Influence of The Remote Celestial Event Like Gamma Ray Bursts GRB 190114C and GRB 110918A on The Total Electron Content of The Earth's Ionosphere: A Case Study

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***Abstract*: During a supernova or super luminous supernova, an intense gamma radiation is released, known as Gamma Ray Burst (GRB).Two bright gamma-ray bursts (GRB 110918A and GRB 190114C) were detected on the earth in the year 2011 and 2019. The influence of these bursts on the total electron content (TEC) of the earth's ionosphere is studied using the data provided by the international GPS service network (IGS) for the stations at high, middle and low latitudes in both hemispheres in Asian-Australian region. Just after the time of spectroscopic detection of GRB in late night, due to prompt emission though no remarkable effect was observed in case of 1st GRB but remarkable unusual variations (maximum 2 TECU) are observed in case of 2nd GRB in the diurnal TEC curves mainly at high latitude stations in both hemispheres. In the following day due to the afterglow emission isotropic influences are observed for both the GRB bursts at almost all the stations in both the hemisphere. The maximum diurnal TEC increases by 5-8 TECU and 1-3 TECU for GRB 110918A and GRB 190114C respectively at different stations in compare to the day of events. So evident effects are found on the total electron content of the earth's ionosphere due these remote celestial events i.e. gamma ray bursts mainly in their afterglow periods. The results are explained with the theory available till the date.**

Keywords— GRB, TEC, IGS, GPS

1. INTRODUCTION

Gamma ray bursts (GRB) are the most energetic phenomena in the universe which are associated with the creation or merging of neutron stars or black holes. This results in an explosive outburst of material moving incredibly close to the speed of light. During a supernova or super luminous supernova, as a high-mass star implodes to form a neutron star or a black hole, an intense radiation is released which is termed as GRB. These energy finally races through our solar system even after billion of years. The GRB lasts from fractions of a second to minutes, which emit the bulk of their energy in the gamma-ray regime (above ~ 0.1 MeV). It is unpredictable in occurrence, which form one of the most long-standing and challenging puzzles in modern astrophysics.GRB was accidentally discovered over sixty years ago with the Vela series of nuclear-testing surveillance satellites. GRBs occur at random intervals (~ 1/day); they do not seem to repeat and they are isotropic in their distribution, coming from every direction in the sky. Each burst is different in its temporal structure, which can vary dramatically in duration and complexity from burst to burst.

GRB is a two step radiation process, namely i) prompt emission ii) afterglow emission. A prompt emission may last from fraction of a second to few seconds or minutes and afterglow emission may last from few days to several days. In prompt emission γ rays are emitted but in afterglow emission X ray, UV ray, Visible ray, IR or radio waves are emitted.GRB may be of short or long duration. The afterglow phase can be detectable for several days in X-rays, and often weeks or even months in the optical and radio bands.

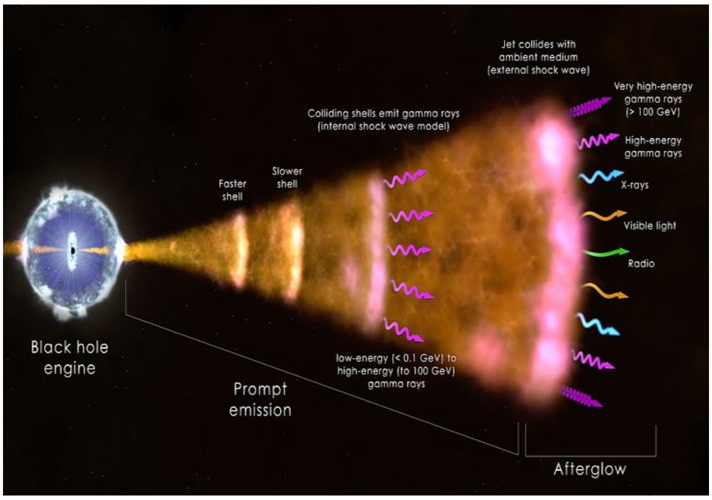

Figure 1: Two steps of GRB radiation process namely i) prompt emission ii) afterglow emission

