Impact of Solar Activity on Ionosphere: A Review Article

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ABSTRACT: The paper describes results of the studies referred to the solar activity impact on the low, mid and high latitude ionosphere. The sun activity governs the interaction of magnetosphere with solar wind and Earth's magnetic field, this influence of magnetosphere is called Geomagnetic storm. The main point to study Geomagnetic storm is used to understand the current passing through the ionosphere. We have used ionospheric data at Low, mid and high latitude station. The absorption and ionization of the ionospheric medium depends on solar activity. The value of foF2 increased from their normal value at all the three latitudes. This is due to geomagnetic storms that occurred around the same time. A very interesting feature that can be seen in the figures is that the increase of foF2 at Low latitude is much more intense as compare to high and mid latitude. Comparison among all the latitudes shows that the values of foF2 at high latitude are quite less as compared to low and mid latitude. We have found that the effect of solar and geomagnetic storm disturbances is strongest at the low latitude and weakest at the high latitude during the geomagnetic storm time.

Keywords: Geomagnetic Storm, Solar activity, frequency, Ionosphere, Ionization.

1. Introduction

There are many studies which have been done regarding the solar activity impact on the lower, mid and high latitude Ionosphere. The response of the ionosphere to magnetic storms is important for understanding the energy coupling process between the Sun and the Earth, and for forecasting space weather changes. Intensive magnetospheric and ionospheric currents during geomag-netic storms disturb the quiet ionosphere and cause the observed shortterm variations of the ionospheric characteristics.
Geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and cloud of magnetic field that interacts with the Earth'smagnetic field. The increase in the solar wind pressure initially compresses the mag-netosphere. But when the solar wind's magnetic field interacts with the Earth's magnetic field, transfers an increased energy in to magnetosphere.

1.1 IMPACT ON HIGH FREQUENCY RADIO COMMUNICATIONS:

The Space weather impacts radio communication through various ways. The frequencies in the range of 1 to 30 mega Hertz (known as "High Frequency" or HF radio), the changes in ionospheric density and structure alter the transmission path and even stop transmission of HF radio signals completely. These frequencies are used by amateur (ham) radio operators and many industries like commercial airlines. The Federal Emergency Management Agency and the Department of Defense etc also make use of these signals.

There are several types of space weather that can impact HF radio communication. In a typical sequence of space weather storms, the first impacts are felt during the solar flare itself. The solar x-rays from the sun penetrate to the bottom of the ionosphere (to around 80 km). There the x-ray photons ionize the atmosphere and create an enhancement of the D layer of the ionosphere. This enhanced D-layer acts both as a reflector of radio waves at some frequencies and an absorber of waves at other frequencies. The Radio Blackout associated with solar flares occurs on the dayside region of Earth and is most intense when the sun is directly overhead.

The Radiation Storm caused by energetic solar protons, can also disrupt HF radio communication which is also a type of Space weather. The protons are guided by Earth's magnetic field such that they collide with the upper atmosphere near the north and south poles. The fast-moving protons have an affect similar to the x-ray photons and create an enhanced D-Layer thus blocking HF radio communication at high latitudes. During auroral displays, the precipitating electrons can enhance other layers of the ionosphere and have similar disrupting and blocking effects on radio communication. This occurs mostly on the night side of the polar regions of Earth where the aurora is most intense and most frequent.

Communication, many communication systems use the ionosphere to reject radio signals over long distance. Ionospheric storms can affect radio communication at all latitudes. Some frequencies are absorbed and others are rejected, leading to rapidly fluctuating signals and unexpected propagation paths. TV and commercial radio stations are little affected by solar activity, but ground to air, ship to shore, short wave broadcast and amateur radio (mostly the bands below 30 MHz) are frequently disrupted. Radio operators using HF bands rely upon solar and geomagnetic alerts to keep their communication circuits up and running. Some military detection or early warning systems are affected by solar activity. The over horizon radar bounces signals of the ionosphere to monitor the launch of air craft and missiles from long distances. During geomagnetic storm, this system can be severally hammered by radio clutter. Some submarine detection systems use the magnetic signatures of submarines as one input to their locating schemes. Geomagnetic storms can mask and distort these signals and also telegraph lines. Geomag-netic storms also affect long-haul telephone lines, including undersea cables unless they are fiber optic. Damage to communications satellite can disrupt non-terrestrial telephone, television, radio and internet links. The national academy of sciences re-ported in 2008 on possible scenarios of wide spread disruption in the 2012-2013 solar peak. Navigation, Systems such as GPS (global postioning systems), LoRAN (long range navigation) and the new defunct OMEGA are adversely affected when solar activity disrupts their signal propagation. The OMEGA system consists of eight transmitters located throughout the world. Airplanes and ships used the very low frequency signals from these transmitters to determine their positions. During solar events and geomagnetic storms, the system gave navigators information that was in accurate as much as several miles. If navigators had been alerted that a proton event or geomagnetic storm was in progress, they could have switched a backup system. GPS signals are affected when solar activity causes sudden variations in the density of the ionosphere causing the GPS signals scintillate. Another problem for satellite operators is differential charging, during Geomagnetic storms the number and energy of the electron and ions increases. When a satellite travels through this energized environment the charged particles striking the spacecraft differentially charge portions of the spacecraft. Discharges can across space craft components, harming and possibly disabling them. Buck changing also called deep charging occurs when energetic particles, primarily electrons penetrate the outer covering of a satellite and deposit their charge in its internal parts. If sufficient charge accumulates in any one component it may attempt to neutralize by discharging to other component. This discharge is potentially hazardous to the satellite andsatellite's electronic system.

