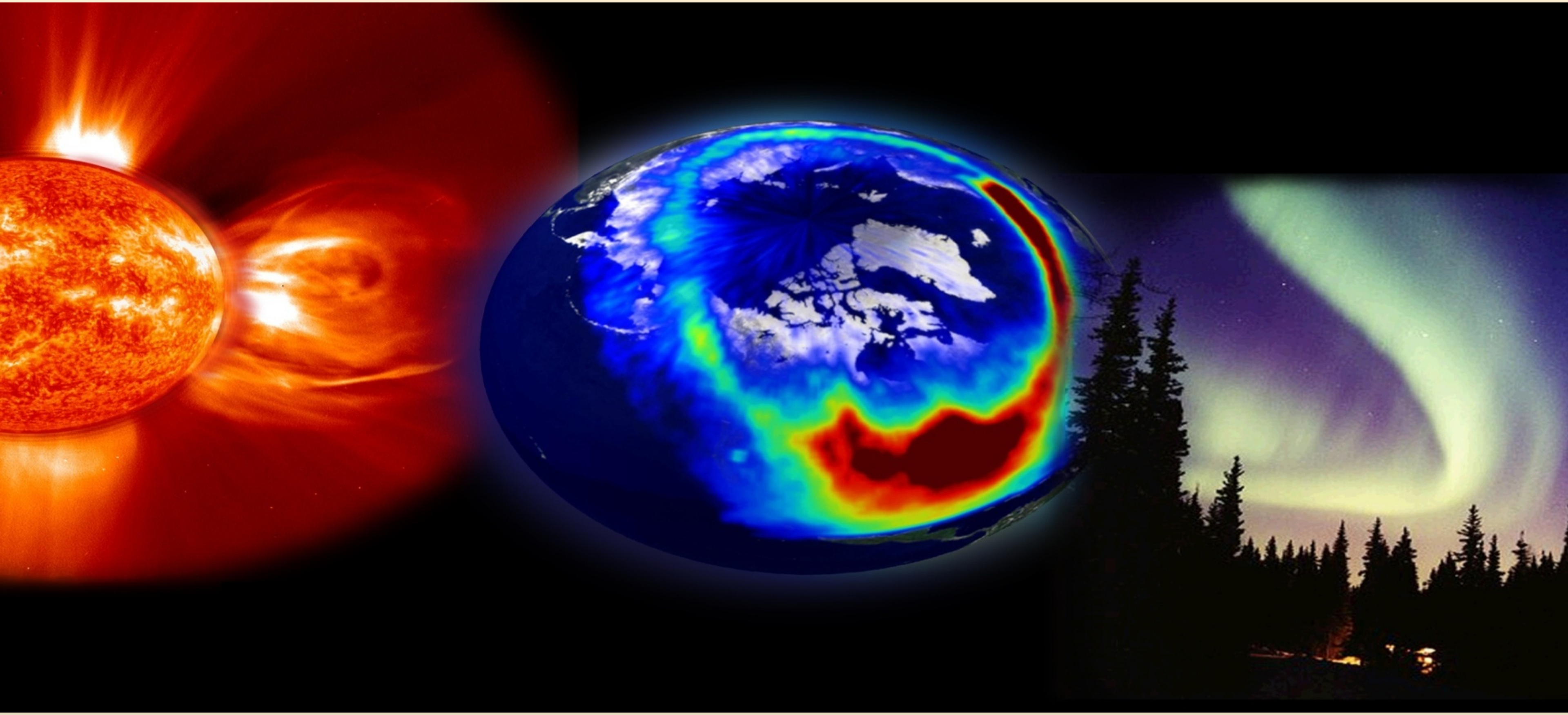
# Stratospheric warmings & Ionospheric F2- region Variability: O(1S)dayglow a proxy to thermospheric dynamics



*2014 AOSWA (Asia-Oceania Space Weather Alliance) Workshop*
*on*
*"Space Environment Impacts and Space Weather Forecast Models"*

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A.K Upadhayaya
CSIR-National Physical Laboratory, New Delhi, India

SSW & Ionospheric F2- region Variability: O(1S) dayglow
a proxy to thermospheric dynamics contd……..

Outline of talk :

- **Meteorological Influence on Ionosphere : SSW**
- **Observations and Results**
- **F2 region response to geomagnetic disturbances across Indian latitudes: $O(^1S)$ dayglow as a proxy to thermospheric dynamics**
- **Observations and Results**
- **Summary & Conclusions**

## Objective:

To examine Ionospheric F2- region, variability and sudden stratospheric warmings

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# Introduction

➢The possibility of links between the meteorological phenomena and the upper atmosphere have been discussed very profoundly during the last decade (***e.g. Hagan et al.,2001; Abdu et al., 2006; Lastovicka ,2006 ; Fuller-Rowell et al.,2008***) .

➢ One of the well known meteorological phenomenon which could be an important agent in this link is the large meterological variation in the winter time polar stratosphere, called the sudden stratospheric warming (SSW). During a SSW there is a sudden increase in stratospheric temperature, (**which could be as large as 70 K**), the polar vortex shifts off the pole and the zonal wind (U) become weak. This type of warming is designated as minor. However, if the vortex breaks up, and the zonal wind (U) changes direction then the event is designated as a major SSW.

➢Although there have been some early attempts for identifying any ionospheric response to meteorological events like the sudden stratospheric warmings from theory, as well as from measurements (**e.g. Liu and Roble 2002, Kazimirovsky et al., 1971 , Danilov and Vanina 2003**), the field has seen relatively a vigorous activity only recently.

Continue….

Most of these studies have been confined to the western hemisphere, particularly the 75ºW meridian. In view of the large longitudinal dependence of the equatorial electrodynamic perturbations during SSWs, we have attempted to examine ionospheric effects following SSW events of 2007, 2008 and 2009 in the Asian zone by using ionosonde data from six different stations. These stations cover a broad latitude range from 23º N to 45º N.

We find there are some perceptible changes in the ionosphere following these warmings at these stations.

We then compare the magnitude of these changes with the normal day-to-day and hour-to-hour variability which exists in the ionospheric F2 region even at times when there are no SSWs and solar and magnetic indices are quite stable and close to their lowest values.

# Observations and Analysis:

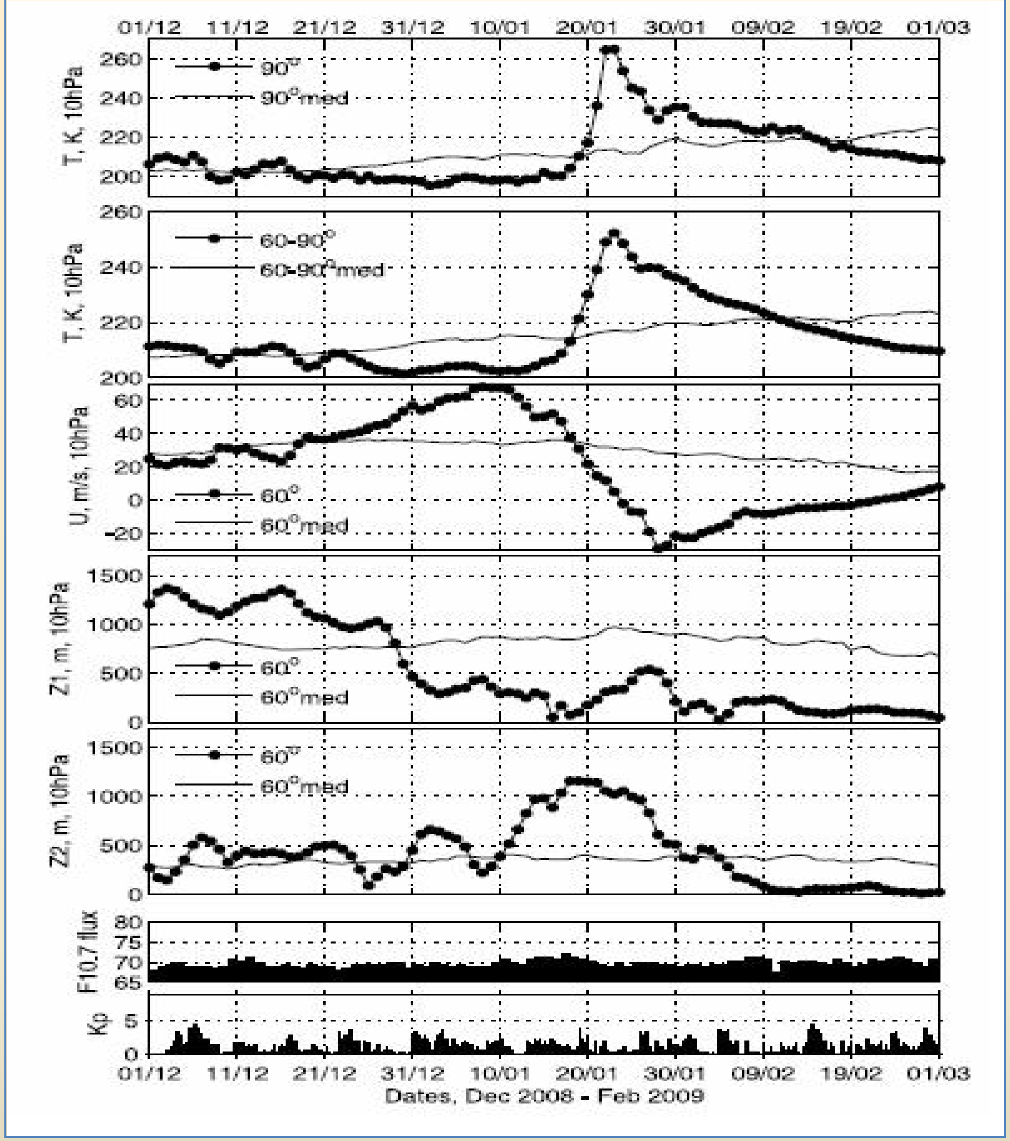
In our study for examining the ionospheric response to SSWs, we have used the hourly data of F layer critical frequency (foF2) from four Japanese stations namely Kokubunji, Okinawa, Yamagawa, Wakkanai and three Indian stations. Geographic and geomagnetic co-ordinates of these stations along with other relevant parameters are given in Table1. The foF2 data are based upon vertical sounding with ionosondes and have been downloaded from SPIDR web, managed by National Geophysical Data center, Boulder and from NICT Japan world data center. The ionosondes at these stations produce ionograms, which are recorded digitally on a computer storage medium. The digitally-recorded ionograms are collected from each station by a central computer and these are reduced to numerical values and to summary plots by an automatic processing system. In addition to Japanese stations, we have also used the ionospheric data from the low-mid latitude station Delhi and the equatorial crest anomaly station Bhopal. These data are obtained by using digital ionosonde system IPS-71 of Kel Aerospace Ltd.

