

The Effects of Solar Radiations on Telecommunications

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ABSTRACT

Solar radiations and other solar activities affect the total electron content of the ionosphere and also affect various radio frequencies used in telecommunications. We studied the effects of electron densities of the ionosphere and how they affect telecommunications. A case study of the year 2000, which was a year of solar maximum, was used to show the variations of electron density of the ionosphere. Hours of maximum disturbance due to increased electron density of the ionosphere were obtained and the ways of measuring the electron density of the ionosphere suggested. The result of this study will provide information for weather forecasting and also enable telecommunication industries to make predictions and necessary adjustments to maximize their operational frequencies and thus achieve optimum results.

(Keywords: radio frequencies, ionosphere, solar activity, electron density, communication disturbance)

INTRODUCTION

Telecommunications are based on the studies of James Clerk Maxwell, who developed the mathematical theory of electromagnetic waves, and Heinrich Hertz, who devised an apparatus for generating and detecting them. Guillermo Marconi, recognizing the possibility of using these waves for a wireless communication system, gave a demonstration (1895) of the wireless telegraph using Hertz's spark coil as a transmitter and Eduardo Branly's coherer (a radio detector in which the conductance between two conductors is improved by the passage of a high-frequency current) was the first radio receiver.

The effective operating distance of this system increased as the equipment was improved, and

in 1901, Marconi succeeded in sending the letter S across the Atlantic Ocean using Morse code.

The beginning of radio telephony (the transmission of music and speech) began in 1906 with the work of Reginald Fessenden and Ernst F.W. Alexanderson. However, it was not until Edwin H. Armstrong patented (1913) the circuit for the regenerative receiver that long-range radio reception became practicable. The major developments in telecommunication initially were for ship-to-shore communications. Following the establishment (1920) of station KDKA at Pittsburgh, the first commercial broadcasting station in the United States, technical improvements in the industry increased, as did radio's popularity. Particularly in the United States, the radio receiver became a standard household fixture. Subsequent research gave rise to countless technical improvements and to such applications as radio facsimile, radar, and television.

Radios that combine transmitters and receivers are now widely used for communications. Police and military forces and various businesses commonly use such radios to maintain contact with dispersed individuals or groups. Citizens band (CB) radios, two-way radios operating at frequencies near 27 megahertz, most typically used in vehicles for communications while travelling, became popular in the 1970s. Cellular telephones, despite the name, are another popular form of radio used for communication.

Long distance propagation of radio waves depends on an invisible layer of charged particles, which envelops the Earth. The layer of charged particles known as the ionosphere has been in existence for millions of years.

The atmosphere of the Earth may be divided into several distinct layers, as the following figure indicates.

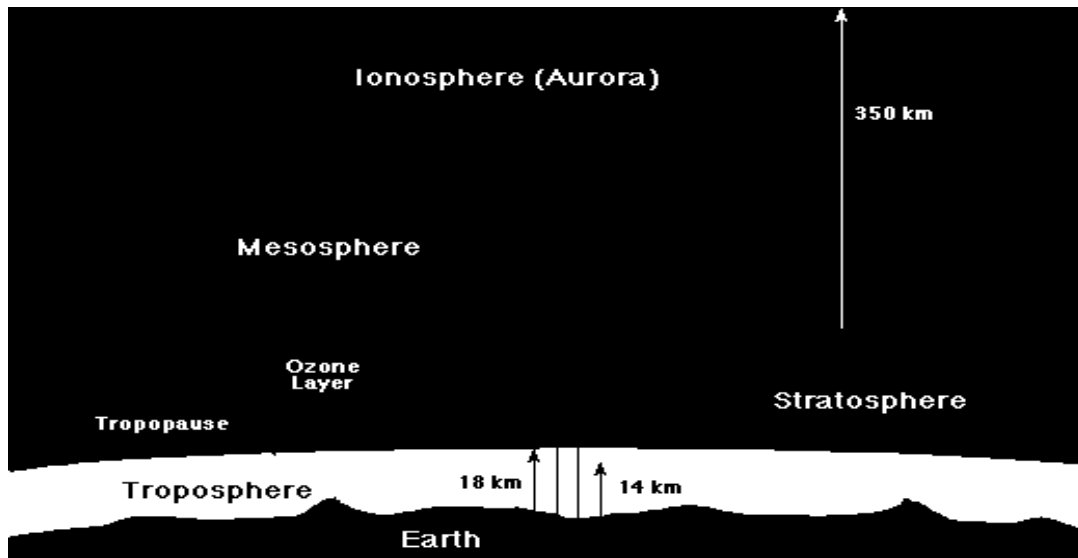


Figure 1: Layers of the Earth's Atmosphere [1,2].

