Ionospheric plasma fluctuation response to space weather events over the equatorial and low latitude region.

Patrick Essien, C.A.O.B Figueiredo, H. Takahashi,
C.M. Wrasse,

Atmospheric Physics Lab
Department of Physics
University of Cape Coast
Ghana

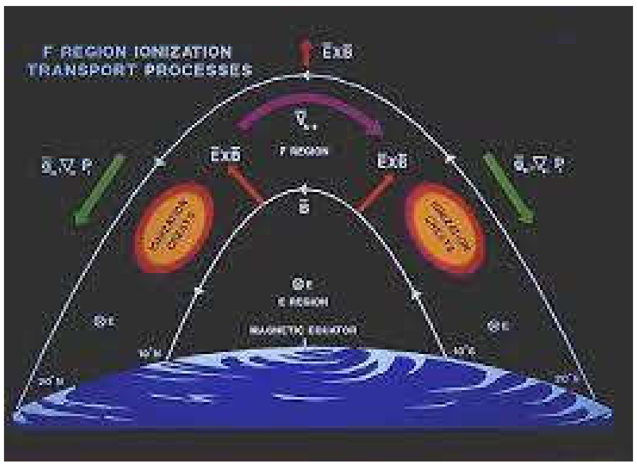
Outline

- Introduction
- Geomagnetic storms
- Ionospheric Plasma Fluctuation Response
- Conclusion

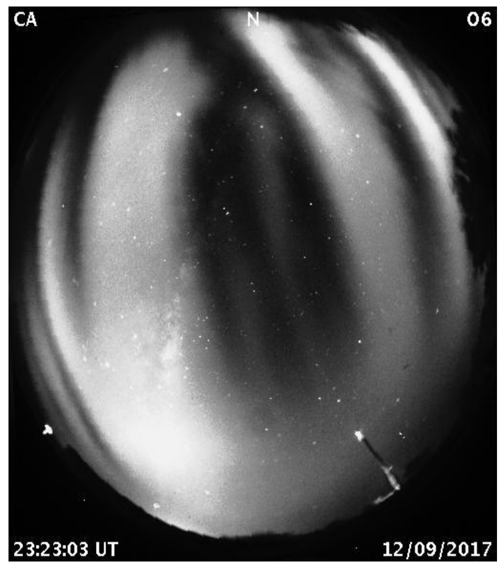
Equatorial and low latitude ionosphere

- In the equatorial and low latitude ionosphere, there are specific variabilities that are important for the ionospheric weather

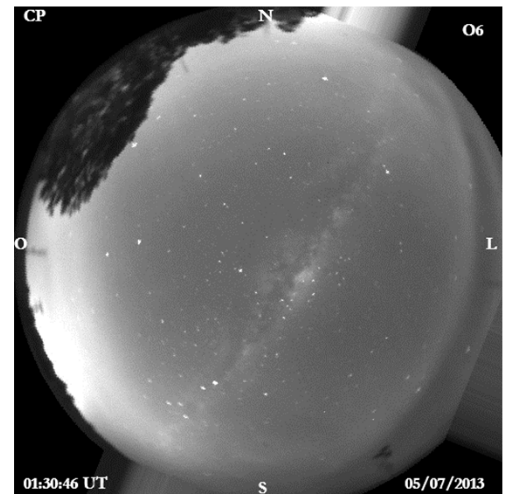
Equatorial Ionization Anomaly (EIA)



Equatorial Plasma Bubbles (EPBs)



Travelling Ionospheric Disturbances (TIDs)

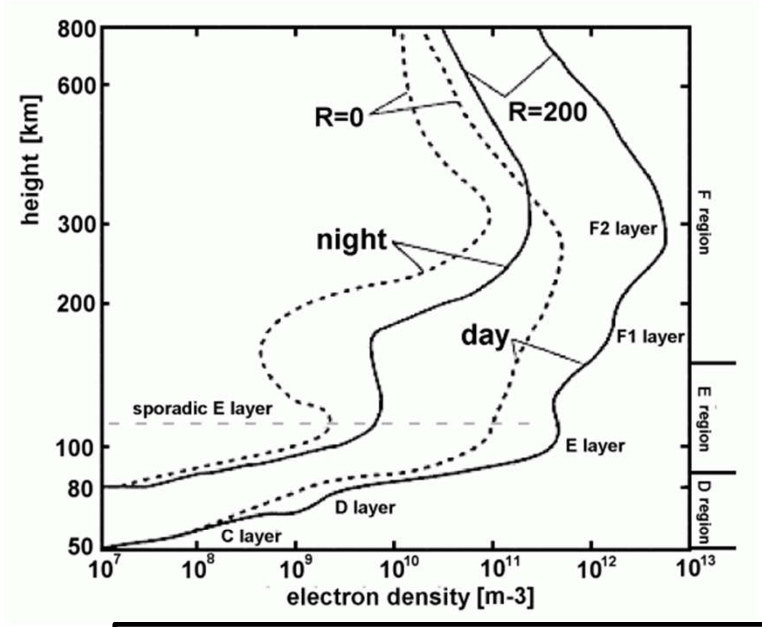


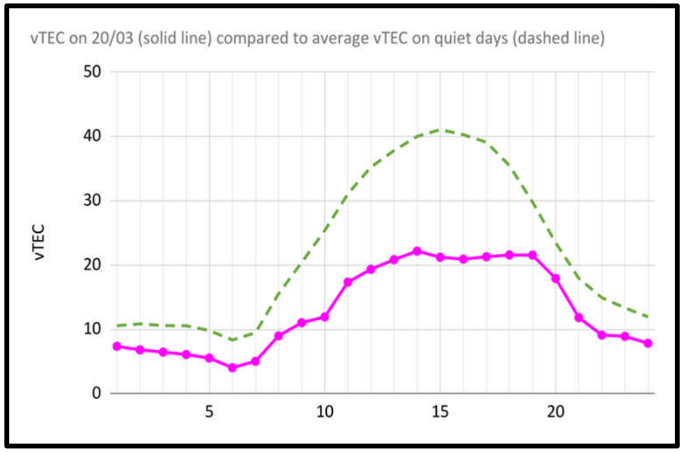
These irregularities/disturbances in the ionosphere can disrupt radio waves causing errors in radio wave GNSS positioning systems.

The Ionosphere: a layered structure

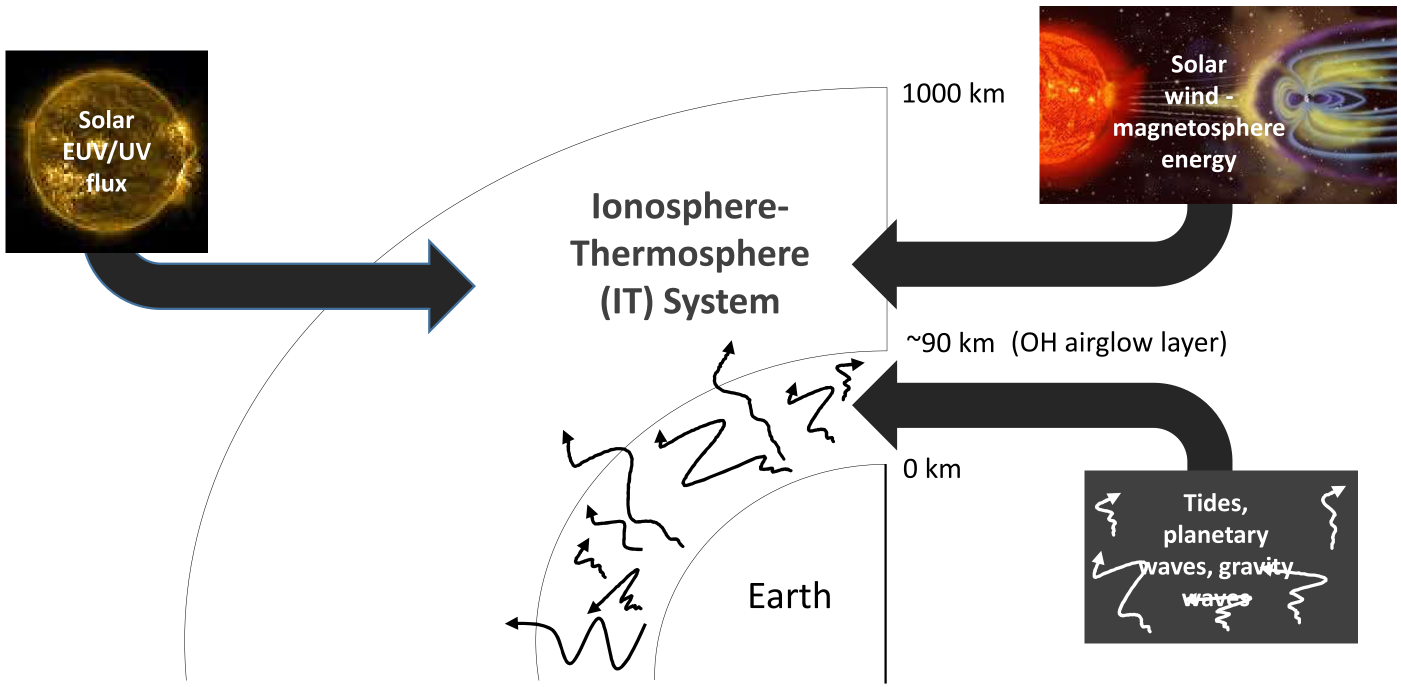
Due to different ionization production and loss processes the electron density profile with altitude shows a layered structure that varies with:

- Time of day
- Day-to-Day
- Seasonal
- Location on Earth
- Solar activity and Space Weather conditions



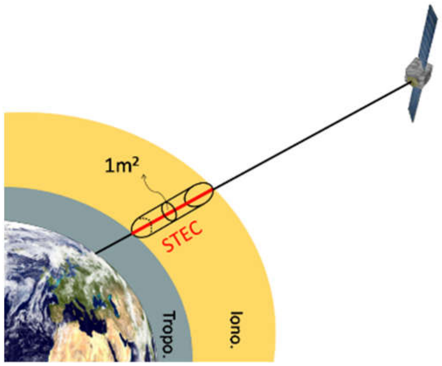


Drivers of Ionosphere Thermosphere Weather



Courtesy J. Forbes

METHOD



■GNSS TEC MAP

1. Total Electron Content (TEC) is calculated from dual-frequency GNSS data.

$$TEC = \int_r^s N_e ds$$

2. Slant TEC is converted to vertical TEC.

3. 1-hour running average is subtracted from the original TEC to obtain perturbation component of TEC.

