Ionospheric Plasma Anomaly Using GPS TEC Measurements Over Nepal

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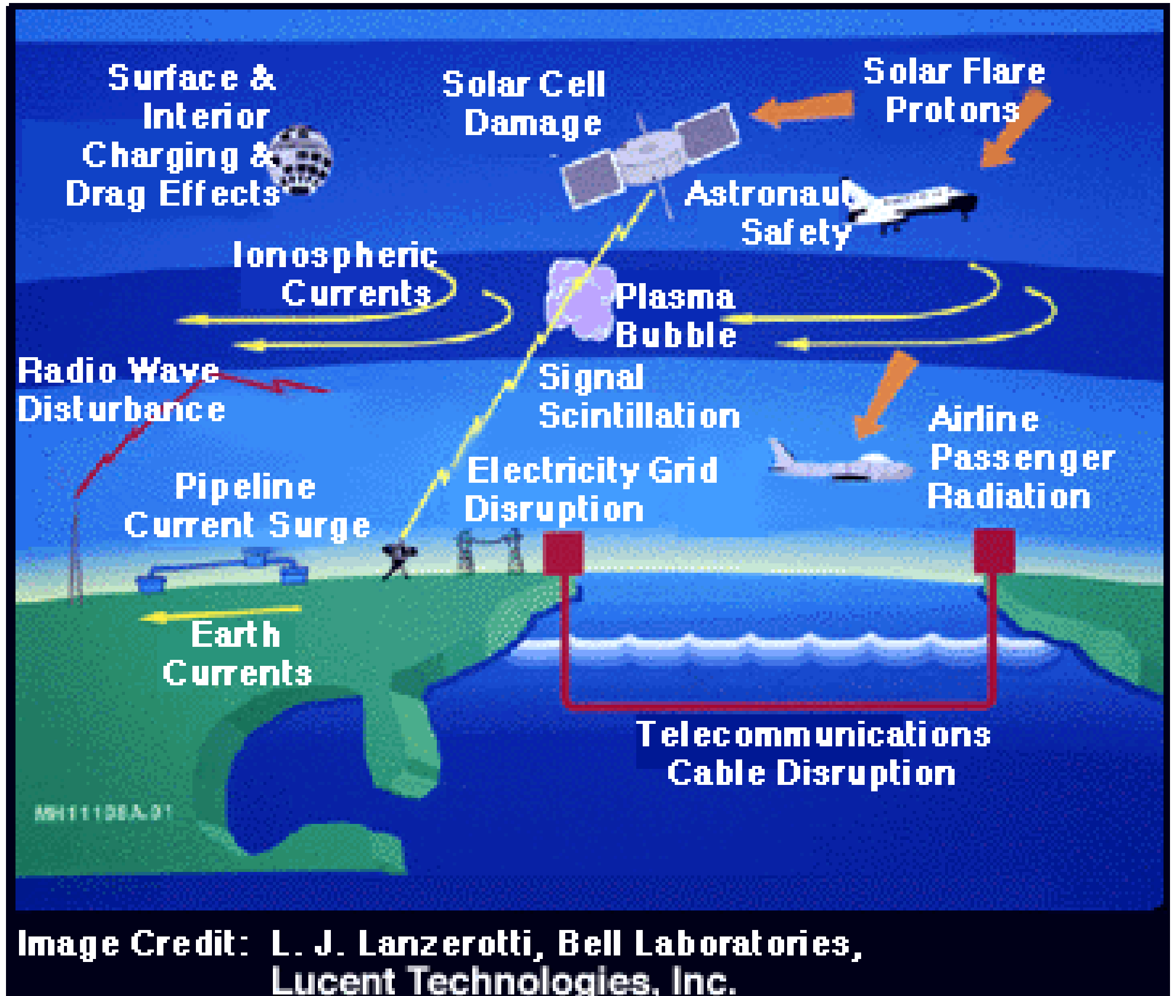
Space Weather and Its Effect

- **Extraterrestrial (Storm effects)**
  Mainly Associated with solar activities
  - Impact on the IONOSPHERE

- **Terrestrial**
  - Earthquake
  - Volcano Eruption
  - Atmospheric Behavior
  - Thunderstorm

- **Effects**
  - Technologically complex systems
  - Communications
  - Transportation
  - Electrical power systems



(https://www.windows2universe.org/space_weather/sw_intro/sw_affect_us.html)

Total Electron Content (TEC)

$$STEC = \int_{receiver}^{satellite} N ds$$

$$STEC = \frac{1}{40.3}\left(\frac{f_1^{\,2} f_2^{\,2}}{f_1^{\,2} - f_2^{\,2}}\right)(P_1 - P_2) + TEC_{cal}$$

$$VTEC = STEC \times \cos\chi$$

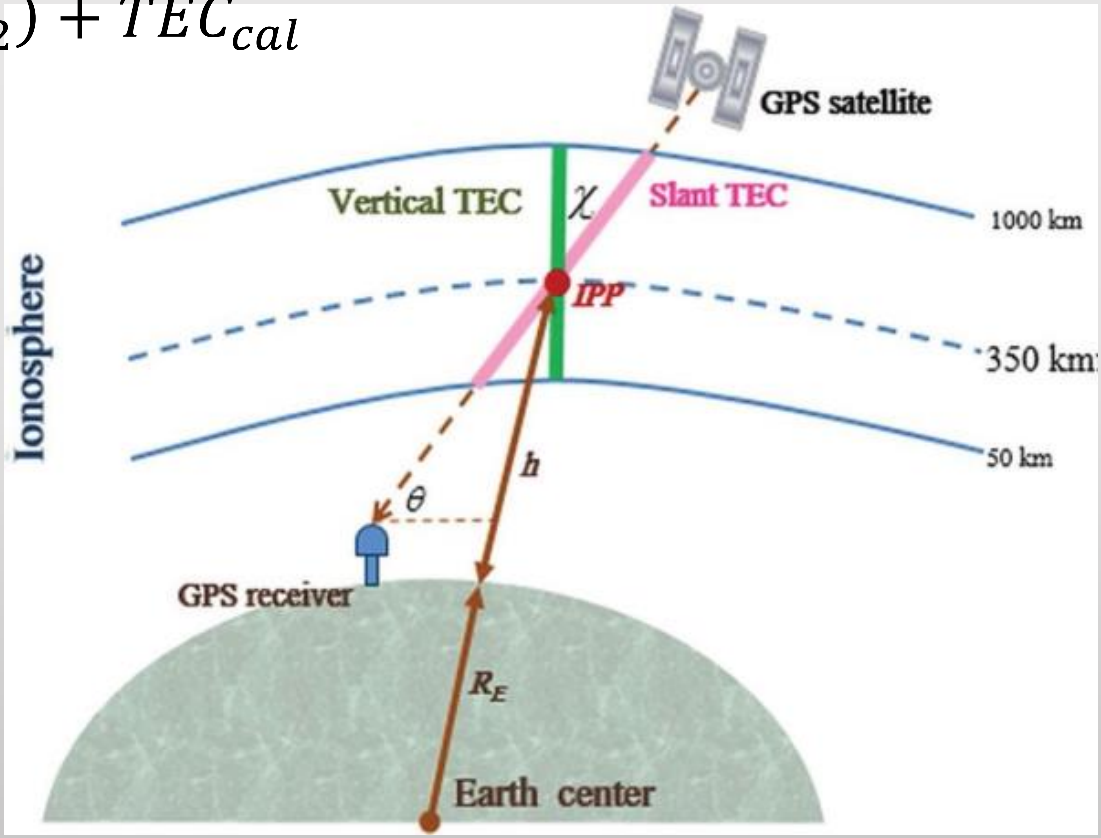
$$Sin\chi = \frac{R_E}{R_E + h} cos\theta$$