1.2 Medium- and long-term ionospheric changes due to alteration in solar and geomagnetic activity:

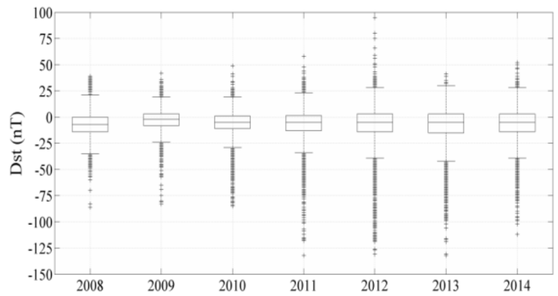
The main factor generating medium-term changes is the repeatable influence of active regions on the Sun's surface that rotate with a period of 27 days. Kutiev et al.(2012) demonstrate that the 27-day oscillations of the TEC at low-latitudes closely correlate with those of F10.7-index, considered as a proxy for the EUV solar irradiance. These authors analyzed the relative deviations of TEC (rTEC) over Japan obtained in the years 2000–2008 and found that the correlation between rTEC and F10.7 is highest during the maximum phase of solar activity, when the 27-day amplitude of rTEC is almost equal to its total deviation. They also show that the 27-day variation of rTEC plays a role of a background variation, which is
disrupted by disturbances produced by geomagnetic storms. Recurrent geomagnetic storms, produced by coronal holes, overcome the effect of solar irradiance on the ionosphere during declining and minimum phases of solar activity. Mukhtarov & Pancheva (2012) reveal the main features of the global ionosphere response to the recurrent geomagnetic activity with period a of 9 days. The latter correlates with recurrent solar wind HSSs which are related to coronal holes distributed roughly 120^{o} apart in solar longitude. The global observations of electron density profiles from the COSMIC satellites are used by the authors, for the time period of 1 October 2007–31 March 2009, when the 9-day oscillations in external forcing (solar wind, Kp-index, and the NOAA Power Index) are strong. Long-term trends in the upper atmosphere-ionosphere

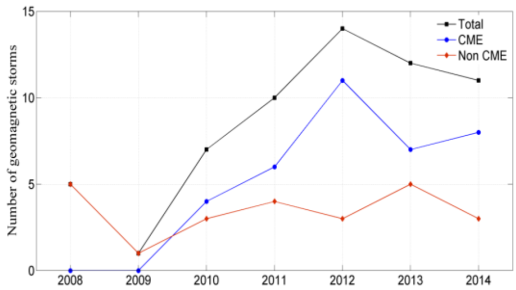
are reviewed by Lastovicka et al. (2012). The trends are due to simultaneous presence of several drivers, which
behave in a different way, with the main driver being the increasing atmospheric concentration of greenhouse gases, mainly CO2 and long-term changes of geomagnetic and solar activity. Authors conclude that the role of space weather/climate in long-term changes and trends in the ionosphere was more important in the past, when it controlled the trends in ionospheric parameters, than it is at present, when the dominant controlling parameter seems to be increasing concentration of CO2. Jakowski et al. (2011) reveal that the coherent variations of TEC with F10.7 at three selected latitudes during the last solar cycle and assess the changes of the large-scale horizontal gradients with solar activity. They found that the sudden increase of EUV during the large CME (as that on 28 October2003) has an immediate effect in TEC, preceding the geomagnetic storm.