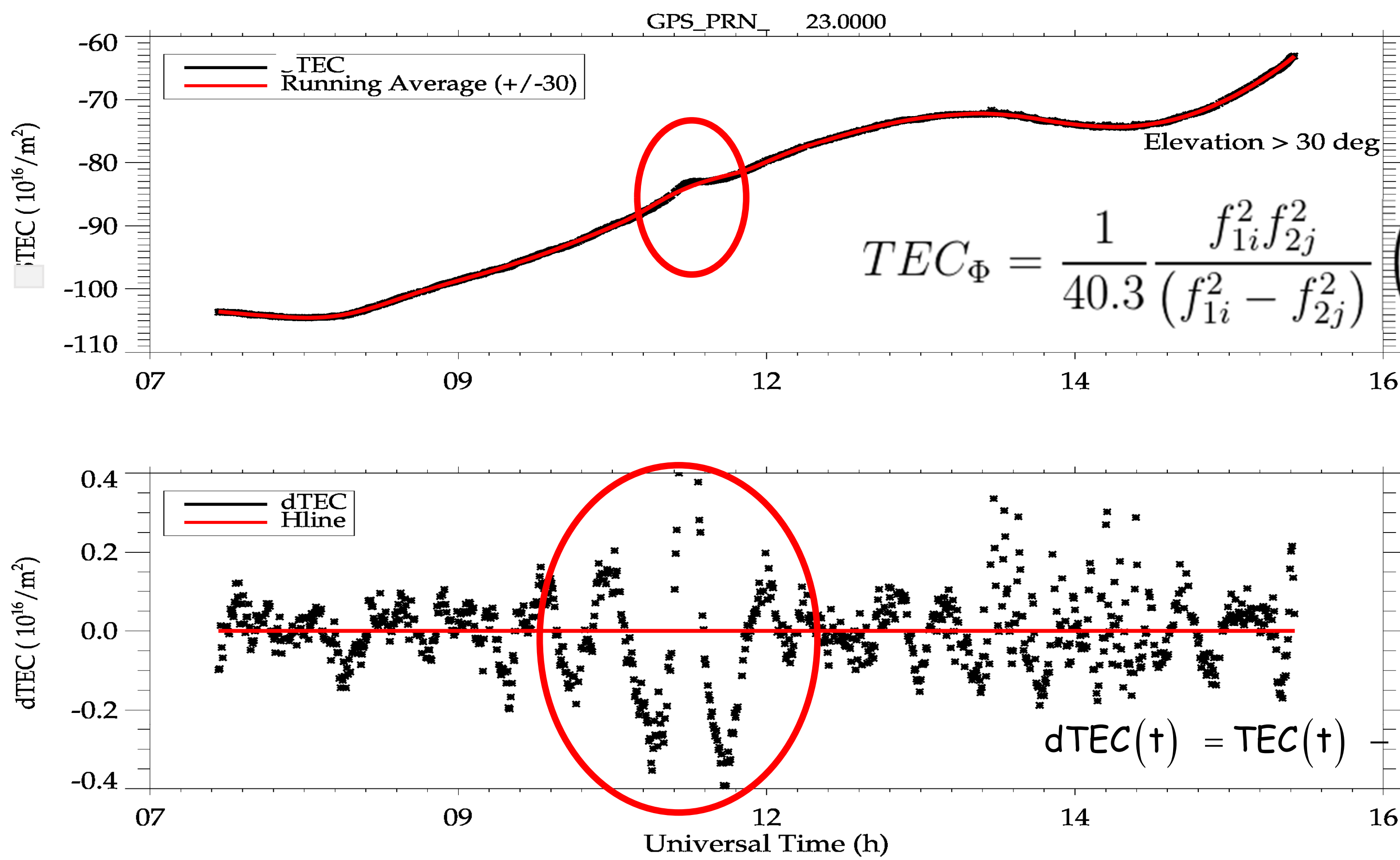
$$dTEC(t) = TEC(t) - \langle TEC(t \pm 30\ \text{min}) \rangle .$$

2. Map the TEC data onto the ionospheric shell at an altitude of 350 km with grid of 0.25°x 0.25° in lat. and long.

- The ionospheric delay (I) on GPS signals can be described in terms of TEC, inversely proportional to a square of frequency

$$\Delta^{iono} = \frac{40.3}{f^2} TEC$$

Detrending TEC

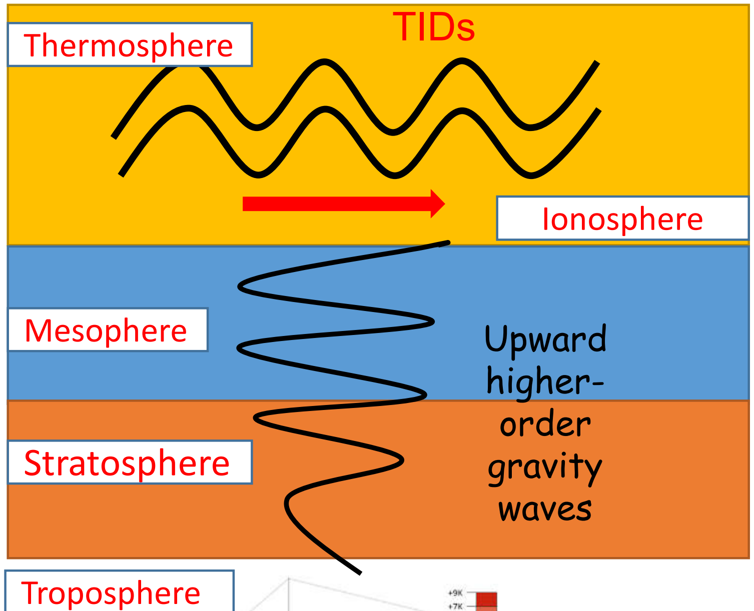


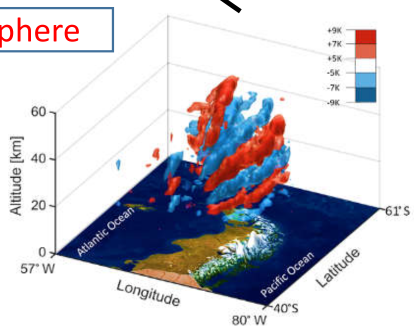
$$TEC_{\Phi} = \frac{1}{40.3} \frac{f_{1i}^2 f_{2j}^2}{\left(f_{1i}^2 - f_{2j}^2\right)} \left(\frac{L1}{f_{1i}} - \frac{L2}{f_{2j}}\right) c$$

$$dTEC(t) = TEC(t) - \langle TEC(t \pm 30\ \text{min}) \rangle .$$

Essien et al., 2021

Traveling Ionospheric Disturbances (TIDs)

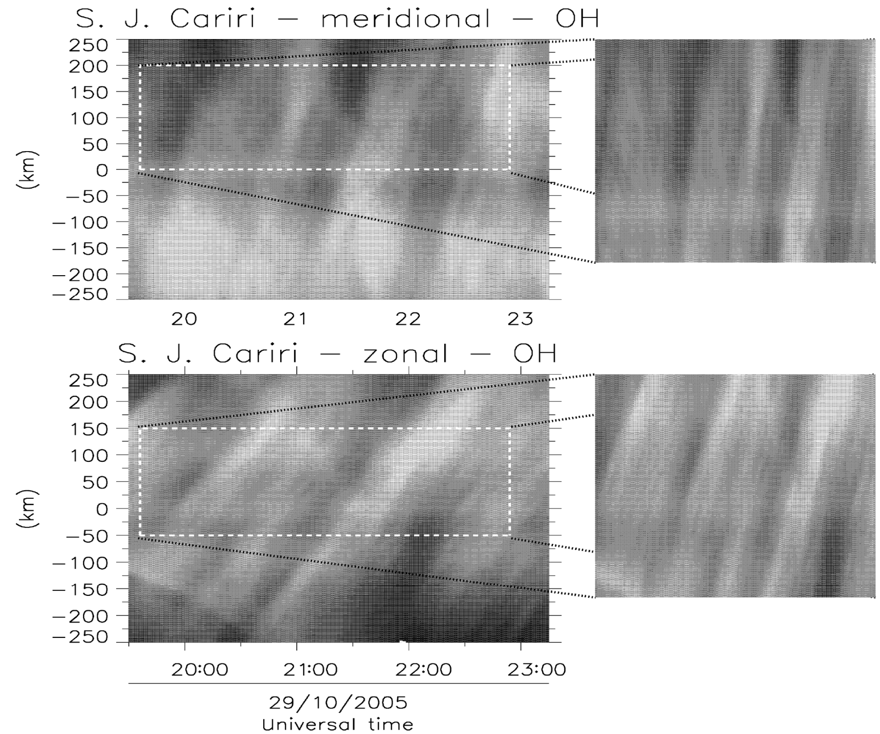




Source of gravity waves

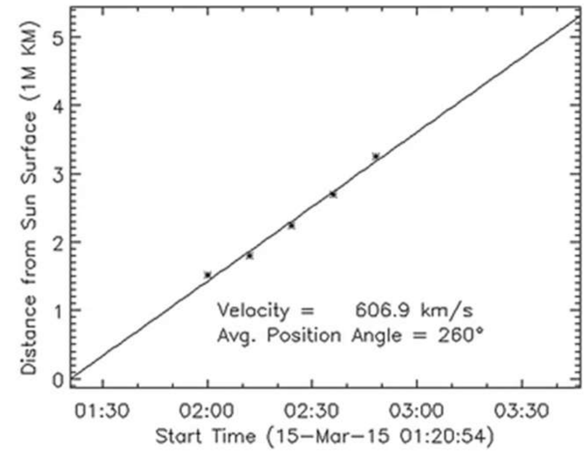
Perturbation Temperature from AIRS – AQUA satellite

Wright et al., 2017



Essien et al., 2018

March 2015 (St. Patricks Day) Storm

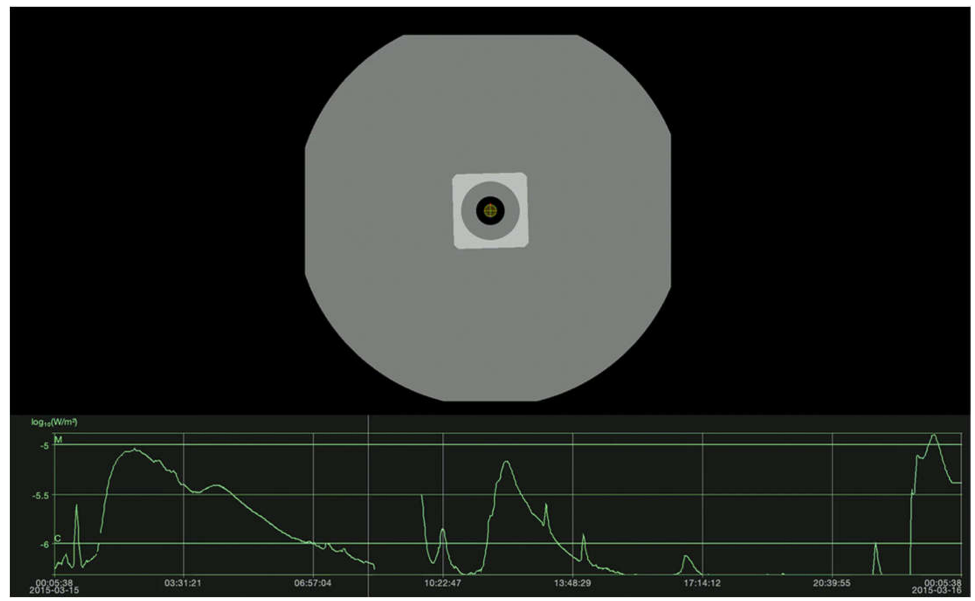


(Wu, CC., Liou, K., Lepping, R.P. et al.)