θ = Elevation angle of the satellite

R_E = Earth's Radius

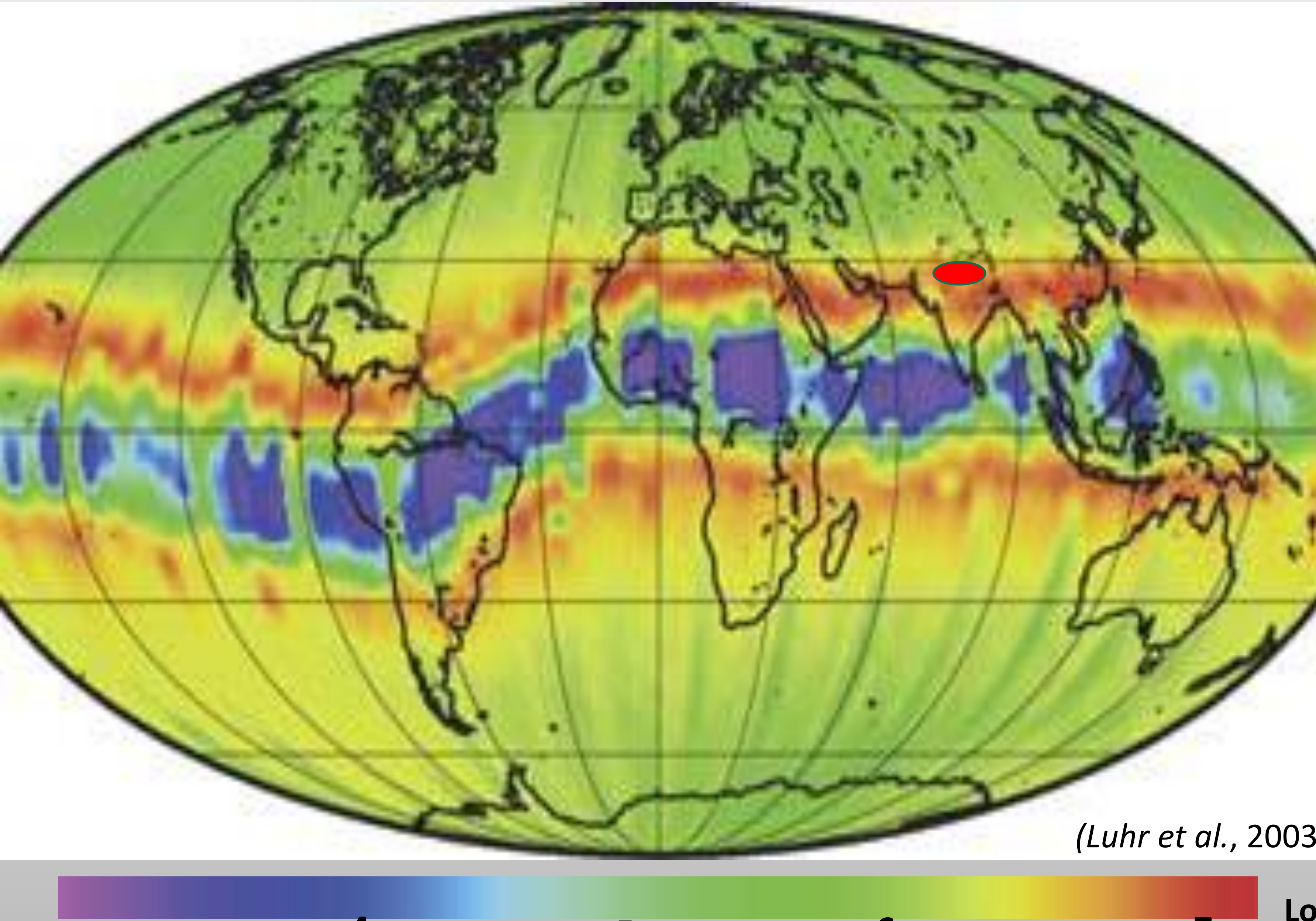
h = Height of ionospheric layer

χ = Satellite Zenith angle



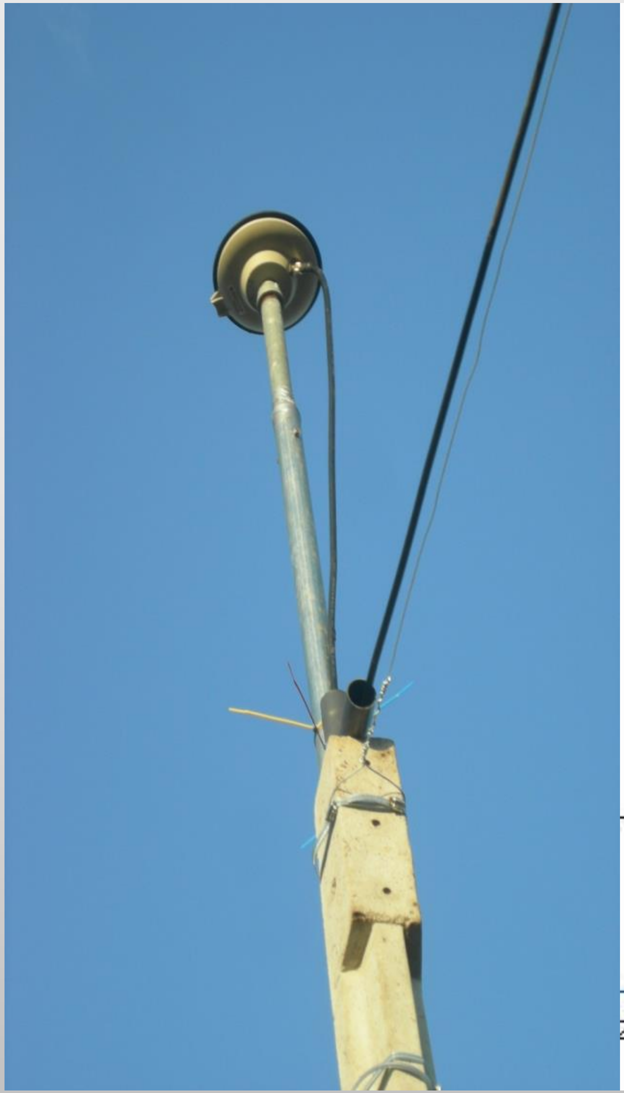
Conversion of STEC to VTEC

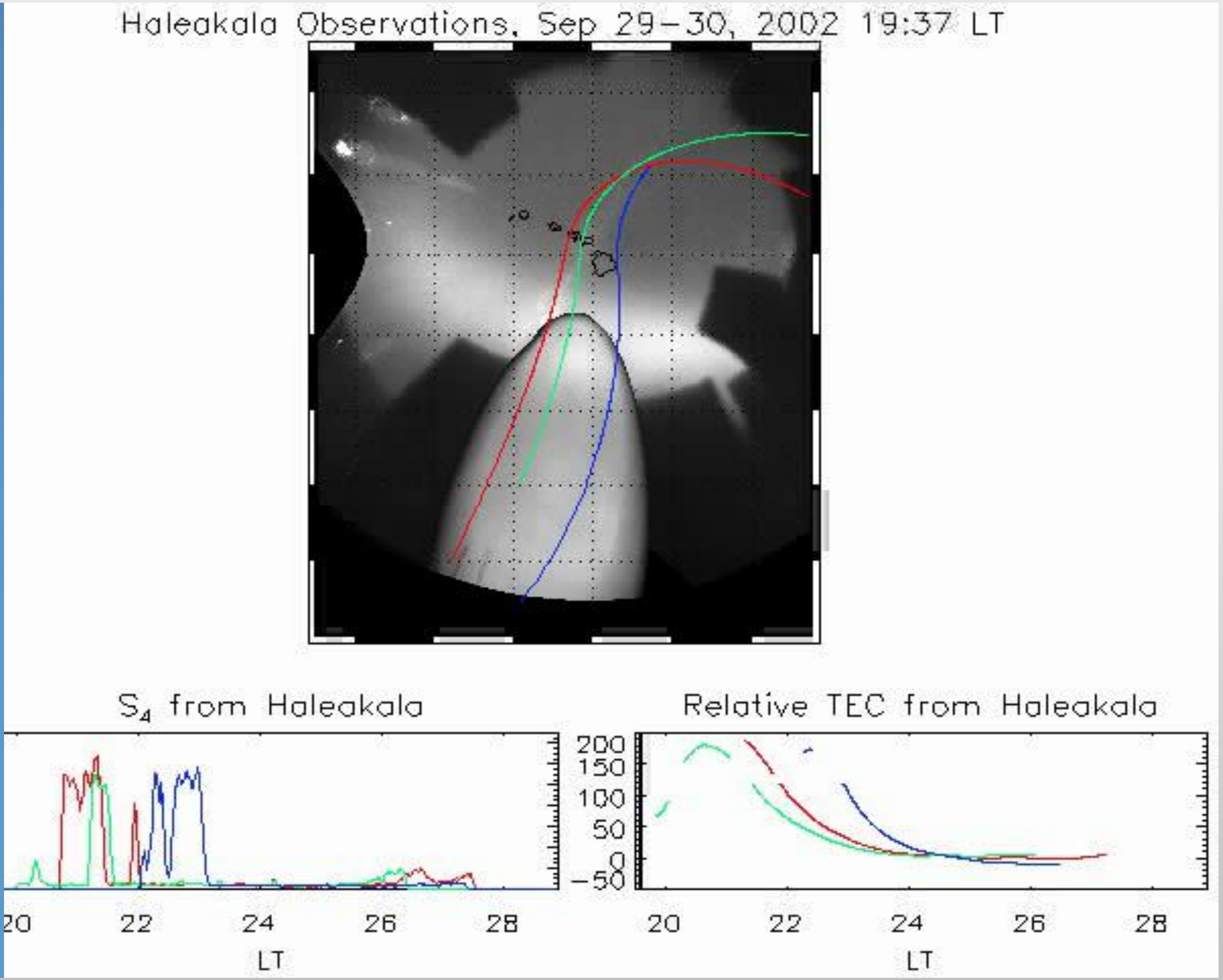
TEC Global Variation



(Luhr et al., 2003)

Coincidence Measurements of GPS and Optical Imaging Systems

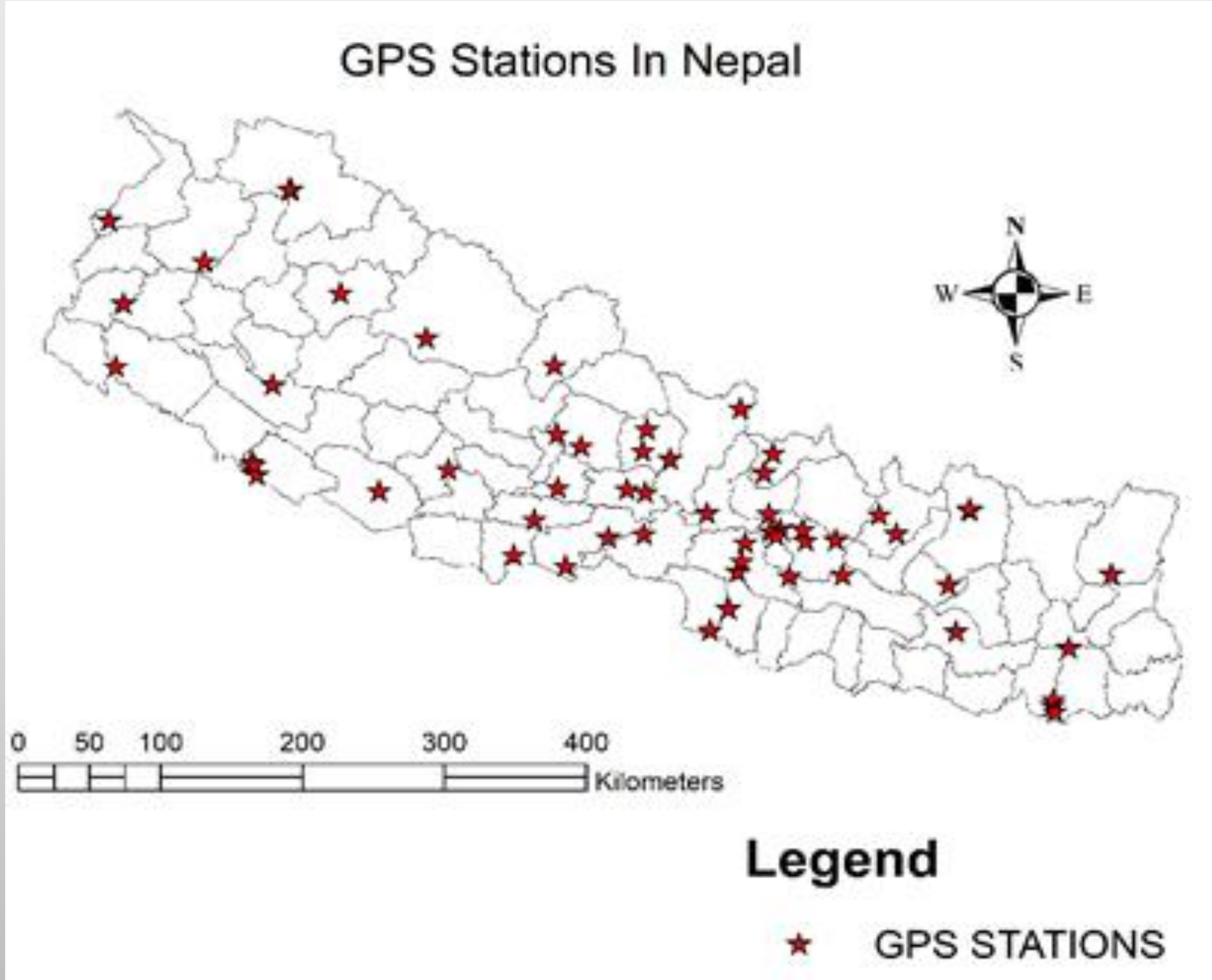




Makela et al.

