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Investigation of TEC Variation at Indian Arctic Station-'Himadri'

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Abstract: In the modern technological world, communication and navigation are very much dependent on the satellites. The satellite signals, before reaching to the earth's surface, pass through the dynamic ionosphere and thereby get altered that could lead to errors in communication and navigation. Signals of the global positioning satellites (GPS) are continuously received by suitable receivers on the ground and the changes in the ionospheric electron concentration could be indirectly inferred. In this report, a statistical study of the variation of Ionospheric Total Electron Content (TEC) at the polar latitude of Indian Arctic station – Himadri has been carried out. Himadri station is located at geographic latitude 78°55'N and longitude 11°56'E at the International Arctic Research base, Ny-Alesund. Over Himadri station, TEC values were calculated from the recordings of a dual frequency GSV4004A (Novatel Make) GPS receiver which was operated during 16 January 2009 to 06 June 2009. We observed that the TEC values at Himadri station clearly vary with season which was attributed to the changing solar zenith angle with Arctic season. Several other processes, for example, solar flares and geomagnetic activity are known to influence the TEC. During the period of interest, solar activity level was quite low. Efforts were extended to delineate the impact of solar and geomagnetic activity on the TEC parameter.

Keywords: Ionosphere, Total Electron Content, Solar Zenith Angle, Solar Activity, Geomagnetic Substorm.

I. INTRODUCTION

A. Atmosphere

Our atmosphere is a mixture of gases mostly consist of nitrogen (78.09%), oxygen (20.95%)[1], argon (0.93%), carbon dioxide(0.04%) and others that surrounds Earth. With height, the atmosphere becomes thinner until it gradually reaches space. The atmosphere blocks dangerous rays coming from Sun from reaching Earth which makes our planet livable. It traps heat, making Earth a comfortable temperature. And the oxygen within our atmosphere is essential for life. It is basically divided into five layers.

Troposphere, starts from the Earth's surface and extends to about 12-15 kilometers high till the region known as tropopause. The troposphere contains roughly 80% of the mass of Earth's atmosphere.[2] As the height of troposphere increases, the heat from the surface of the Earth decreases and hence the atmospheric temperature in the troposphere decreases with average lapse rate of about 6.5°C per kilometer. The air in the troposphere is more unstable and with strong convection. Almost all weather phenomena such as clouds, fog, rain, and snow, occur in this layer. Stratosphere starts just above the troposphere and extends up to 50 kilometres of height. In the stratosphere, the temperature increases with altitude at the average rate of 5 °C per kilometre due to the presence of ozone layer in this layer which absorbs and scatters the solar ultraviolet radiation and warm up the upper stratosphere. Mesosphere is present just above the stratosphere and extends to about 85 kilometres height. The temperature in this layer usually decreases as the height increases up to the top of the mesosphere where the temperature can be as low as - 85 °C[3] or even lower. Mesosphere is known as coldest region of the Earth's atmosphere. Air density of mesosphere is very less as compare to the stratosphere and thermosphere and there are fewer air molecules to absorb incoming electromagnetic radiation from the Sun. Due to presence of thin air and small amounts of ozone prevent the air from warming much. Thermosphere starts just above the mesosphere and extends to about 700 kilometers height. In thermosphere temperature increases with height due to the absorption of solar X-rays by the nitrogen and oxygen molecules in this outer. Exosphere is the upper limit of the Earth's atmosphere. It extends from the top of the thermosphere up to 10,000 km. The exosphere contains gases like hydrogen and helium, but they are very spread out. There is a lot of empty space in between.

B. Ionosphere

A shell of partially ionized atmosphere surrounding the Earth from approximately 60-1000 km is known as ionosphere[4]. It partially overlaps mesosphere and thermosphere. Absorption of short wavelength radiation from the Sun photo ionizes gases in the atmosphere to produce the ionosphere. Gas dynamics and electromagnetic interactions dominate the behaviour of the ionized gases. The gases ionize during daytime and recombine during night. The ionosphere is composed of three main parts: the D, E, and F regions. The electron density is highest in the upper, or F region.(Fig.1)

D Region is the lowest layer of the ionosphere extending from approximately 60-85 km and dominated by NO^+ ions generated by absorption of Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometre. The D Region disappears at night in low latitude. E Region, extending from approximately 85-140 km and dominated by O_2^+ and NO^+ ions generated by the absorption of soft X-rays. F1 Region is extending from approximately 140-200 km and dominated by O_2^+ and NO^+ ions at the lower boundary and transitioning to O^+ at the upper boundary. Absorption by radiation between 200-900 angstroms generate the F1 layer. The F1 layer disappears completely at night. F2 Region, extending from approximately 200-1000 km and dominated by O^+ and some N^+ ions. Ion density peaks between 200-400 km and then slowly tapers off. Unlike the F1 layer, the F2 layer does not disappear at night.