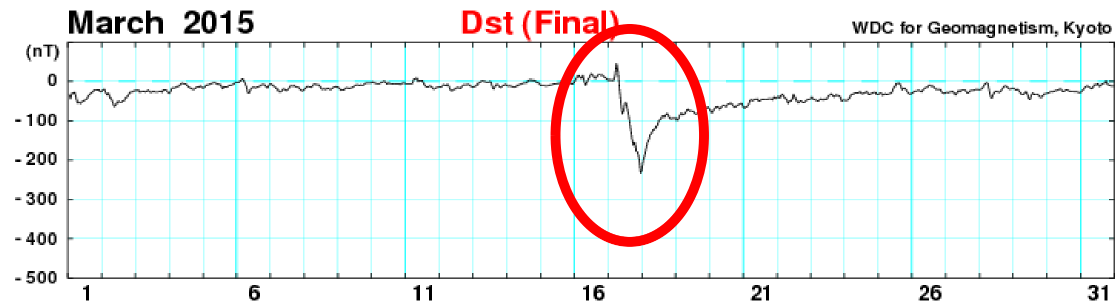
- Coronal images recorded during 00:00–03:12 UT (**a**–**h**) on 15 March 2015

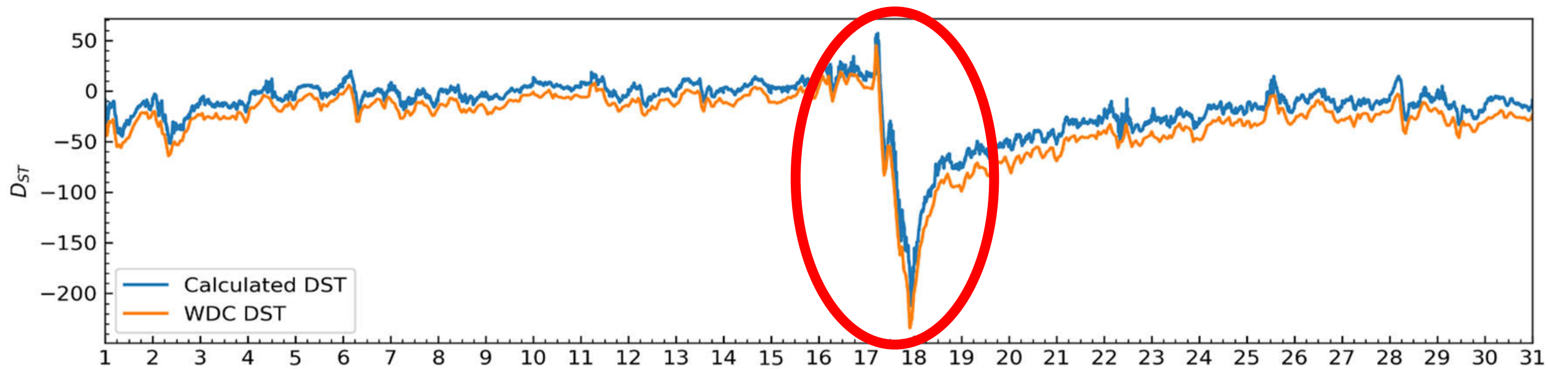
- Flare with partial halo CME in March 2015 (One was a magnitude C9.1).

- Velocity of larger CME calculated to be ~ 606 km/s corresponding to ~ 2-3 day arrival time



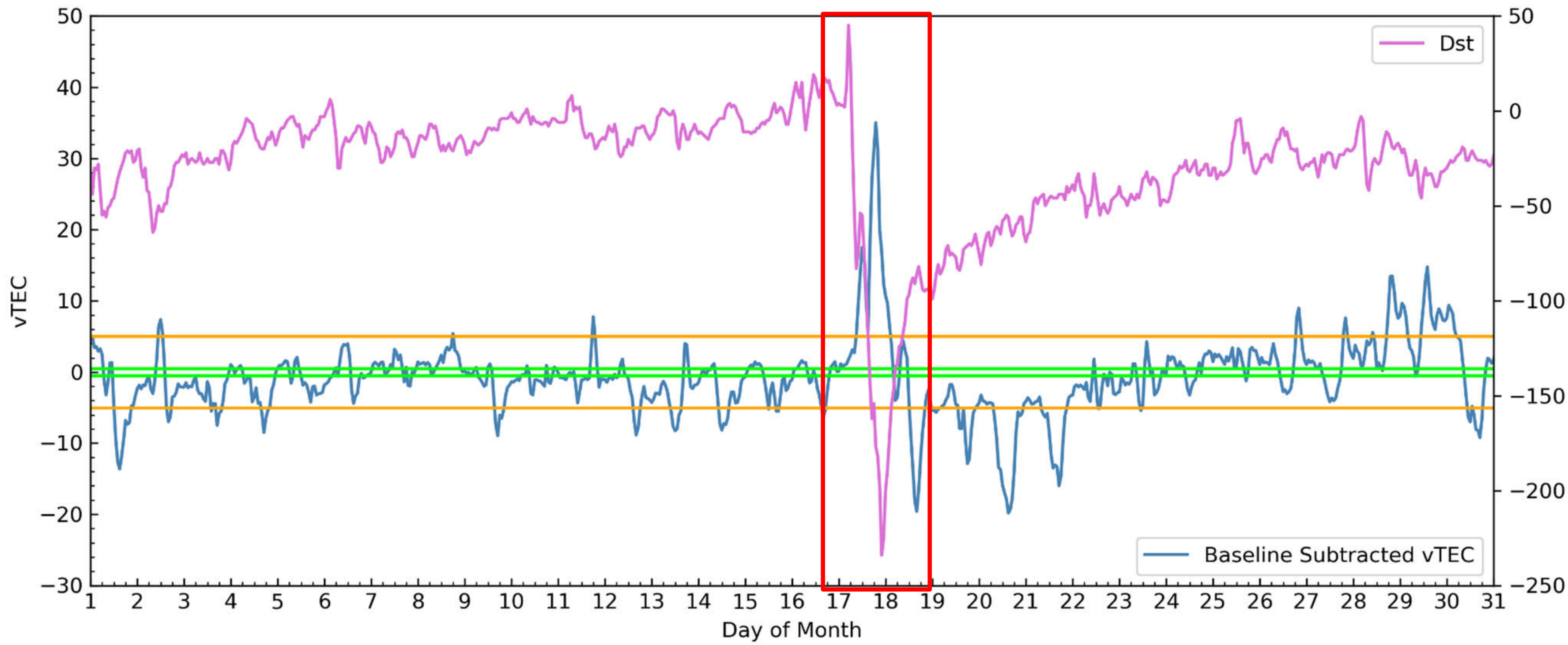
Geomagnetic Index (Dst)





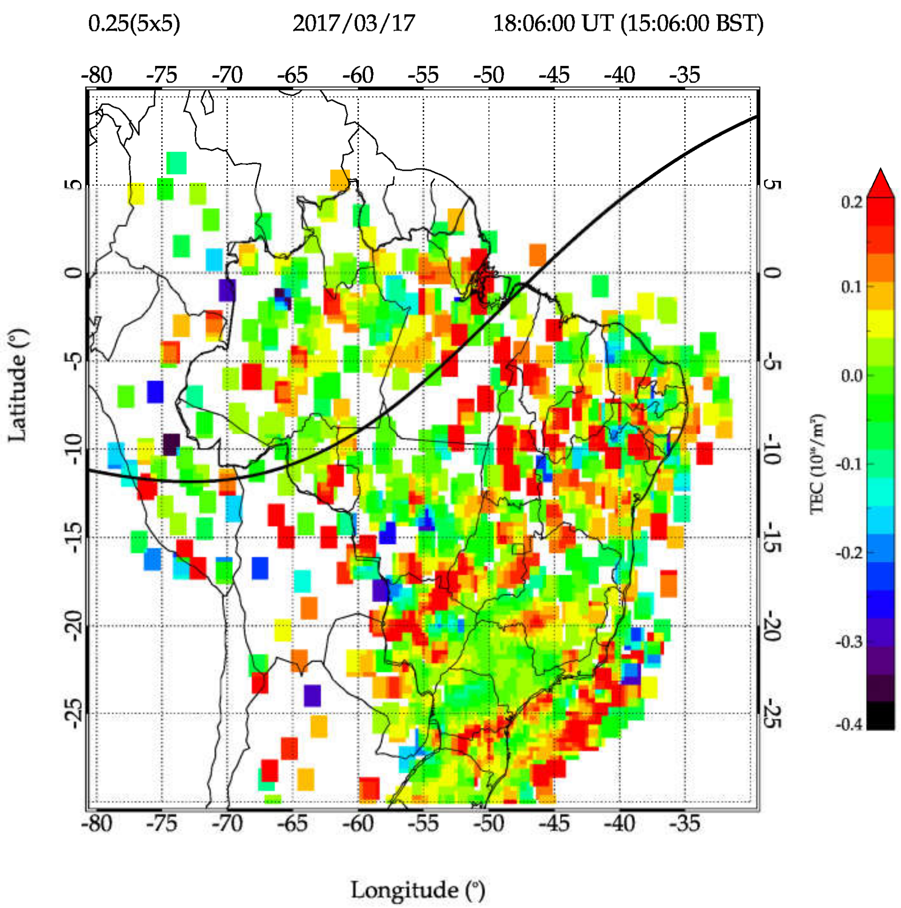
- Strong (~50 nT) compression on 17th indicative of shock reaching magnetosphere.
- Magnetic storm took place on 17th with index as high as -223 nT showing generation of strong ring current.
- Main phase onset occurs for ~ 1 day.
- The recovery phase of the storm was slow - long lasting ring current.

