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Climatology of Conjugate Hemisphere Ionospheric Response to Geomagnetic Storms along 95°E during Solar Cycle 24

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Abstract

The ionospheric response to geomagnetic storms over the low-latitude ionosphere along 95°E is statistically investigated for the full solar cycle 24. GPS/GNSS total electron content (TEC) data from two magnetically conjugate stations, Dibrugarh (27.5°N, 95°E, 43° dip) and Cocos Islands (12.2°S, 96.8°E, 43° dip) from 2009 to 2019 are used for the study. The results are presented for three categories of geomagnetic storm: moderate ($-100 \leq$ Dst < -50nT), major ($-200 \leq$ Dst < -100nT), and super storms (Dst<-200nT) based on the minimum Dst index criterion. The distribution of occurrence of ionospheric storms is related to the intensity and onset time of geomagnetic storms and have solar cycle, season, latitudinal as well as hemispherical dependencies. The number of occurrences of geomagnetic storms follows the solar activity and mostly occurred during the equinoctial months (Mar-Apr and Sep-Oct) than the solstices. The results show that the onset time of the main phase (MP) of the most frequent and intense geomagnetic storms shows significant preference for midnight (00:00UT) and around midday (13:00UT). During solar cycle 24, the positive ionospheric storms are found to be dominant along this longitude sector and mostly occurred in the southern hemisphere. Seasonally, the negative ionospheric storms mostly occur in the summer hemisphere and positive ionospheric storms are more frequent in the winter hemisphere. The observed preferences in the occurrence of positive and negative ionospheric storms on the MP onset are not obvious i.e. positive (negative) storms are mostly found for afternoon (morning) onset of geomagnetic storms. Thus, solar cycle, seasonal and local time dependence of the ionospheric storm of different intensities along with notable interhemispheric asymmetries are revealed in this study.

Keywords: Ionospheric storm, TEC, low-latitude Ionosphere.

1 Introduction

In addition to the quiet time variability, the ionosphere varies significantly during the geomagnetically disturbed period. The ionospheric response to geomagnetic disturbances is extremely complex as it depends not only on the incoming disturbance itself but also on the ionospheric background that is varying with local time and location on Earth. Traditionally, a large-scale deviation of the ionospheric parameters from its typical daily behaviour during the geomagnetic storm is referred to as ionospheric storm. The ionospheric density often increases (decreases) from its average quiet time level and the storms are known as positive (negative) ionospheric storms that have a dependency on the onset time of storms, latitude and longitude, local time, season and solar cycle [1, 2, 3, 4, 5, 6].

The study of ionospheric variabilities along the 90-100°E is significant from the perspective of radio communication since the strongest maxima of the global longitudinal wave number 4 (WN4) structure [7] in EIA is reported from this longitude [8]. The solar cycle 24 has special significance, considering the very low and extended solar minimum and relatively lower solar activity than the earlier solar. A study on the effects of geomagnetic storms on the low-latitude ionosphere along 95°E that occurred from 2009 -2019 during solar cycle 24 is carried out. The TEC data obtained from two magnetically conjugate locations Dibrugarh (North) and Cocos Islands (South) are used in the present work. Through this work, an attempt has been made to create a long term climatology of disturbed time ionosphere over this longitude sector of high ionization density, which will also help in improving space weather models.

2 Data and Methodology

The primary ionospheric parameter used for this study is TEC which is the height integrated electron density along the ray path from the satellite to the receiver. TEC at Dibrugarh is derived from the instruments NOVATEL GSV4004B receiver and NOVATEL GNSS Ionospheric Scintillation and TEC Monitor (GISTM) receivers. TEC data at Cocos Islands (12.2ºS, 96.8ºE, 43º dip) is obtained from the International GPS Service (IGS) stations. Cocos Islands at a magnetically conjugate location to Dibrugarh provides an estimate of the southern EIA. The detailed procedure for the calculation of TEC data from different GPS/GNSS receivers is described in [9]. The hourly values of the geomagnetic activity index (Dst) are obtained from the World Data Centre for Geomagnetism, Kyoto (http:// http://wdc.kugi.kyoto-u.ac.jp).

3 Results and Discussion

3.1 Statistics of Geomagnetic Storms

The storms are categorized into moderate, intense and severe/super based on the classification provided by [10]. A total of 140 geomagnetic storms with minimum Dst≤ −50nT occurred in 2009-2019, which include 118 moderate storms (−100 ≤ Dst < −50nT), 20 major storms (−200 ≤ Dst < −100nT) and 2 super storms (Dst<-200nT).