Besides the sun, these burst events with energetic photons at cosmological distances, especially γ-ray bursts or X-ray bursts, may also influence the ionosphere. Brown (1973) found that a γ-ray burst at cosmological distance had a very large effect on the propagation of radio waves. Fishman et al (1988) experimentally observed the ionization of the bottom of the ionosphere caused by GRB. Huang W. et al (2008) investigated the influence of an extremely strong gamma-ray burst, GRB041227 which swept across the earth and caused the part of the terrestrial upper atmosphere exposed to it to produce extra ionization and found that in the course of the burst the average ionospheric TEC increased, to a maximum size of about 0.04 TECU, equivalent to a solar flare with importance of C or lower. Gamma-ray bursts (GRBs) made significant impacts on the Earth during the last billion years. The gamma radiation from a burst within a few kiloparsecs may quickly deplete much of the Earth's protective ozone layer and allows an increase in solar UVB radiation that reaches to the earth's surface. This radiation is harmful to life, which damages the DNA and causes sunburn. In addition, NO_2 produced in the atmosphere may cause a decrease in visible sunlight reaching the surface and may cause global cooling. Nitric acid rain may stress portions of the biosphere From literature survey it is found that there are very few studies on GRB and no study on the effect of afterglow emission on the ionosphere. In this paper we shall investigate the Influence of the different gamma ray bursts on the total electron content of the earth's ionosphere in both prompt and afterglow emission periods.

2. DATA SOURCES AND METHODOLOGIES

The influence of the GRB 190114C and GRB 110918A on the ionospheric total electron content (TEC) of the earth's ionosphere is studied using the data provided by the international GPS service network (IGS) from the stations at high, middle and low latitudes in both hemispheres in Asian-Australian region.

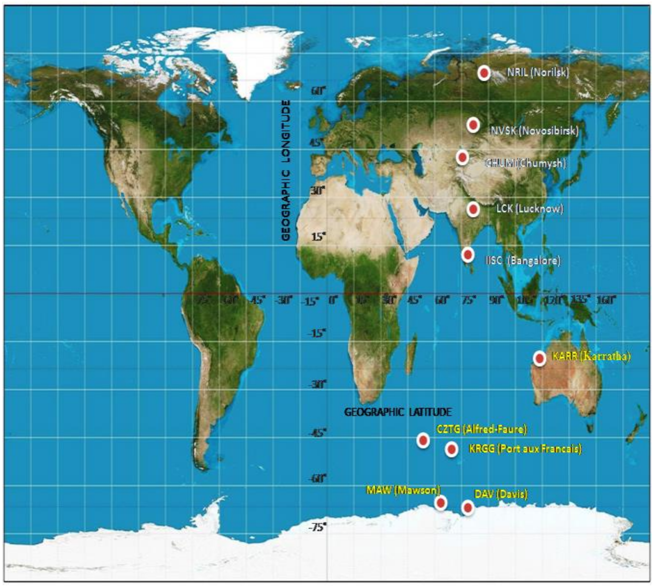

Figure 2: The location of the selected IGS stations (RED CIRCLES) for Total Electron Content in the Low, middle and high latitude ranges in both northern and southern hemisphere.

Table 1: Details of IGS stations selected for study

IGS station short name	IGS station full name	Latitude	Longitude	Country
DAV	Davis	-68.5	77.9	Antarctica
MAW	Mawson	-67.6	62.8	Antarctica
KRGG	Port aux Francais	-49.3	70.2	French Southern Territories
CZTG	Alfred-Faure	-46.4	51.8	French Southern Territories
HOB	Hobart	-42.8	147.4	Australia
KARR	Karratha	-20.9	117.09	Australia
IISC	Bangalore	13.02	77.5	India
LCK	Lucknow	26.9	80.9	India
HYDE	Hyderabad	17.41	78.5	India
CHUM	Chumysh	42.9	74.7	Kazakhstan
NVSK	Novosibirk	54.8	83.2	Russian Federation
NRIL	Norilsk	69.3	88.3	Russian Federation

TEC of the ionosphere is the number of electrons in a column with 1 m2 cross-section areas centered on the GPS signal path and is presented in TEC unit (TECU) which corresponds to 10^{16} e/m^2.