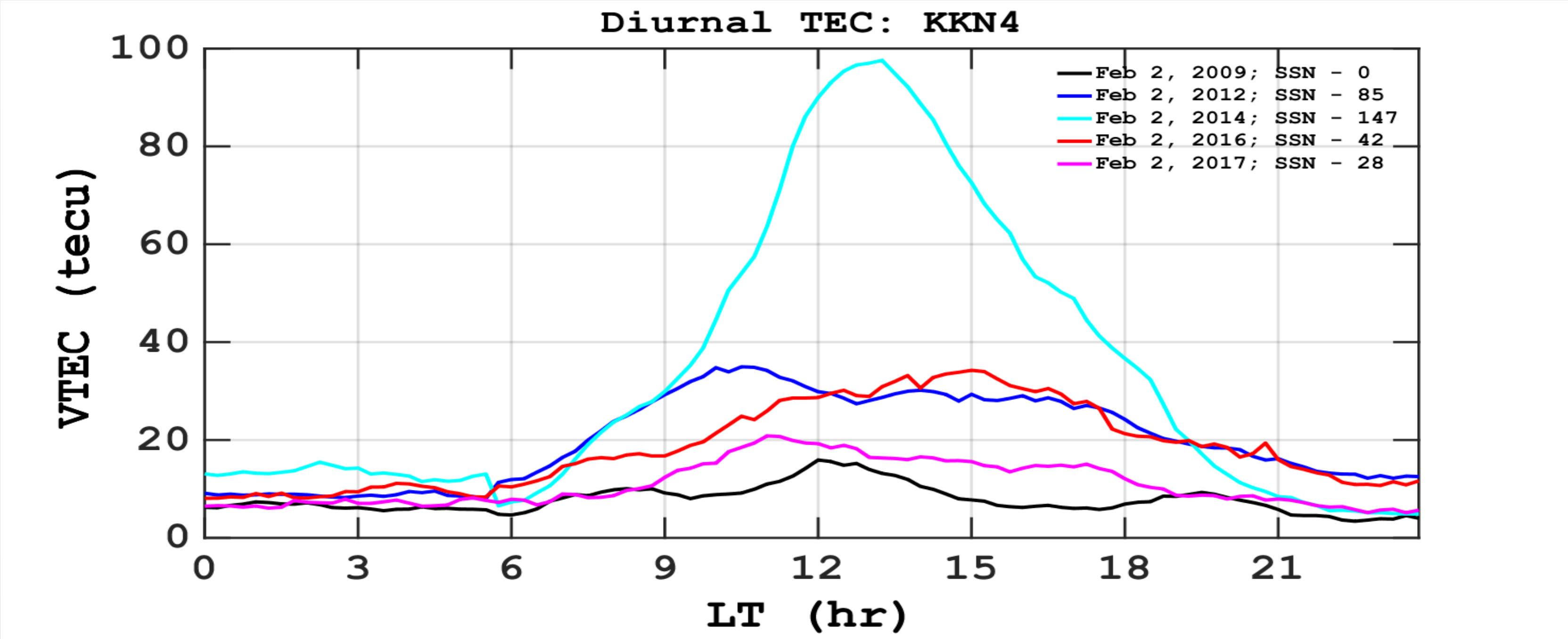
GPS Stations Over Nepal

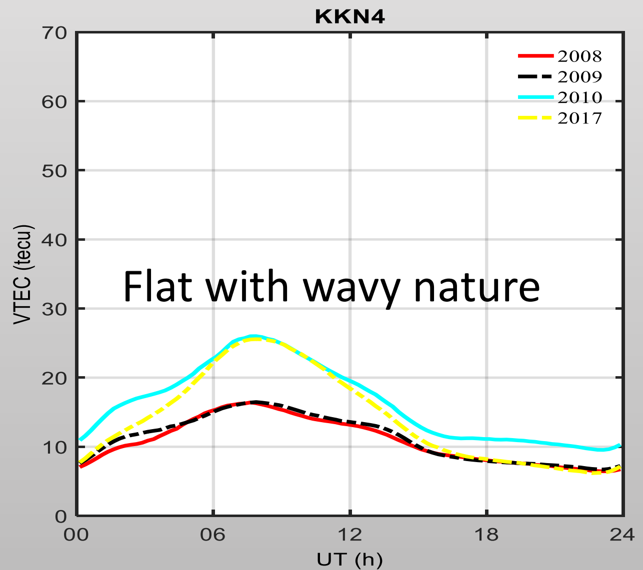
GPS TEC data from 53 stations during 2000 – 2019 (UNAVCO)