RADIO WAVES

Radio waves (or radio frequency waves) are electromagnetic waves having frequency range from a few Hertz up to 10^8 Hz. These waves, which are used in telecommunications such as television, radio broadcasting, telephone, aeronautic and maritime, etc., are generated by electronics devices, mainly oscillating circuits.

They are also used for wireless transmission of sound, messages or information, for communication, as well as maritime and air craft navigation. The information is imposed on the electromagnetic carrier wave as amplitude modulation (AM), frequency modulation (FM), or in digital form as pulse code modulation (PCM).

Transmission therefore involves not a single frequency electromagnetic wave but rather a frequency band whose width is proportional to the information density. Examples include:

- Telephone bandwidth - 10KHZ
- High fidelity sound bandwidth - 20KHZ
- High definition sound bandwidth - 5MHZ

As radio waves travel away from their point of origin, they become attenuated as a result of spreading out and because of energy lost by absorption during travel. The amount of this

attenuation depends on the frequency of the wave, the time of the day, and the season of the year, and the character of the earth's surface.

Also the reflection of radio waves back to earth a distance from the transmitting antenna by the ionosphere facilities reception of information from radio waves despite the curvature of the earth. Long distance propagation of radio waves depends on an invisible layer of charged particles, which envelops the Earth known as the ionosphere.

There are many ranges of frequency of Radio waves with different means of propagation and usage as shown in Table 1.

Despite the fact that the introduction of artificial communication satellites for long distance radio communication made communication more reliable and there is very little role to be played by the ionosphere in the professional telecommunication networks, it still draws the attention of communication enthusiasts, armed forces, spies, and ham radio operators.

The ionosphere is a gift of nature. Unlike costly artificial satellites, there is no need for a subscription for anybody to get access to a facility, which can transfer our radio message to distant parts of the world. It is worthwhile for radio user to learn more about the ionosphere to further their understanding about radio systems.

Table1: Radio Frequencies Together with their Primary Propagation Characteristics and their Uses [3, 6].

S/N	Name	Frequency Range	Primary Mode of Propagation	Primary Uses
1.	Extremely Low Frequency (ELF)	3 KHz	Earth and the ionosphere. Wave guide penetrates sea water.	Land to sub-marine communications.
2.	Very Low Frequency (VLF)	3 – 30 KHz	Between ground and lower ionosphere. It is a ground wave and uses wave guide also.	Navigation, communication, standard frequency, and time
3.	Low Frequency (LF)	30 – 300 KHz	Wave guide, ground wave.	Maritime and broadcasting.
4.	Medium Frequency	300 – 3000KHz	E region of the ionosphere reflection (might). Ground wave.	Maritime, aeronautical, international distress, and maritime/land mobile.
5.	High Frequency (HF)	3 – 30 MHz	Reflection from E and F region of the ionosphere.	Maritime and aeronautical fixed services and broadcasting.
6.	Very High Frequency (VHF)	30 – 300 MHz	Line of sight, scatter from ionosphere. Reflection by active satellites.	Television, frequency modulated broadcasting , public safety, and aeronautical
7.	Ultra High Frequency (UHF)	300 – 3000 MHz	Line of sight (affected by ionosphere irregularities). Active satellites.	Space communications, TV, radar, broadcasting, and navigation (fixed mobile)
8.	Super High Frequency (SHF)	300 – 3000 MHz	Line of sight (troposphere affected by ionosphere irregularities)	Space communication, TV, radar, broadcasting, and navigation (fixed mobile)

PROPAGATION OF RADIO WAVES (MECHANISM)

A variety of mechanism exists through which radio waves travel from a transmitter to the receiver. Amongst the most important modes include:

(i) Ground/surface wave: These are waves that are able to travel along the ground following the curvature of the earth's surface due to its diffraction ability. As the ground wave travels it is attenuated for two reasons;

1. The wave front diverges as it travels so that the field strength is inversely proportional to the distance.
2. Energy is being absorbed from the wave by the earth.

