave propagation, which allows radio signals to travel over long distances by bouncing between the Earth's surface and the ionosphere. The F2-layer is particularly important for high-frequency signals (about 10–30 MHz), as it allows them to reflect back to Earth.

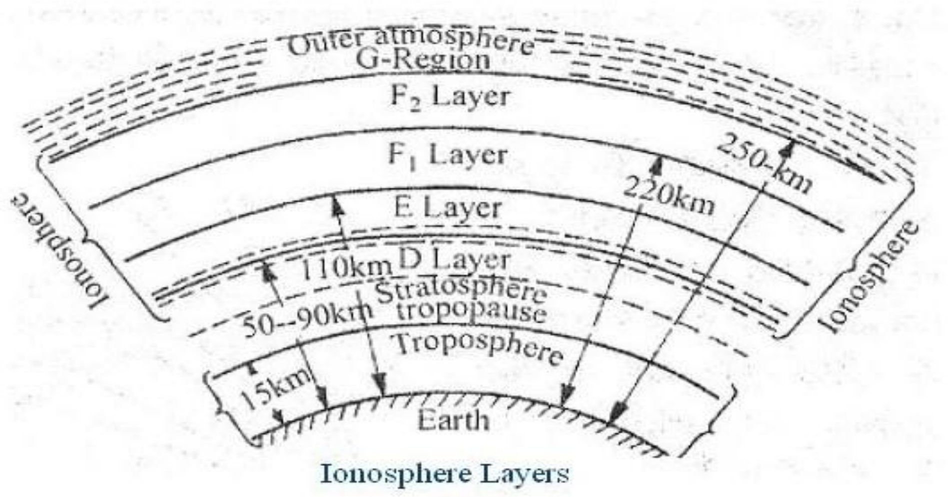


Figure 1: layers of ionosphere

Data and method

For this study the data from the sources like projects like the TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) satellite. This gives the useful deta about the ion density of ionosphere . The major of the data was from https://irimodel.org/. the model that provides data on the ionospheric ion concentration at various altitudes. Some of the cruicial input like Electron density: daytime: 65 - 30,000 km, nighttime: 80 - 30,000 km Electron and ion temperature: 60 - 2,000 km (IRI-95 option: 60 - 3,000 km) Ion composition: 75-2,000 km (DS95/DY85 option: 80-2,000 km) were from from the above web address.

The real time data about the ionosphere was also obtained from the ground based stations like *SuperDARN*, *DIGIT* arrays, Ionogram stations.

About the coronal mass ejections the NASA and NOAA provided the useful information The major source of our data were obtained from the from the ui.adsabs.hatvard.edu which is the database provided by the astrophysics data system (ADS) by NASA. The ESU European space agency also provided the useful data about the geomagnetic storms the impact of coronal mass ejections on the space weather and earths magnetic field and hence on the geomagnetic effects. A major chunk of data was obtained the NOAA using http://www.swpc.noaa.gov and https://soho.nascom.nasa.gov/. they have also provided the extensive images and the data related to those images. The kinetic energy and mass of the mjor ejections is summed in the table 3 below.

Date	Mass (KG)	Kinetic energy (JOULE)	DATE	MASS(kg)	Kinetic Energy (Joule)
1/14/2022	2.60E+28	9.40E+13	24/08/2022	5.50E+15	6.20E+30
2/21/2022	2.40E+28	2.50E+14	12/09/2022	3.50E+15	1.20E+30
23/02/2022	2.40E+28	8.10E+13	15/09/2022	4.3e+15[*2]	6.1e+30[*2]
24/02/2022	3.40E+28	1.60E+14	21/10/2022	6.80E+14	8.20E+29
14/03/2022	1.6e+31[*2]	5.8e+15[*2]	22/10/2022	1.20E+15	3.90E+29