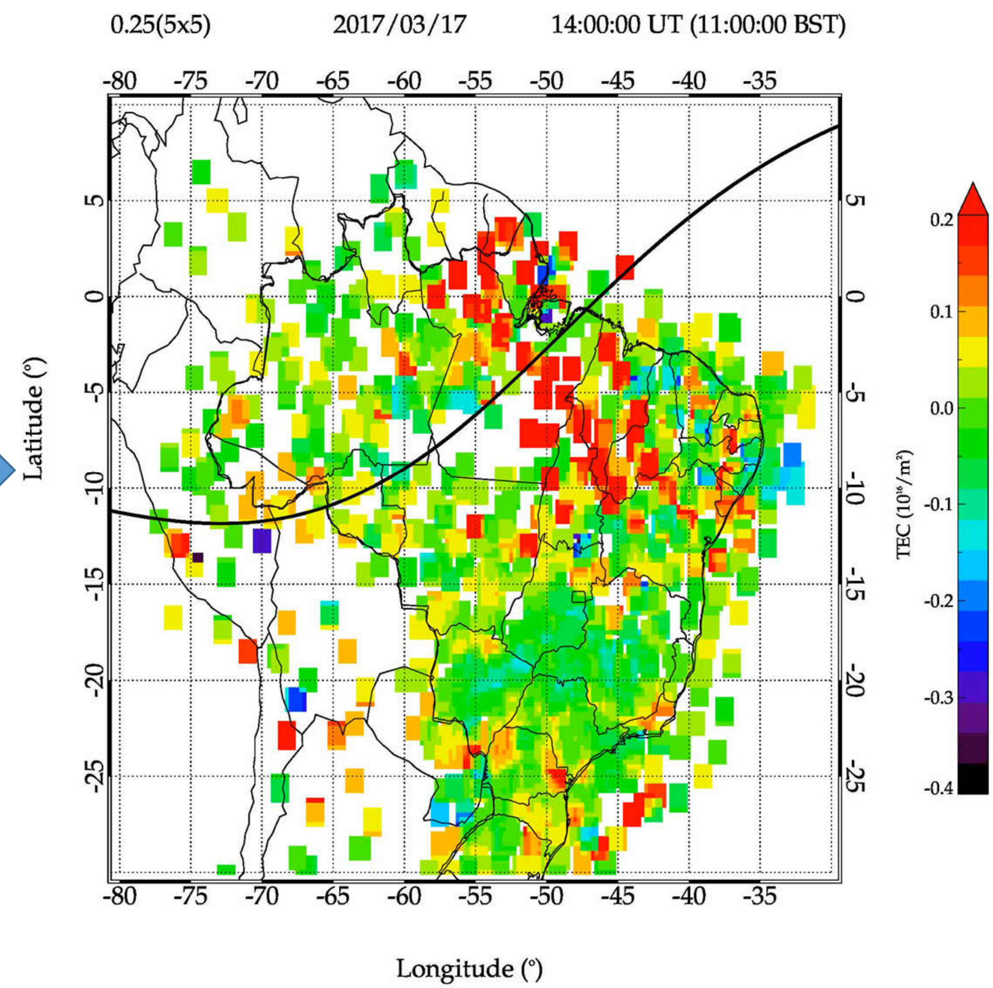
ΔTEC in Mar 2015

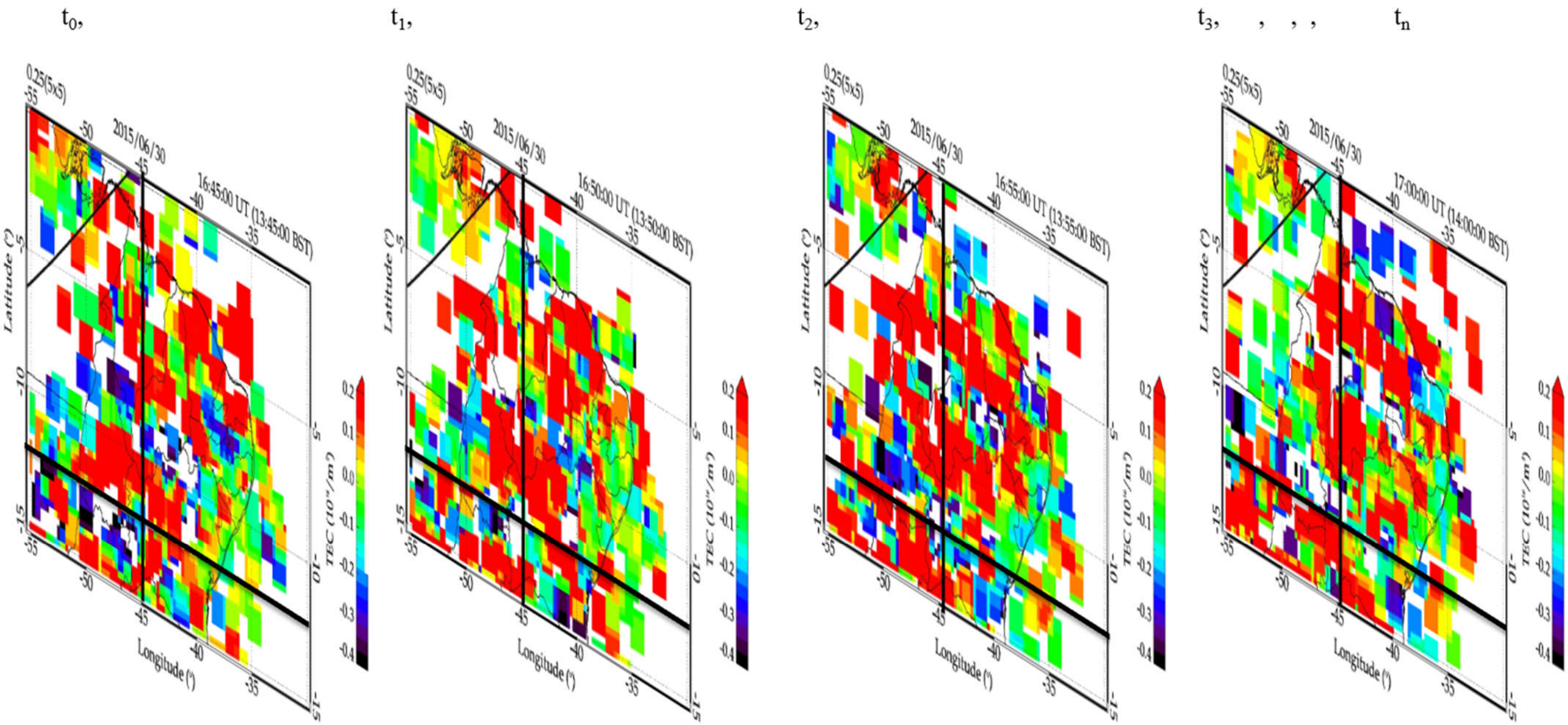


17-18

TIDs generated during 2015 St. Patricks day Geomagnetic Storm

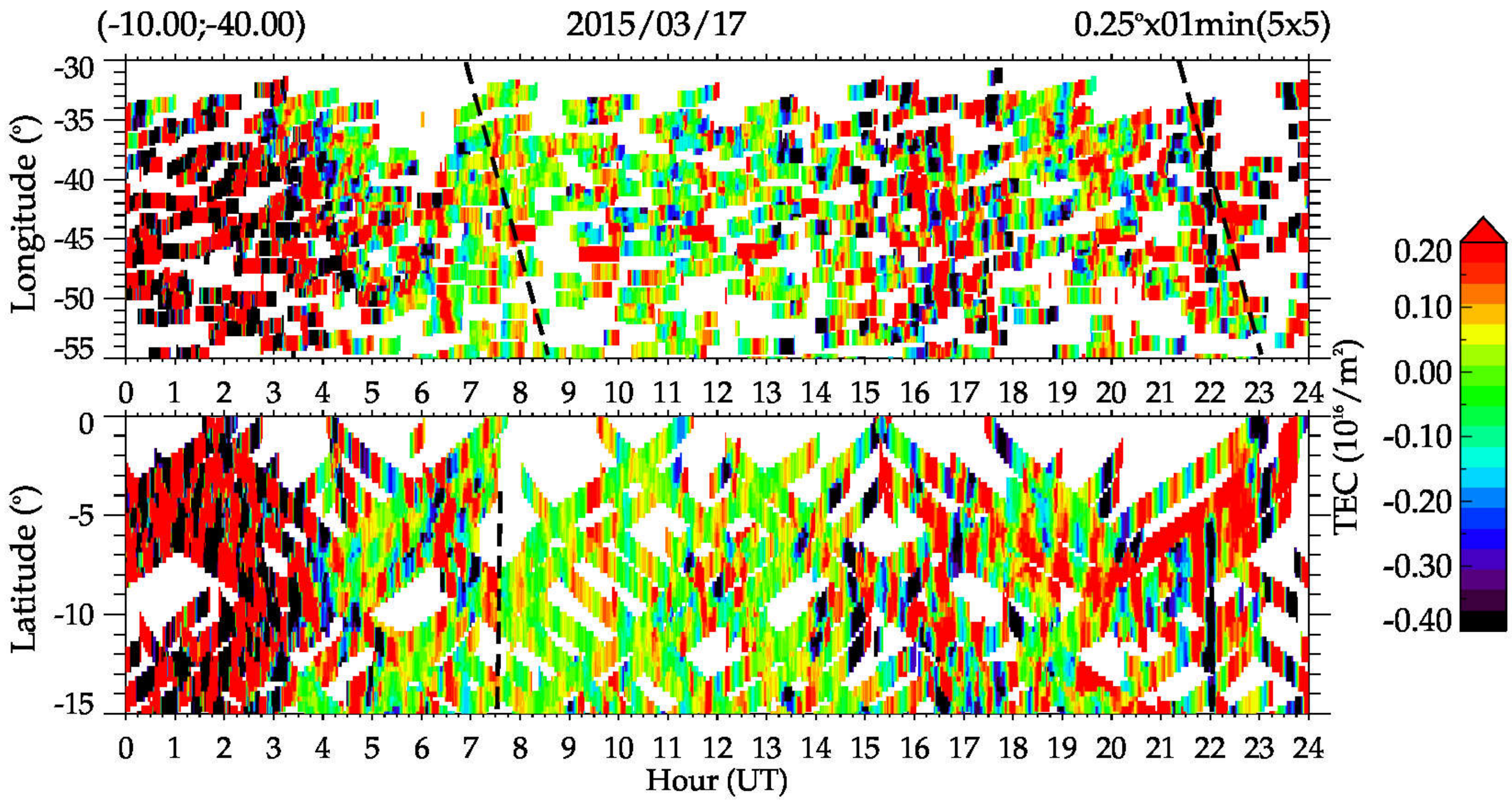




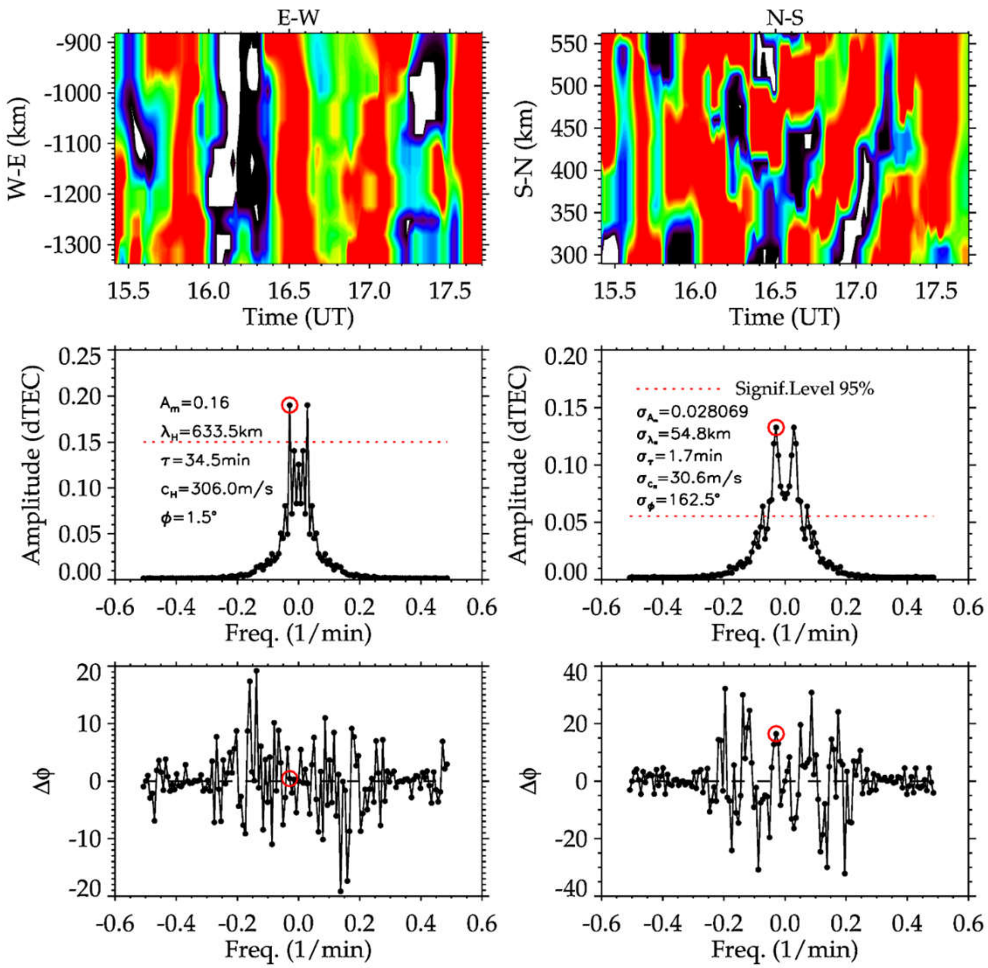


t_0,
t_1,
t_2,
t_3, , , , t_n
0.25(5x5)
2015/06/30
16:45:00 UT (13:45:00 BST)
16:50:00 UT (13:50:00 BST)
16:55:00 UT (13:55:00 BST)
17:00:00 UT (14:00:00 BST)
Latitude (°)
Longitude (°)
TEC ($10^{16}/m^2$)

Plasma Fluctuations begun at 14:00



