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Observations of Storm-Time Thermospheric O/N_2 Ratio and TEC in the Northern Hemisphere during Intense Geomagnetic Storms of 2015-2017

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Abstract

It has already been established that during the main phase and recovery phase of any geomagnetic storm, thermospheric O/N_2 column density ratio decreases in the high latitudes because of auroral heating (indicated by Auroral Electrojet (AE) index). This decrement subsequently propagates to lower latitudes depending on the intensity and nature of the storm. This propagation extent depends on several parameters associated with the storm. In this paper latitudinal extent of decrement of O/N_2 ratio is observed for three storms during moderate solar activity periods (2015-2017). The maximum latitudinal extents observed are 22.28°N for March 17-21, 2015 storm, 16.93°N during October 13-17, 2016 and September 7-11, 2017 storm in the northern hemisphere. The correlation between AE index and latitudinal extent of this propagation has been studied. The longitudinal swaths where the extent is maximum or minimum are also observed.

1. Introduction

Thermospheric O/N_2 column density data is optically obtained from NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics satellite (TIMED/GUVI) Far Ultraviolet (FUV) airglow instruments [*Zhang et al.,* 2004]. O/N_2 data is obtained from the ratio of total path integrated ratio between atomic and excited oxygen and molecular nitrogen. Atomic oxygen is obtained from (OI) 135.6 nm wavelength radiances. This is obtained using recombination of energized oxygen ion. Nitrogen molecule is obtained from Lyman Birge Hopfield (LBHS) (141.0–152.8 nm) wavelengths [*Strickland et al.,* 2004; *Kil and Paxton,* 2011]. This data is used to determine the amount of thermospheric composition change incurred during the geomagnetic storm periods. During any geomagnetic storm event (Dst < -50 nT) Joule heating is observed at auroral region. Due to Joule heating and particle precipitation near auroral oval, the local atmosphere is upwelled. This uplifted atmosphere contains less ionized particles (oxygen atoms) but they are fully enriched in neutral nitrogen molecules [*Mayr and Volland,* 1972; *Prolss,* 1980]. Meridional neutral wind transports these atmospheric compositions (comprising of less O/N_2 ratio) towards middle to low latitudes. This causes reduction in Total Electron Content (TEC) in mid to low latitude region.

2. Methodology

In this paper latitudinal extents of propagation of decrement of O/N_2 ratio from high latitudes are calculated during three geomagnetic storms. They are 1) March 17-21, 2015, 2) October 13-17, 2016 and 3) September 7-11, 2017. The geophysical parameters related to these storms are summarized in Table 1.

Table 1. Geophysical Parameters Related to the Storms

Sl No.	Storm Duration		Maximum Dst index (nT)	Maximum AE index (nT)	Class
	Main Phase	Recovery Phase			
1.	17 March, 2015	18-21 March, 2015	-223	1570	G4
2.	13-14 October, 2016	14-16 October, 2016	-104	1200	G2
3.	7-8 September, 2017	8-11 September, 2011	-142	1442	G4

The discussions of latitudinal discussions are limited in northern hemisphere in this paper.

Latitudinal extent of decrement of O/N_2 ratio is quantified by observing any change in O/N_2 ratio by 20% or more than that obtained from the average of O/N_2 from three geomagnetic quiet days ($Kp < 3$) during same month.

3. Latitudinal extent of O/N_2 ratio during March 17-21, 2015

Latitudinal extents of changes in O/N_2 (in percentage) from the quiet days are shown in Figure 1 for one representative geomagnetic disturbed date, 17 March, 2015 during 10:13-10:22 LT.