Table 1. Locations of Ionosonde Stations

| Station | Geographic Latitude. | Geographic Longitude. | Geomagnetic Latitude | Dip |
|---|---|---|---|---|
| Trivandrum | 8.36°N | 76.6°E | $0.63^0$S | $0.5^0$ |
| Bhopal | 23.29°N | 77.46°E | 14.2° N | $33.2^0$ |
| Okinawa | $26.6^0$N | $121.8^0$E | $17.0^0$N | $36.8^0$ |
| Delhi | $28.2^0$N | $77.6^0$ E | $19.2^0$N | 42.4° |
| Yamagawa | 31.2° N | 130.6° E | 21.7° N | 43.8° |
| Kokubunji | 35.71°N | 139.49°E | 26.8°N | 49° |
| Wakkanai | 45.1° N | 141.7° E | 36.4° N | 59.3° |

**We have examined ionospheric response to the following SSW events.**

- **Winter of 2008-2009**
- **Winter of 2007-2008**
- **Winter of 2006-2007**



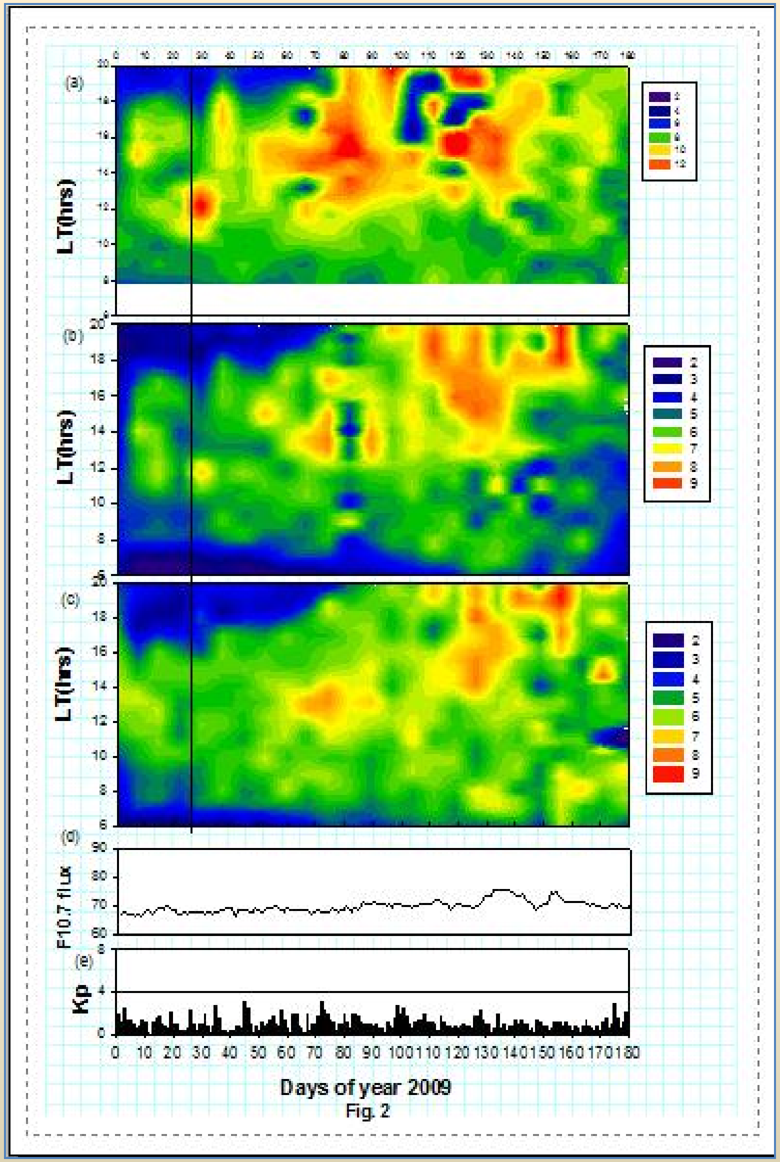

**Summary of stratospheric and geomagnetic conditions for the winter of 2008–2009.**

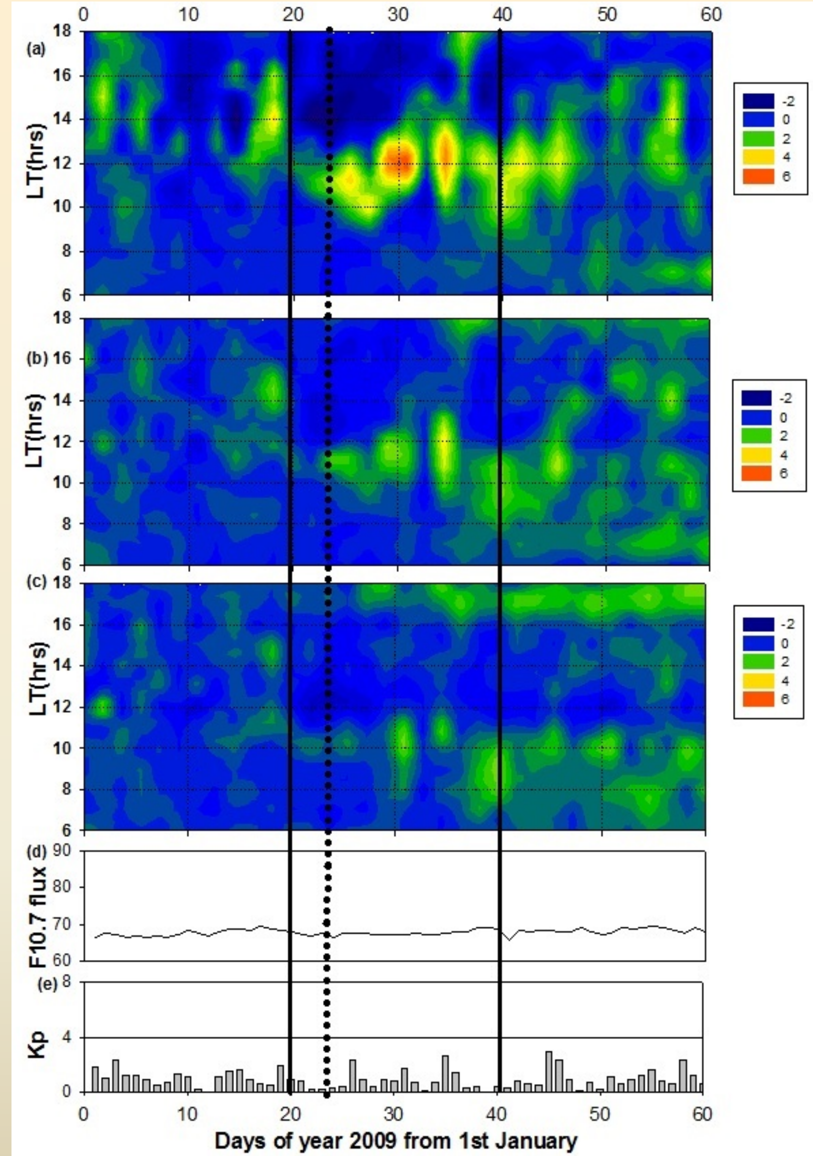
Peak of warming: 23-24 Jan 2009

**Fig 1. (Top to bottom): Stratospheric temperature at 90˚ N and 10 hPa (~32 km), zonal mean stratospheric temperature at 60˚ N–90˚ N, zonal mean zonal wind at 60˚ N, planetary wave 1 activity at 60˚ N and10 hPa, planetary wave 2 activity at 60˚ N and 10 hPa, F10.7 index, and Kp index. Lines indicate 30 year means of stratospheric parameters, and solid circles indicate data for the winter of 2008–2009.( From Goncharenko 2010 )**

# Winter of 2008-2009

Quiet period 3-12 Jan 2009 was used to characterize the normal behavior of quiet-time ionosphere.




**Plots of F2 layer critical frequency (foF2) and (ΔfoF2) with days of the year 2009 at (a) Okinawa, (b) Yamagawa and at (c) Kokubunji. Plots of F10.7 (d) and Kp indices (e) with days of the year 2009**

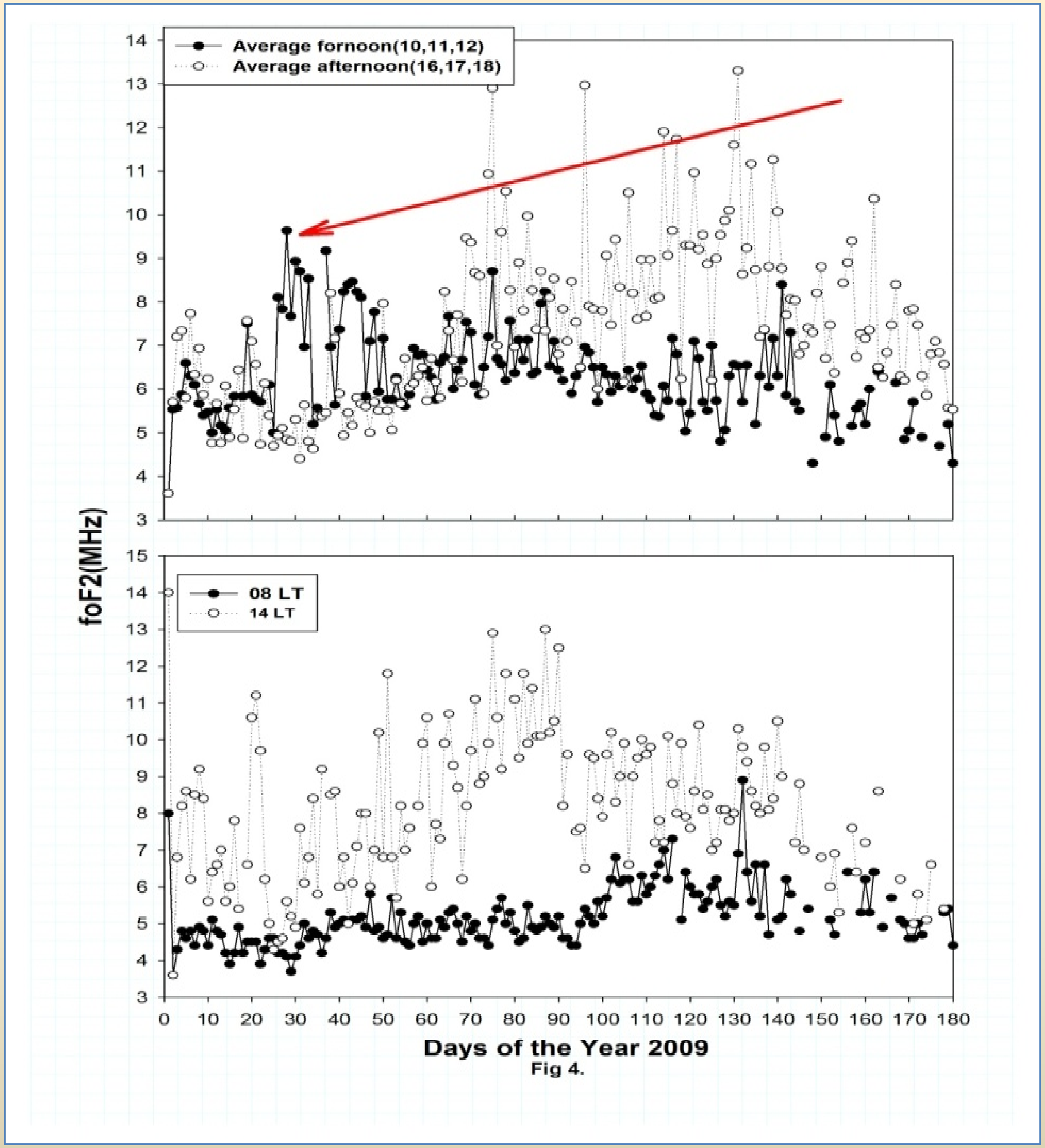
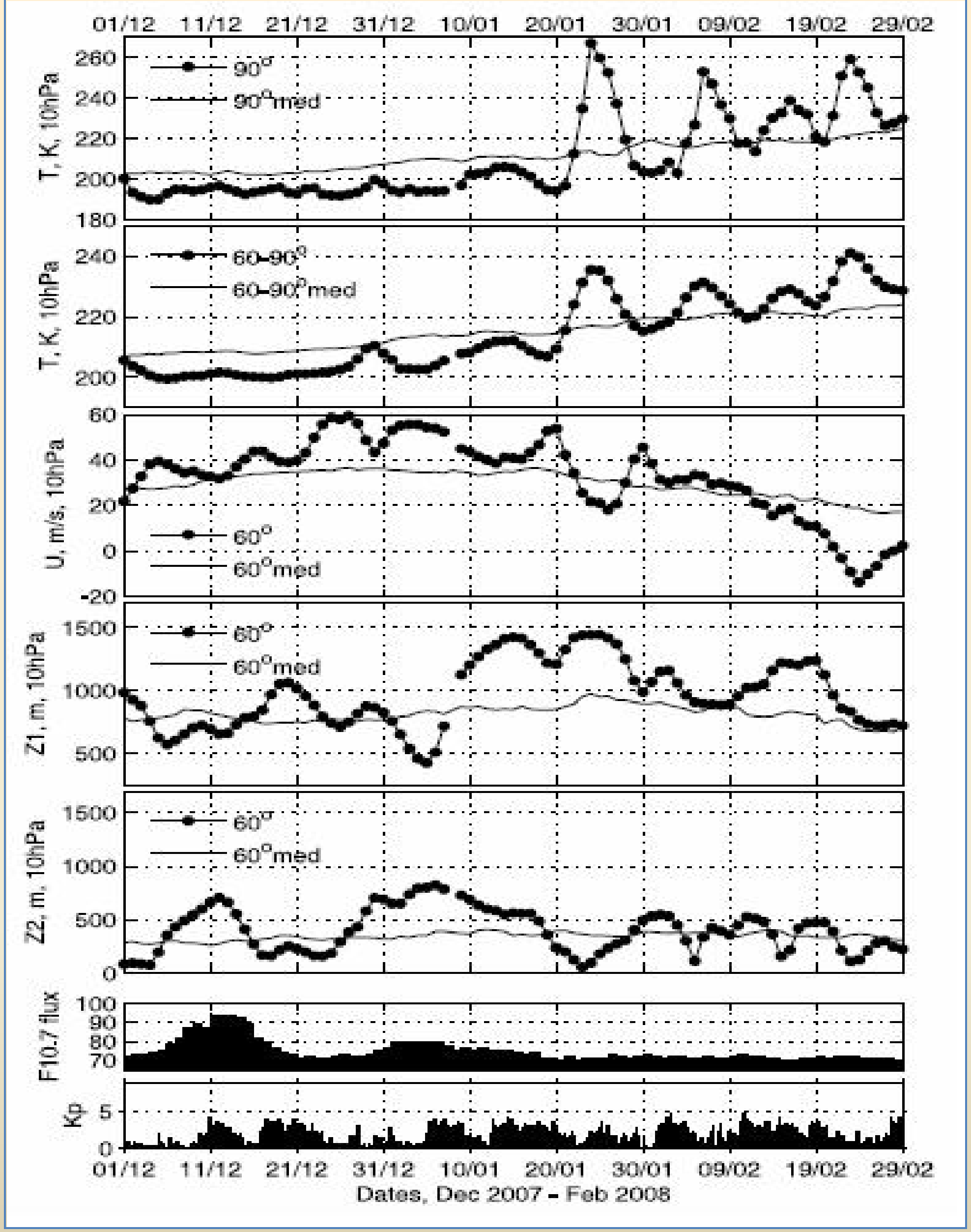