Analysis of the fluctuations using 1D-FFT cross-spectrum



A_m=0.16
Λ_H=633.5km
τ=34.5 min
C_H=306.0m/s
Φ=1.5°

- Period [min.] $\tau = \frac{1}{f(\omega)}$
- Wavelength [km]

$$\lambda_H = \frac{\lambda_{NS}\lambda_{EW}}{\sqrt{\lambda_{NS}^2 + \lambda_{EW}^2}}$$

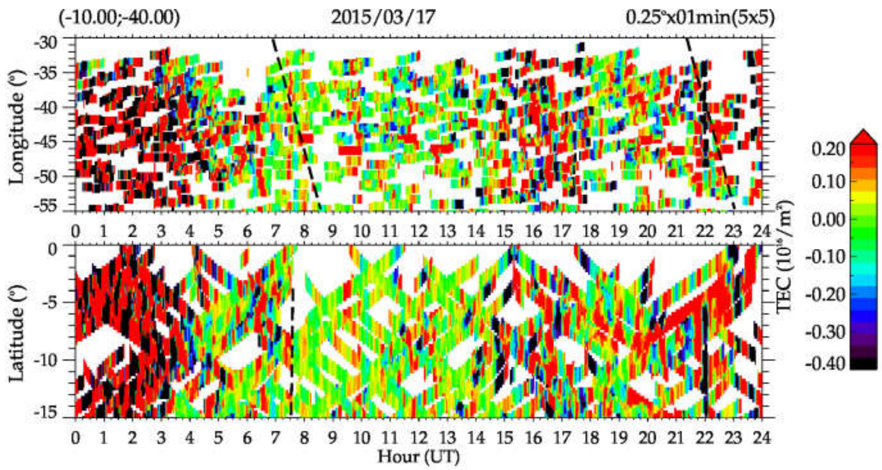
- Phase Velocity [m/s]

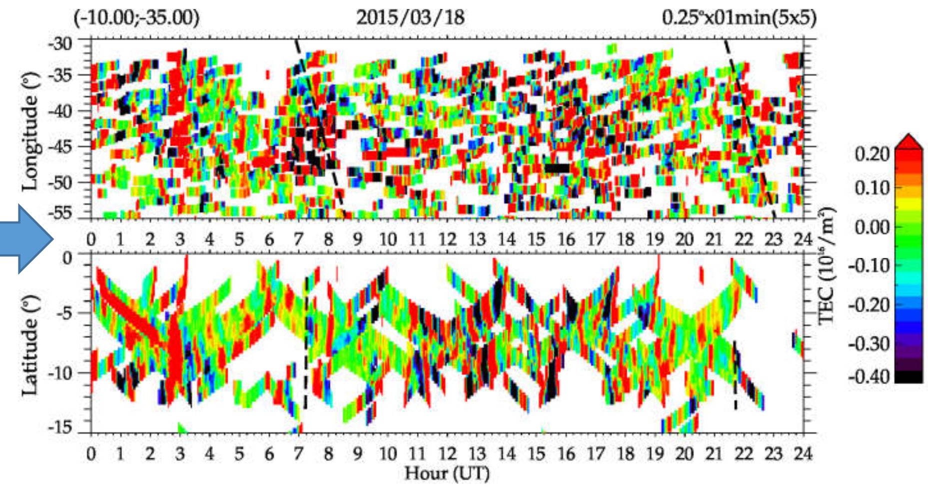
$$C_H = \frac{\lambda_H}{\tau}$$

- Propagation Direction [degree]

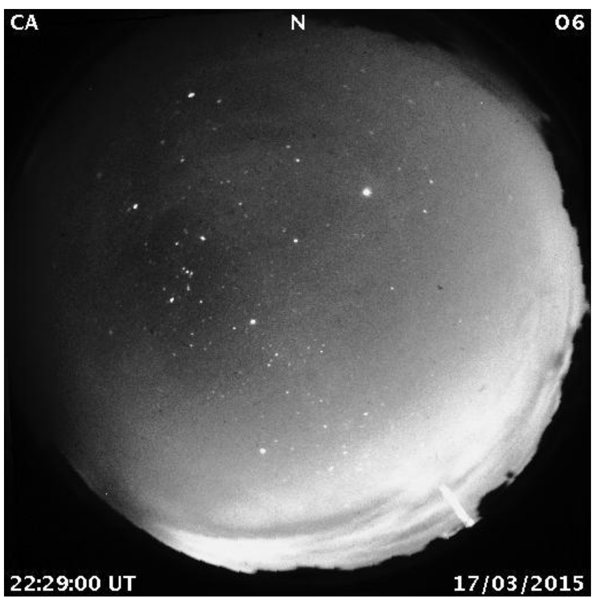
$$\theta = \cos^{-1}\left(\frac{\lambda_H}{\lambda_{NS}}\right)$$