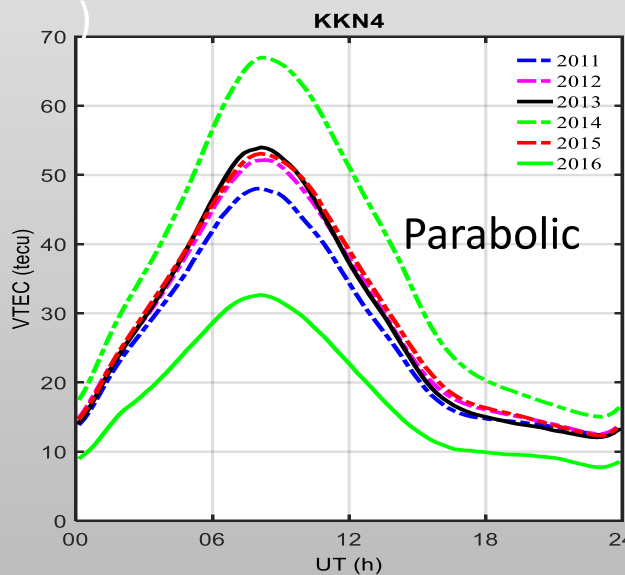


GNSS Receiver

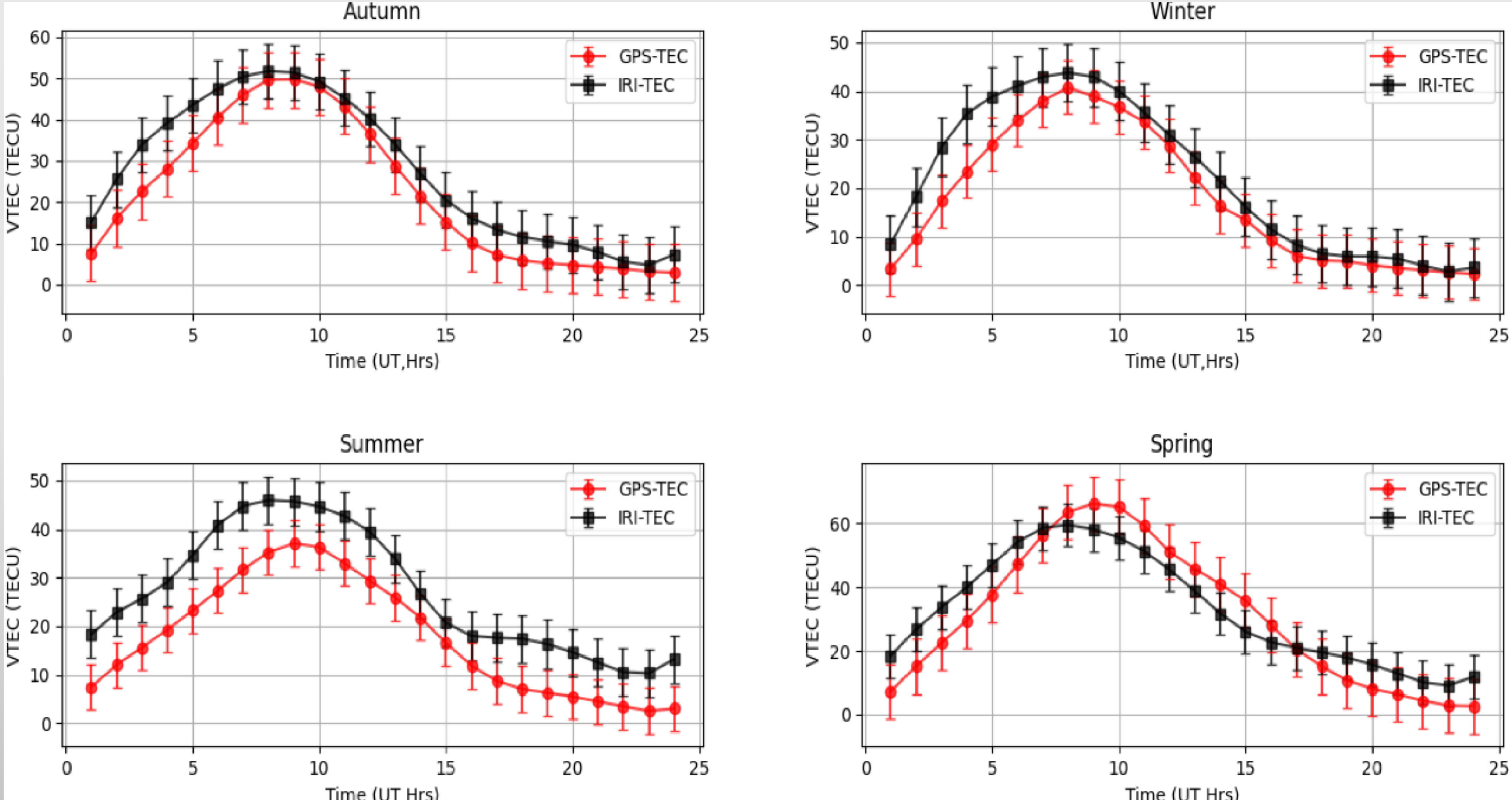
Diurnal Variations GPS -TEC







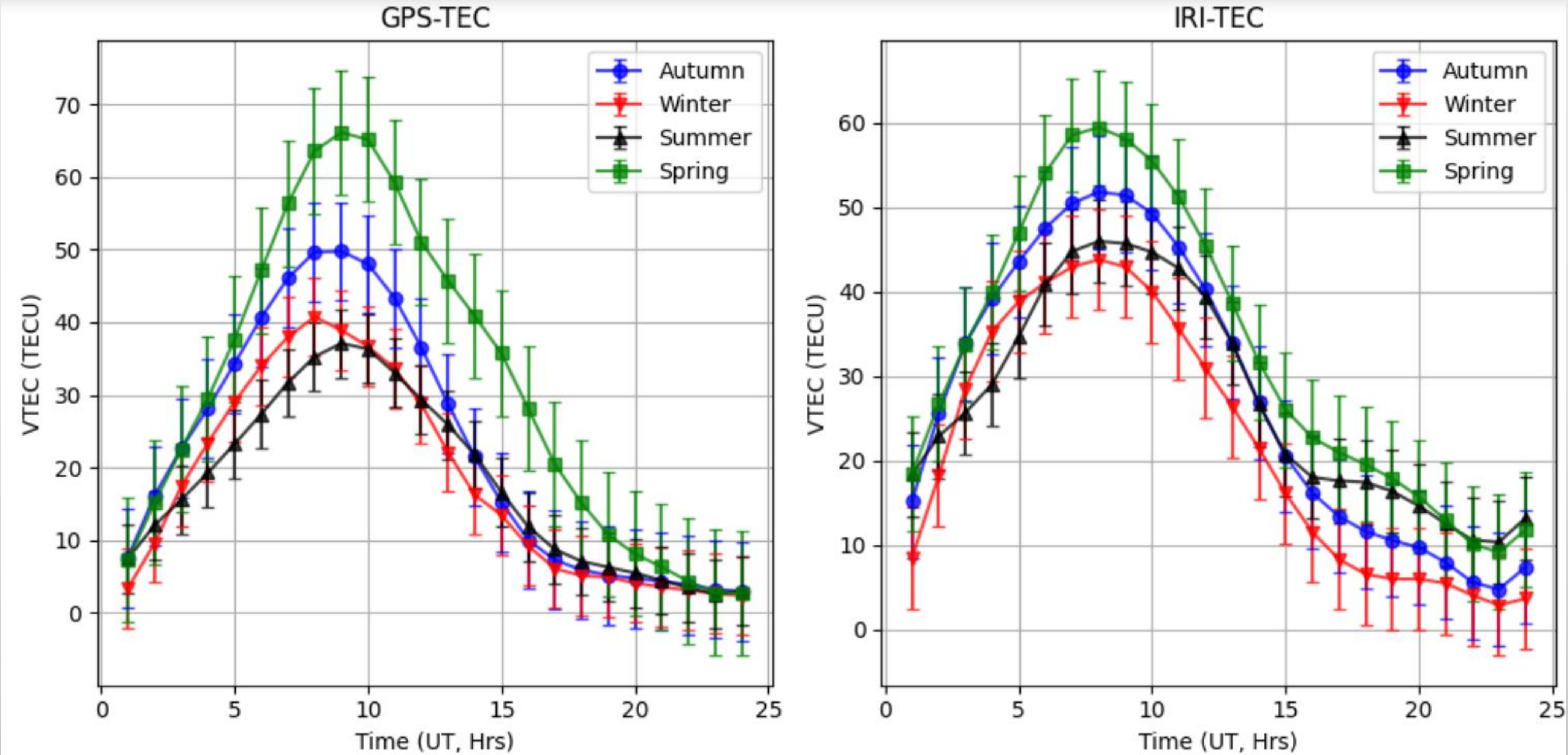
Comparision of Seasonal GPS TEC with IRI-Models



Seasonal trends of GPS-TEC and IRI-TEC for the Year of 2016

LT = UT+5:45 hr

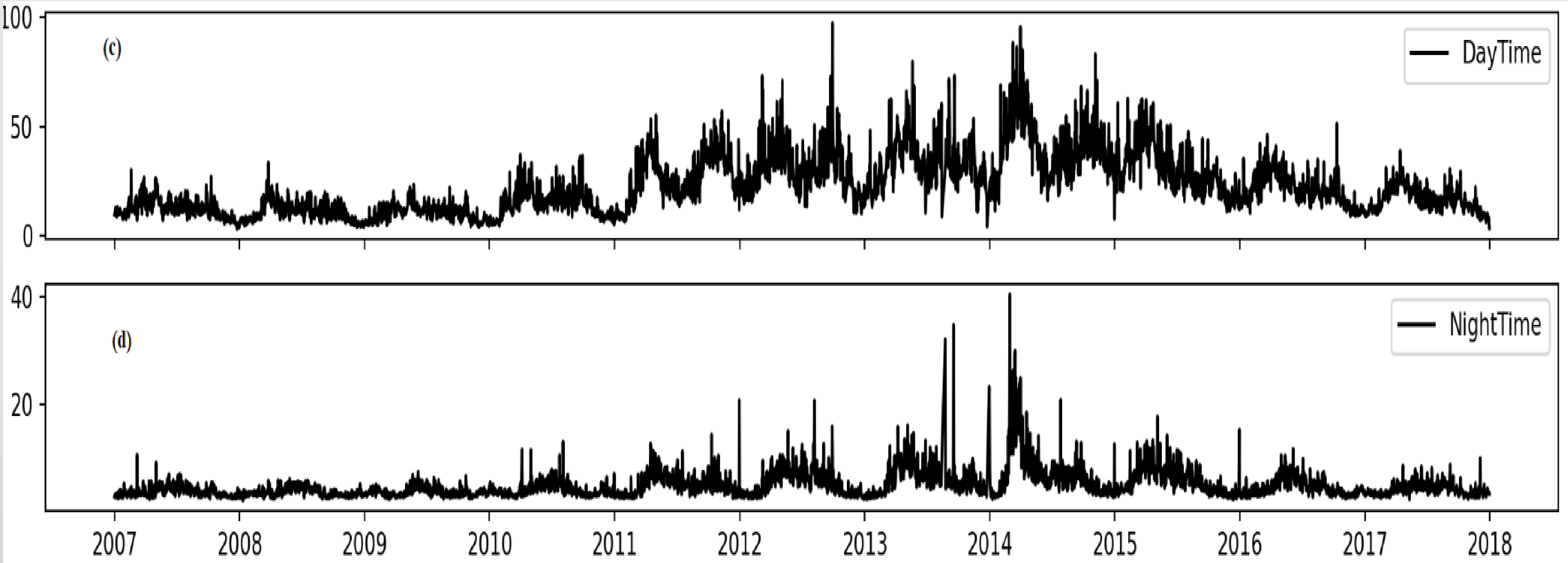
Comparision of Seasonal Variations GPS -TEC with IRI-Models



Seasonal trends of GPS-TEC and IRI-TEC for the Year of 2016

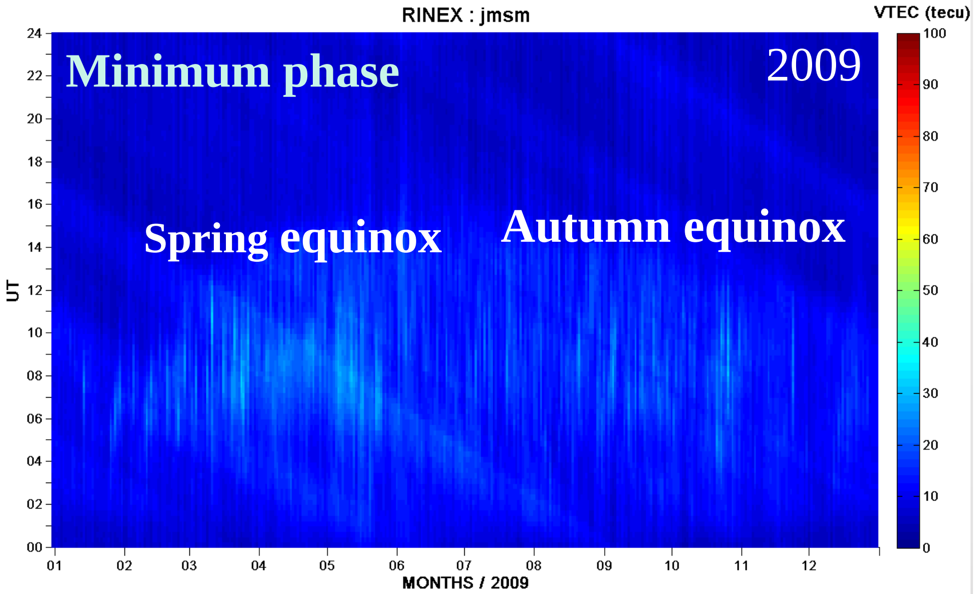
TEC in Spring > TEC in Autumn > TEC in Summer > TEC in Winter