23/03/2022	2.40E+28	8.10E+13	03/11/2022	3.20E+15	1.90E+30
14/04/2022	8.20E+29	2.20E+15	1/14/2022	1.9e+15^{*2}	5.0e+29^{*2}
14/04/2022	1.70E+30	1.70E+15	2/21/2022	8.60E+14	2.70E+29
24/04/2022	2.00E+30	1.40E+15	23/02/2022	7.30E+14	2.40E+30
05/05/2022	2.50E+29	5.10E+14	12/08/2022	3.10E+15	1.60E+30
05/12/2022	3.70E+30	1.50E+15	24/08/2022	5.1e+15^{*2}	1.2e+31^{*2}
15/05/2022	1.2e+30^{*2}	2.9e+15^{*2}	20/11/2022	5.50E+15	6.20E+30
26/06/2022	1.3e+31^{*2}	6.1e+15^{*2}	22/11/2022	3.50E+15	1.20E+30
07/07/2022	5.70E+29	3.60E+14	01/12/2022	4.3e+15^{*2}	6.1e+30^{*2}
04/08/2022	2.2e+30^{*2}	1.8e+15^{*2}	17/12/2022	6.80E+14	8.20E+29
12/08/2022	1.30E+30	1.50E+15			

Table 3 kinetic energy and mass of coronal mass ejections in 2022

Effects of Solar Activity on the Ionosphere

There has been a considerable increase in the number of Sunspots in solar cycle 25. This is evident from the sharp rise in the no of solar activities like solar flares and coronal mass ejections: The level of ionization in the ionosphere is strongly influenced by solar activity, particularly sunspots. Sunspot activity leads to an increase in solar radiation, which ionizes the atmosphere more, especially in the F-layer. This improves radio wave reflection and long-range communication. we have related at least 50 coronal mass ejections in the first phase of of this solar cycle 25: Solar flares and Coronal Mass Ejections (CMEs) can cause rapid and intense changes in the ionization levels of the ionosphere. This can lead to radio blackouts or signal degradation at certain frequencies, especially in the HF bands (3–30 MHz). this was evident from the number of radiation black out being observed in the first phase of solar cycle 25. The coronal mass ejections was mostly full halo which can seen from the data of central width and angular width as tabulated in table 2.

First C2 Appearance	**Central PA**	**Angular**
DATE	**(deg)**	**Width [deg]**
1/14/2022	122	32
3/13/2022	99	71
3/14/2022	242	38
4/14/2022	229	42
7/7/2022	207	225
10/22/2022	242	38
2/27/2023	317	92
2/28/2023	243	103
3/23/2023	211	81
3/24/2023	266	62
4/23/2023	67	91
4/24/2023	257	159
8/5/2023	208	129
9/12/2023	276	65
9/19/2023	114	152
10/21/2023	193	120
4/19/2024	264	97
5/2/2024	80	102
5/10/2024	254	125
5/11/2024	282	77
5/12/2024	160	107

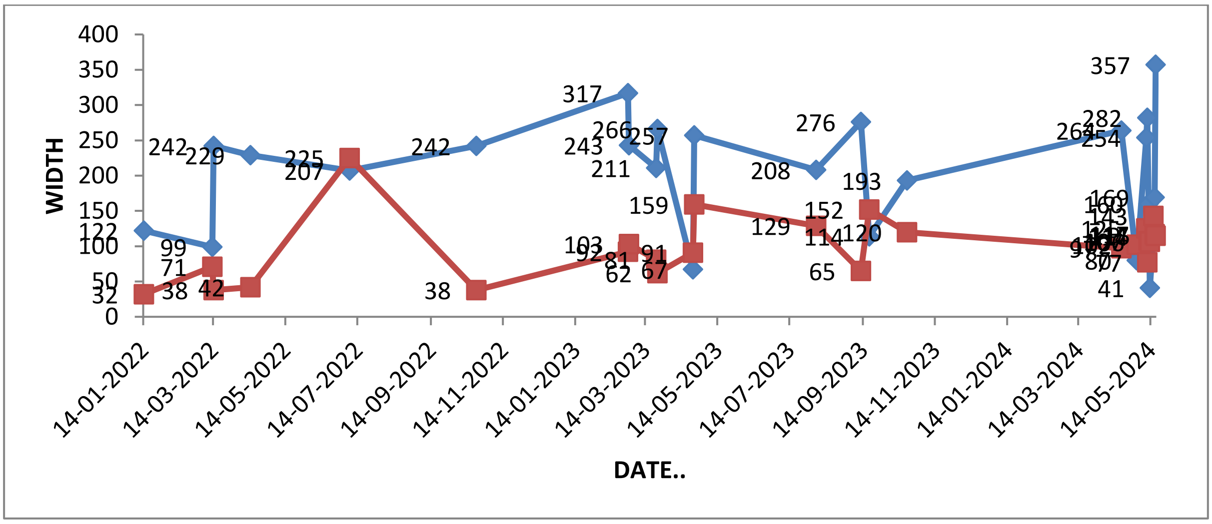
5/13/2024	41	106
5/16/2024	114	143
5/17/2024	169	117
5/18/2024	357	115