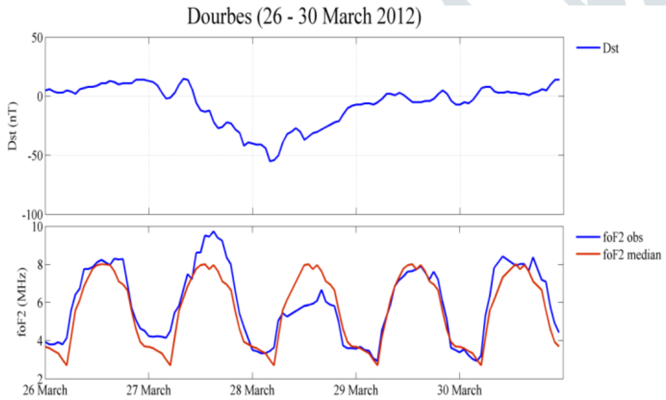
1.3Long term predictions of space weather effects in the ionosphere During solar cycle 24 over Europe *(Tsagouriet al., 2015)*

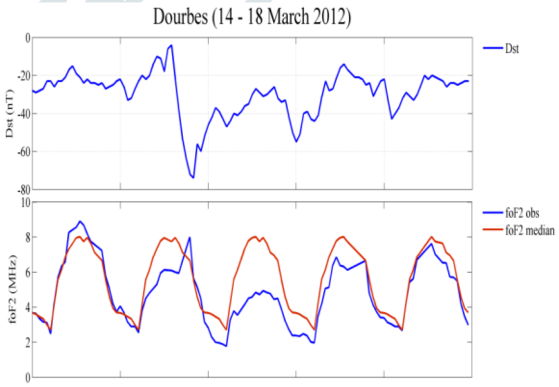
Solar minimum conditions are related to weak-to-moderate geomagnetic activity (-100 nT< minDst), while solar maximum conditions are related to intense geomagnetic disturbances (minDst< -100nT).

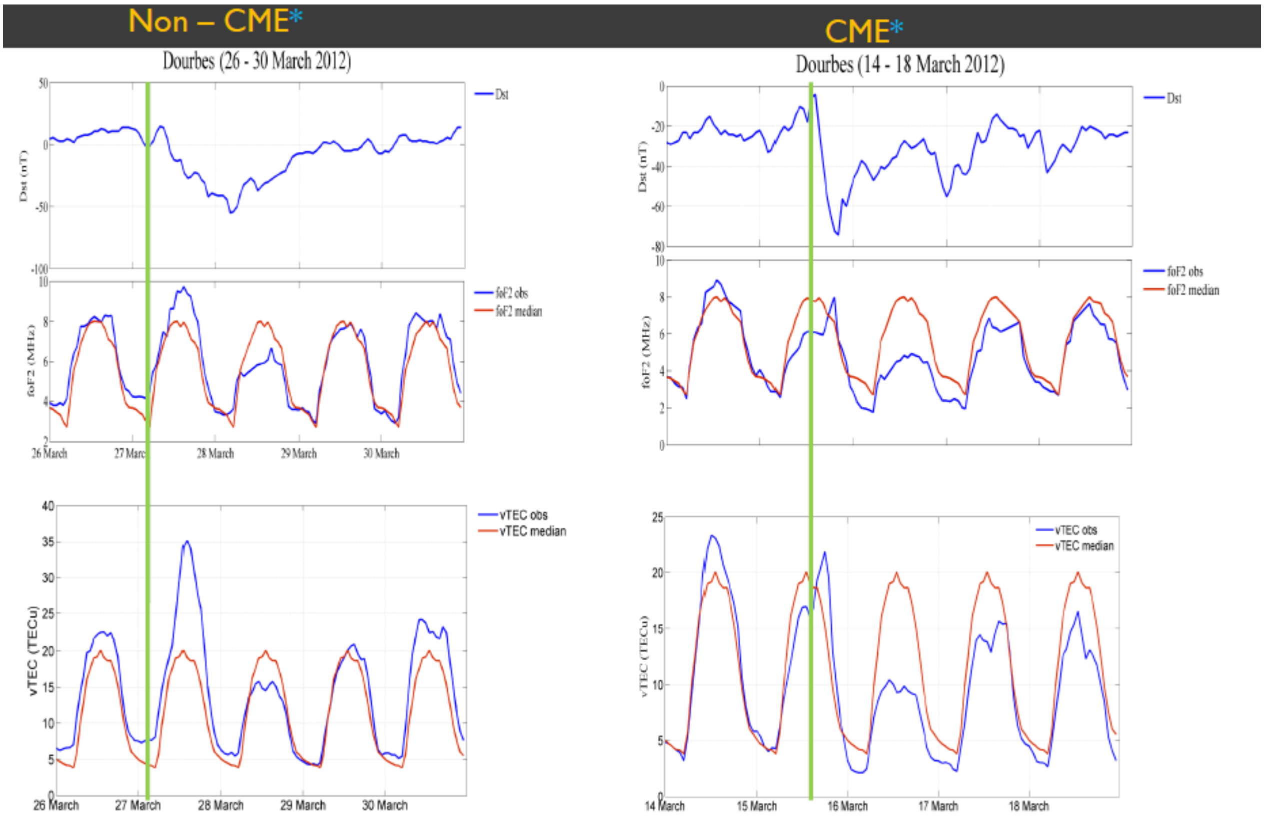
The storm activity during solar minimum (i.e., 2008) is related entirely with non CME events (mainly HSSs), while the storm activity towards the solar maximum is mainly driven by CMEs.