**Fig 4. Plot of average F2 layer critical frequency (foF2) with days of the year 2009 for forenoon and afternoon. Forenoon foF2 values remain higher than the afternoon for several days after the warming. On other days forenoon values are lower than the afternoon foF2 values.**

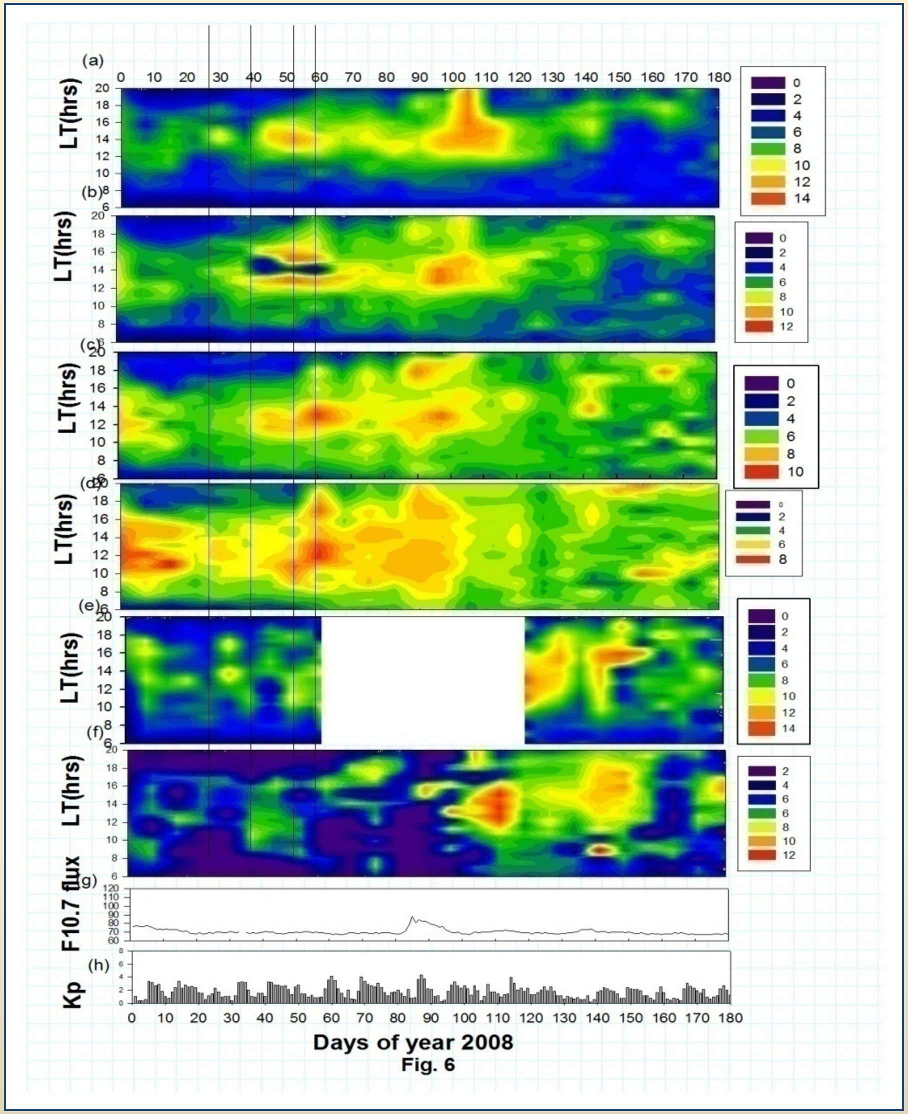


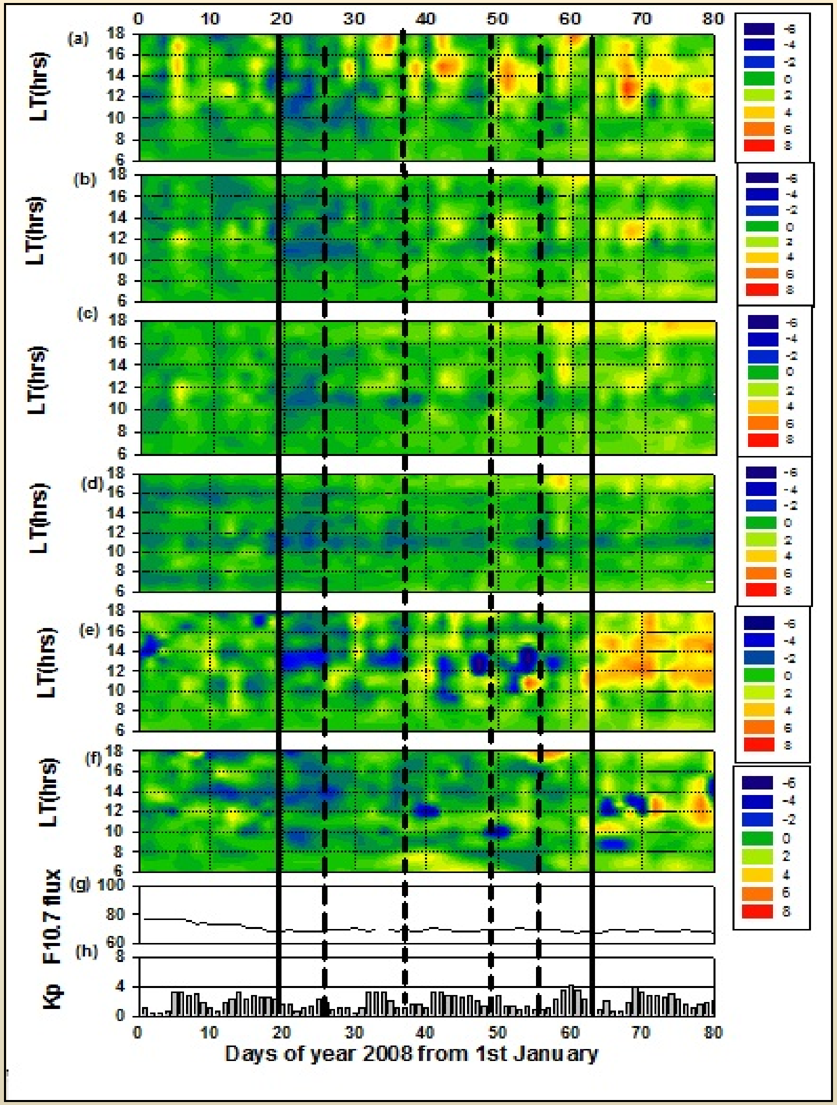

## Summary of stratospheric and geomagnetic conditions for the winter of 2007-2008

Quiet period 2-11 Jan 2008 was used to characterize the normal behavior of quiet-time ionosphere.

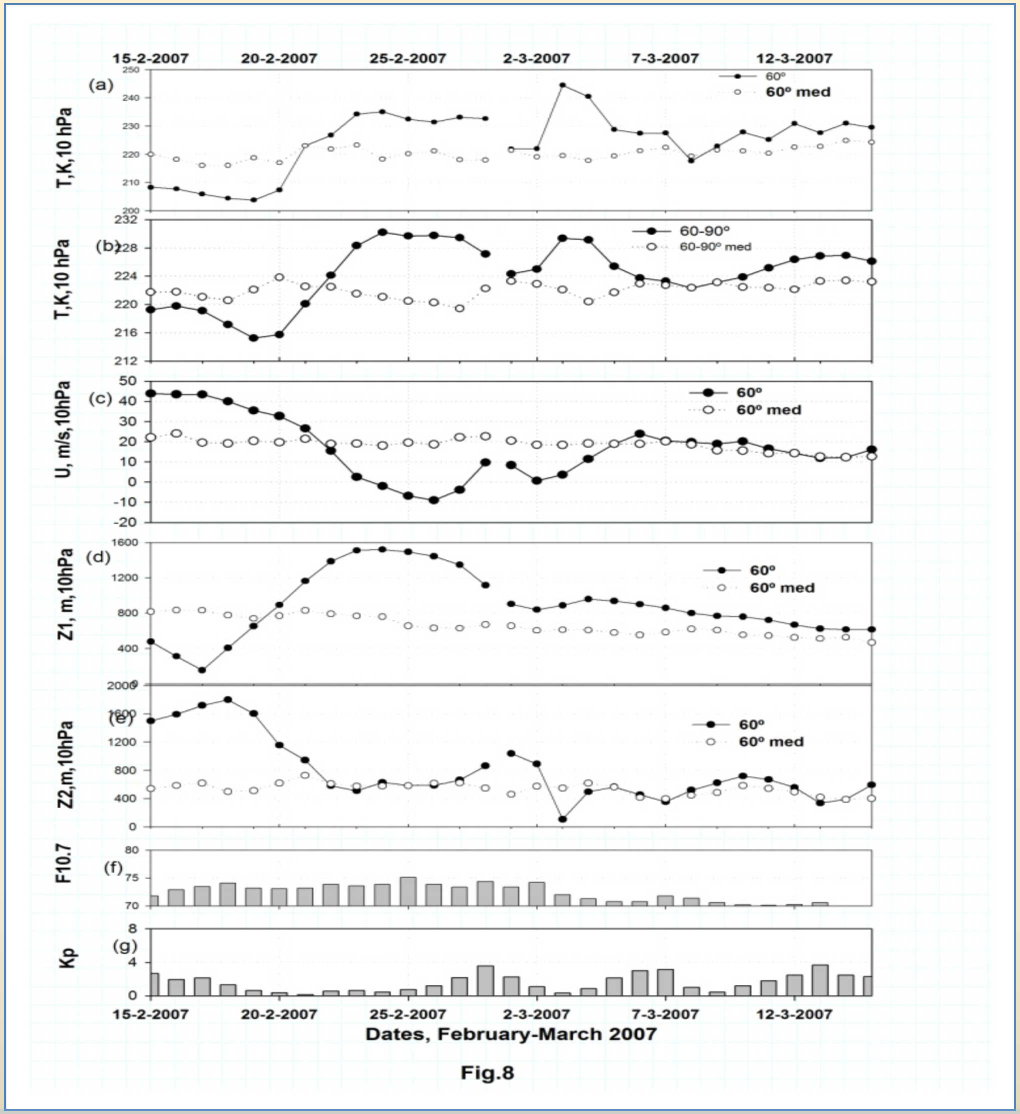
Same as Figure 1, but for the winter of 2007–2008. Four stratospheric warmings occurred, with peaks on 24 January, 6 February, 16 February, and 23 February, 2008.
(***From Goncharenko 2010*** )

# Winter of 2007-2008




**Plots of F2 layer critical frequency (foF2) and (ΔfoF2) with days of the year 2008 at (a) Okinawa, (b) Yamagawa and at (c) Kokubunji ,(d) Wakkanai (e) Bhopal, and (f) Delhi. Plots of F10.7 (g) and Kp indices (h) with days of the year 2008.**