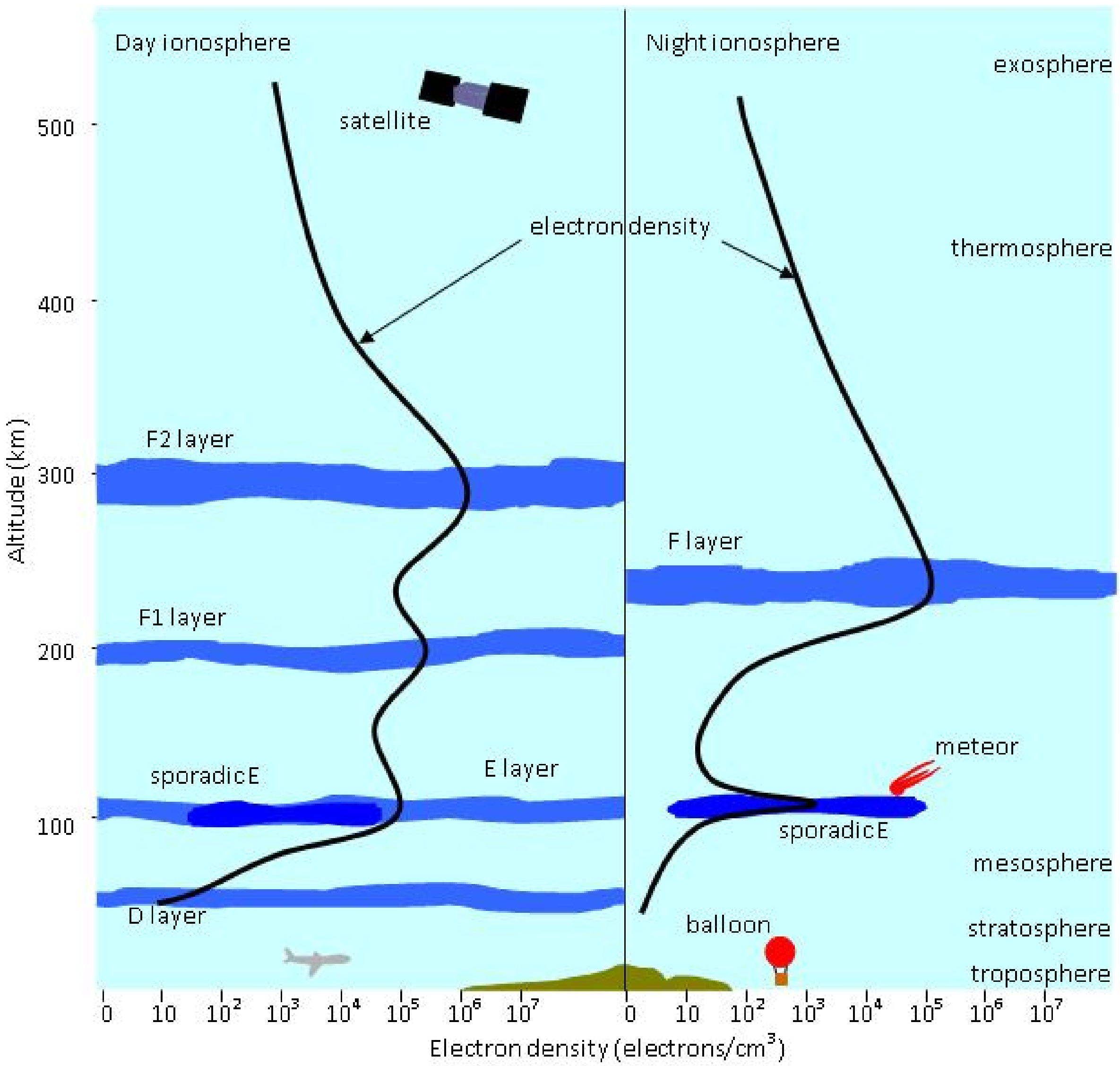

Fig 1: Region of Ionosphere during daytime and night time.