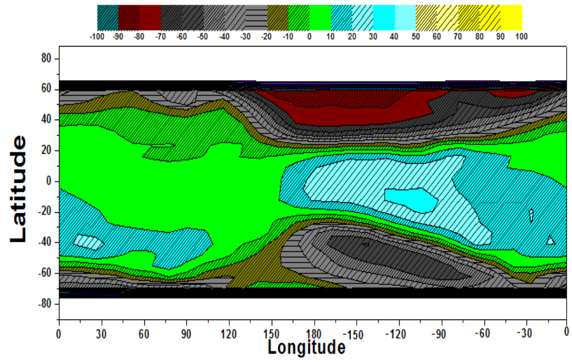

Figure 1. Percentage variation of O/N_2 ratio on 17 March, 2015 from quiet days of the same month

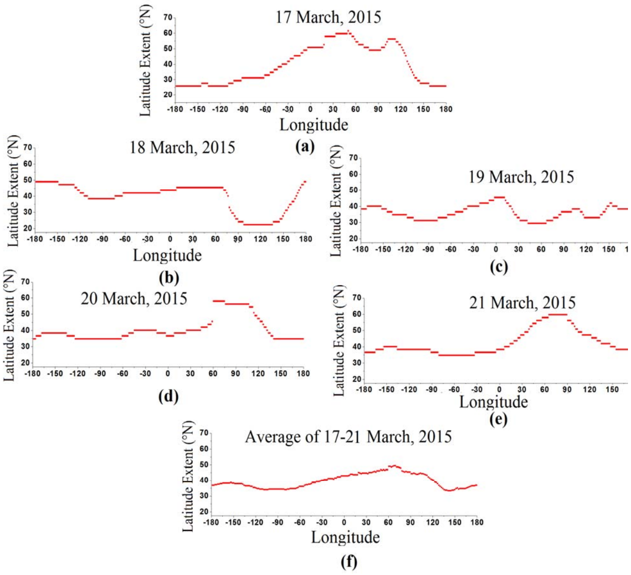

Figure 2. (a)-(e) Latitudinal extent of the 20% decrement in O/N_2 from quiet days during March 17-21, 2015 and (f) the average latitudinal extent of the 20% decrement in O/N_2 from quiet days during March 17-21, 2015

During March 17-21, 2015, maximum latitudinal extent of 20% decrement in O/N_2 ratio is observed during 17 and 18 March, 2015 (latitudinal extent 25.84°N and 22.28°N respectively). These results are shown in Figure 2. Maximum decrement of Dst index occurred in 22 UT of 17 March, 2015 (-223 nT). Dst goes above -100 nT during 11 UT of 18 March, 2015 and goes above -50 nT during 3 UT of March 21, 2015 (recovery phase). Maximum AE index is observed during 17 March (maximum 1570 nT, during 14 UT). AE index above 1000 nT is observed during 18 and 19 March as well (1043 and 1134 nT during 15 UT and 12 UT respectively). The maximum latitudinal swaths during these days are 22.28°N and 29.41°N respectively. AE index does not peak above 1000 nT during 20-21 March, 2015 and corresponding latitudinal extent is also not as higher as seen during 17-19 March, 2015 (34.75°N both the days). These results are shown in Table 2.

Table 2. Comparative study between maximum hourly averaged AE index and maximum latitudinal extent of 20% decrement in O/N_2 ratio during March 17-21, 2015

Date	Maximum Hourly Averaged AE Index (nT)	Maximum Latitudinal Extent (°N)	Local Time (LT)
17 March, 2015	1570	25.84	10:13-10:22
18 March, 2015	1043	22.28	10:02-10:11
19 March, 2015	1134	29.41	9:52-10:01
20 March, 2015	719	34.75	9:40-9:50
21 March, 2015	561	34.75	9:29-9:38

The corresponding correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index for March 17-21, 2015 is shown at Figure 3.