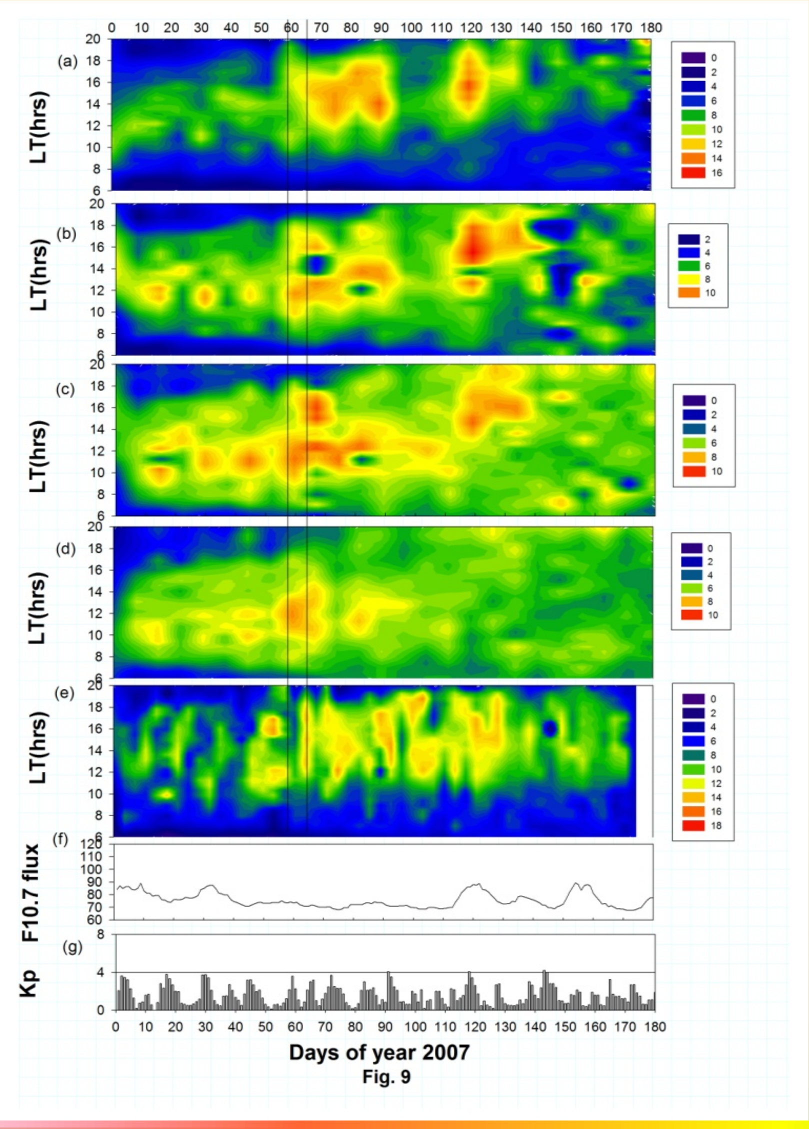

## Summary of stratospheric and geomagnetic conditions for the winter of 2007–2008.

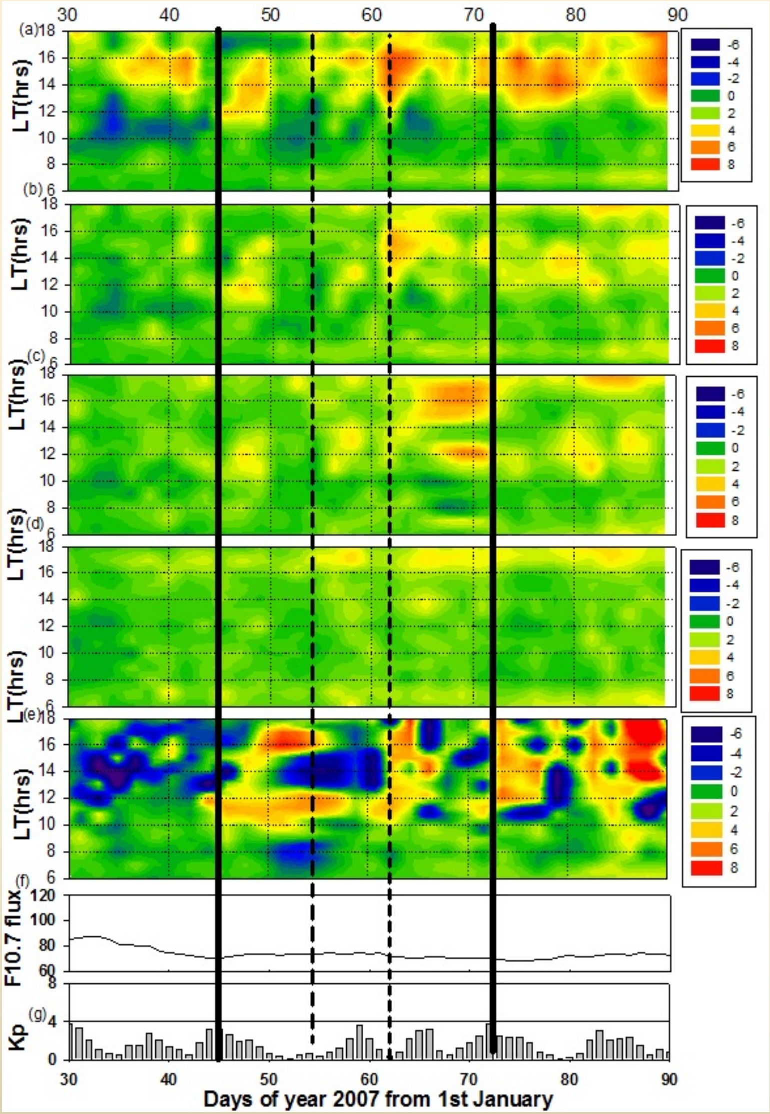
Peak of warming: 24-27 Feb 2007

2-4 March 2007.

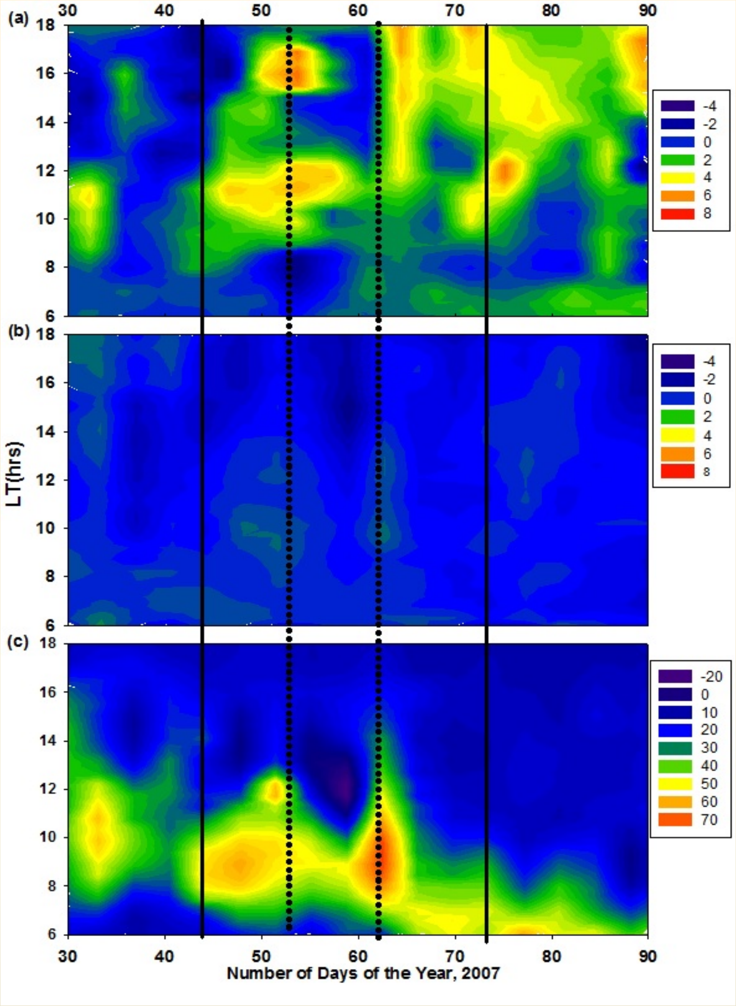
**Fig 1. (Top to bottom): Stratospheric temperature at 90° N and 10 hPa (~32 km), zonal mean stratospheric temperature at 60° N–90° N, zonal mean zonal wind at 60° N, planetary wave 1 activity at 60° N and10 hPa, planetary wave 2 activity at 60° N and 10 hPa, F10.7 index, and Kp index. Lines indicate 30 year means of stratospheric parameters, and solid circles indicate data for the winter of 2007–2008).**