C. Major Geographic Regions of the Ionosphere

There are three major geographic regions of the global ionosphere. These are the high-latitude, mid latitude and equatorial regions. The equatorial region has maximum electron density. The effect of the high radiation level from the sun, and the electric and the magnetic fields of the earth results in the electrons rising and moving along the horizontal lines of the magnetic field. The electrons move as far as the geomagnetic latitudes of 10 to 20 degrees causing the high concentration of electrons there which are often termed equatorial anomalies.

The mid-latitude ionosphere is the least variable and undisturbed among the different ionospheric regions. It is usually free of the effect imposed by the horizontal magnetic field geometry peculiar to the equatorial region.

With photon ionization, collision of ionization plays an important role in ionization in the high-latitude region. The main reason for this is the fact that the geomagnetic field lines are nearly vertical in this region leading to the charged particles descending to E layer altitudes (about 100 km). These particles can collide with the neutral atmospheric gases causing local enhancements in the electron concentration, a phenomenon which is associated with auroral activity. Auroral activity can also be regarded as an interaction between magnetosphere, ionosphere, and atmosphere. The auroral zones are relatively narrow rings situated between the northern and southern geomagnetic latitudes of about 64 and 70 degrees. In general, the intensity and the positions of the auroral ovals arerelated to geomagnetic disturbances. The ovals expend towards the equator with increasing levels of geomagnetic disturbance [5].

D. Total Electron Content

The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. The more electrons in the path of the radio wave, the more the radio signal will be affected. The TEC is affected by the Solar activity such as flares and Coronal Mass Ejections (CMEs) , geomagnetic conditions and sometimes effected by longitude, latitude, season also which produces large variations in the particle and electromagnetic radiation above the earth. The perturbations cause large disturbances in Total Electron Content (TEC) and ionospheric current system. The TEC measurements obtained from dual frequency GPS receivers are one of the most important methods of investigating the earth's ionosphere [6].

TEC is measured in electrons per square meter. Conventionally 1 TEC Unit (TECU) $=10^{16}$ electrons/m^2[7]. Vertical TEC values in Earth's ionosphere can range from a few to several hundred TECU. During quiet solar activity, the daytime maximum TEC occurs around noon and past noon local time while the minimum TEC occurrence is post midnight. The change in the path and velocity of radio waves in the ionosphere has a big impact on the accuracy of satellite navigation systems such as GPS/GNSS. Neglecting changes in the ionosphere TEC can introduce tens of meters of error in the position calculations.

E. Solar Activity

Solar activity directly or indirectly influences the near-earth environment. Solar flare and coronal mass ejection are the most important contributors for the TEC variations. Solar flares are huge outbursts of electromagnetic radiation from the Sun lasting from minutes to hours. They are caused by magnetic reconnection associated with large-scale eruptions of magnetic flux called "coronal mass ejections" (CMEs). It emits huge amount of X-rays and UV radiation which can affect Earth's upper atmosphere and interrupt long-range radio communications[8]. Direct radio emission at decimetric wavelengths may distract the operation of radars and devices that use those frequencies. The first solar flare recorded in astronomical literature was on September 1, 1859 popularly known as Carrington's Event.[9]

Energetic charged particles (known as Solar Wind) continuously escape from the Sun's gravitational attraction and fill the interplanetary medium. In addition, short-lived and distinct impulsive ejections of tremendous amount of plasma particles are occasionally observed from Sun's surface.

A geomagnetic storm is a major disturbance of Earth's magnetosphere that happens when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. These storms result from variation in the solar wind that creates significant changes in the currents, plasmas, and fields in Earth's magnetosphere. The solar wind conditions that are effective for creating geomagnetic storms are sustained periods of high-speed solar wind, and most importantly, a southward directed solar wind magnetic field (opposite the direction of Earth's field) at the dayside of the magnetosphere. This condition is favourable for exchanging energy from the solar wind into Earth's magnetosphere.