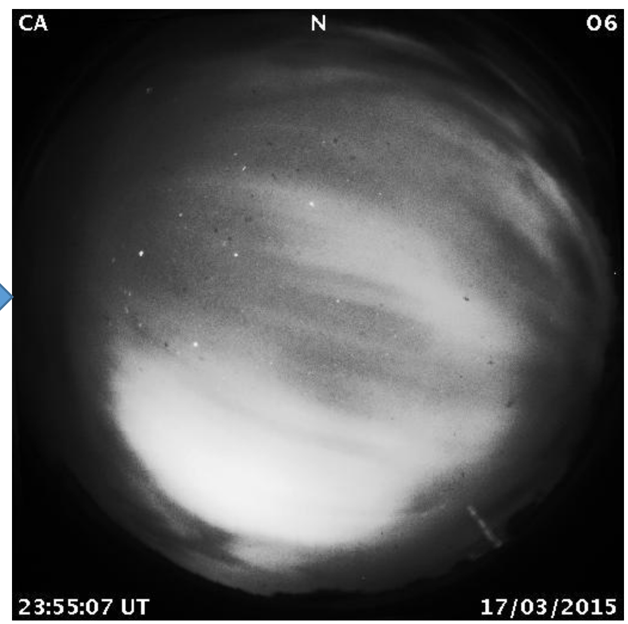
Essien et al., 2021

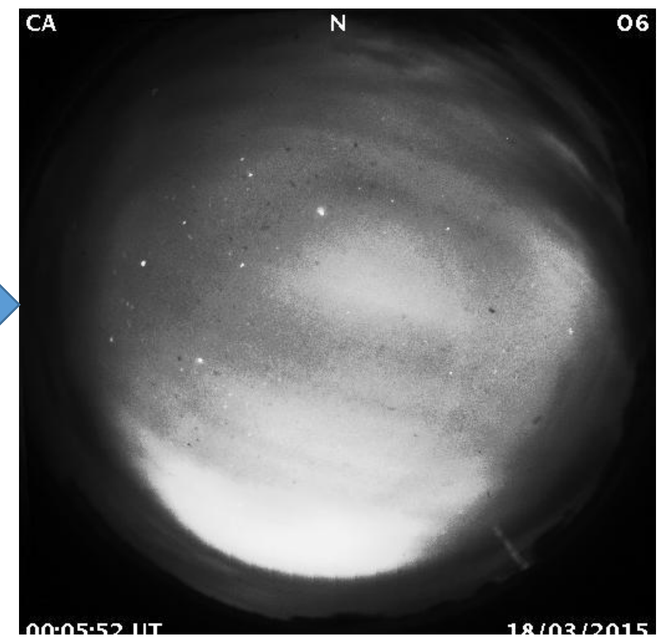




Analysis of MSTIDs using 1D-FFT cross-spectrum





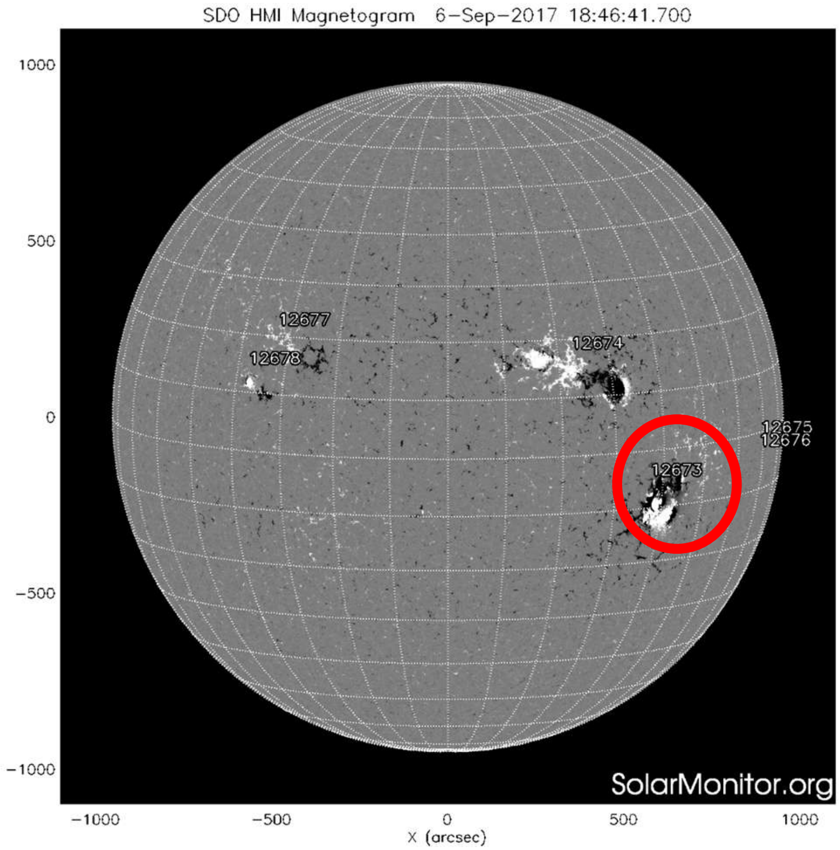


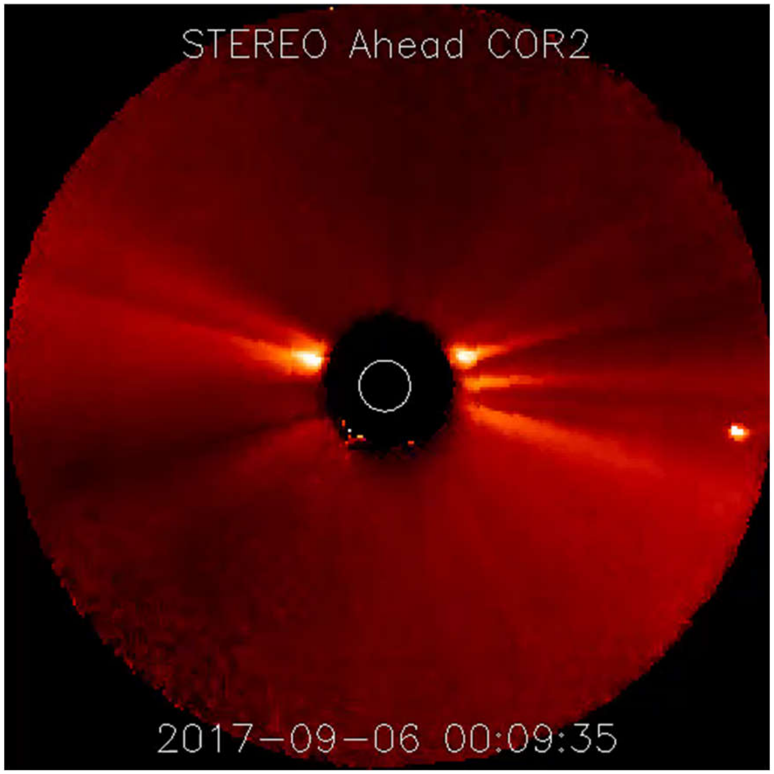
2017 September Storm

Active Region 12673

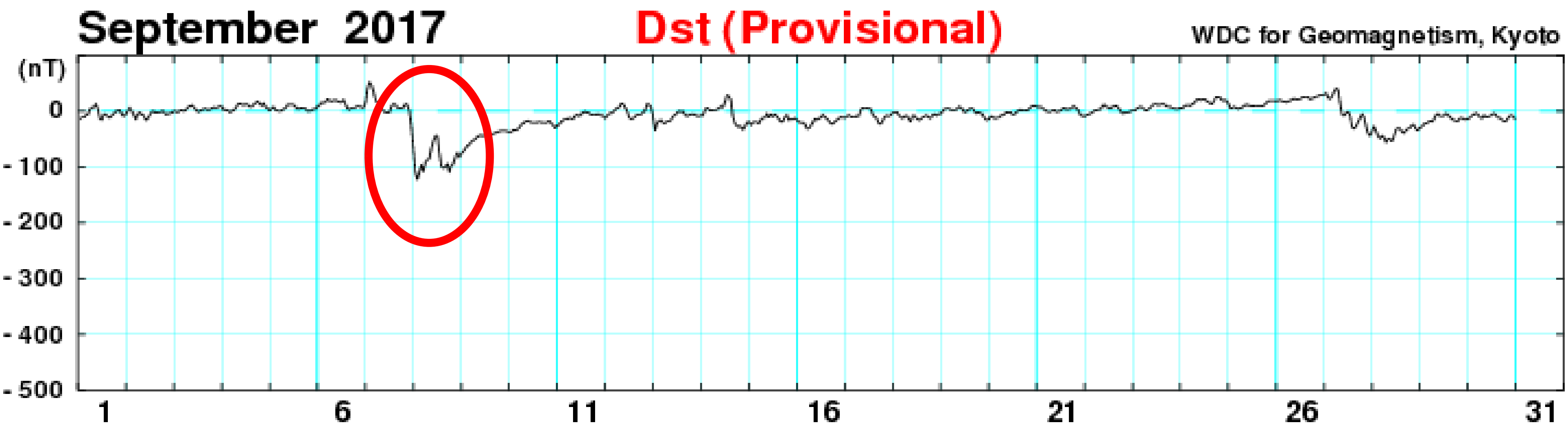
Solar Flares:

X9.3(11:53)
X2.2(08:57)
C2.7(07:29)
C1.5(20:00)
/ M2.3(17:37)
C4.6(17:11)
C3.7(16:14)
C6.9(13:26)
C2.2(12:30)
C5.4(10:13)
M3.2(04:33)
M1.0(03:42)
M4.2(01:03)
C9.8(00:30)

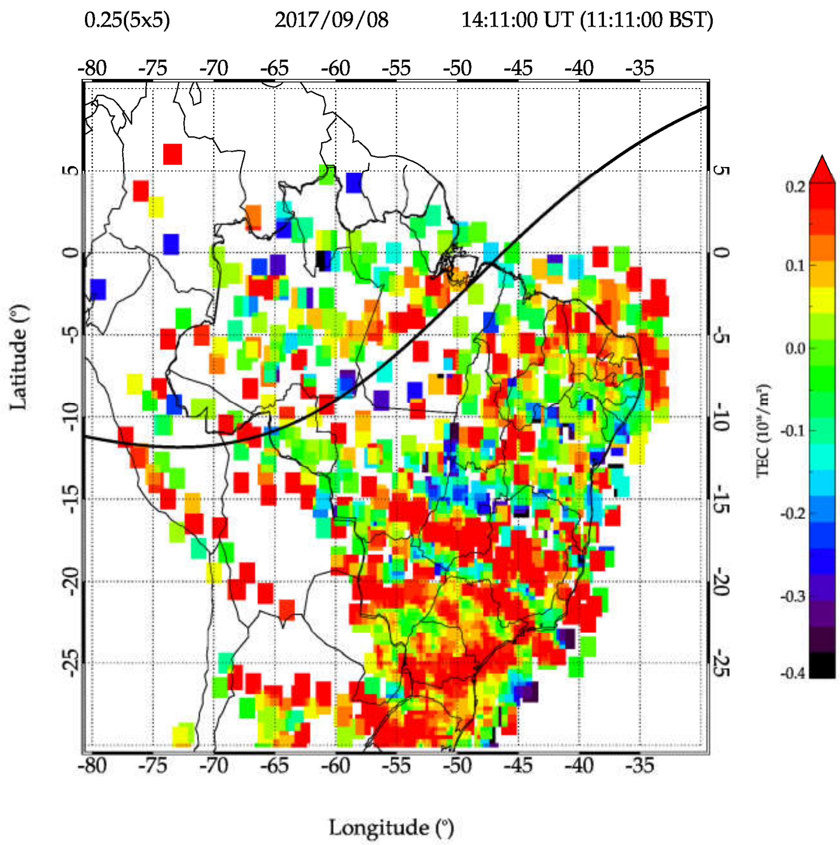


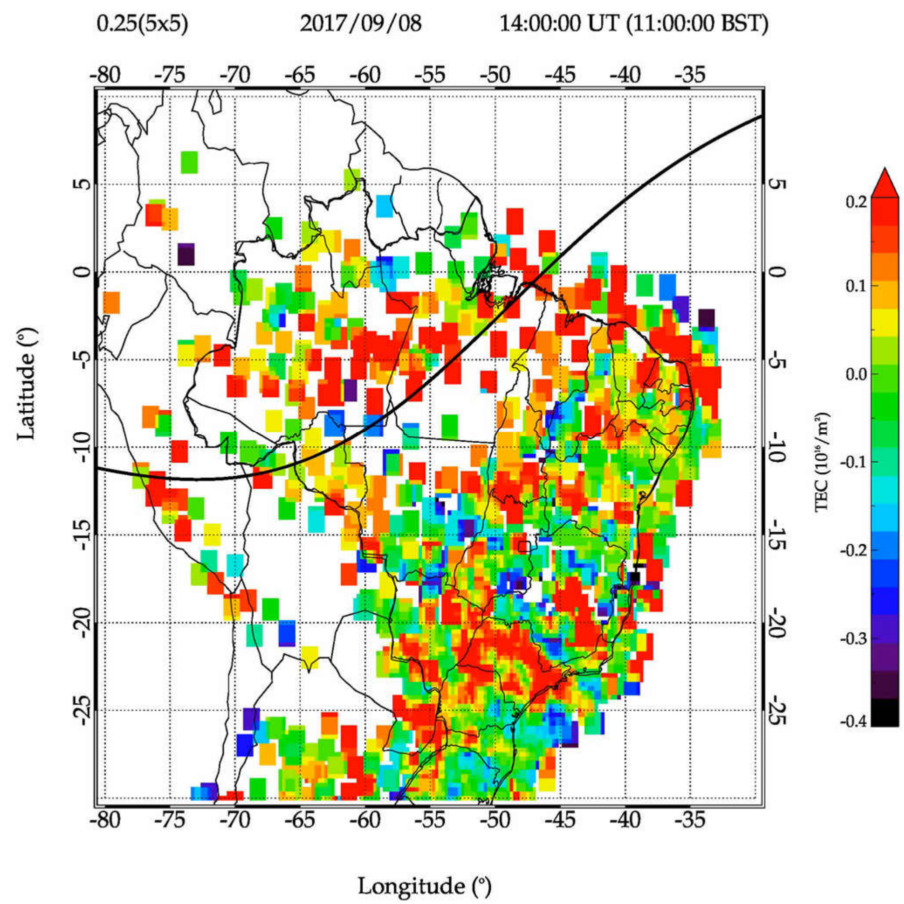


There was geomagnetic storm after the 2 days of the solar storm



Ionospheric Fluctuation Response to the Storm





- Period [min.] $\tau = \frac{1}{f(\omega)}$
- Wavelength [km]