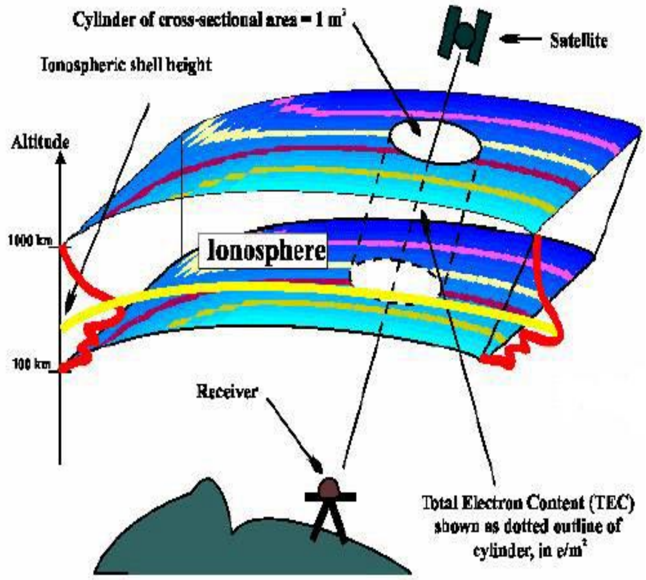

Figure 3: GPS & Total Electron Content (TEC)

The TEC processing of RINEX data files of IGS stations is performed using software developed by Gopi Krishna Seemala.

The monthly mean or the background VTEC is computed by taking the average of the VTEC values of 10 international quiet days.

TEC data are obtained from-(http://geoftp01.ucsd.edu/pub/rinex). Solar, interplanetary and geomagnetic index data are collectedfrom-(https://omniweb.gsfc.nasa.gov/form/dx1.html)
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3. RESULTS AND DISCUSSION