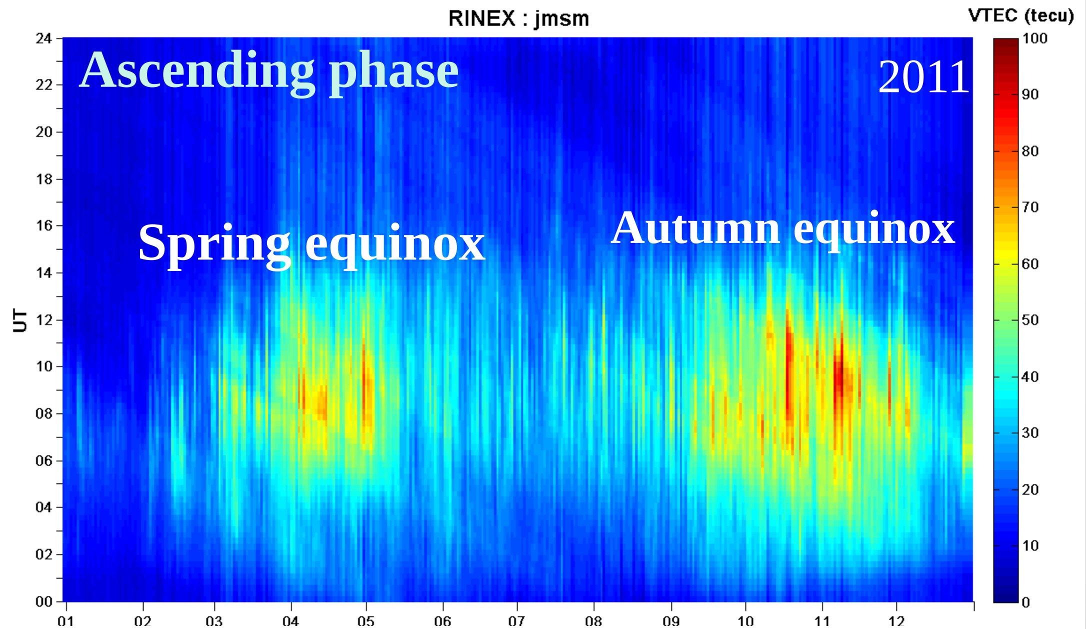
Long-term Variations in GPS TEC

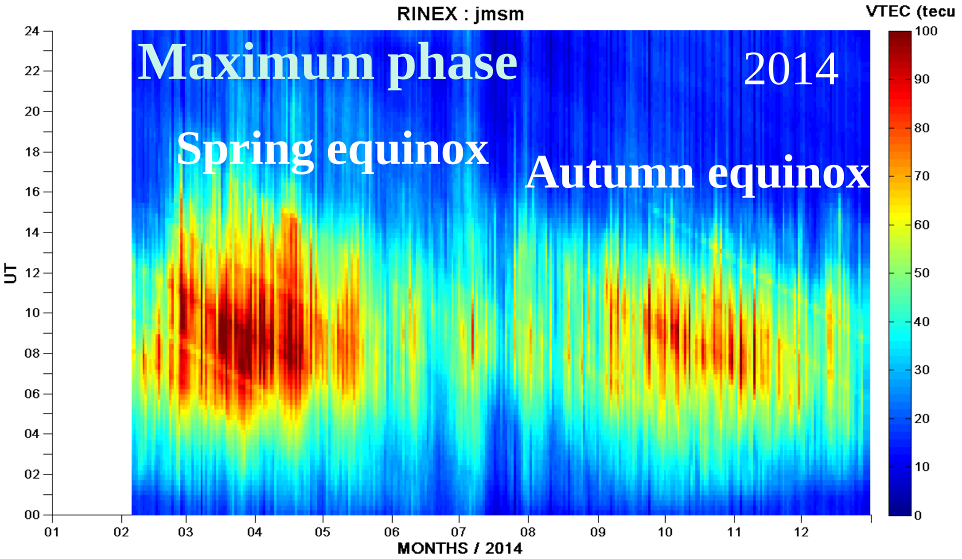


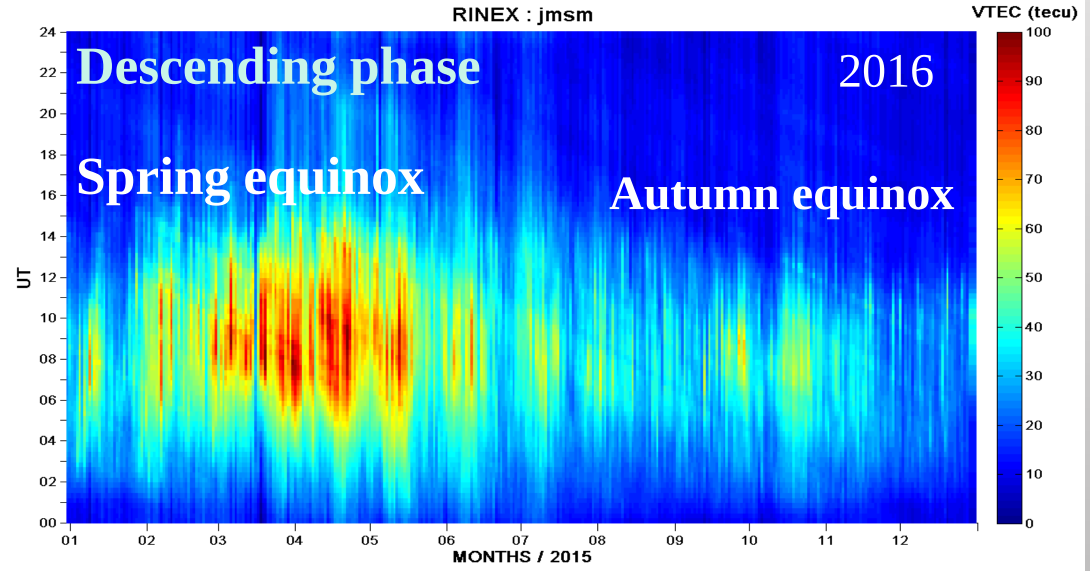
(a) Day-time and (b) Night-time TEC time-series plots of data during 2007-2017