http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.html

2. Discussion:

The most important characteristic of the ionosphere is its ability to reflect radio waves. However, only radio waves within a certain frequency range will be reflected and this range varies with a number of factors. Ionosphere may be described by different parameters. The most widely used description of its state are called critical frequency. Critical frequency is well defined and commonly measured quantity. The CRITICAL FREQUENCY is the maximum frequency that a radio wave can be transmitted vertically and still be refracted back to Earth. Critical frequency of an ionospheric layer is the highest plasma frequency of given layer, for example, critical frequency of E, F1, and F2 layer is foE, foF1 and foF2 respectively when standard daily stratification is present. We used foF2 values for our analysis. Plasma frequency is directly connected to the electron concentration.

The TEC is another useful parameter representing the ionospheric state. The TEC values are mostly derived from GNSS signals and are largely available and easily accessible through the specific web sites. TEC is more robust parameter than

foF2, because it is available even during severe geomagnetic storms, when foF2 is frequently missing. Whereas groundbased TEC measurements provide valuable information on the horizontal structure of the ionospheric ionization, spacebased

GNSS measurements onboard Low Earth Orbiting (LEO) satellites are capable to explore the vertical structure of electron density distribution (Heise et al. 2002; Belehaki et al. 2006). Thus, considering LEO missions such as CHAMP, GRACE, and Formosat3/COSMIC, the radio occultation techniques are already well established to monitor the shape of vertical electron density structure on global scale (Jakowski et al. 2011). The geodetic network is permanently growing. Data gaps over the oceans can be compensated by dual frequency satellite altimetry as demonstrated by TOPEX/Poseidon. Due to the high value of radio occultation measurements for monitoring the current tropospheric weather conditions, a follow on mission of COSMIC/Formosat is planned which will provide a huge database for ionosphere sounding. The long time series of ionospheric data were of crucial

importance for climate change studies. The role of space weather/climate in long-term changes and trends in the upper atmosphere-ionosphere was more important in the past, when it controlled the trends in ionospheric parameters.At present, however, when the dominant controlling parameter seems to be increasing concentration of CO_2, monitoring of tropospheric constituents and especially the trace gases has

become of primary importance (Lastovicka et al. 2012). Concerning space weather, future studies should focus on analysis of the long-lasting and very deep solar cycleminimumand related very low level of geomagnetic activity in order to estimate its influence on long-term trends in the ionosphere, particularly on future trends, as we can expect weak solar cycles in the coming decades.
Earth's magnetic field disturbed due to different events of the Sun. Distribution of ionospheric currents and electric field can be altered by the perturbations of the solar wind magnetosphere and ionospheric wind dynamo. The east-west electric field in conjunction with the earth north-south magnetic field lines produces the ExB force that causes vertical plasma drift. Therefore, higher frequencies are mostly affected by ionospheric storms. The study suggests that wherever possible a lower frequency can be used to minimize the effects of an ionospheric storm on communication.

Conclusion:

In the above study we have found that the variation of foF2 parameter is higher at
low and mid latitude than at high latitude during the geomagnetic storm days. Therefore the ionospheric effects are dependent on the time of storm and intensity as well as the latitude of a station and its location. It is clear from the observations that a variation in F2 layer parameters at the time of the geomagnetic storm strongly depends upon the intensity of storms.
Types of ionospheric disturbances found during geomagnetic storms [from*Prölss*, 1995]. While intended to describe only winter storm effects in*N*maxat subaurorallatitudes, this classification scheme is appropriate for the general characterization of TEC storm patterns in any season:
(1) magnetospheric convection-driven "dusk effect" in the positive phase, (2) wind-driven positive phase, (3) auroralprecipitation-induced enhancement of the trough's polewardwall, (4) negative phase due to postsunriseconvection effects plus longer-lived composition-induced depletions, and (5) termination of the dusk effect in item 1 via the convection-induced appearance of the trough (Mendillo, 2006).

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