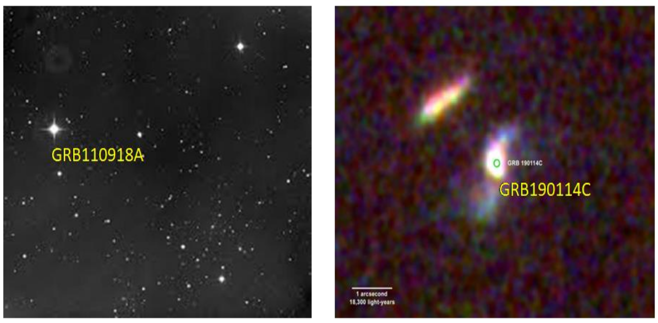

Figure 4: Spectroscopic detection of GRB110918A and GRB 190114C

3.1 *GRB110918A detected during 18-19 September, 2011*

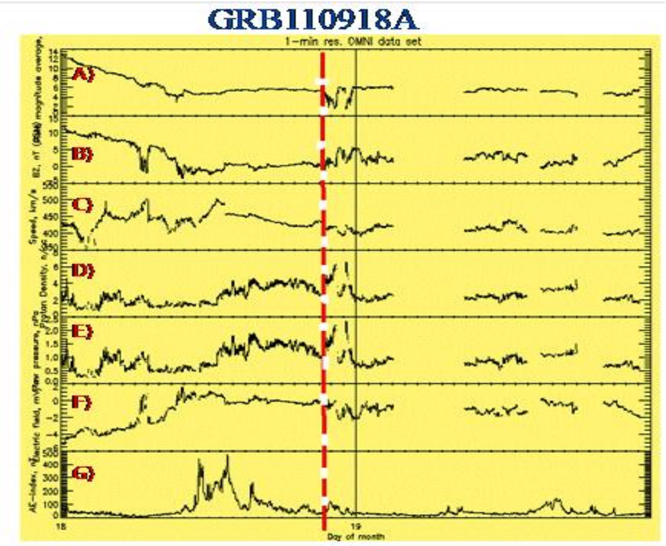

Figure 5. Temporal variations of A) avg. magnetic field B) IMF Bz, C) solar wind speed, D) proton density E) ram pressure, F) electric field G) AE during 18-19 September, 2011 ie. the day of prompt emission and afterglow emission of GRB110918A

Figure 5 shows the temporal variations of average. magnetic field , z-component of magnetic field Bz, solar wind speed, proton density ram pressure, electric field and AE index during 18-19 September, 2011 ie. the day of prompt emission and afterglow emission of GRB110918A.From the figure it is clear that the day of the event and it's following day are geomagnetically quiet. Figure 6 shows the TEC variation at stations in northern (upper panel) and southern (lower Panel) hemisphere on 18th and 19th September, 2011. Here the dotted red vertical line at 21:26 UT, September 18 indicates the time of spectroscopic detection of GRB 110918A on the earth. From the upper panel we find that
after the time of spectroscopic detection of GRB in late night at 21:26 UT due to prompt emission no remarkable variation is observed in diurnal TEC curve in both hemispheres. But in the following day due to afterglow effect isotropic influences are observed at almost all the stations in both the hemisphere i.e. TEC at all the stations from low to high latitudes are influenced and the diurnal max varies from 5 TECU to 8 TECU in