TEC Seasonal Equinox with Solar Cycles

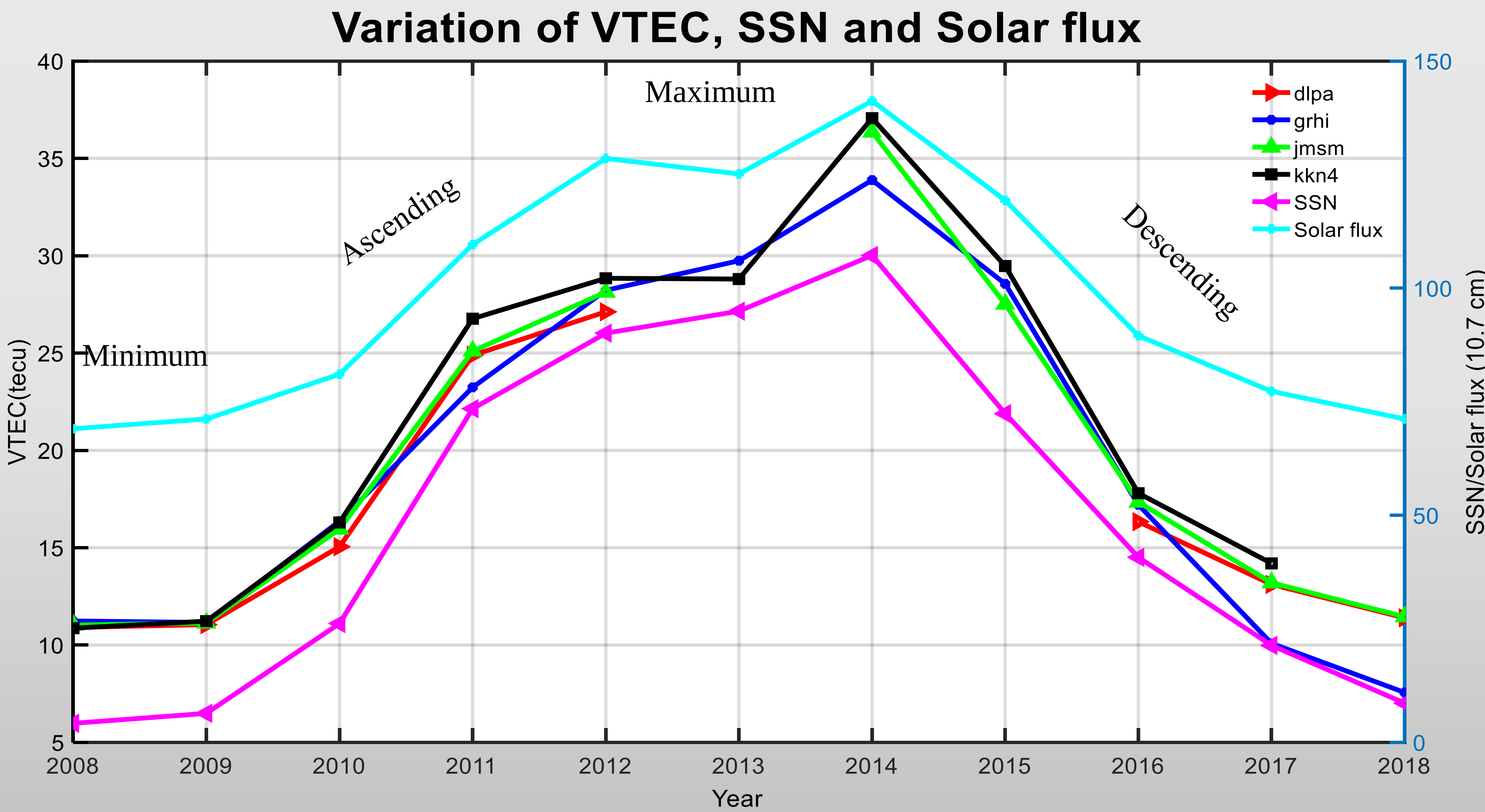






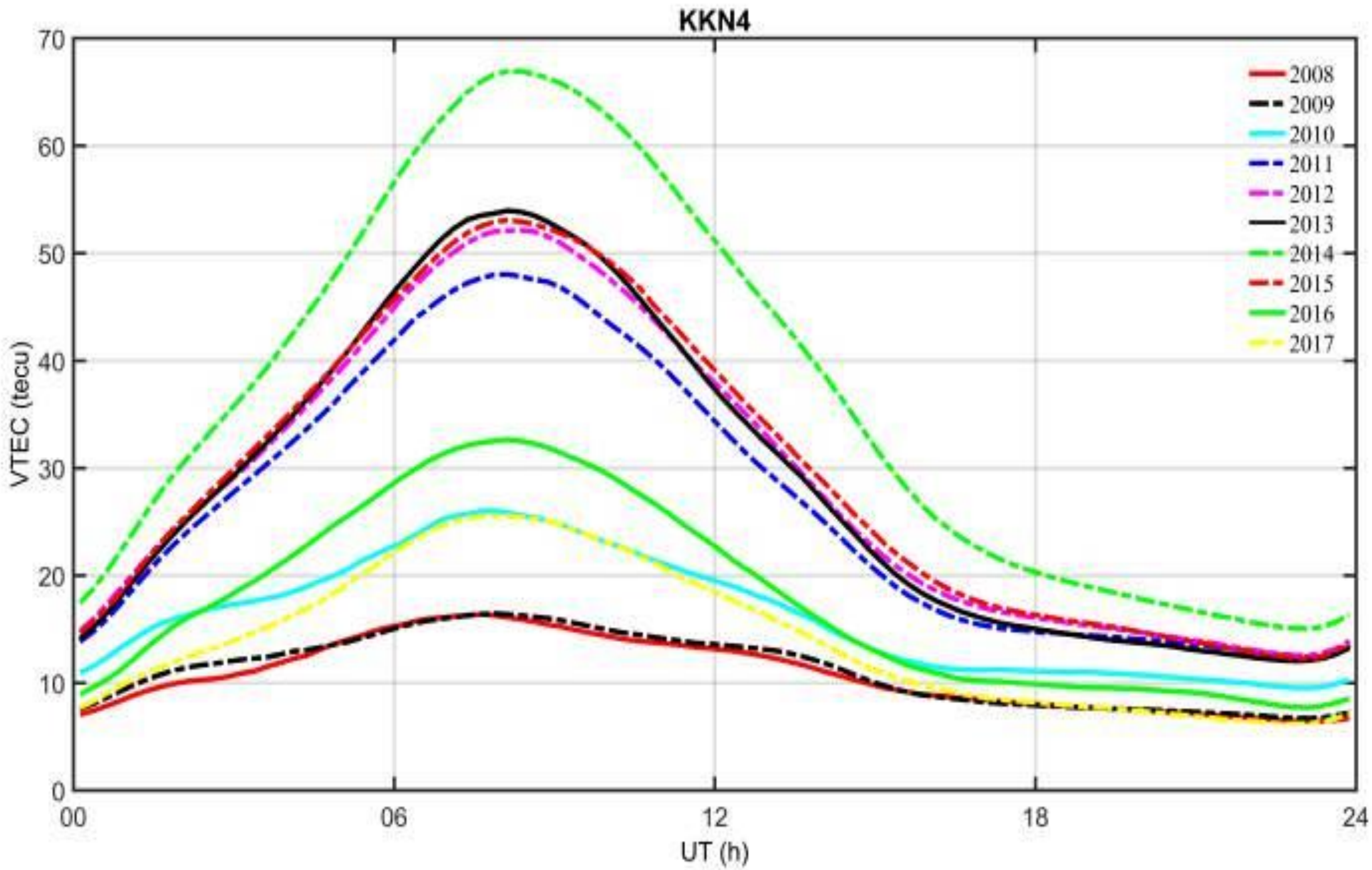


Yearly Variations in GPS TEC



VTEC along with SSN and solar flux

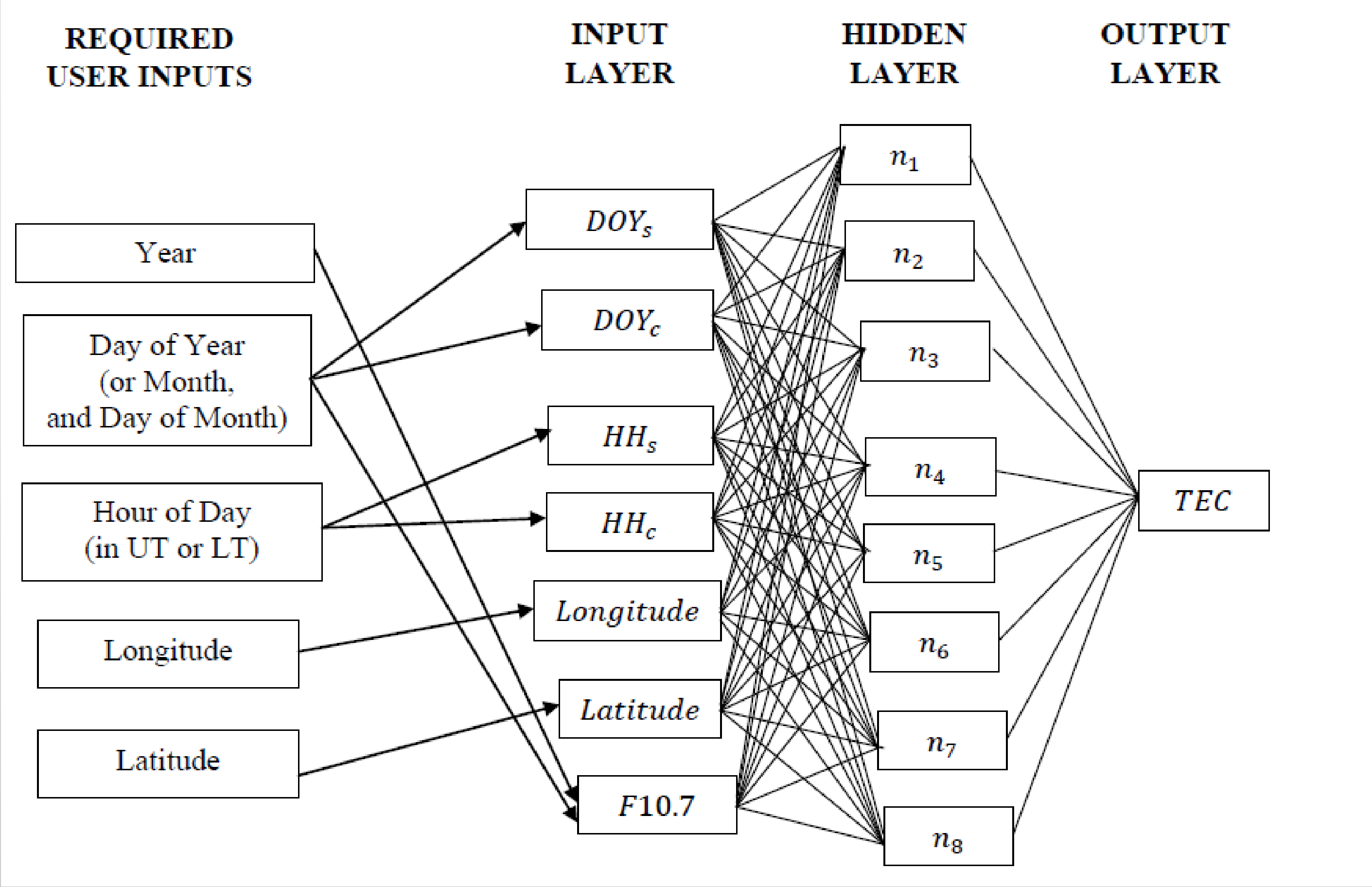
Mean Yearly Variations in TEC 2008-2017



Neural Network (NN) Model

Neural networks basically consist of

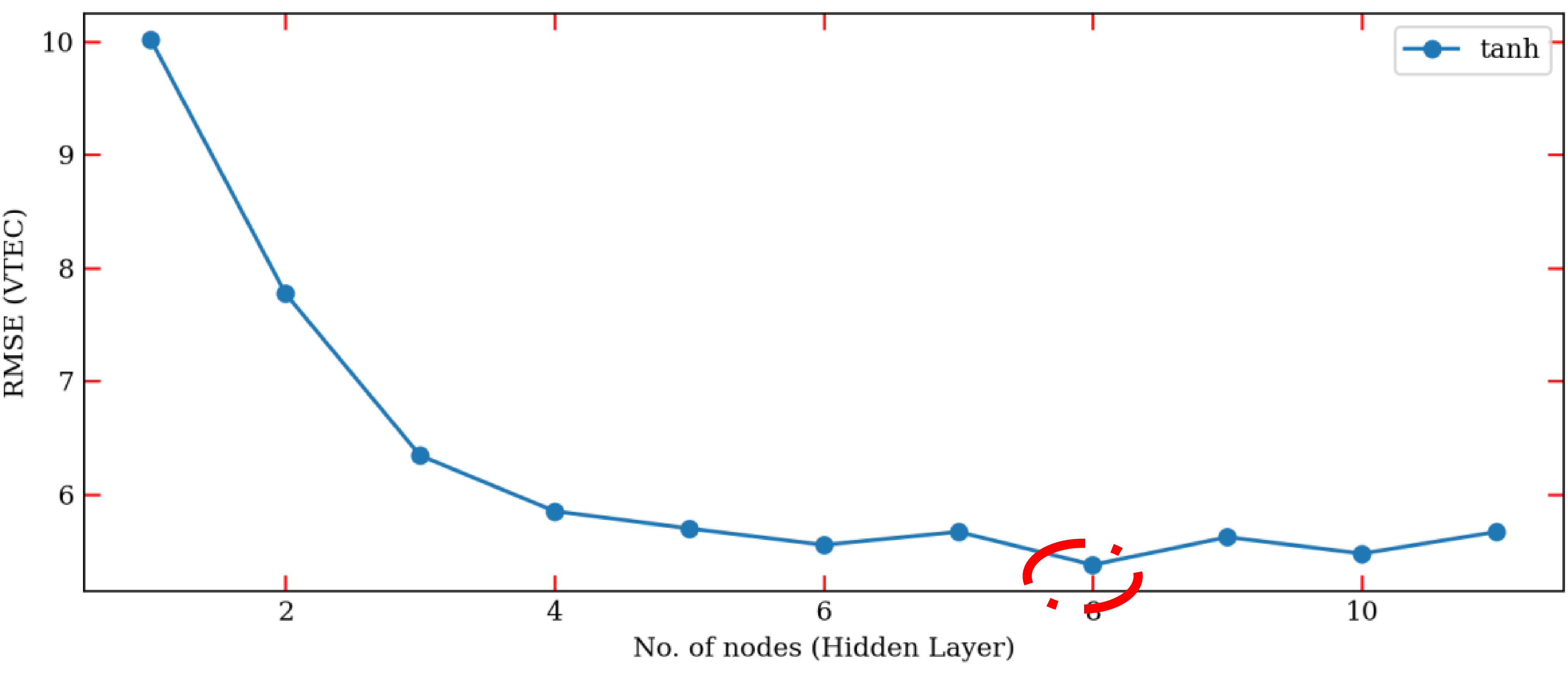
- An input layer(7)
- A hidden layer(8)
- An output layer(1)
- Each of the layers contains one or more neurons