Since the range of the waves is limited by the degree to which the energy is absorbed from it by the ground and the higher the frequency of the wave, the greater the absorption by the ground, radio waves of all the lower frequencies

tend to travel along the surface of the earth without attenuation. Very low frequency (VLF) and low frequency (LF) radio waves are transmitted mainly as ground waves.

(ii) Sky waves: The sky wave is that component of the wave from the transmitter radiated at an angle to the earth's surface. The sky wave reaches the receiving antenna after bending of its wave path due to reflection (precisely, continuous refraction) in the ionosphere back to earth. It thus returns to the earth at very great distances from the transmitter and thus is the means of long-distance radio communication. The medium frequency (MF) and especially the high frequency (HF) radio waves are propagated as sky waves. One major defect of the sky wave is that the arrival of radio waves at a distant location after travelling different paths will lead to fading of the radio waves signal.

(iii) Space waves: This wave is capable of passing through the ionosphere. At frequencies in the very high frequency (VHF), ultrahigh frequency (UHF) and super high frequency

(SHF) bands, the range of the surface wave is severely limited and the atmosphere is unable to refract radio waves. Such waves pass into outer space. Only straight line-of-sight propagation is possible for such waves; thus the transmitting and receiving aerials have to be high enough from the ground to avoid obstacles.

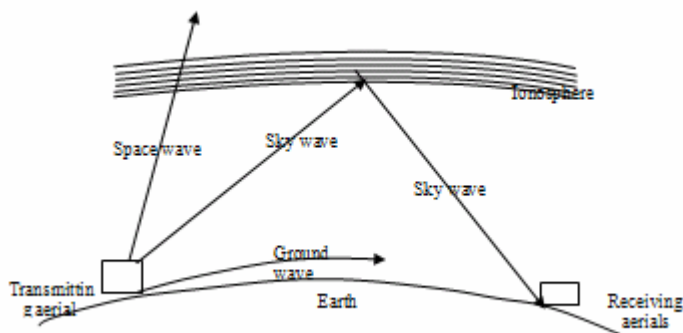


Figure 2: The Ionosphere and T Radio Wave Propagation.

Other means of propagation include:

- (i) Propagation via a communication satellite in which a communication satellite is launched into atmosphere (above the ionosphere) to reflect incident radio waves back to earth. The ionosphere has negligible effect on the path of the radio waves. This method of propagation is used especially for waves in the SHF band to provide multi-channel telephony links and sometimes TV signals.
- (ii) Troposphere scatters communication in which a large amount of high-power radio wave is transmitted upwards from the earth by a highly directive antenna. A very small fraction of the transmitted energy is forward scattered by the atmosphere and directed downwards the receiving aerial on earth. However, since the troposphere scatter system involves the use of high-power radio receivers with a high-gain, low noise factor, and high sensitivity, it is only provided when no other alternative is available. It also provides multi-channel telephony links.

MEASUREMENT OF ELECTRON DENSITY OF THE IONOSPHERE

The ionosphere introduces frequency-dependant delays for radio signals that transit the ionosphere. For these frequencies, an additional delay that is a function of an inverse fourth power of frequency can be observed. This additional delay is a function of the peak electron density. Therefore, by measuring the delay as a function of frequency over a large range of frequencies above the plasma frequency, it is possible to estimate the slant total electron content (TEC), gyro-frequency (ω), and peak electron density (N_e) of the ionosphere.

The ability to measure dynamic ionosphere structure and variability over a wide range of scale sizes would greatly improve operational models of navigation and communication and improve interdependent models of atmosphere, ionosphere, and space weather physics and prediction.

METHODS OF MEASURING ELECTRON DENSITY

(a) Ionosonde

The advent of digital ionosondes has brought two new major developments to ionospheric sounding. The first is automatic scaling of edoc traces to derive ionospheric parameters and true height profiles of electron density. The second is the combination of angle-arrival and Doppler shift measurement to routinely determine ionospheric motions.

(b) International Reference Ionosphere (IRI) Model

The IRI model is a mathematical model using monthly means calculated from an international network of ionosondes and some space-borne sensors. In general, IRI measured electron density corresponds relatively well with ionosonde-derived electron density over mid-latitudes.