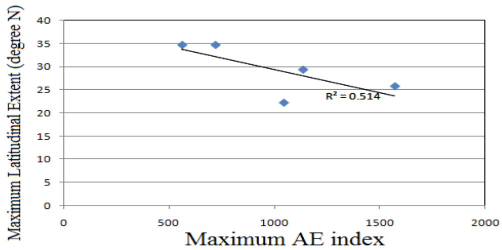

Figure 3. Correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index during March 17-21, 2015

During the period of March 17-21, 2015 maximum average latitudinal extent of 20% decrement of O/N_2 ratio was observed at wide Pacific and US west coast region (105°-180° W) in the local hours of 9:29-10:22 LT (Figure 2). The maximum latitudinal extent was observed on 18 March, 2015 (22.28°N geographic, 12.58°-13.54°N geomagnetic). This decrement in O/N_2 ratio is positively correlated with decrement of TEC in this region. The vertical TEC depletion is shown using global CEDAR Madrigal worldwide GPS network. Some representative dates (17-19 March, 2015) are shown in Figure 4 at the Pacific and US west coast region. The latitudinal extent of decrement in O/N_2 ratio was minimum at the longitude sector of 30°-105°E (Asia-Europe continent latitude region).

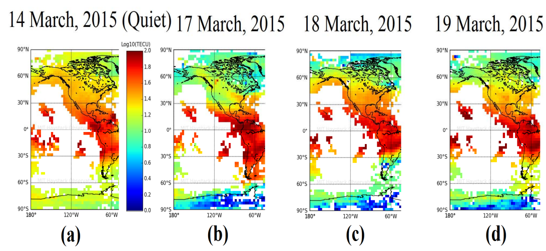

Figure 4. Median Vertical TEC deviation during March 17-19, 2015 from geomagnetic quiet day (March 14, 2015) at 22-23 UT (10-11 LT at 180°) using CEDAR Madrigal GPS TEC data.

4. Latitudinal extent of O/N_2 ratio during October 13-17, 2016

During this storm, maximum latitudinal extent of 20% decrement in O/N_2 ratio is observed during 14 October, 2015 (16.93°N geographic, 18.75°-19.04°N geomagnetic, Figure 5). Minimum Dst index has been observed during 23 UT of 13 October, 2016 (-104 nT). Maximum AE index has been observed during 15 UT of October 13, 2016 (1200 nT). AE index remained above 500 nT up to 8 UT, 14 October, 2016. A secondary enhancement of AE index is observed during 16-17 October, 2017 which is maximized during 18 UT of 16 October, 2016 (770 nT). Table 3 has shown the comparative study between hourly maximum AE index and maximum latitudinal extent of 20% decrement of O/N_2 ratio in each day.

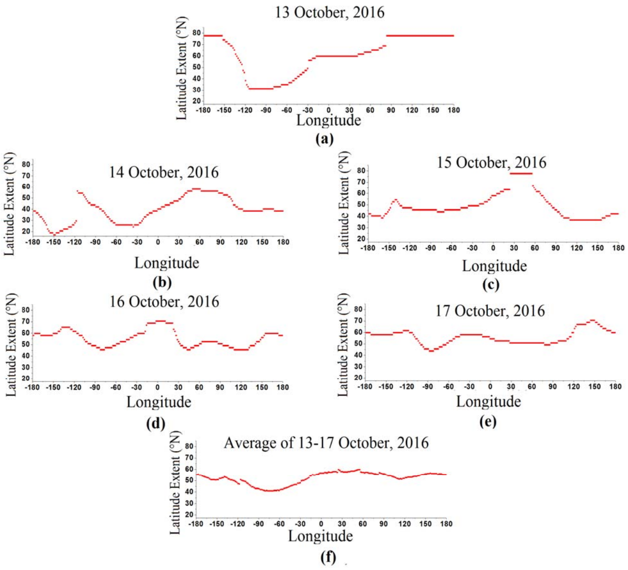

Figure 5. (a)-(e) Latitudinal extent of the 20% decrement in O/N_2 from quiet days during October 13-17, 2016 and (f) the average latitudinal extent of the 20% decrement in O/N_2 from quiet days during October 13-17, 2016.