# Winter of 2007-2008

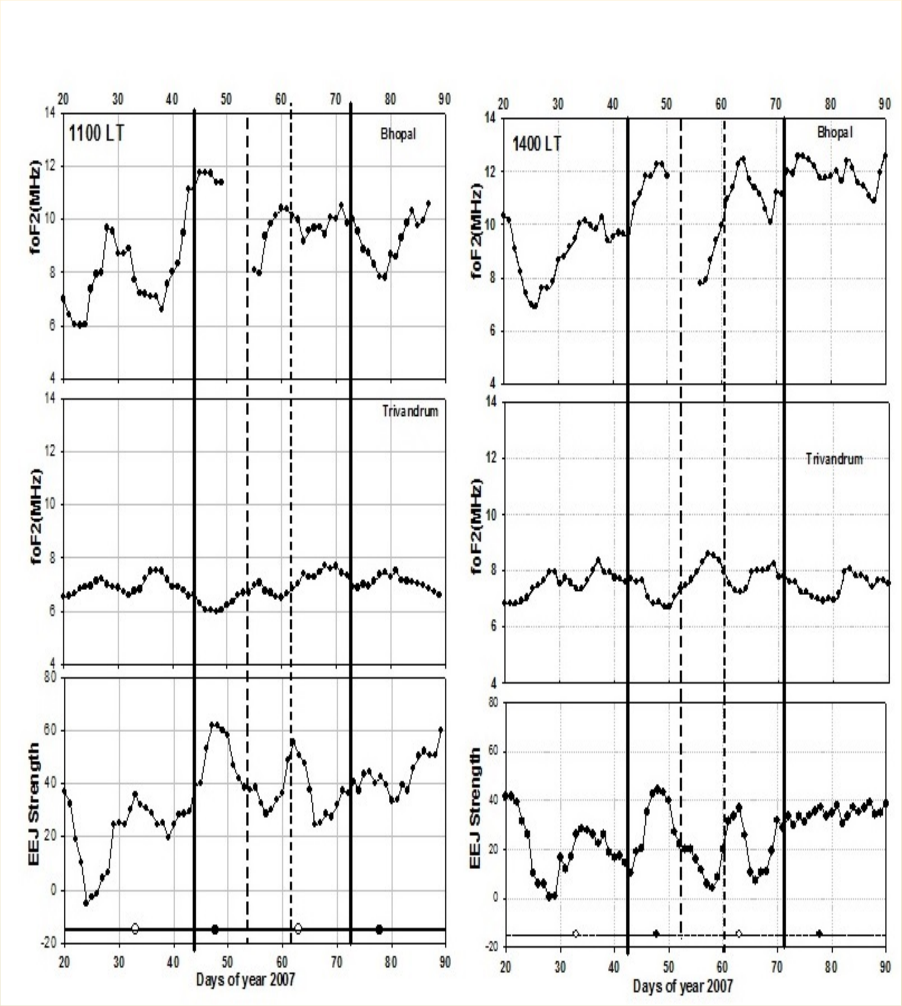


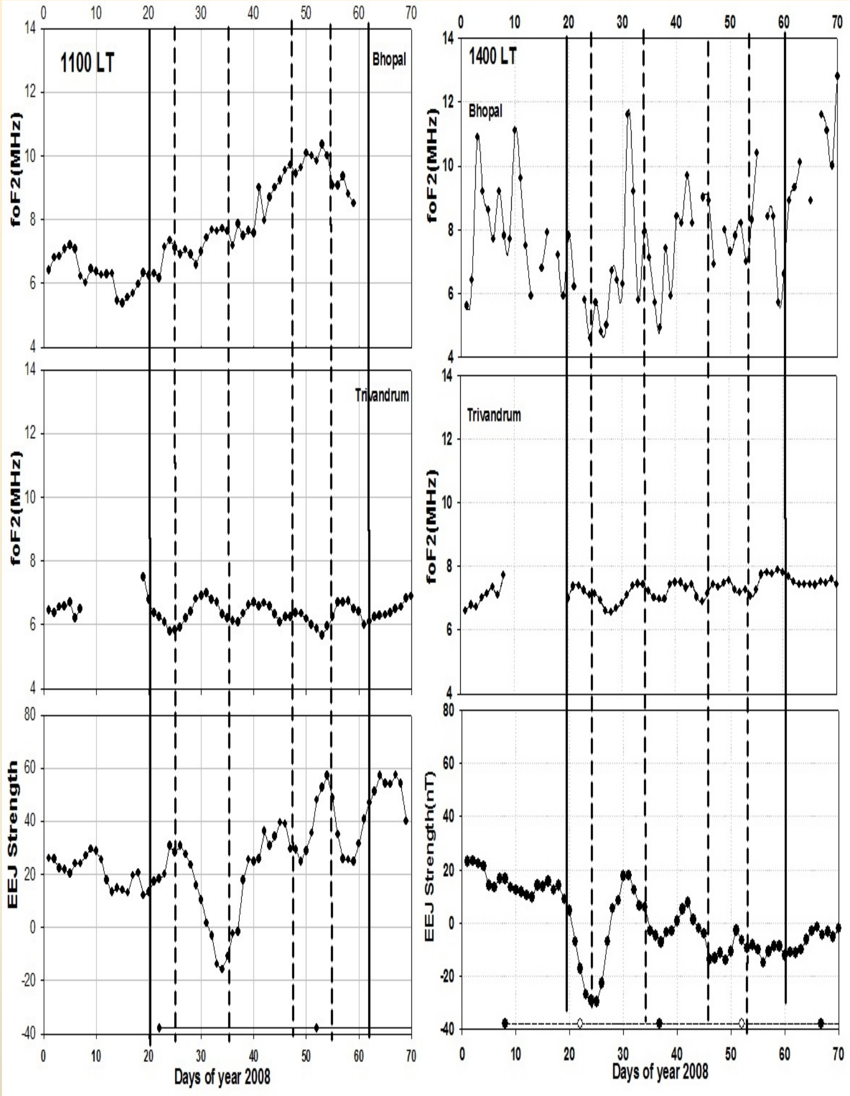

Plots of F2 layer critical frequency (foF2) and (ΔfoF2) with days of the year 2008 at (a) Okinawa, (b) Yamagawa , (c) Kokubunji ,(d) Wakkanai and (e) Bhopal. Plots of F10.7(g) and Kp indices(h) with days of the year 2007.



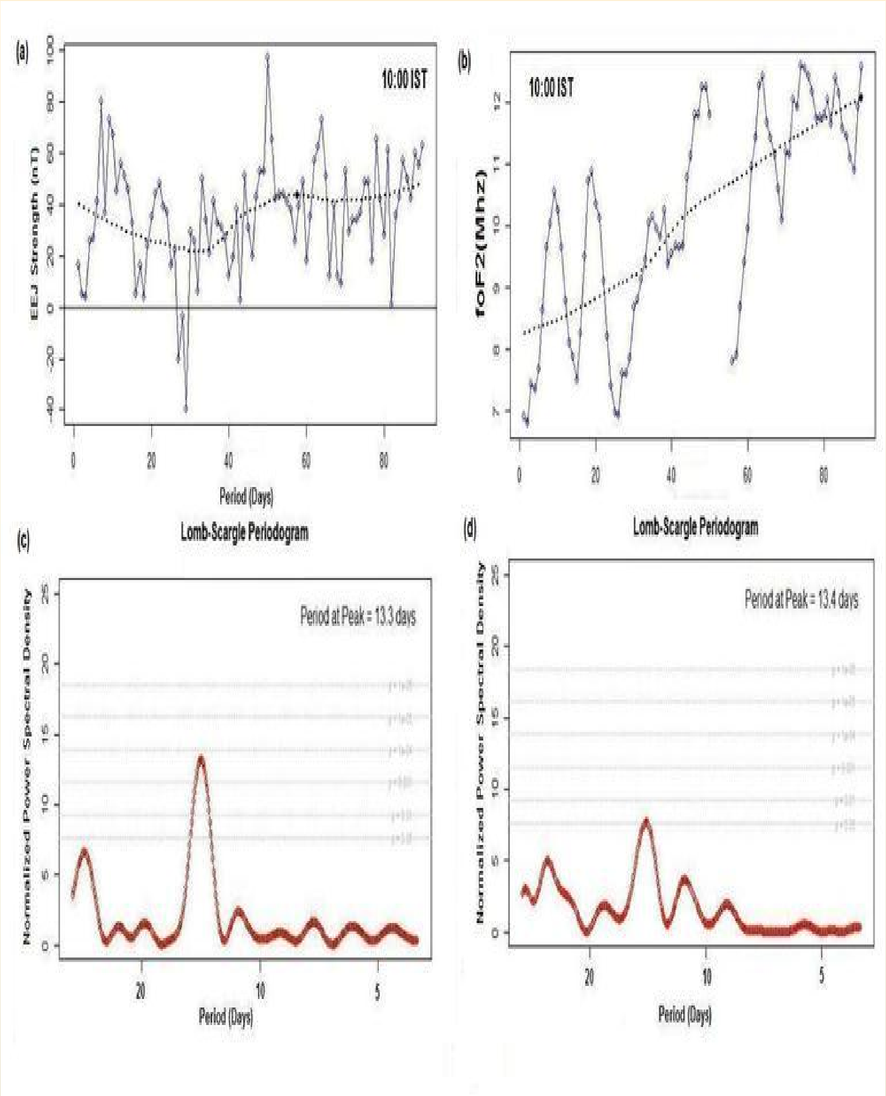

Plots of variation of foF2 (ΔfoF2) from normal quiet period at (a) Bhopal and at (b) Trivandrum along with the EEJ strength (c) for the first six months of 2007



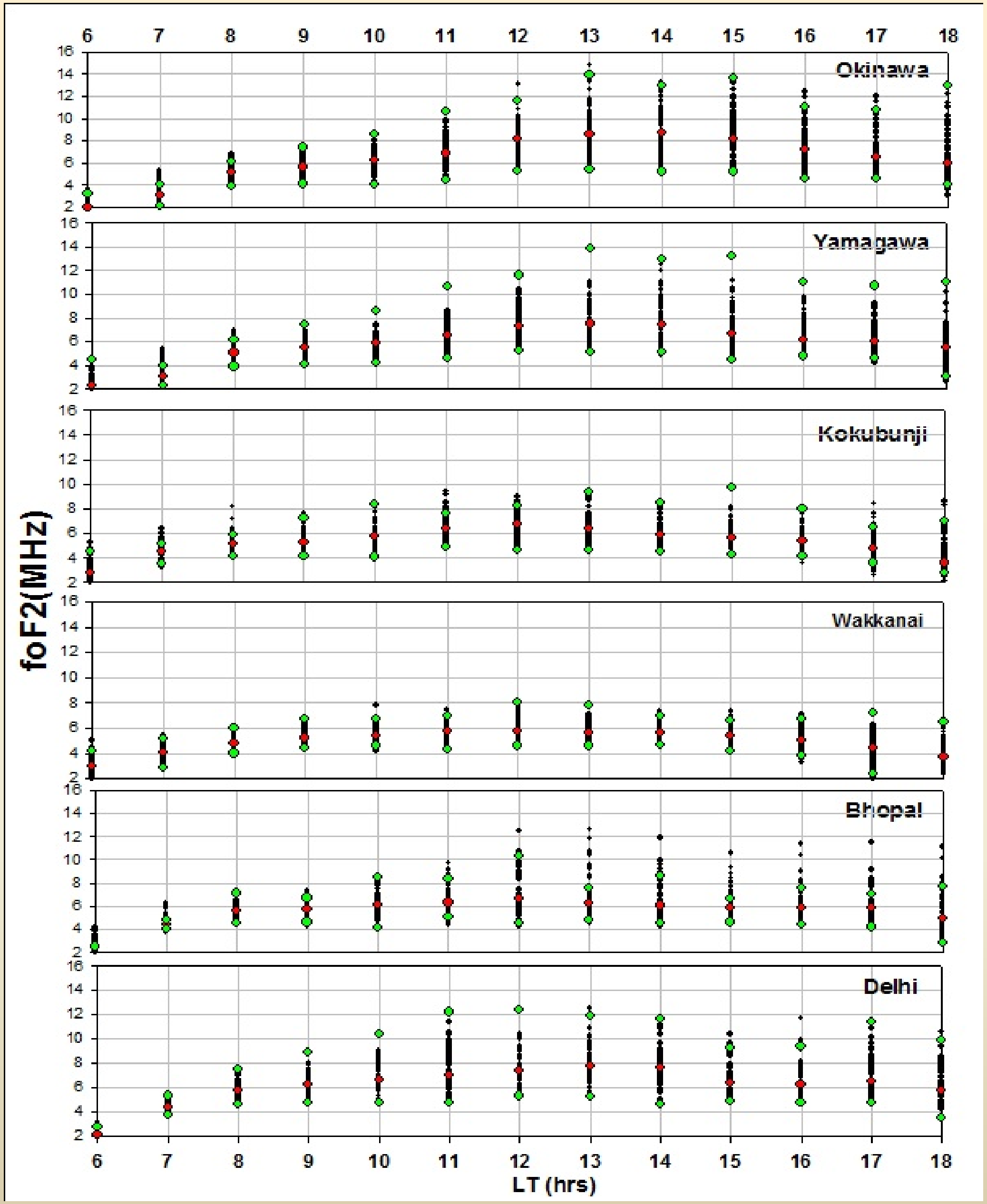

Plot of 5- point running average of foF2 at Bhopal and Trivandrum along with EEJ strength at 14:00 and 16:00 hrs Indian Standard Time (IST) for first three months of the year 2007




Plot of 5- point running average of foF2 at Bhopal and Trivandrum along with EEJ strength at 14:00 and 16:00 hrs Indian Standard Time (IST) for first three months of the year 2008




(a) EEJ and (b) foF2 over Bhopal during January to March 2007 and (c, d) their Lomb-Scargle spectral analysis.




**Plot of foF2 for all local times for the first six months of the year 2008**

# Results:

Based on our investigation on the extent of ionospheric changes observed following the three SSW events of 2007, 2008 and 2009 using ionosonde data from six different stations in the Asian zone, the following conclusion are drawn from the analysis.

- There are perceptible ionospheric perturbations which can be linked to these warmings.
- These perturbations are in the form of enhancements and depressions in foF2 resulting in peak electron density variations which could be larger than 200% when compared with the normal magnetically quiet time ionosphere.
- The low latitude station Okinawa (26.6$^0$N ,121.8$^0$E ) showed semidiurnal ionospheric perturbations during the SSW event of 2009, a feature previously reported from the total electron content measurements (e.g. Goncharenko et al., 2010b, Liu et al., 2011a, Anderson and Araujo-Pradere, 2010, Yue et al., 2010 , Sripathi and Bhattacharyya, 2012). This feature was not found during the SSW event of 2008. On the other hand the "EIA Crest" station Bhopal (23.29ºN, 77.46ºE), showed some evidence of 6-hour periodicity in ionospheric changes during the SSW event of 2007.
- During the SSW event of 2008, ΔfoF2 was predominantly depressed soon after the first warming. In the other two cases ΔfoF2 was enhanced.
- A 13-14 day periodicity in ionospheric perturbations was seen for the SSW event of 2007. Similar periodicity in ionospheric perturbations has earlier been reported by Fejer et al., 2010, 2011 and Sripathi and Bhattacharyya, 2012 during such SSW events. However we found some evidence of 3-4 and 4-5 day periodicities in ionospheric perturbation following the SSW events of 2009 and 2008 respectively.
- The highest and lowest values of foF2 during the six month period, January to June for the years 2007, 2008 and 2009 generally occurred during the SSW events at almost all the stations.
- In view of the large variability within the ionosphere, it is difficult to quantify the changes as well as the response times in the ionosphere to these stratospheric warmings.

Acknowledgments.

The authors are thankful to NICT Japan World Data Center for making the ionospheric data available on its web site

# Objective:

**F2 region response to geomagnetic disturbances across Indian latitudes: O($^1$S) dayglow as a proxy to thermospheric dynamics**

**Upadhayaya, A. K    JASTP ( 2015)**

# Introduction

➢The responses of the upper atmosphere to geomagnetic activity have been studied for a long period of time to the present, using experimental techniques as well as theoretical models. Many reviews on this topic cover the subject in details (e.g., Abdu, 1997; Fuller-Rowell et al., 1997; Rees, 1996; Schunk and Sojka, 1996; Buonsanto, 1999, Danilov and Lastoviˇcka 2001; Kelley et al., 2011, Balan et al., 2011).