(c) Signal from dual Frequency GPS

For more than a decade, the Global Positioning System (GPS) has been used for the accurate determination of position on the earth's surface

as well as navigation. The system consists of approximately thirty satellites, managed by the US Department of Defense, orbiting at an altitude of 20200 kilometers, as well as thousands of stationary ground-based and mobile receivers. It has become apparent, and has been shown in numerous studies, that GPS can also be used to study the atmosphere, particularly to determine the precipitable water vapor content of the troposphere and the total electron content as well as electron density of the ionosphere.

ANALYSIS OF DIURNAL VARIATION

In measuring electron density of the ionosphere, we usually refer to Total Electron Content (TEC) in which a trans-ionospheric ray path vertically above the location of the receiver (i.e. at an deviation of 90°) is used. Using the pseudo-vertical TEC and assuming that ionosphere is horizontal and stratified at a given height typically 350km - 400km, which corresponds approximately with the average daytime height of the peak electron density. The slant TEC is calculate from the difference between the L₁ and L₂ GPS signals. Mathematically:

$$\Delta f = f_1 - f_2 = \frac{40.3}{f_1^2} Ne$$

where Δf is Doppler shift f_1 is frequency of incident radio wave and f_2 is frequency of the received wave [4].

A case study of the year 2000, which is year of solar maximum, using the data from IRI was used to explain the effect of solar radiation on telecommunication as a function of electron density of the ionosphere. The plot of electron density (N/m³) versus time in hours is shown below.

Figure 3 shows typical variations of the electron density with the time of the day. There is general trend characterized by a maximum appearing around noon and minimum at night. From 5.00 hours local time (LT), the electron density increased sharply to maximum at around 12.00 hours and drops to zero at around 18.00 hours.

The result is consistent with the studies of Adeniyi (2001) et al and Tereshchenko (2002) [10, 11]. The sudden drop in the electron density is explained to be as a result of sudden faster drift of electrons away from the equator. It also attributed to the spread in of electron over a higher height range during this period. The electron density in year 2000 at 12.00hours is 16000 N/m³.

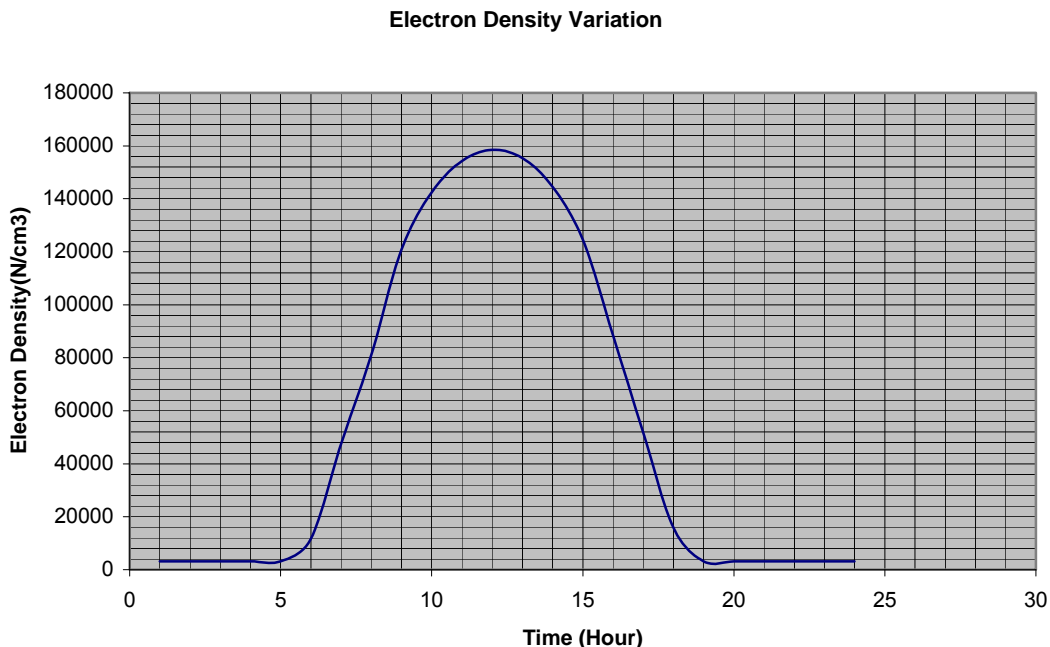


Figure 3: Electron Density (N/m³) of the Ionosphere versus Time (Hr).