Graphical Representation of Neural Network used in developing Model

(Okoh et al., 2016)

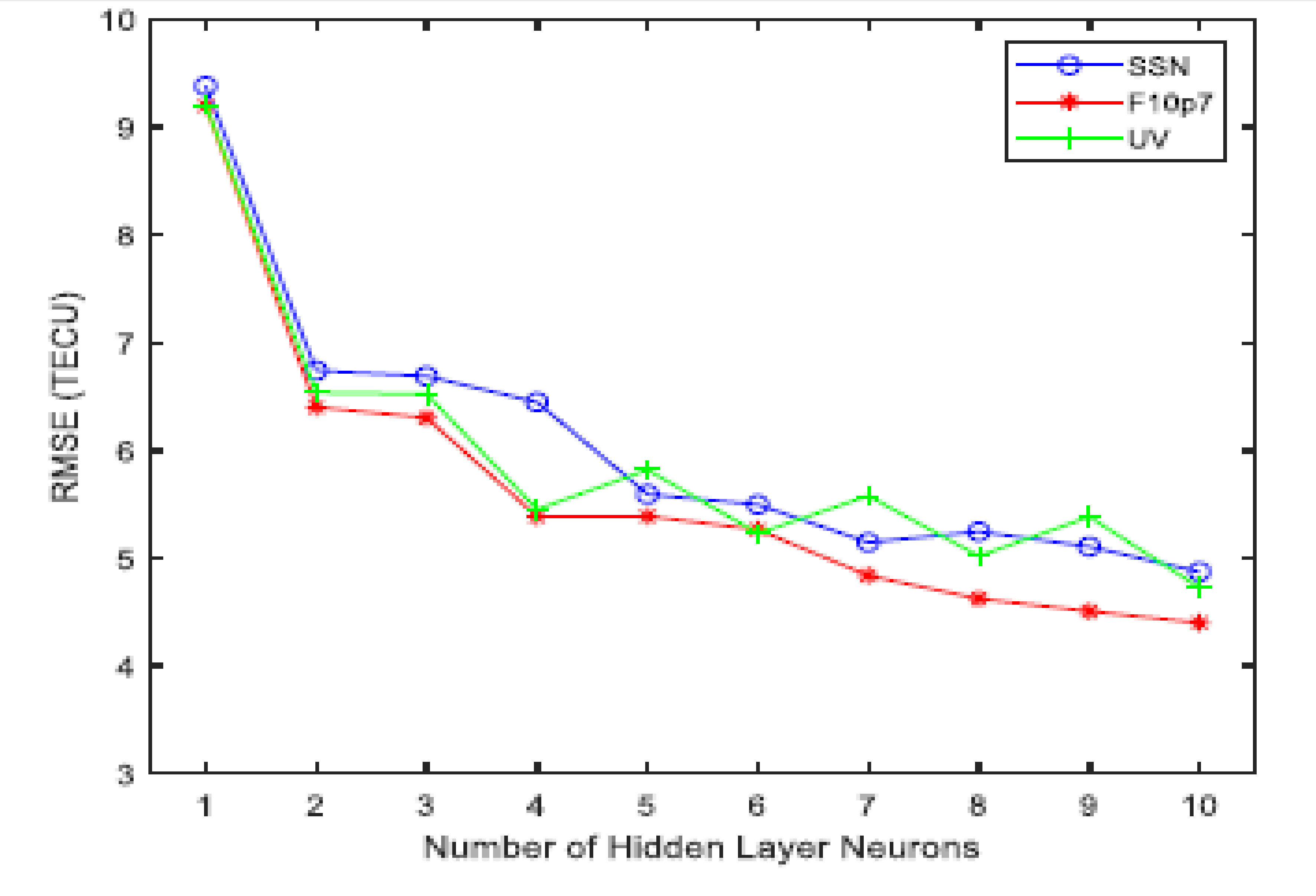
Neural Network (NN)



RMSEs correspond to different numbers of hidden layers.

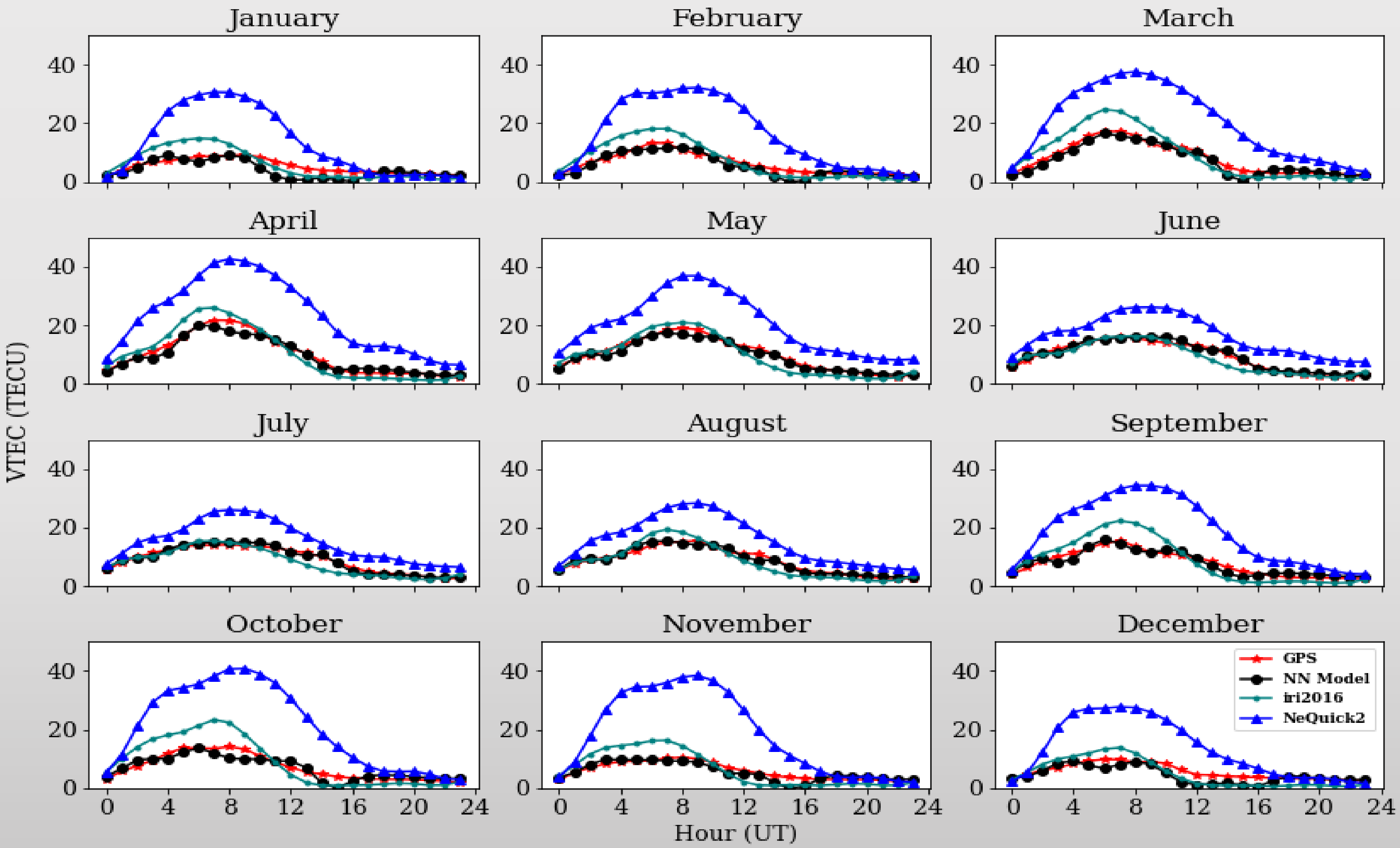
$$RMSE_i = \sqrt{\sum_{i=1}^{n} (GNSS\ Receiver_i - Neural\ Network_i)^2 \times \frac{1}{n}}$$