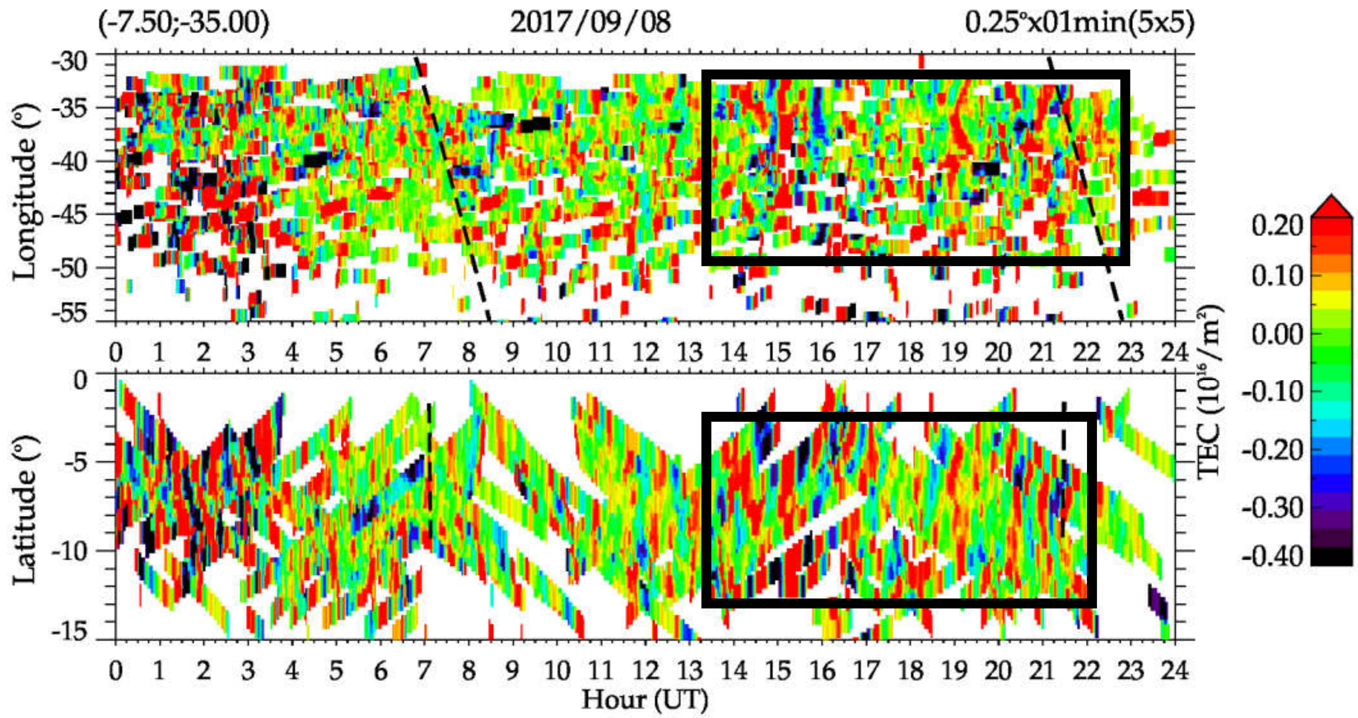
$$\lambda_H = \frac{\lambda_{NS}\lambda_{EW}}{\sqrt{{\lambda_{NS}}^2 + {\lambda_{EW}}^2}}$$

- Phase Velocity [m/s]

$$C_H = \frac{\lambda_H}{\tau}$$

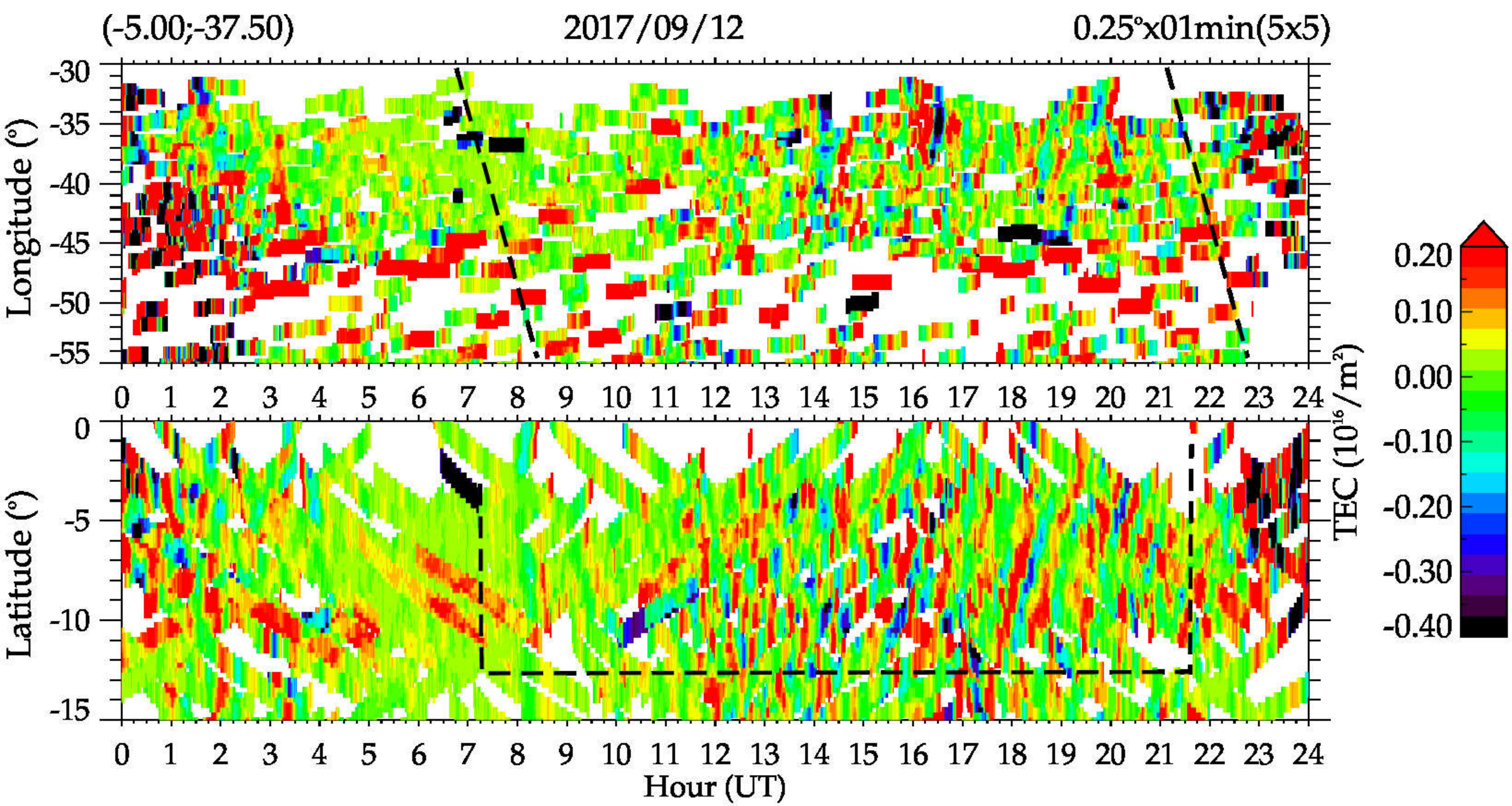
- Propagation Direction [degree]

$$\theta = \cos^{-1}\left(\frac{\lambda_H}{\lambda_{NS}}\right)$$

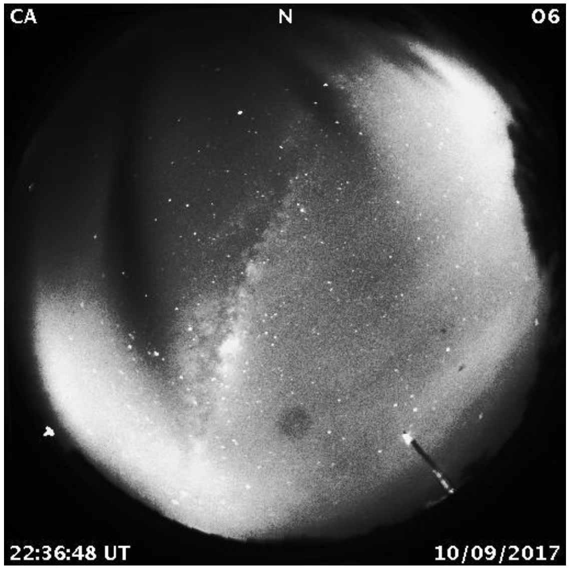


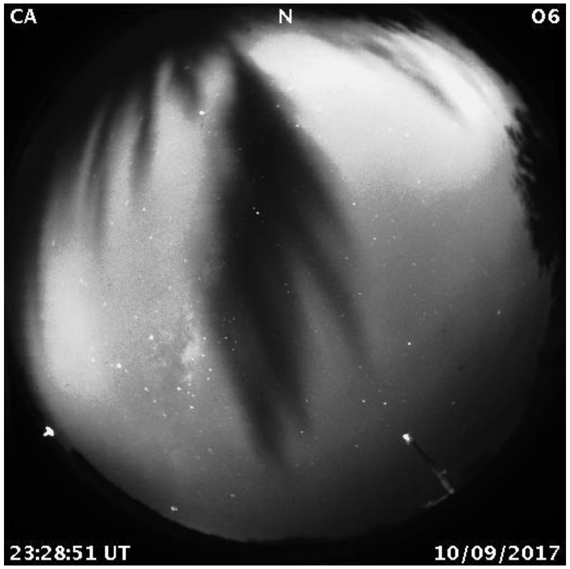
TID characteristics on 8th September 2017