The Geomagnetic storms remain localized in the lower latitude regions and typically last for a few days. In polar region, shorter episodes (for a few 10's of minutes) of solar wind energy transfer known as substorms are commonly observed, which become extremely intense during storm times. Spectacular colorful display in polar regions in the form of aurora are observed during substorms. Extremely intense substorms could disrupt navigation systems such as the Global Navigation Satellite System (GNSS) and create harmful geomagnetic induced currents (GICs) in the power grid and pipelines. Disturbance Storm Time(DST) index is used to monitor the storm event and substorm is monitored by Auroral Electrojet (AE) index.

F. Global Positioning System

The Global Positioning System (GPS) which is primarily launched by the U.S. Department of Defense (DoD) [10] is a satellite-based navigation system made up of a network of 24 Medium Earth Orbit satellites that transmit precise microwave signals which enables GPS receivers to determine their current location, time and velocity. It is also known as the NAVSTAR (Navigation System for Timing and Ranging).GPS works all across the world and in all weather conditions, thus helping users track locations, objects, etc.

II. DATASET

Total Electron Content (TEC) data collected during 16 January 2009 to 06 June 2009 by a dual frequency GSV4004A (Novatel Make) GPS receiver installed at Indian Arctic station – HIMADRI. . Himadri is located at geographic latitude 78°55′N, longitude 11°56′E at the International Arctic Research base, Ny-Alesund in Norway.[11]

In order to examine the auroral activity in relation to geomagnetic activity, 1-min resolution AE index has been used for the period when TEC data were available. The AE index data is available from World Data Centre for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/dstae/index.html). Changing solar zenith angle (SZA) is an important factor which contributes to the TEC variations. Solar zenith angle data is accessible from the website of National Oceanic and Atmospheric Administration (NOAA) (https://www.esrl.noaa.gov/gmd/grad/solcalc/NOAA_Solar_Calculations_day.xls). Solar flares, covering the entire spectrum of the electromagnetic radiation intermittently occur on the Sun. Considering the Solar X-Ray Flux monitored by instrument onboard GOES-10 satellite to examine the occurrence of solar flare in the period of interest. Solar X-Ray Flux data can be downloaded from SPIDR (Space Physics Interactive Data Resource)http://spidr.ionosonde.net/spidr

III. METHODOLOGY

The data that we get from GPS receivers are in terms of Slant TEC (STEC) [12]. Later on this STEC is converted into Vertical TEC (VTEC) by taking the Ionospheric pierce point (IPP) at around 250 km above the surface of the earth by using this formula which is given below,

$$VTEC = STEC \times \cos(x) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(i)$$

Where, x = Satellite zenith angle at IPP.

To avoid tropospheric delay a mask at ±30º elevation angle is used because at lower satellite elevation angle, the delay due to troposphere is higher than the ionospheric contribution.

IV. OBSERVATIONS AND RESULTS

A. Seasonal Variation in TEC

In order to study the seasonal variations in the TEC, we binned 1-min resolution data of each day into months and took the average and depict in the left panel of Figure 2. Electron content was minimum for January month (bottom curve) and maximum for June (top curve) at Himadri station. However, we see a persistent cyclic variation in TEC of period around 5-6 hours. For a clear season variation, a quadratic fit was applied to the TEC data of respective months and shown in the right panel.

In a given month electron content exhibits clear diurnal variation, viz., minimum around local midnight and maximum around noon as evident in the right panel of Figure 2. During January, Arctic region remain in complete darkness whereas during June it was polar summer.

In order to establish clear relationship with the polar day-night condition related TEC variation, we next plot the monthly averaged TEC with solar zenith angle in Figure 3. Quadratic fit to the monthly TEC values and zenith angle curves are shown for different months. In January and February month, Sun was below horizon (SZA>90º) and the electron content was lower than those months when Sun was above horizon (SZA < 90º).

It is known that the impinging solar radiation changes even during the day time. Out of phase TEC and zenith angle variations for a given month are suggestive of changes in electron concentration in response to the diurnal changes of the SZA.

B. TEC Variation with Solar Flares

Solar flares are monitored in the X-ray band by instruments onboard geosynchronous satellites. We visually scanned X-ray flux data in 2 different wavelength bands (0.5-3 Aº and 1-8 Aº) for the occurrence of solar flares. As mentioned above, the period of interest was quiet solar period, no prominent solar flares were observed to study the effect of flares on TEC.