➢ It is quite often seen that the normal ionospheric variability (which cannot be associated with an event) is at times even larger than the variability due to a transient (solar storm) or meteorological event. A good part of this unanswered reason for the variability could perhaps be related to possible changes in the neutral composition in thermosphere. While there are daily indices like F10.7 and Ap or Kp for solar ionizing radiation and magnetic activity respectively, there are none to represent daily changes in neutral atmosphere and electrodynamics. Briefly, this seems to be a major reason for the inability to explain the day-to-day and hour-to- hour variability seen in ionospheric F2- layer.

➢In the present study an attempt is made to examine the response of equatorial and low latitudes F-region ionospheric parameters (foF2 and h’F) during the disturbed periods of geomagnetic storms and to investigate the response of green line dayglow emission under quiet and strong geomagnetic conditions.

# Observations and Analysis:

The variation in F2 layer parameters over equatorial stations Thiruvananthapuram (8.5°N, 76.8°E), and low latitude station, Delhi (28.6°N, 77.2° E) are examined during five geomagnetic storms occurred at different local times of varying strength. The change in the orientation of Z component of Interplanetary Magnetic Field (IMF), Bz and variation in Dst index intensity are taken as the indicator of magnetic conditions. The geomagnetic storm events occurred during April, October and November - 2001, November-2003 and April-2006 having minimum Dst excursion of –271, -148, -221, –422 and -98 nT respectively are considered for the present study. The NRLMSISE-00 [Picone et al., 2002] and IRI-2007 [Blitza and Reinisch, 2008 ] empirical models which is incorporated in the GLOW model is used to specify the neutral atmosphere and initial electron density profile with HEUVAC solar flux model (Richard et al., 2006) . The 3- hour indices Ap are used in NRL MSIS00E for considering the magnetic activity dependence of the neutral constituents and temperature. The Glow model run is carried out under quiet (Ap=20) and strong (Ap=200) geomagnetic conditions in a common medium solar EUV ionizing radiation condition (F10.7=130)

### Summary of the Magnetic storm events.

| Year | Month | Begin Day | SSC* (EMT(EMT=UT+ 5) | Minimum Dst (nT) |
|---|---|---|---|---|
| 2001 | 04 | 11 | 2100 | -271 |
| 2001 | 11 | 24 | 1000 | -221 |
| 2001 | 10 | 1 | 0025 | -148 |
| 2003 | 11 | 20 | 1700 | -422 |
| | | | | |

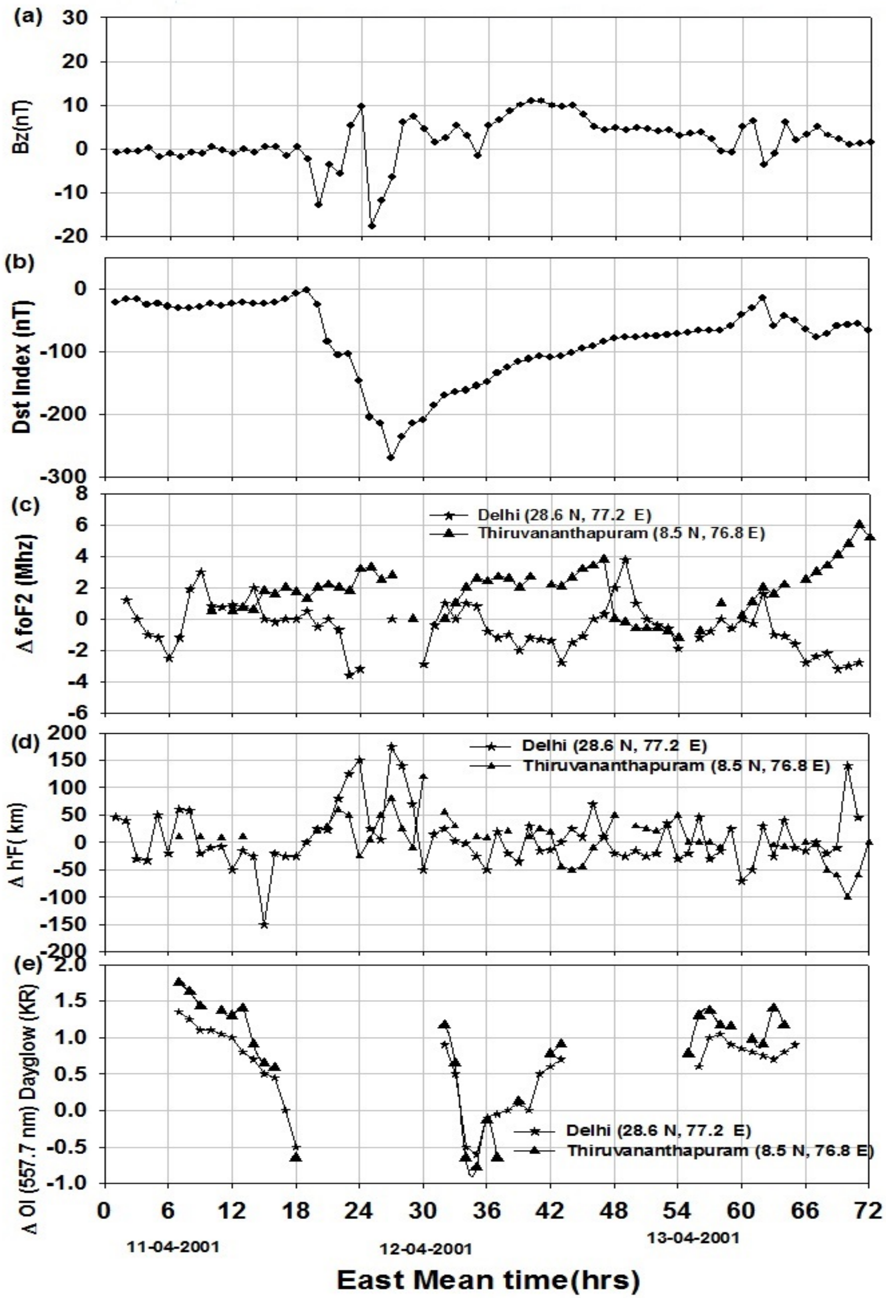

(a)
Bz(nT)
(b)
Dst Index (nT)
(c)
Δ foF2 (Mhz)
Delhi (28.6 N, 77.2 E)
Thiruvananthapuram (8.5 N, 76.8 E)
(d)
Δ h'F( km)
Delhi (28.6 N, 77.2 E)
Thiruvananthapuram (8.5 N, 76.8 E)
(e)
Δ OI (557.7 nm) Dayglow (KR)
Delhi (28.6 N, 77.2 E)
Thiruvananthapuram (8.5 N, 76.8 E)
11-04-2001
12-04-2001
13-04-2001
East Mean time(hrs)

Fig1.

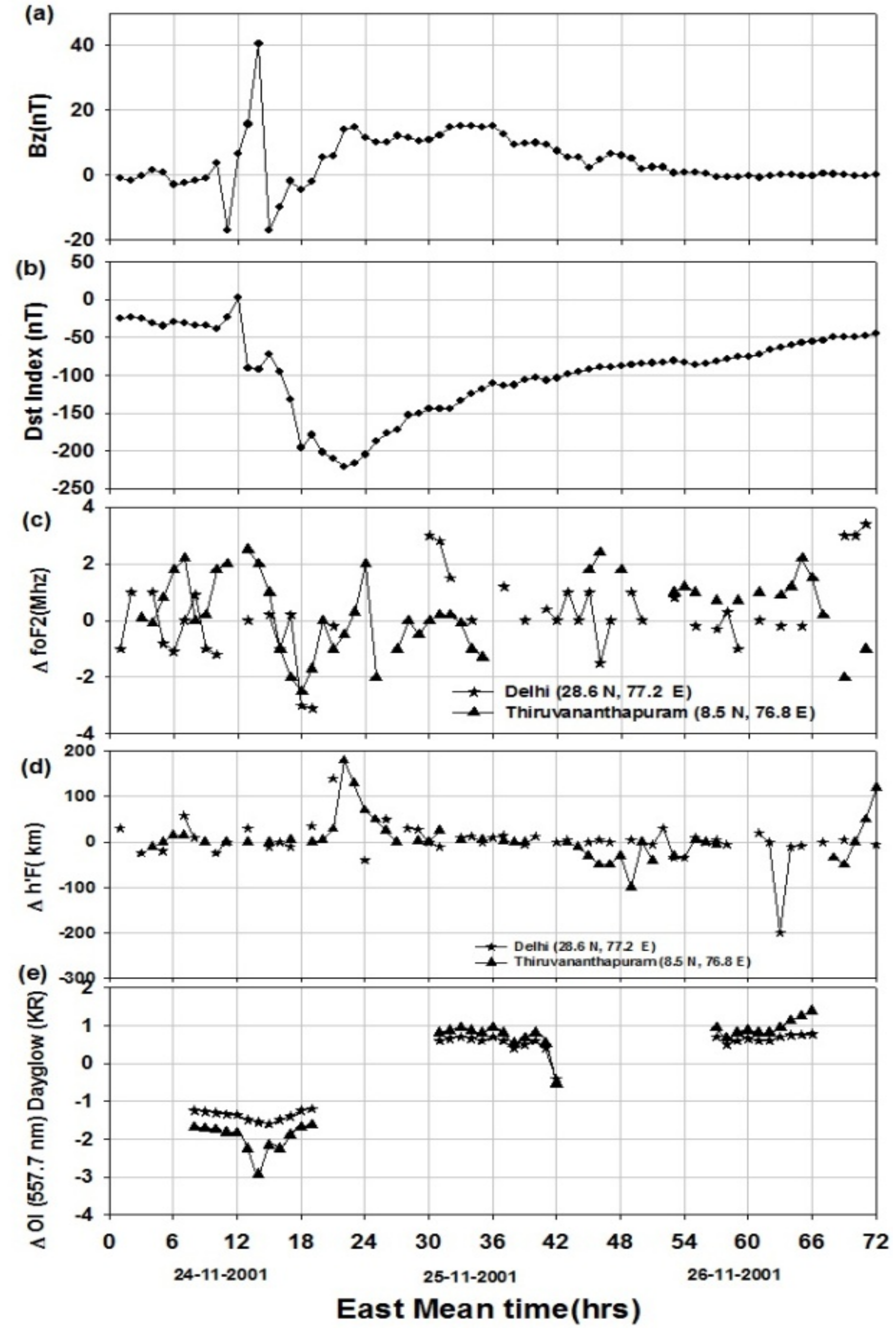

(a)
Bz(nT)
(b)
Dst Index (nT)
(c)
Δ foF2(Mhz)
Delhi (28.6 N, 77.2 E)
Thiruvananthapuram (8.5 N, 76.8 E)
(d)
Δ h'F( km)
Delhi (28.6 N, 77.2 E)
Thiruvananthapuram (8.5 N, 76.8 E)
(e)
Δ OI (557.7 nm) Dayglow (KR)
24-11-2001
25-11-2001
26-11-2001
East Mean time(hrs)

Fig 3.