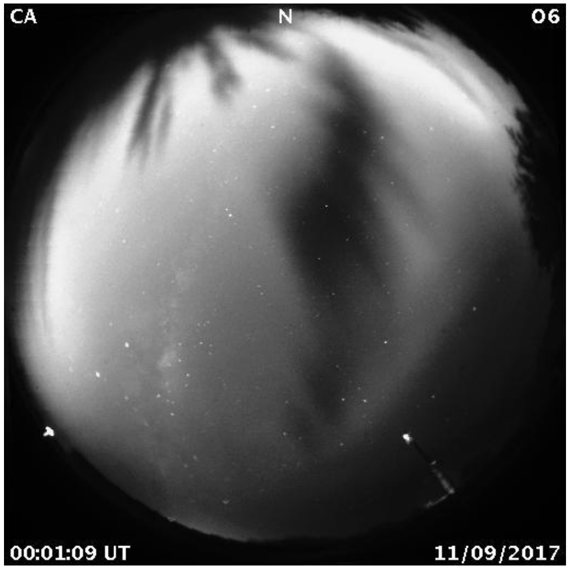
A_m=0.12
Λ_H=641.6km
τ=40.7 min
C_H=263.0m/s
Φ=346.3°


(-5.00;-37.50)
2017/09/12
0.25°x01min(5x5)
Longitude (°)
-30
-35
-40
-45
-50
-55
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Latitude (°)
0
-5
-10
-15
Hour (UT)
TEC ($10^{16}/m^2$)
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40

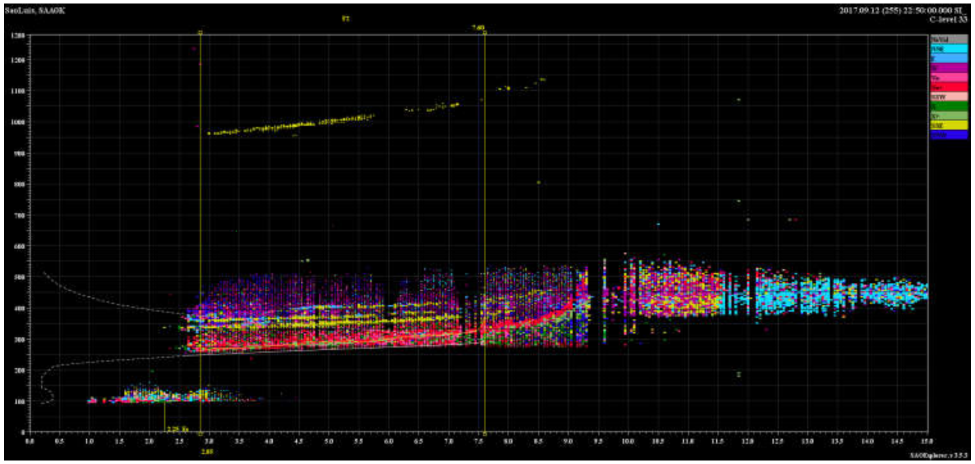
Equatorial Plasma Bubbles



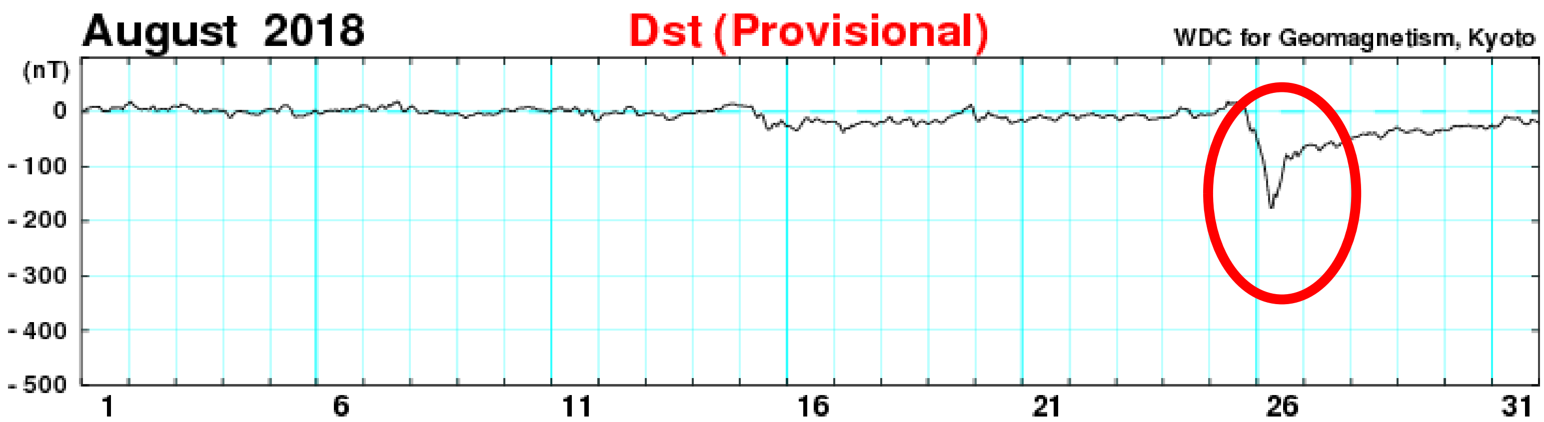




Equatorial SpreadF



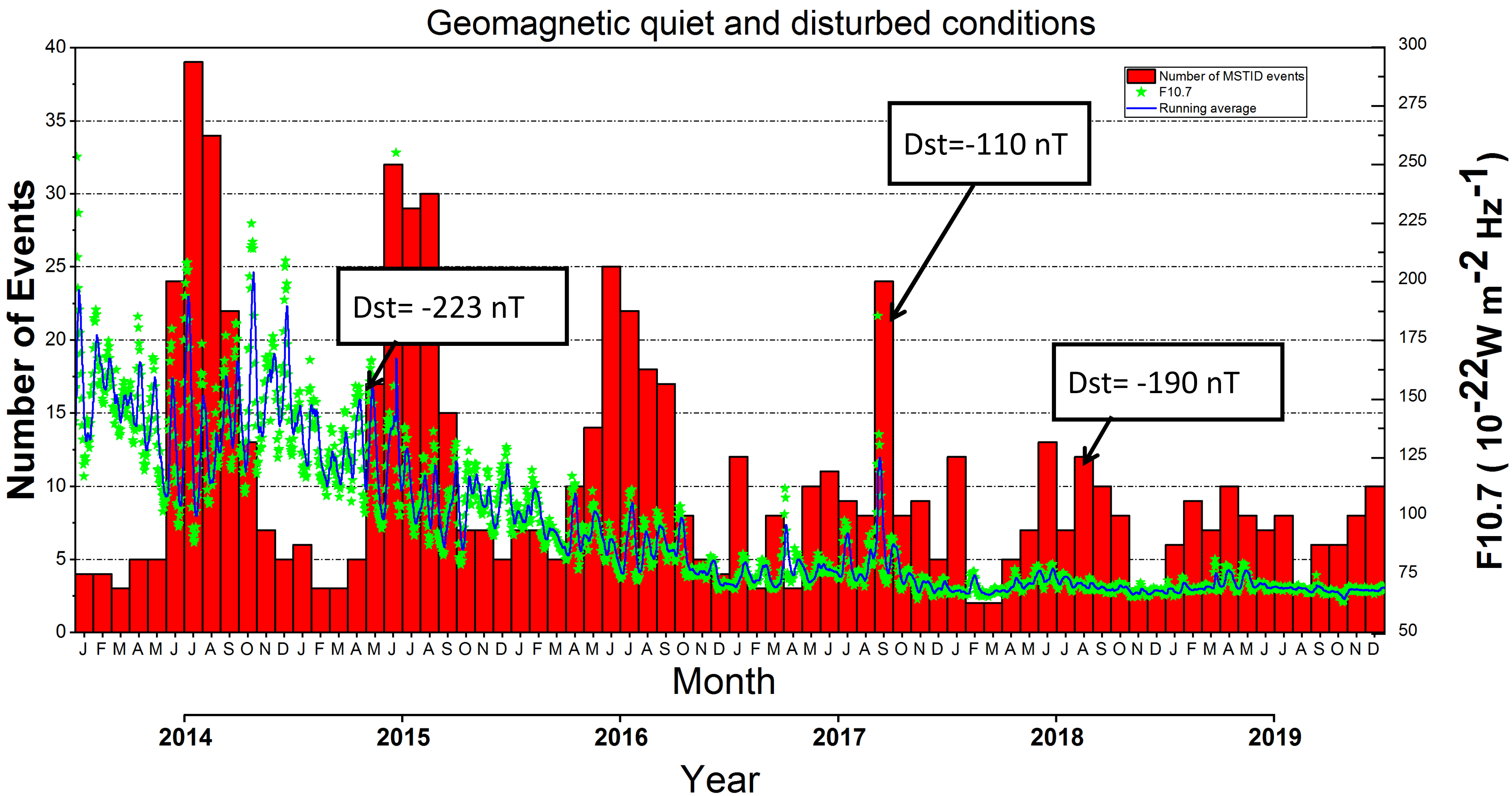
2018 August Storm



TID characteristics on 26th August

A_m=0.11
Λ_H=644.1km
τ=26.5 min
C_H=344.0m/s
Φ=344.0^o

Seasonal variation of TIDs during Geomagnetic Quiet and disturbed Time



Conclusion

- Ionospheric plasma fluctuations are generated during geomagnetic storms as well as the recovery phase.
- Those TIDs can trigger EPBs which is the post sunset event.
- The statistics of the seasonal variation of the TIDs changes when series of geomagnetic storms occur within a particular month or season.

Storm	Dst Index (nT)	TIDs Velocity (m/s)	TIDs Wavelength (km)
March 2015	-233	306.0	633.5
September 2017	-110	263.0	641.6
August 2018	-190	344.0	644.1

Acknoweledgement

UNITED NATIONS
Office for Outer Space Affairs

UNOOSA

INTERNATIONAL SPACE WEATHER INITIATIVE
ISWI

UNIVERSITY OF
CAPE COAST
VERITAS NOBIS LUMEN

CAPES

AIMS
African Institute for
Mathematical Sciences
RWANDA

CNPq
Conselho Nacional de Desenvolvimento
Científico e Tecnológico


Thank
you