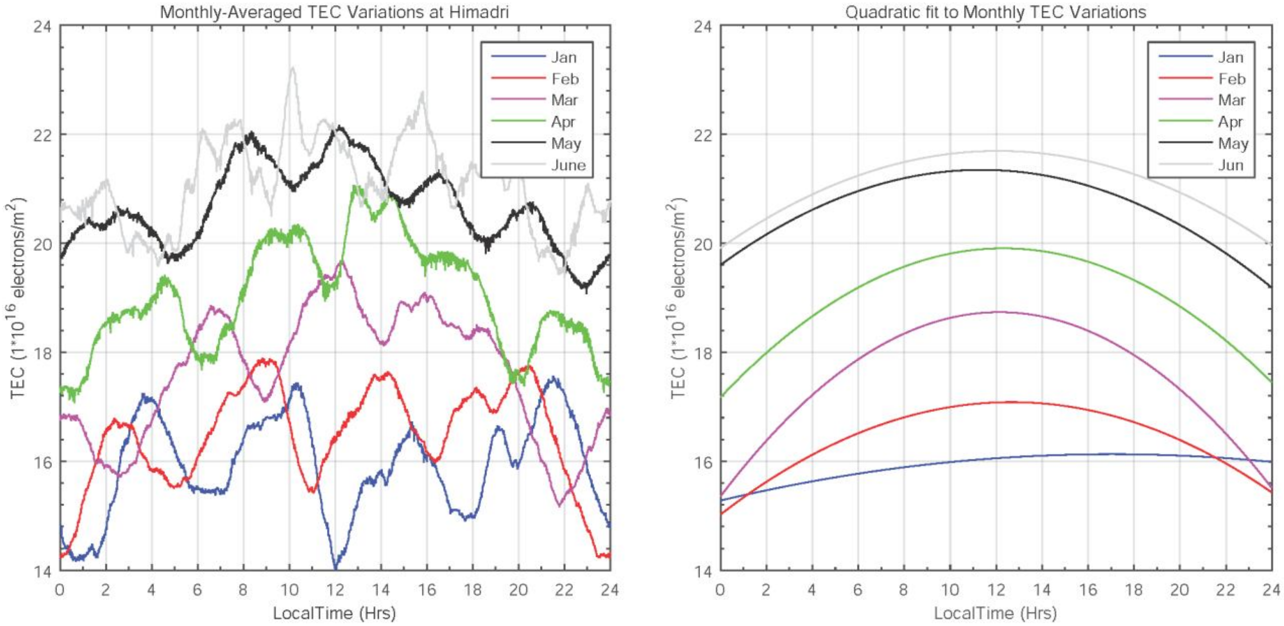

Figure 2: Monthly averaged TEC variation at Himadri in the left panel. Quadratic fit in the right panel.