IONOSPHERIC DISTURBANCES AND TELECOMMUNICATIONS

Effects of Ionospheric Disturbances on Radio Waves

Radio waves which is the ultimate wave used in telecommunication suffer lots of disturbances as a result of the irregular behavior of ionosphere which is caused by erratic solar radiation from the sun. During solar quiescent periods, ionospheric conditions can be assumed to be nearly constant with respect to time. However, ionospheric conditions changes rather rapidly during and following solar disturbances.

The frequency of these disturbances varies throughout the 11 (eleven) year solar sunspot cycle, becoming more frequent as sunspot numbers increase. The sun undergoes an approximately 11 years cycle of changing radiation known as solar (sunspot) cycle. During periods of solar maximum (most sunspots) the ionosphere has a higher electron density than other periods. The primary sources of this disturbing phenomena have not been satisfactorily described in detail.

Many ionospheric perturbations can be attributed to solar disturbances called flares. Flares have been shown to be impulsive sources of both electromagnetic and corpuscular radiation. Solar flares and coronal mass ejections (CMEs) impact the ionosphere and high frequency radio transmissions. The effects can be subdivided into three categories as summarized by Table 2.

Sudden Ionospheric Disturbances (SIDs)

SIDs are caused by a huge increase in ultraviolet and x-ray photons coming from a solar flare. This radiation travel down to the D layer where it causes an immediate increase in electron density, resulting in greatly increased HF absorption. The absorption can be so great that the lowest usable frequency (LUF) becomes higher than the maximum usable frequency (MUF), therefore completely cutting off the HF window and preventing HF transmission at any frequency. SIDs travel at the speed of light and are therefore the first sign that a solar flare is affecting the Ionosphere.

Their onset is very rapid, giving the radio user no warning. They affect the entire daylight portion of the earth. Specific events affecting particular aspects of radio propagation in SIDs are as shown.

(i) Short Wave Fadeout (SWF): This is most pronounced at frequencies around one megahertz. Short wave radio waves are absorbed by the increase particles in the low altitude ionosphere. Large flares can cause complete "blackout" of large distance short wave radio communications. Short wave fadeout last for a few minutes to a few hours and are the most severe in the equatorial regions where the sun is most directly over head.

(ii) Sudden Enhancement of Atmospherics (SEA): This is a low frequency (10-500KHZ) phenomenon. Atmospherics refer to electrical impulses of natural origin, mainly originating in lightning discharges, which cause crashing or grinding noise in a wireless receiver.

(iii) Sudden Cosmic Noise Absorption (SCNA): High frequency signals of extraterrestrial origin (cosmic noise) are attenuated by flare induced effects (principally by absorption in the D layer). Studying characteristics of SCNA's is useful in deducing ionospheric processes.

(iv) Sudden Phase Anomaly (SPA): In addition to changes in the amplitude, changes in phase of low frequency radio wave are also observed. The cause is similar to that responsible for SEA, (i.e. a lowering of the reflection level for low frequency signals by the enhancement of the electron concentration in the D layer). A lowering of the reflection height will change the phase of the received signal.

(v) Sudden Frequency Deviation (SFD): This effect is observed on high frequency (~ 20 MHz) radio signals. As the refractive index in the E and F layer change due to increased ionization in these layers, the phase path also changes, and this result in a change of frequency proportional to the rate of change of the Ionization. Hence the more impulsive the event, the more pronounced the SFD.

Table 2: Effects of Solar Flares and CMEs to HF Radio Transmissions [3,6].

Event	Arrival Time on Earth after Solar Flare	Typical Duration Time	Types of Radiation Released	Effects
Sudden Ionospheric Disturbances (SIDs)	8.3 minutes	10-60 minutes	Ultraviolet and X-Ray Photons	Increase in D-layer absorption in all daytime regions.
Polar Cap Absorption (PCA)	15 minutes to several hours	1 to 2 days (sometimes several years)	High Energy Protons and Alpha Particles	Increase in D-layer absorption especially in polar regions.
Ionospheric Storms	20-40 hours	2-5 days	Low Energy Protons and Electrons	Increase in D-layer absorption, and depression of F2 MUF, auroras, and sporadic E events.

Polar Cap Absorption (PCA)

This event is associated with Coronal Mass Ejections (CMEs), often but not always in conjunction with solar flares. PCA is caused by light energy charged particles that are accelerated during the CME to velocities much greater than the solar wind, a sizable fraction of the speed of light. These particles are trapped by the earth's magnetic field and brought down into the D layer in the polar regions. The disturbances then propagate towards the equator to a latitude of about 65 degrees. They can completely cut-off transmission that cross the polar regions by raising the lowest useable frequency (LUF).