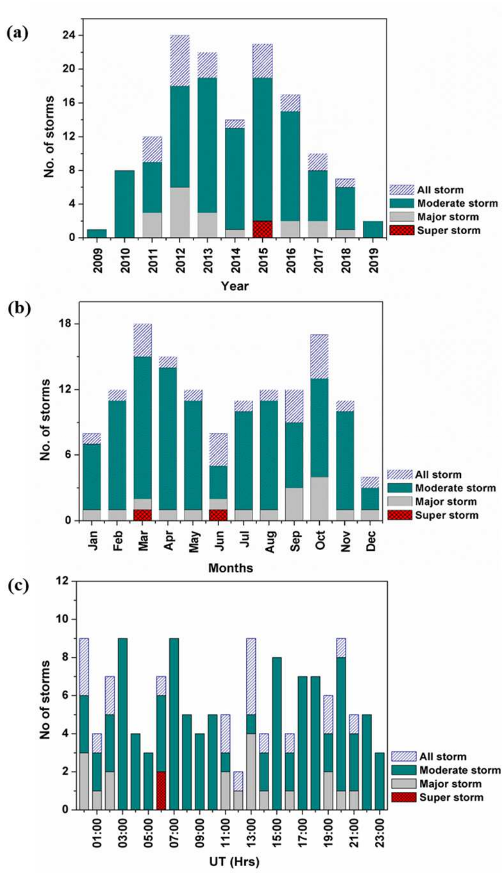

Figure 1. The number of occurrence of geomagnetic storms (with minimum Dst<-50nT) from 2009 to 2019 as a function of (a) Year, (b) Months and (c) onset time of Main Phase (MP) of the storm.

Figure 1 shows the number of occurrence of geomagnetic storms during solar cycle 24 for the period 2009 to 2019 as a function of (a) year, (b) months, and (c) Universal time (UT). The number of occurrences of storms follows solar activity. The maximum number of storms occurred during 2012 at the peak of the solar cycle followed by 2015 and 2013 moderate to high activity period. The number of occurrence of major storms is maximum in 2012. However, 2 most intense storms (super storm: Dst<-200) occurred in the year 2015 which is a moderately-high solar activity period. Figure 1(b) shows that the storms mostly occurred during the equinoctial months. During this period the maximum number of storms occurred during March and most major storms occurred during October. Figure 1 (c) shows the occurrence frequency of storms with MP onset Universal time (UT). The figure shows onset time of MP of the most frequent and intense geomagnetic storms generally lies at midnight (00:00UT) and around midday (13:00UT). The two super storms occurred in March 2015 and June 2015 and the main phase onset time is 06:00UT.

3.2 Classification of Ionospheric Storms

The ionospheric storms are further classified into five groups based on the variations of TEC during the storm with respect to quiet times. The storms are classified as positive storms (PS) or negative storms (NS) depending on whether a deviation in TEC is positive or negative following the onset of geomagnetic storms. Some ionospheric storms show initial positive deviation in TEC followed by negative deviation, which is classified as PNS. Several storms are found to have initial negative deviation followed by positive; they are classified as NPS. There are also non-significant ionospheric storms (NSS) for which deviation in TEC during the storm is weak. There exists a variety of definitions in the literature to identify the positivity/negativity like quiet day value, monthly mean, seasonal mean, or median values, or a weekly mean value before storm commencement [2, 6, 11]. In the present work, we calculate quiet day monthly mean and standard deviation of the hourly TEC values (Kp index 0-1) of the most quiet days of the corresponding months. The geomagnetic storm is considered as effective ionospheric storm if the storm day hourly TEC is above or below the quiet day value for above 2-3 hours and thereby observing the deviation for 3 days from the onset of the storm to identify the different groups of PS, NS, PNS, NPS and NSS.

3.3 Occurrence of Ionospheric Storms according to geomagnetic storm intensity, solar activity, seasons and MP onset time

Figure 2 shows the yearly variation of the number of ionospheric storms of different categories for which TEC data are available for (a) Dibrugarh and (b) Cocos Islands for the period 2009-2019. From the figure, some clear differences in the distribution of occurrence of ionospheric storms at the two stations are evident. Negative storms show better dependence on solar activity and the distribution of geomagnetic storms than positive storms at both stations. The occurrence of PNS and NPS are comparatively more over the northern hemisphere than in the southern hemisphere. Few NSS are also observed at both the stations irrespective of the solar cycle and storm distribution.

From the figure, it can be clearly seen that the PS effects are dominant over both the stations for all the geomagnetic conditions. At the low latitudes, the eastward directed PPEF coincident with the eastward ionospheric electric field gives rise to enhanced vertical drift during the daytime resulting in positive storms [12, 13, 14]. During nighttime, PPEF turns westward resulting in negative ionospheric storms. During the super geomagnetic storms of 2015, only negative deviations occurred at Dibrugarh while negative and NP deviations occurred at Cocos Islands. The severe negative effect is due to the depletion in the ionospheric density mainly due to large suppression in the O/N_2 ratio.