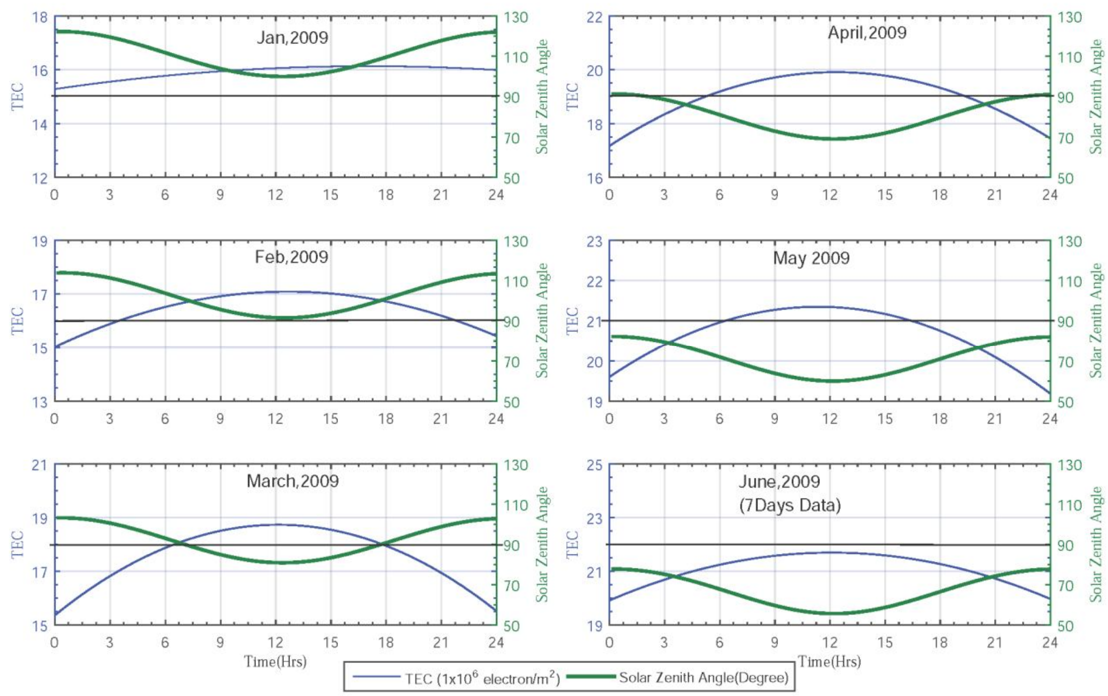

Figure 3: Smoothed TEC variation with solar zenith angle for different months of January – June 2009. Horizontal lines represent horizon.

C. TEC Variation with Substorm

Geomagnetic substorm is a major source of charged particles precipitation into the auroral ionosphere which expectedly change the TEC. However, period of interest (January – June 2009) was a solar quite period. We first scanned for intense substorm events (AE > 500 nT) and identified 3 such events occurring on 4 and 14 February and 8 March 2009.

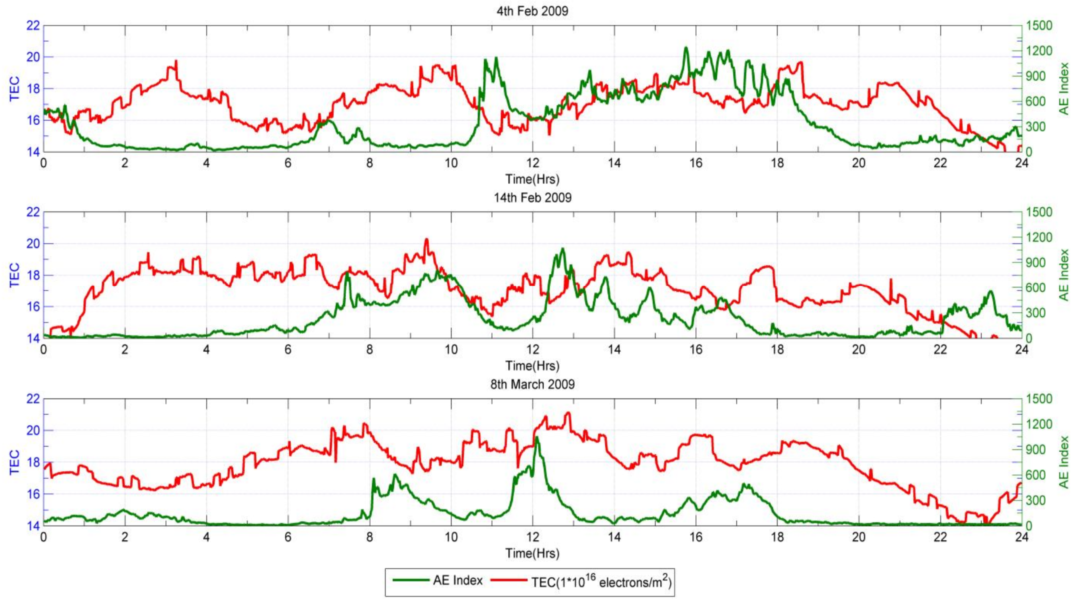

Fig 4: TEC and AE Index Varitions on 4 & 14 February and 8 March 2009. No clear signature of substorm is evident in the TEC for the events under consideration.

TEC and AE index data are plotted in Figure 4. It is noted that the TEC variability is quite large on any given day. As such, we did not find close correspondence between the substorm activity for the events considered probably due to the fact that daily TEC variability at Himadri was much larger than that of produced by the substorms.

V. CONCLUSION

Total electron content data from Indian Arctic station – Himadri were analyzed in conjunction with solar zenith angle, X-ray flux for solar flares and auroral electrojet index to address the long and short-term TEC variations specific to the location of Himadri. We observed the following:

A. TEC varies during the course of a day as well as with changing seasons. Around the local noon electron concentration maximizes whereas minimum was observed during the mid-night.