Ionospheric Storms

These are the last major events to occur after a CME. They are caused by subatomic particles (primarily protons and electrons) that are at a lower energy than the PCA particles. The large increase in particles from a CME creates shock waves in the solar wind. The particles are affected by the sun's magnetic field and follow a spiral course away from the sun, on entering the earth's magnetic field, the particles can cause Auroras and a host of problems for HF communications and other systems. One effect is to decrease the F layer MUF and increase the LUF due to D layer effects. The result is a narrowed and sometimes nonexistent of HF transmission windows.

Transient Phenomena

As the name implies, these phenomena occur for short periods of time, typical not more than an hour. They are associated with "clouds" of free electrons that move horizontally in the ionosphere.

Traveling Ionospheric Disturbances (TIDs)

These wave phenomena (sometimes called "acoustic-gravity waves") travel horizontally through the F region. They are seen as large fronts having a sideways scale of several hundred kilometers. They cause oscillations in the electron density that can last few minutes to several hours. This causes the height of refraction and MUF to undergo rapid variations. TID effects on HF communications are usually not too serious. The largest TIDs start in the auroral zones and propagate towards the equator. Thunderstorms can cause smaller TID fronts that travel about 200km before dissipating.

Scintillation

Ionospheric scintillation is a rapid fluctuation in the signal strength of a trans-ionospheric signal (e.g. from satellite to ground station) and vice versa. Fluctuation in signal strength may be increased or decreased. Scintillation is thus an additional low frequency noise component on the signal.

Scintillation, which is similar to the visible twinkling of stars in the night sky, is caused by small-scale irregularities in the ionosphere. That is, instead of a uniform layer of ionization, certain regions of the ionosphere are subject to lower or large density of ionization.

These irregularities preferentially form in two different regions over the Earth; the polar, or more correctly the auroral regions (both north and south), and the equatorial regions. In the polar regions, ionospheric irregularities are caused by particles precipitating down into the ionosphere from the magnetosphere (the same particles that produce the visible aurora). Flows of these particles cause bubbles and troughs which are not stable and at whose edges scintillations are the strongest. Auroral scintillations may occur at any time of day, but tend to be stronger at night, and when geomagnetic activity is high (i.e. during geomagnetic storms). In the equatorial regions, after sunset, bubbles of ionization form at the bottom of the ionosphere and rise upward during the night forming vertical plumes (which can also be moving horizontally).

Signals that propagate near the edges of these plumes are subject to the most intense scintillations. Equatorial scintillations are thus basically a night-time phenomenon, with most of the plumes disappearing by midnight, although some do persist into the early morning hours. Equatorial scintillations increase in strength as the sun's UV and x-ray output increases (this produces a thicker and/or more strongly ionized ionosphere), and their intensity thus follows the approximately 11 year solar cycle. They also display a 27 day periodicity due to the solar rotation (because UV producing plague is distributed unevenly across the solar surface).

Both the phase and intensity of a trans-ionospheric signal are affected by scintillations. Intensity fluctuations, which may occasionally be large enough to cause deep signal fades, are not caused by signal absorption within the ionospheric irregularities, but rather by a phase change of various parts of the signal wave front. Constructive and destructive interference of various signal paths as observed on the ground, producing the observed changes in signal strength.

Ionospheric scintillations are worse at lower frequencies than high. VHF frequencies (such

the 240 MHz frequencies used in military communications) suffer the most, L-band is moderately affected, and only the strongest scintillations affect C-band and above.

CONCLUSIONS

The improved technologies being enjoyed today are adversely affected by solar activities. There are many warnings from concerned scientists saying that electromagnetic space storms from the sun may wipe out telephone lines and television signals, cripple aircraft navigation systems, and leave cities without power supplies. The effects may be particularly strong in high latitude, and trigger powerful currents in telephone and electrical equipments.

The lack of *in situ* observations make specifying the currents state of the weather difficult and forecasting its future state out to a few days nearly impossible. The ability to carefully observe and monitor conditions on the sun and characterize in detail the nature of solar emission would allow forecasters to broaden the range of events for which they could provide timely warnings and forecasts and a welcoming development will be achieved.

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