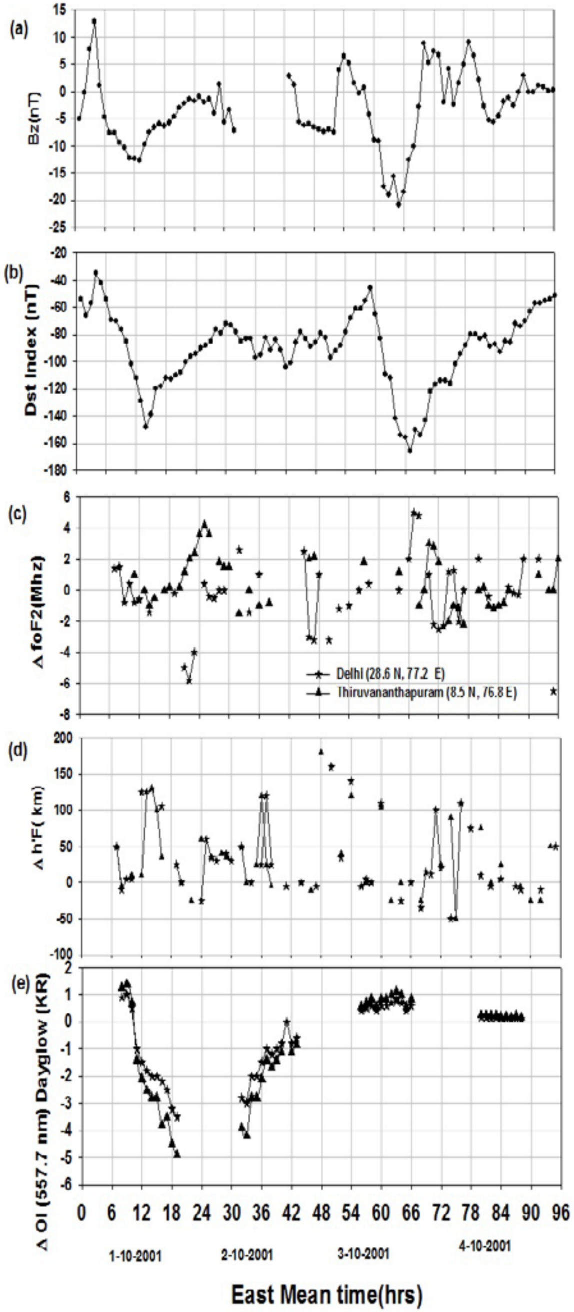



Fig 4.

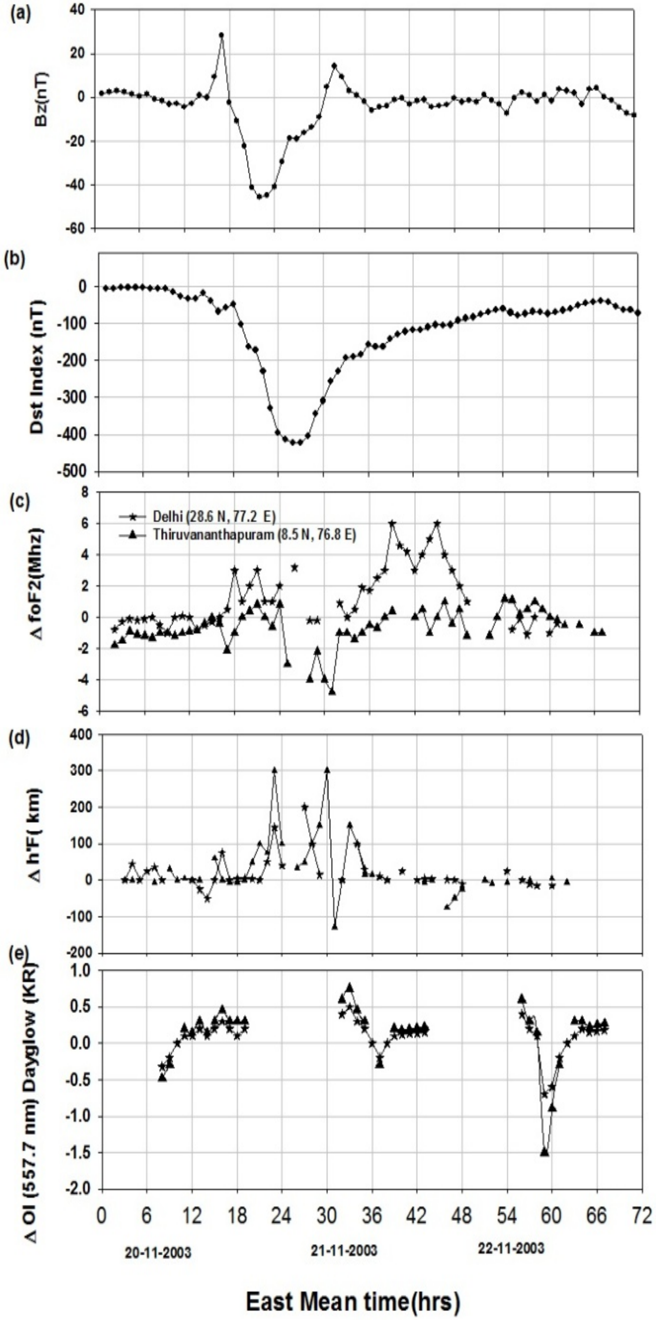



Fig 5.

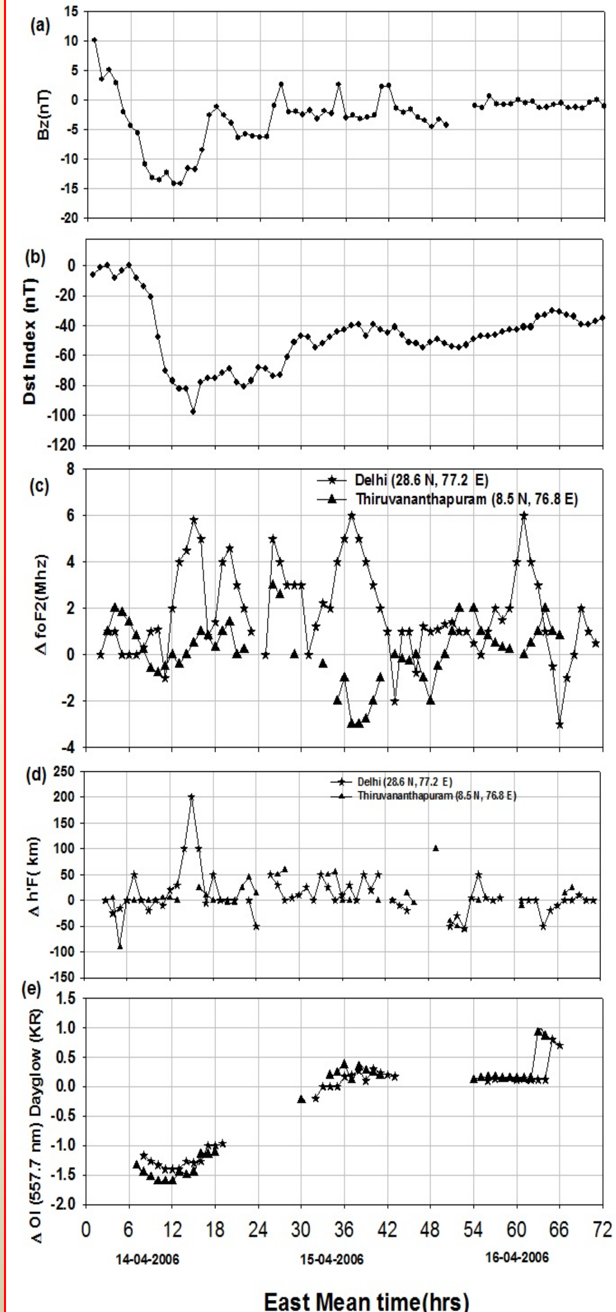
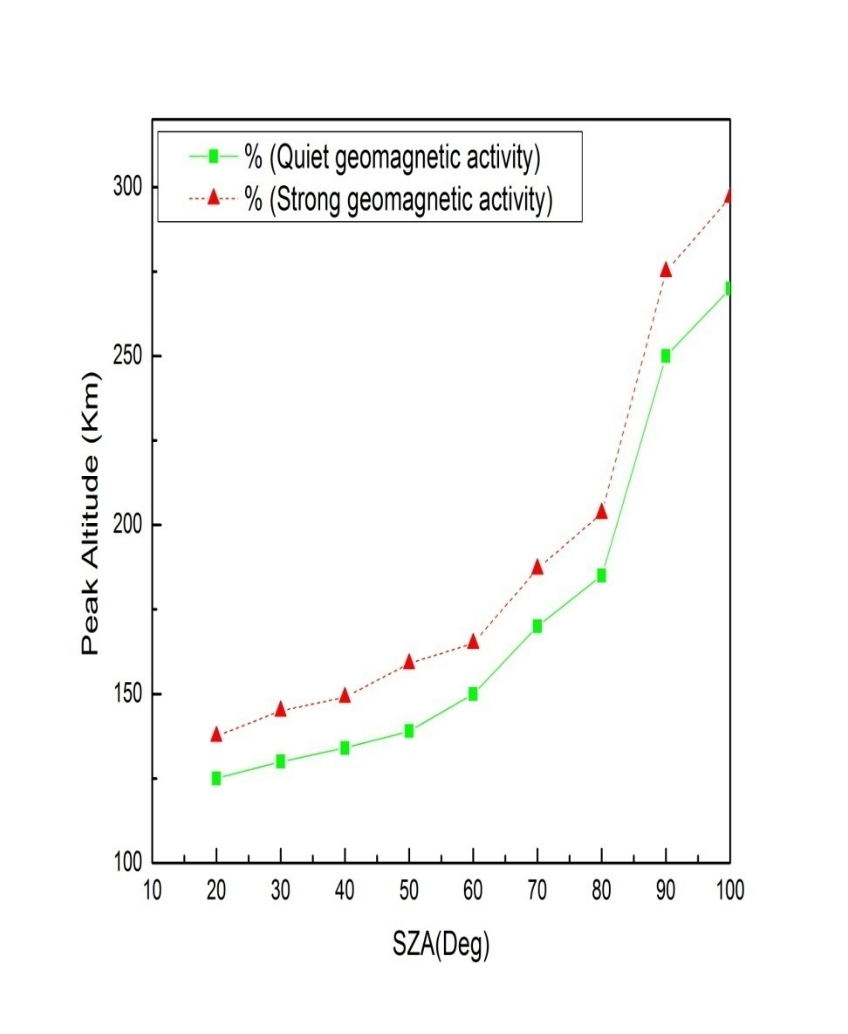
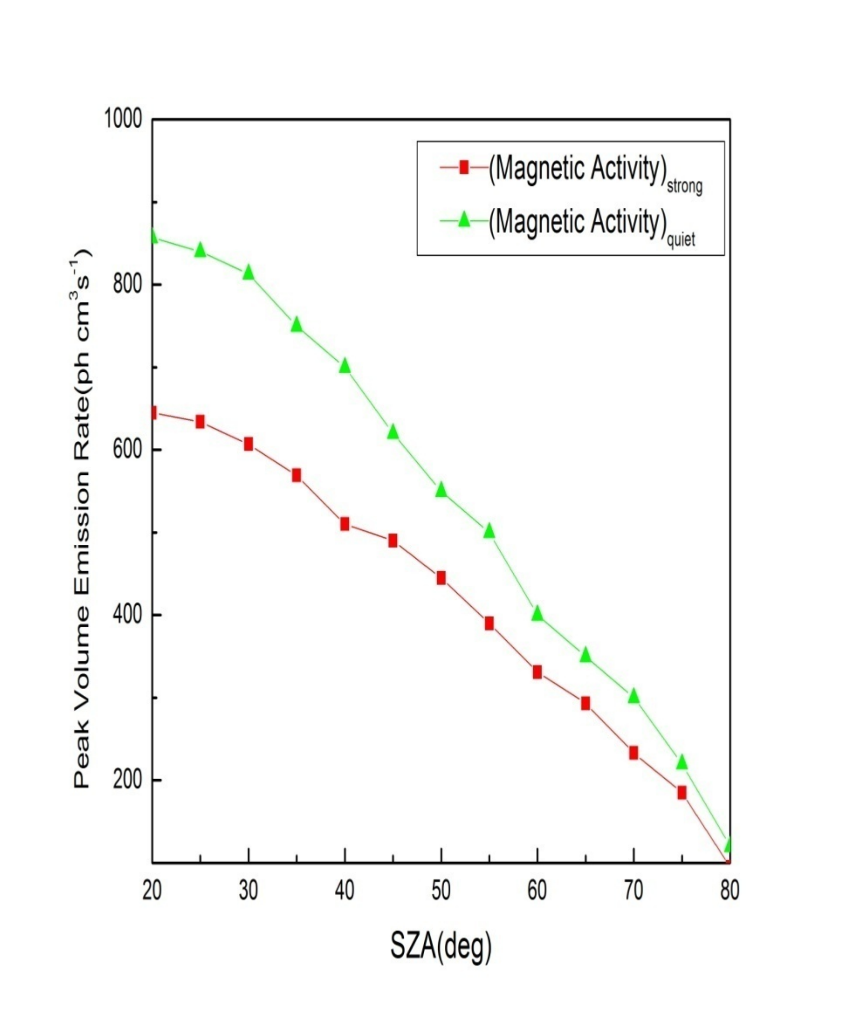