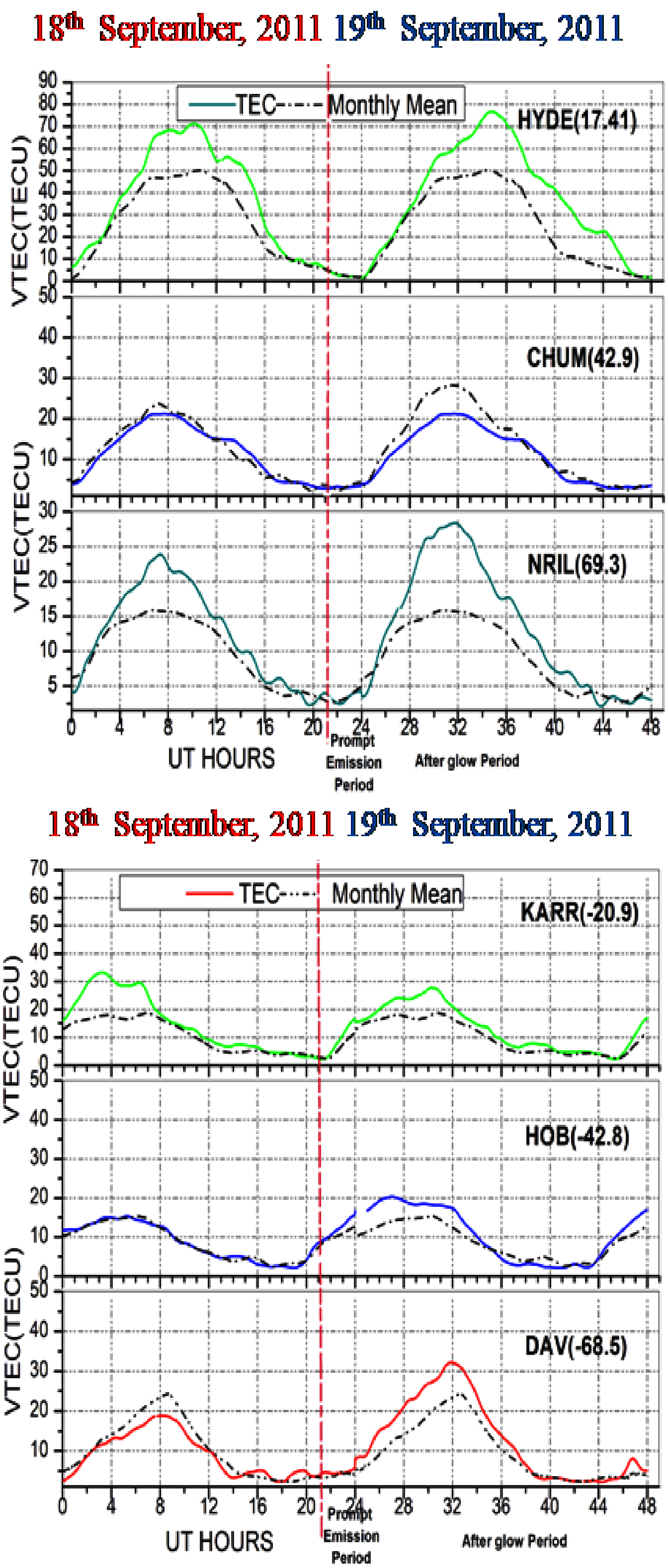

FIGURE 6: TEC variation at stations in northern (upper panel) and southern (lower Panel) hemisphere on 18th and 19th September, 2011(Dotted red vertical line at 21:26 UT, September 18 indicates the time of detection of GRB 110918A on the earth)

compare to that at the day of event at different stations. So evident effects of GRB, on the ionosphere, are found in the afterglow period at different stations of both hemispheres.

3.2 *GRB190114C detected during* 14-15 January, 2019

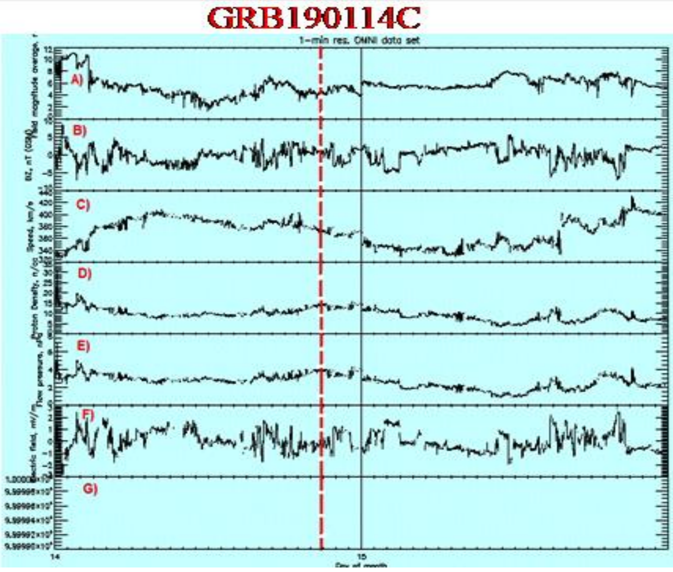

Figure 7. Temporal variations of A) avg. magnetic field B) IMF Bz, C) solar wind speed, D) proton density E) ram pressure, F) electric field G) AE during 14-15 January, 2019 ie. the day of prompt emission and afterglow emission of GRB190114C

Figure 7 shows the temporal variations of average. magnetic field , z-component of magnetic field Bz, solar wind speed, proton density ram pressure, electric field and AE index during 14-15 January, 2019 ie. the day of prompt emission and afterglow emission of GRB190114C. From the figure it is clear that the day of the event and it's following day are geomagnetically quiet. Figure 8 shows the TEC variation at stations in northern (upper panel) and southern (lower Panel) hemisphere on 14th and 15th January, 2019. Here the dotted red vertical line at 20:57 UT, January 14 indicates the time of spectroscopic detection of GRB190114C on the earth. From the upper panel we find that after the time of spectroscopic detection of GRB in late night at 20:57 UT due to prompt emission a remarkable unusual variation (maximum 2 TECU) is observed in diurnal TEC curve at mainly high latitude stations in both hemispheres, which doesn't follow the monthly mean curve.