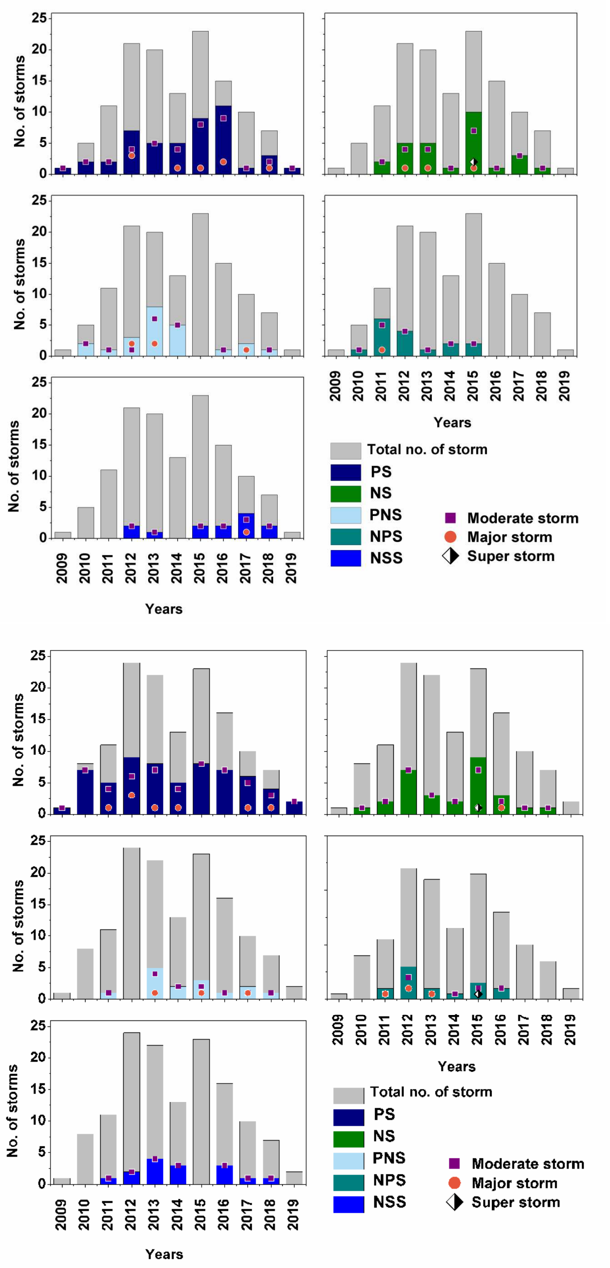

Figure 2. Ionospheric storm (PS, NS, PNS, NPS and NSS) occurrence over (a) Dibrugarh (top) and (b) Cocos Islands (bottom) according to geomagnetic storm classifications viz; Moderate, Major and Super storms as a function of years from 2009 to 2019.

However, the occurrence of positive or negative storms due to PPEF also depends on other background conditions such as the direction of wind circulation and composition of the neutral atmosphere. The results from the present study show that the occurrence of Ionospheric storms over the low-latitudes along this longitude sector does not present any obvious dependency on the storm onset time. At Dibrugarh, the most positive storms are found in the morning to evening (8:30, 13:30, 17:30LT) MP onset. The negative storms are more frequent in the sunrise to the noon sector. Most PN storms occurred at noon-time (12:30LT) and most NP storms occurred at 21:30LT. At Cocos Islands, three distinct peaks in the occurrence of positive storms are observed at 06:30, 09:30 and 19:30LT and negative storms are found at 02:30 08:30, 13:30 LT. Most PN storms occurred mainly during the morning to noontime and the NP storms distributed throughout the whole day except before noon with a peak occurred in the 19:30LT.

To study the seasonal behaviour of the storm time variation of the ionosphere the available TEC data is categorized into four different seasons; March equinox (March- April); June solstice (May-August); September equinox (September-October); December solstice (November-February). The seasonal variations in the ionospheric storms are mainly caused by the wind circulations and the compositional changes in the neutral atmosphere [4, 5]. Seasonal average shows maximum positive storms occur during the southern winter (June solstice ~28 PS) followed by northern winter (December solstice ~18 PS). Whereas the maximum negative storms occur during the southern summer (December solstice ~14 NS). Maximum PNS occurs during the June solstice followed by September equinox over Dibrugarh and December solstice and September equinox at Cocos Islands. Most NPS occur during March equinox at Dibrugarh and September Equinox at Cocos Islands. The mechanism for negative storms explained in [4], according to which the negative storm effect is caused due to the region called "compositional bulge", where the ratio of molecular gas concentration to the atomic oxygen increases. During summer, the wind circulation is directed equatorward during day and night, coincides with the storm induce circulations bring air with a smaller O/N_2 ratio towards the mid-low latitudes. This results in more frequent negative ionospheric storms during summer. Whereas during winter, the compositional bulge is confined at the high latitudes as it is restricted by the poleward wind. Thus there is a decrease in the molecular species at the low-mid latitudes resulting in the possibility for more positive storm during winter.

4. Summary and conclusions

In this work, a statistical study of the ionospheric response to geomagnetic storms along 95°E during solar cycle 24 has been investigated using GPS/GNSS TEC data over two conjugate stations, Dibrugarh and Cocos Islands from 2009 to 2019. Positive ionospheric response is dominant over both stations for both moderate and major geomagnetic storms. The super storms mostly cause severe negative impact at low latitudes of this longitude sector. Most negative storm occurred during winter and most positive storms during summer. A few hemispherical difference is also observed in the distribution of occurrences of ionospheric storms based on the solar cycle, seasons and MP onset time.

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6. References

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