Table 3. Comparative study between maximum hourly averaged AE index and maximum latitudinal extent of 20% decrement in O/N_2 ratio during October 13-17, 2016

Date	Maximum Hourly Averaged AE Index (nT)	Maximum Latitudinal Extent (°N)	Local Time (LT)
13 October, 2016	1200	31.19	16:09-16:17
14 October, 2016	865	16.93	16:01-16:09
15 October, 2016	333	36.53	15:52-15:59
16 October, 2016	770	45.45	15:43-15:51
17 October, 2016	693	43.66	15:32-15:41

The corresponding correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index for October 13-17, 2016 is shown at Figure 6.

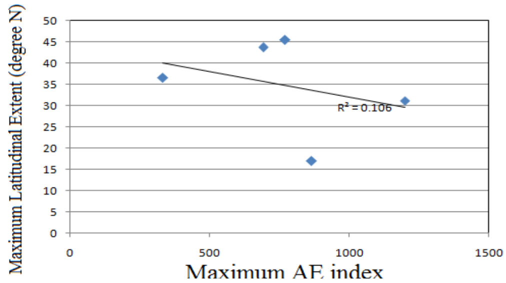

Figure 6. Correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index during October 13-17, 2016.

During the storm period of October 13-17, 2016, the maximum average latitudinal extent of 20% decrement in O/N_2 ratio was observed at US continent region (45°-90° W). This decrement in O/N_2 ratio is also positively correlated with the reduction in vertical TEC in this region obtained from global CEDAR Madrigal worldwide GPS network. Some representative dates (13-14 October, 2016) are shown in Figure 7. The latitudinal extent of the propagation of the 20% decrement in O/N_2 ratio was minimum at the longitude sector of 30°-75°E (Asia-Europe continent sector).

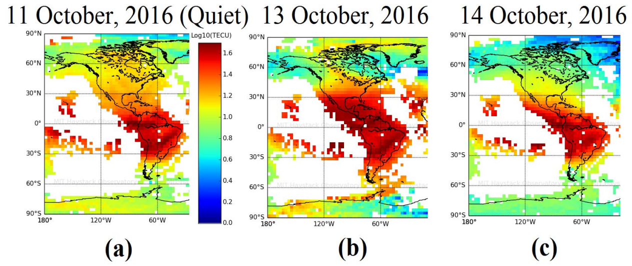

Figure 7. Median Vertical TEC deviation during October 13-14, 2016 from geomagnetic quiet day (October 11, 2016) at 20 UT (16 LT at 60°W) using CEDAR Madrigal GPS TEC data.

5. Latitudinal extent of O/N_2 ratio during September 7-11, 2017

During this storm period, maximum latitudinal extent of 20% decrement in O/N_2 ratio is observed during 8 September, 2017 (16.93°N geographic, 18.17°-19.91°N geomagnetic, Figure 8). Peak Dst index has been observed on the same day 1 UT (-142 nT). AE index surpasses 1000 nT during 7 and 8 September, 2017. Both Dst and AE index have shown secondary enhancement during 13-14 UT of 8 September, 2017. The maximum AE index is observed during 14 UT, 8 October, 2017 (1442 nT). AE index again goes above 500 nT briefly during 0 UT on September 11, 2017. The latitudinal extent is also extended up to 40.09°N on September 11, 2017 from 73.96°N on September 10, 2017. The comparisons between maximum hourly AE index and corresponding maximum latitudinal extent of 20% decrease in O/N_2 ratio from quiet days are shown in Table 4.