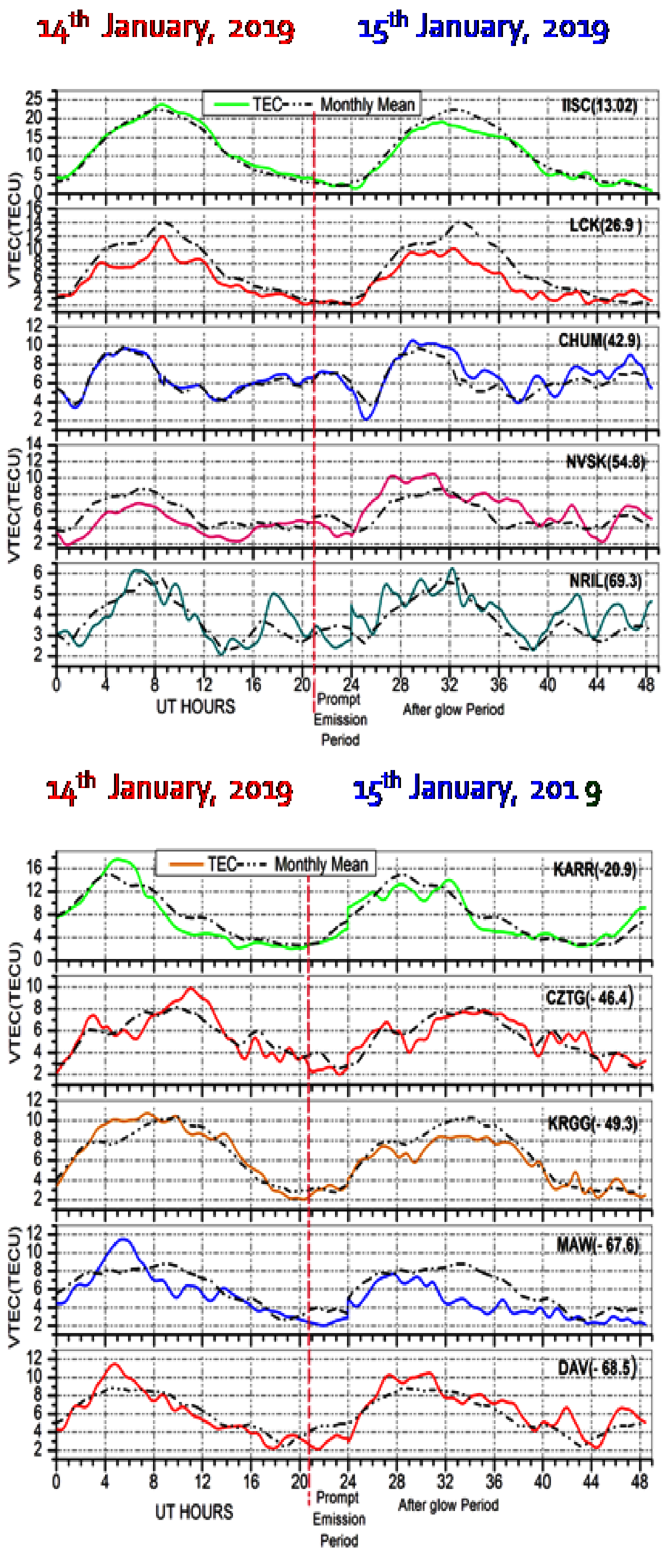

FIGURE 8: TEC variation at stations in northern (upper panel) and southern (lower Panel) hemisphere on 14th and 15th January, 2019 (Dotted red vertical line at

20:57 UT, January 14 indicates the time of detection of GRB 190114C on the earth) In the following day due to afterglow effect isotropic influences are observed at almost all the stations in both the hemisphere i.e. TEC at all the stations from low to high latitudes are influenced and the diurnal max varies from 1 TECU to 3 TECU in compare to that at the day of event at different stations. So in this case also evident effects of GRB, on the ionosphere, are found in the afterglow period at different stations of both hemispheres