Table 2 central width and angular width for most intense CMEs from 2022 to 2024

Coronal Mass Ejections (CME), are emitted from the Sun, and may reach Earth, causing disturbances in the geomagnetic field and in the ionosphere. Coronal holes, regions of the solar corona with diminished X-ray emissions, also emit streams of charged particles that can result in disturbances of the ionosphere. Ionosphere disturbances are especially significant at auroras latitudes, such as over much of Canada, and during magnetic storms and sub storms at these latitudes. Here we have listed some of the storms that have led to the radiation blackout in the regions mentioned.

July 8,1941 - Shortwave channels to Europe are affected [New York Times, p. 1] September 19,1941 - Major baseball game disrupted [New York Times, p. 25]. February 21,1950 - Sun storm disrupts radio cable service [New York Times, p. 5] August 20,1950 - Radio messages about Korean War interrupted. [New York Times, p. 5]April 18,1957 - World radio signals fade [New York Times, p. 25] February 11, 1958 - Radio blackout cuts US off from rest of world. [New York Times, p.62] On August 9,2011 a major solar flare caused fade-outs in the SW broadcasts of Radio Netherlands World, but after an hour, broadcasting had returned to its normal clarity

Coronal Mass Ejections (CMEs) are massive bursts of solar wind and magnetic fields rising from the solar corona and being released into space. These eruptions can have significant effects on Earth, especially on space weather and technology, including high-frequency (HF) radio communications. We have from plotted the central with and angular with width (plot 1) from 2022 to 2024 for major of the coronal mass ejections having high DST. The severe ones were in May 2024 which was indeed where one of the most intense geomagnetic storm was observed of the level of G5. This was evident from the radiation blackout being observed over the low latitudes.



Plot 1 central with and angular width from 2022 to 202

From the above plot the high peaks can be seen densely in May 2024. The D layer was highly concentrated with the charged ions over this period. This lead to the absorption of most of the radiations from the earth's surface. This storm was so intense that on the DST scale the DST index reached below -400nT. The destruptions of this strorm were observed in india also where GPS was affected. In the UT of jammu and Kashmir the communication distruptions was observed for about an hour.

Summery and conclusion

As a result of above study, we arrive at the following conclusion:

A proper understanding of the space environment provides useful information for space weather effects in deep space as well as on the surface of the earth. The specific component of the space weather environment that are known to cause human impact are solar X-ray flares, coronal mass ejections, Geomagnetic storms, galactic cosmic rays, electrostatic discharges and energetic particles in the magnetosphere. Coronal mass ejection emits radiations that ionize the ionosphere causing increased absorption of HF wave. Most coronal mass ejections produces short wave fadeout that affect HF communication. Space surface charging due to sub storm injections of energetic plasma clouds are the most important cause of environmental spacecraft anomalies, but several observations indicate that internal charging by very energetic electrons accelerated in coherence of geomagnetic storms also play a significant role. More careful observation and monitoring the conditions on the sun and to characterize in detail the nature of solar emission could provide timely warnings and forecasts for high frequency communication anomalies.

In this study, the production of coronal mass ejections from the active regions in the beginning of solar cycle lead to radio blackout with R2 value this the ejection with some DST around -437nT.

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