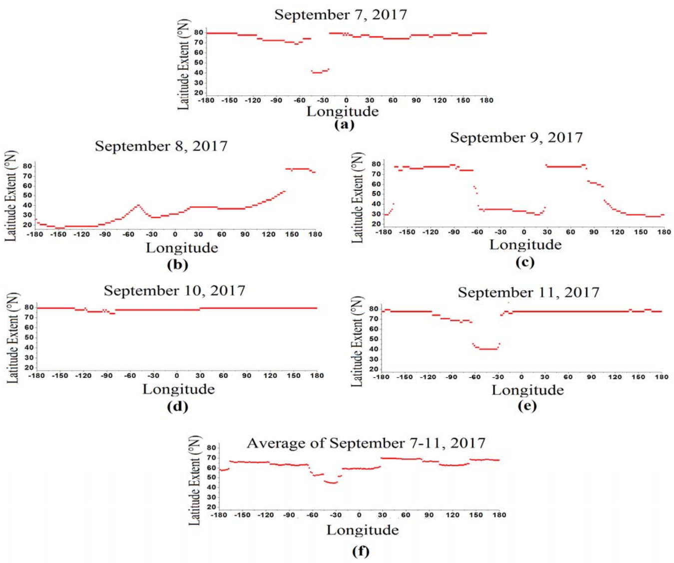

Figure 8. (a)-(e) Latitudinal extent of the 20% decrement in O/N_2 from quiet days during September 7-11, 2017 and (f) the average latitudinal extent of the 20% decrement in O/N_2 from quiet days during September 7-11, 2017.

Table 4. Comparative study between maximum hourly averaged AE index and maximum latitudinal extent of 20% decrement in O/N_2 ratio during September 7-11, 2017

Date	Maximum Hourly Averaged AE Index (nT)	Maximum Latitudinal Extent (°N)	Local Time (LT)
7 September, 2017	1157	40.09	10:47-10:56
8 September, 2017	1442	16.93	10:35-10:45
9 September, 2017	387	27.62	10:24-10:34
10 September, 2017	498	73.96	10:14-10:23
11 September, 2017	521	40.09	10:03-10:12

The corresponding correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index for September 7-11, 2017 is shown at Figure 9.

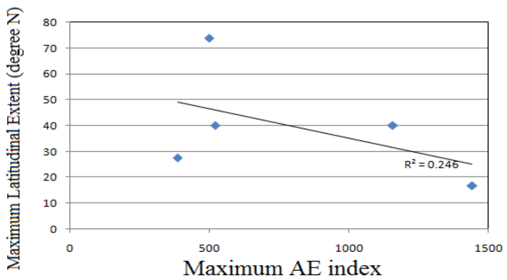

Figure 9. Correlation curve between maximum latitudinal extent of 20% decrement in O/N_2 ratio and AE index during September 7-11, 2017.

During this storm period, maximum average latitudinal extent of 20% decrement in O/N_2 ratio has been observed in 20°-60°W longitudes (Atlantic sector). Effects of this latitudinal extent are studied on GPS TEC from CEDAR Madrigal data. But not much correlation between latitudinal extent of decrease in O/N_2 ratio and vertical TEC variation was observed during this geomagnetic storm. The latitudinal extent was again minimum at longitude sector of 30°-75°E (Asia-Europe continent sector).

6. Summary and Conclusions

The study of latitudinal extent of 20% decrease in O/N_2 ratio is restricted during moderate solar activity periods and into northern hemisphere in this paper. From the studies being conducted, it has been observed that during all three storms, the decrement of O/N_2 ratio and subsequent transfer to middle and low latitude is prominently dependent on AE index. The latitudinal extent of the decrement of O/N_2 ratio is mainly seen near Pacific and Atlantic region. The extent is limited at Asian and European land sectors. A decrement of vertical TEC is also observed using CEDAR Madrigal data in accordance with decrement in O/N_2 ratio during March 2015 and October 2016 storm near Pacific and Atlantic region. Not much effect is observed on vertical TEC during September 2017 storm at Atlantic region.

7. Acknowledgements

The TIMED/GUVI O/N_2 data is obtained from guvitimed.jhuapl.edu. The geophysical information regarding storms such as their intensity, corresponding Dst index, AE index are obtained from World Data Center for Geomagnetism, Kyoto, Japan, The Space Physics Data Facility (SPDF), NASA and spaceweather.com. The authors want to thank Dr. Anthea Coster for providing us Global TEC map from CEDAR Madrigal Database. These TEC data is obtained from Madrigal worldwide GPS receiver Network (1998-2018).

8. References

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