The mechanism of GRB emission is quiet complex. Among the different models regarding the mechanism of GRB the most acceptable model states that during the supernova explosion energetic photons as well as many energetic particles are produced and thrown into the space. These energetic particles move forward as multiple shells that is different shells one after another and they have differences in their velocity. So when fast moving shell collides with the slower shell shock wave is produced which is known as internal shock wave. Due to these shock waves the energy of the particles specially the electrons are amplified and they become relativistic electrons and randomness of the electrons is also increased. When the low energy photons collide with the relativistic electrons then the inverse Compton scattering occurs. Due to transfer of energy from relativistic electrons the energy of photons increases enormously. This is the prompt emission by GRB. The GRB may also be visible through afterglow emission. Relativistic electrons proceed further in space and then after a few hours to several days collide with the surrounding interstellar materials mainly with the gas. As a result another shock wave is produced, which is known as external shock wave. When the electrons pass through this external shock wave due to the local magnetic field the electrons are accelerated in perpendicular direction .As a result magneto-brimsterlung and hence synchrotron emission is produced which appears as afterglow emission. The wavelength range of this emission is higher than that of gamma ray and the entire remaining higher wavelength waves are produced namely UV ray, X-ray visible light, infrared wave and radio wave. The gamma radiation during the prompt emission remains collimated. So if the line joining the star and gamma ray passes through the earth then only the ionosphere of the exposed part of the earth may be affected. Here if the gamma ray hits the earth then an extra ionization occurs in the bottom layers of the ionosphere. This ionization is in addition to natural ionization due to ultraviolet light from the sun and cosmic rays and hence the unusual variation of TEC occurs. On the other hand the afterglow emission is basically a scattered emission and hence the upper layers of the ionosphere suffer extra ionization by the comparatively higher wavelength waves. So the TEC of almost all the stations are affected by the afterglow emission i.e. Isotropic influences are observed.

The day of the event and its following day are geomagnetically quiet as observed from the values of geomagnetic parameters and the associated curve for their temporal variations. More over the event was detected in the late night time when the solar radiation is absent at the longitude range of the stations considered. Here the X-ray as afterglow radiation is obtained due to the interaction of the accelerated electrons and hence loss energy within the blast wave magnetic field. This energy is radiated in the form of synchrotron photons. GRB 190114C is detected on 14th January, 2019 and GRB 110918A is detected on 18th September, 2011. In Asian-Australian region, in the longitude range (50-110), during January there is winter season and during September there is autumn equinox season. So cloud activity is least. As a result possibility of disturbance on ionosphere and hence on TEC due to lightning, cyclone etc is minimum. During the two GRB events selected, specially in afterglow period days were magnetically quiet as obvious from figure5 and international quiet day's list. So the almost isotropic variation or response of ionospheric TEC at the stations in all latitudinal ranges in both hemisphere may be the afterglow effect of the GRBs in the outer space.

4. SALIENT FEATURES AND SIGNIFICANT RESULTS OF THE STUDY

i) Evident effects of GRB are found at many stations of both hemispheres.

ii) In case of GRB 110918AC due to prompt emission no remarkable variation is observed in diurnal TEC curve in both hemispheres.

iii) But due to afterglow radiation isotropic influences are observed at all the stations in both the hemisphere.

iv) In case of GRB 190114C due to prompt emission a remarkable unusual variation is observed in diurnal TEC curve at mainly high latitude stations in both hemispheres.

v) Due to afterglow radiation isotropic influences are observed at almost all the stations in both the hemisphere

5. CONCLUSION

The research work can be concluded as follows:

1. There are very few studies on GRB and the influence of long duration GRB is reported for the first time. This study answers an important question for scientists regarding the potentially harmful influence of the remote celestial event on the terrestrial space.
2. The authors expect the study to be useful in understanding the ionospheric response to gamma ray bursts and also in validating the theories and physical mechanisms established till to date which explains the ionospheric response to different celestial event.

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