B. Polar winter and summer difference in the electron content was about 1.5 times. It was clearly related to the solar illumination of the ionosphere over Himadri.

C. Diurnal TEC variations were quite large as a result of which effect of transient events like substorm was masked in the TEC data.

D. No intense solar flare occurred during the period of study.

Future studies could attempt to identify the sources for periodic (5-6 hrs) fluctuations and threshold of substorm intensity for identifiable signatures in the TEC data at Himadri station.

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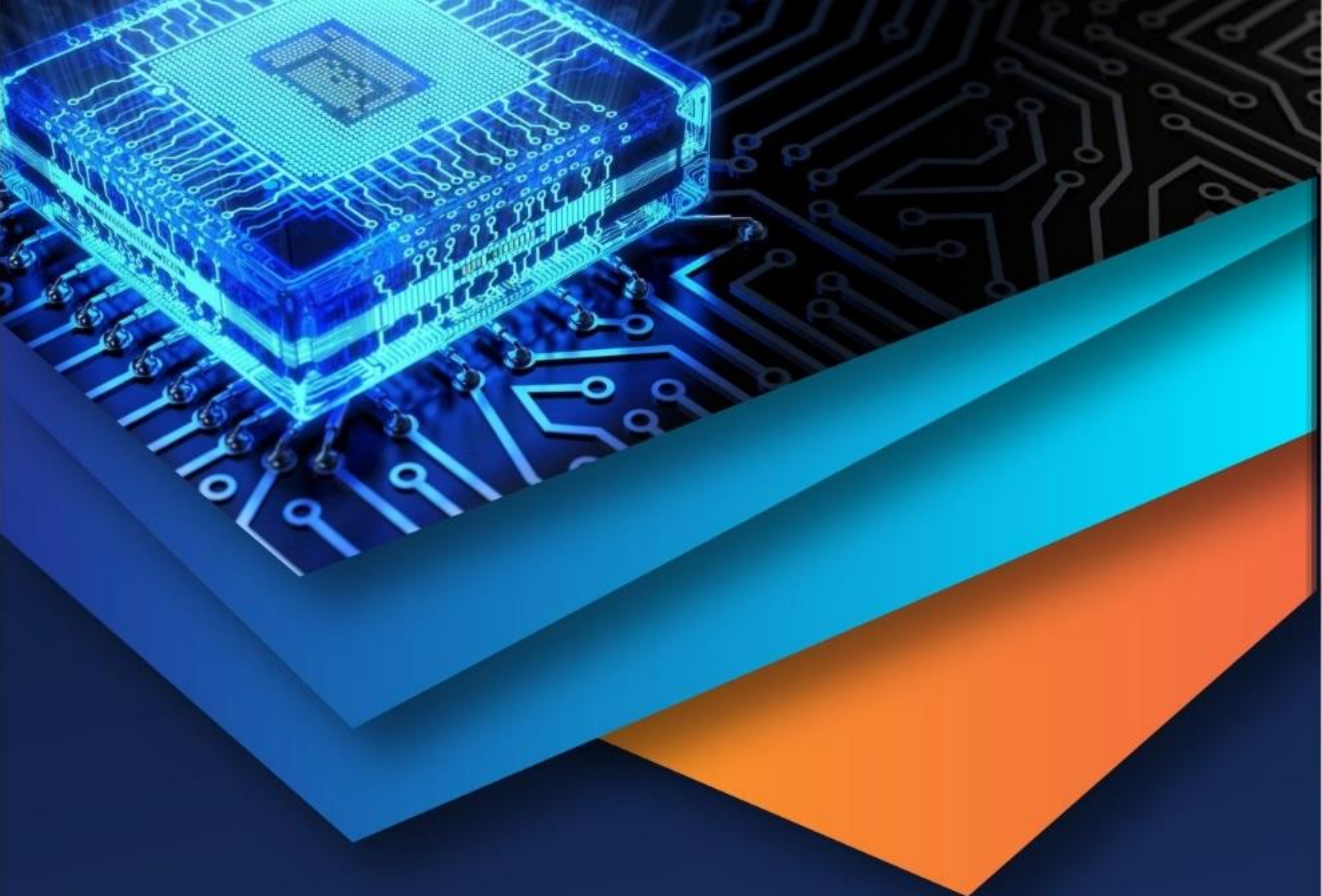

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