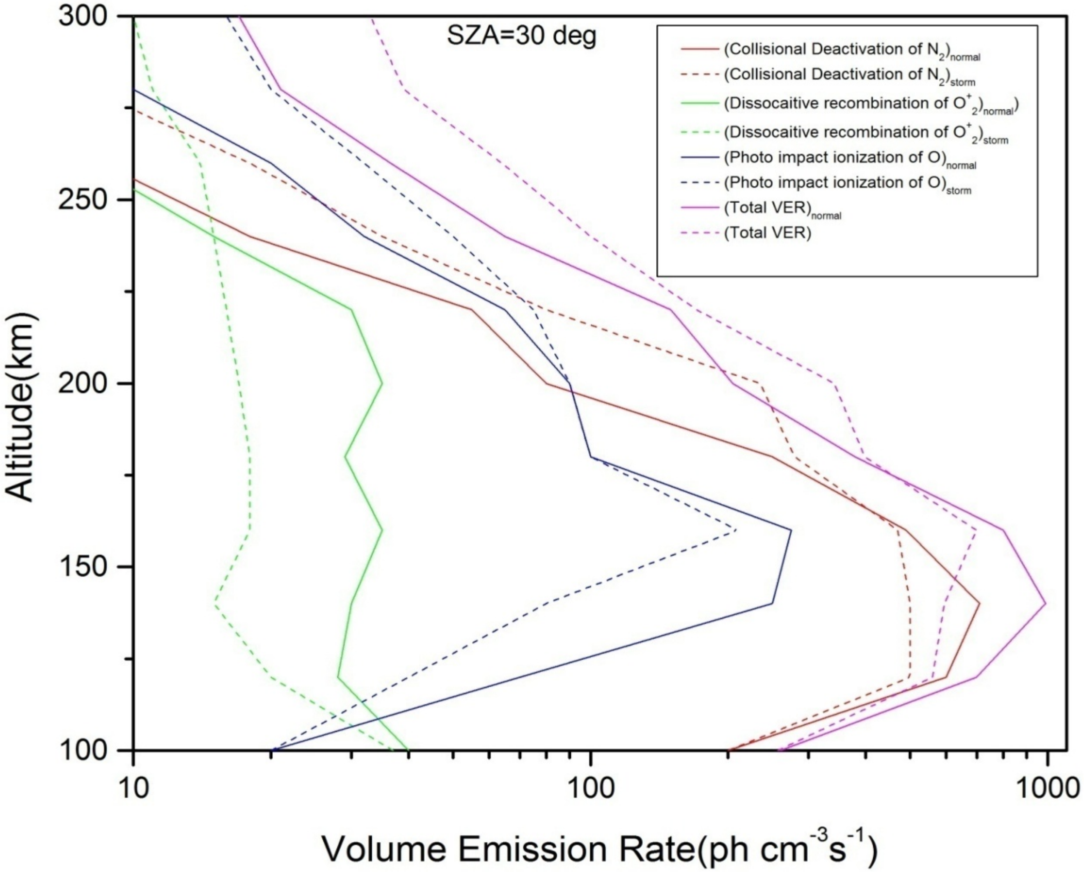

Fig 6



% (Quiet geomagnetic activity)
% (Strong geomagnetic activity)
Peak Altitude (Km)
SZA(Deg)

(Magnetic Activity)$_{strong}$
(Magnetic Activity)$_{quiet}$
Peak Volume Emission Rate(ph cm$^{3}$s$^{-1}$)
SZA(deg)




In the thermospheric emission peak region (150–175km) there are three important reactions which contribute to the production of O(1S). These sources are dissociative recombination (O2$^+$ + e), energy transfer from $N_2(A^3\Sigma u^+)$ to atomic oxygen ($N_2(A3\Sigma_u{}^+)$ +O) and the photoelectron excitation of atomic oxygen (e + O).

The variations under strong geomagnetic conditions causes a decrease in production processes for the reaction $N_2(A^3\Sigma u^+)$ to atomic oxygen, which lead to a decrease in emission rates of greenline dayglow emission

# Summary and Conclusions:

- The responses of F-region ionospheric parameters (foF2 and h’F) to geomagnetic storm at equatorial and low latitude stations are anti-correlated. A correlation coefficient varying from 0.44 to 0.62 was observed in ΔfoF2 between equatorial and low latitude station Thiruvananthapuram and Delhi for the five storm event considered. The reaction as seen at different ionospheric stations may be quite different during the same storm depending on both the geographic and geomagnetic coordinates of the station, storm intensity and the storm onset time.
- It is observed that the maximum deviation in F2 layer characteristic parameters (foF2 and h’F) is observed during the recovery phase of the storm. This indicates that ionospheric response is seen after few hours from the SSC of the storm and this time will in- turn depend on thermospheric dynamics.

- The variation in modeled greenline dayglow intensity at thermospheric peak height at equatorial and low latitude stations during these five storm events by in large showed a decrease coinciding with the onset of the storm. Variations of about 23 to 40 % in modeled greenline dayglow intensities were observed for the five storm events considered. Largest variation in the $O(^1S)$ intensity was seen for the severest of the storm considered.
- The variations under different geomagnetic conditions causes a decrease in production processes for the reaction $N_2(A^3\Sigma u^+)$ to atomic oxygen, which lead to decrease in emission rates of greenline dayglow emission.
- The updated GLOW model results shows that thermospheric peak of greenline dayglow emission shows a response to changing geomagnetic conditions, therefore greenline dayglow emission can be a potential candidate to be considered as a proxy to the thermospheric dynamics. However, the validation of above results is constrained due to lack of observations which will be taken up in future.

Thanks for you kind attention

Looking forward to collaborations…

The three main contributing reactions responsible for production of redline dayglow emission are :

1. The dissociative recombination (shown in green)

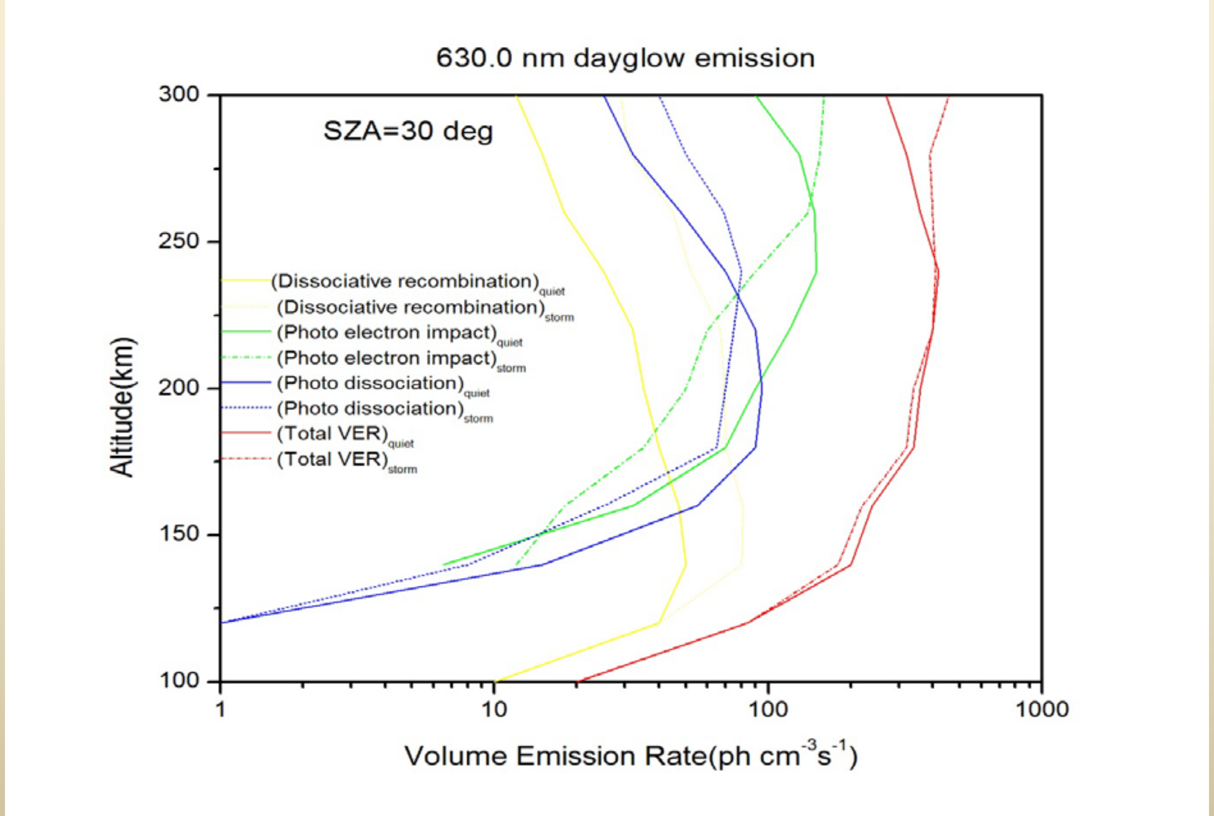
$$O_2^+ + e_{th} \rightarrow O(^1D) + O(^3P)$$

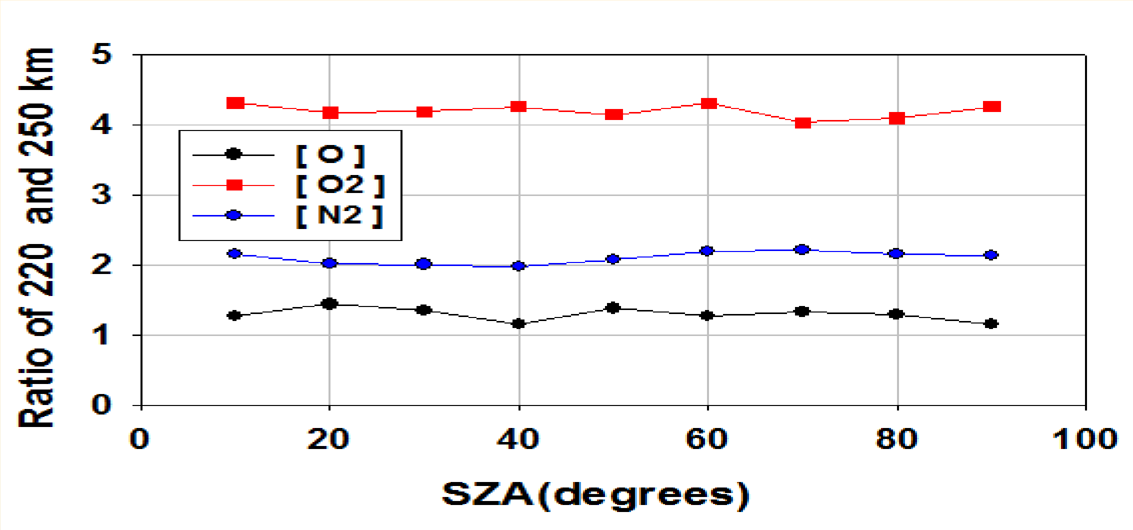
2. The photoelectron impact on atomic oxygen (shown in blue)

$$O(^3P) + e_{ph} \rightarrow O(^1D) + e_{ph}$$

3. Photo dissociation of molecular oxygen (shown in yellow)

$$O_2 + h\upsilon \rightarrow O(^1D) + O(^3P)$$






It can be seen from Fig. 3 that when the activity changes from low to high the ratio of concentration of atomic oxygen increases by a factor of 1.5, molecular oxygen by a factor 2.1 and molecular nitrogen by a factor of 4.3. As seen, the large increase in photo dissociation reaction under strong geomagnetic activity is primarily because of increase in $O_2$ concentration (which roughly increases by a factor of 4.3). The decrease in contribution from dissociative reaction is attributed to a decrease in electron concentration during high geomagnetic activity this result was reported by Culot et al., 2005. It has been found that the quenching of $O(^1D)$ excited state with molecular Nitrogen is the main dominating deactivation process leading to loss under strong geomagnetic conditions. So loss due to this reaction balances the increase in production due to other sources and thus results in a constant emission rate of $O(^1D)$ under varying geomagnetic conditions. Similar results with small variations in magnitudes as compared to our model study were also reported by Culot et al. 2005. In their report they have used one-dimensional fluid/kinetic model code (TRANSAR) to simulate the effects of varying geomagnetic activity on green and redline emissions. They have shown that the variation of green line intensity follows well the variation of the magnetic activity, but that the intensity of redline does not vary in an extent that could be measured or modelled. These observed results are also in accordance to the WINDII observations (Shepherd et al. 993).