RMSEs Corresponding to Solar activity



RMSE value for F(10.7 cm) was observed lowest than SSN and UV

Comparision of Monthly GPS TEC with Models

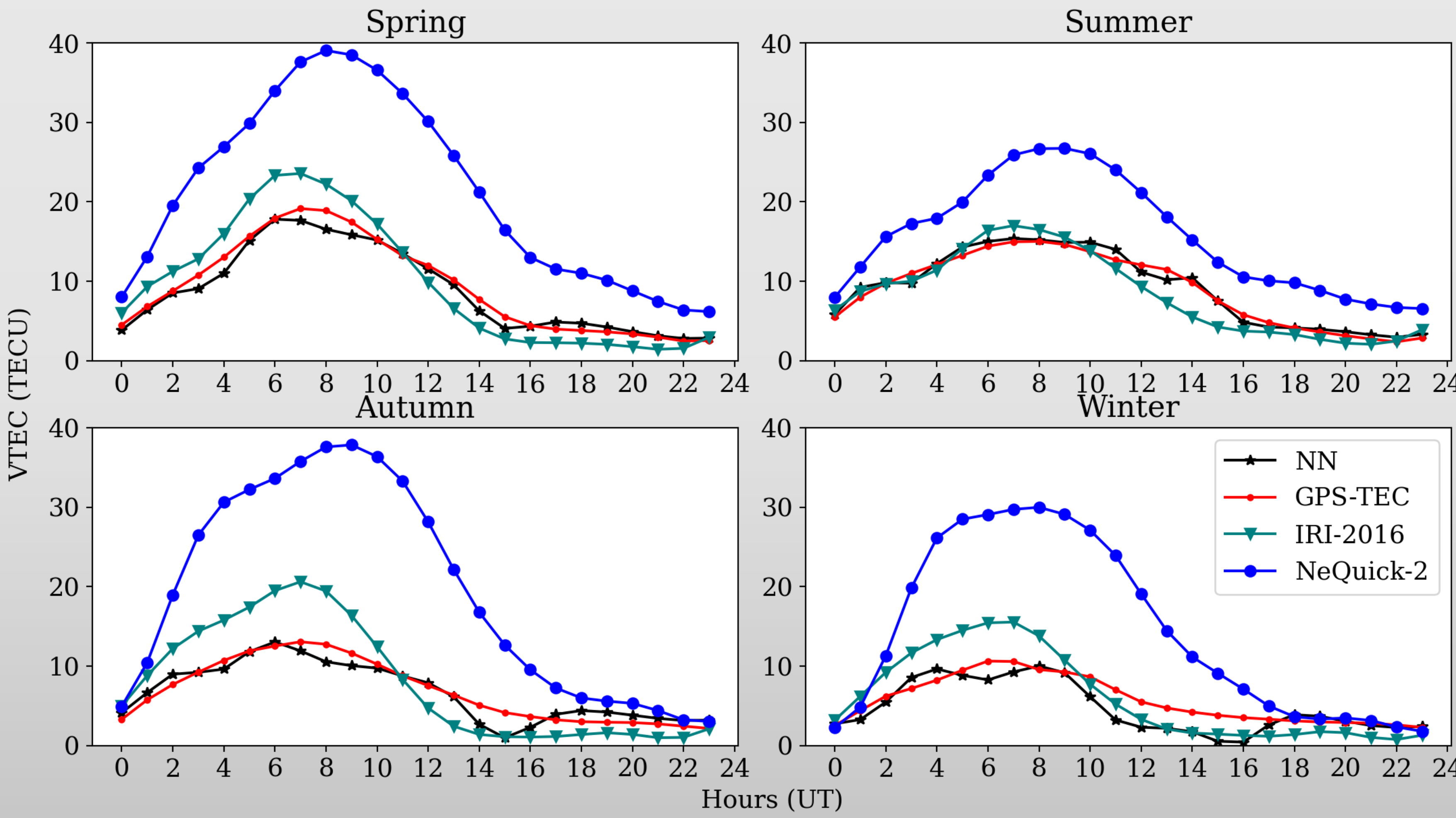


GPS VTEC, IRI, NN and NeQuick-2 models for months of year 2018

Most of the time of months, the NeQuick-2 model overestimates IRI-2016, NN model, and GPS-TEC model from morning to midnight

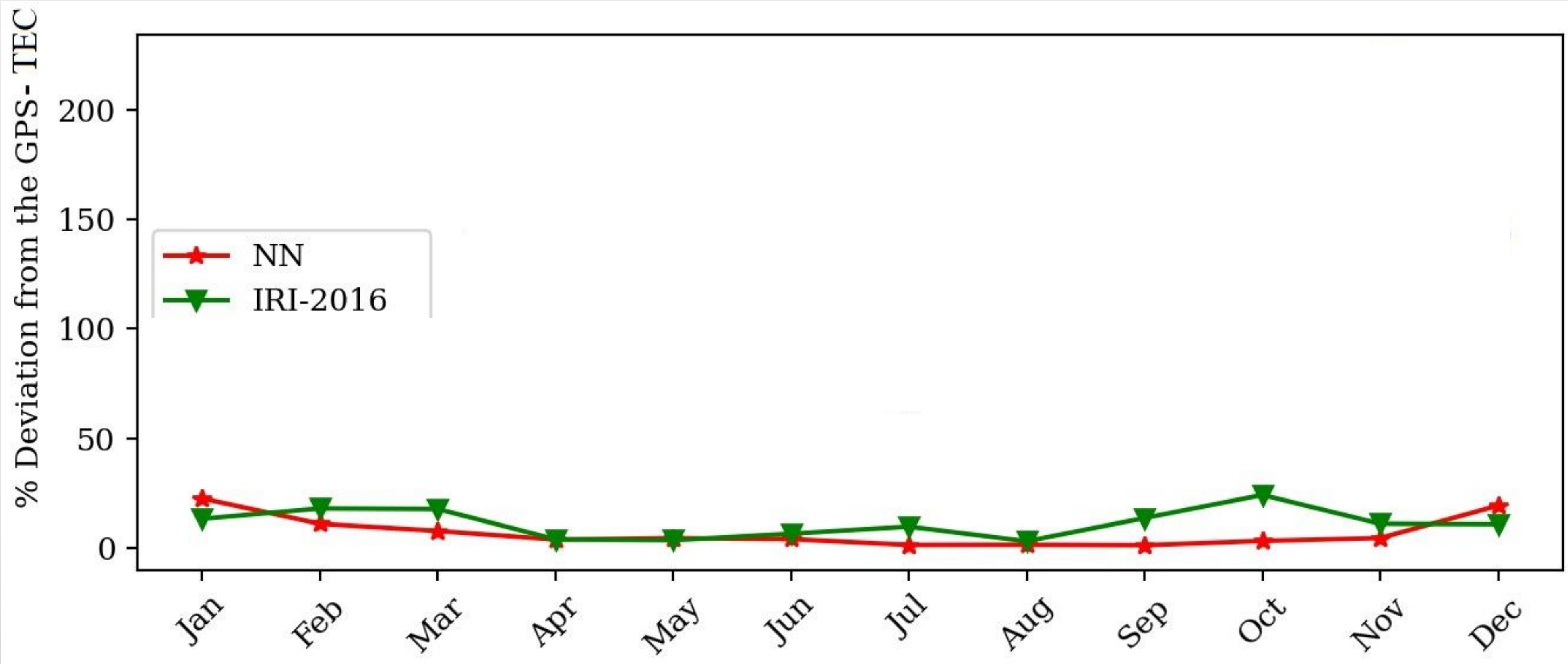
Comparision of Seasonal GPS TEC with Models

GPS-TEC with IRI, NN and NeQuick-2 models for months of year 2018



- All models describe maximum VTEC in the Spring season and minimum in the Winter season

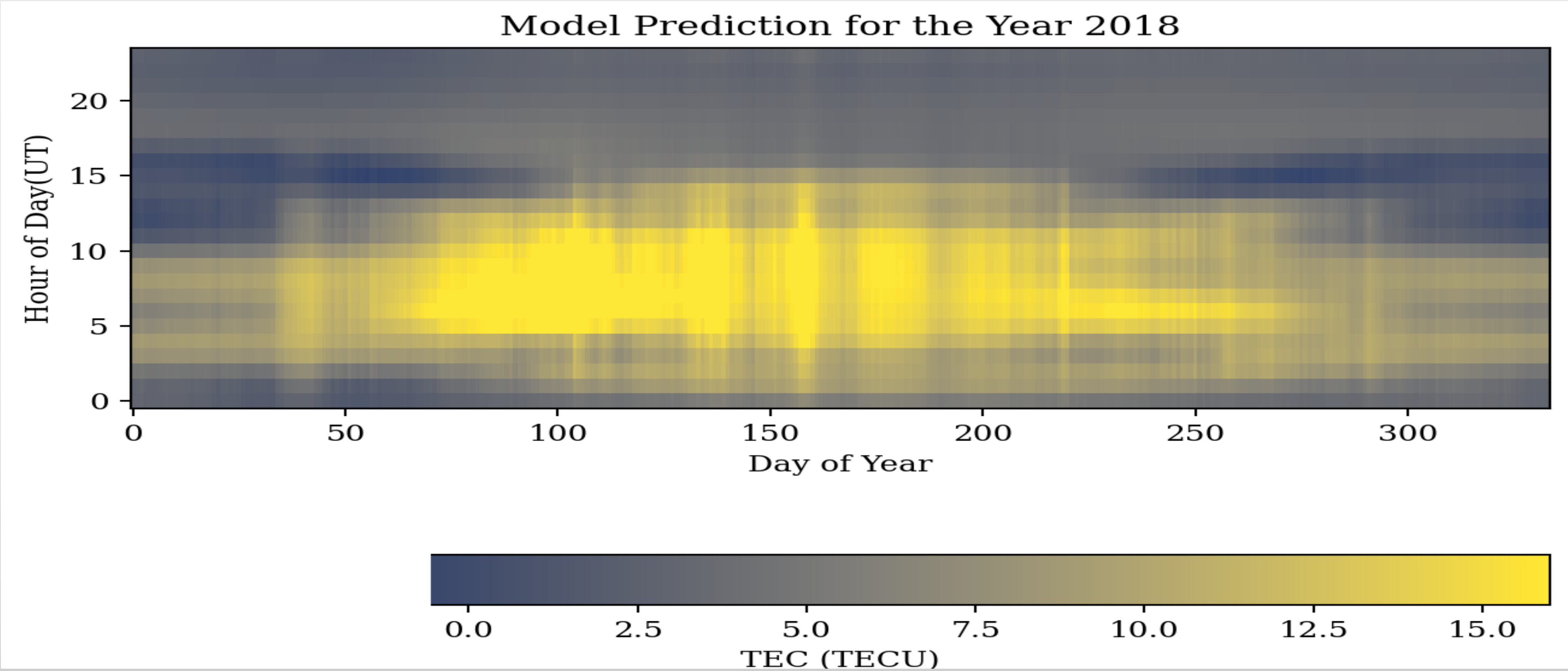
Comparision of GPS TEC with Models



Percentage deviation of IRI-2016, and NN from GPS-TEC

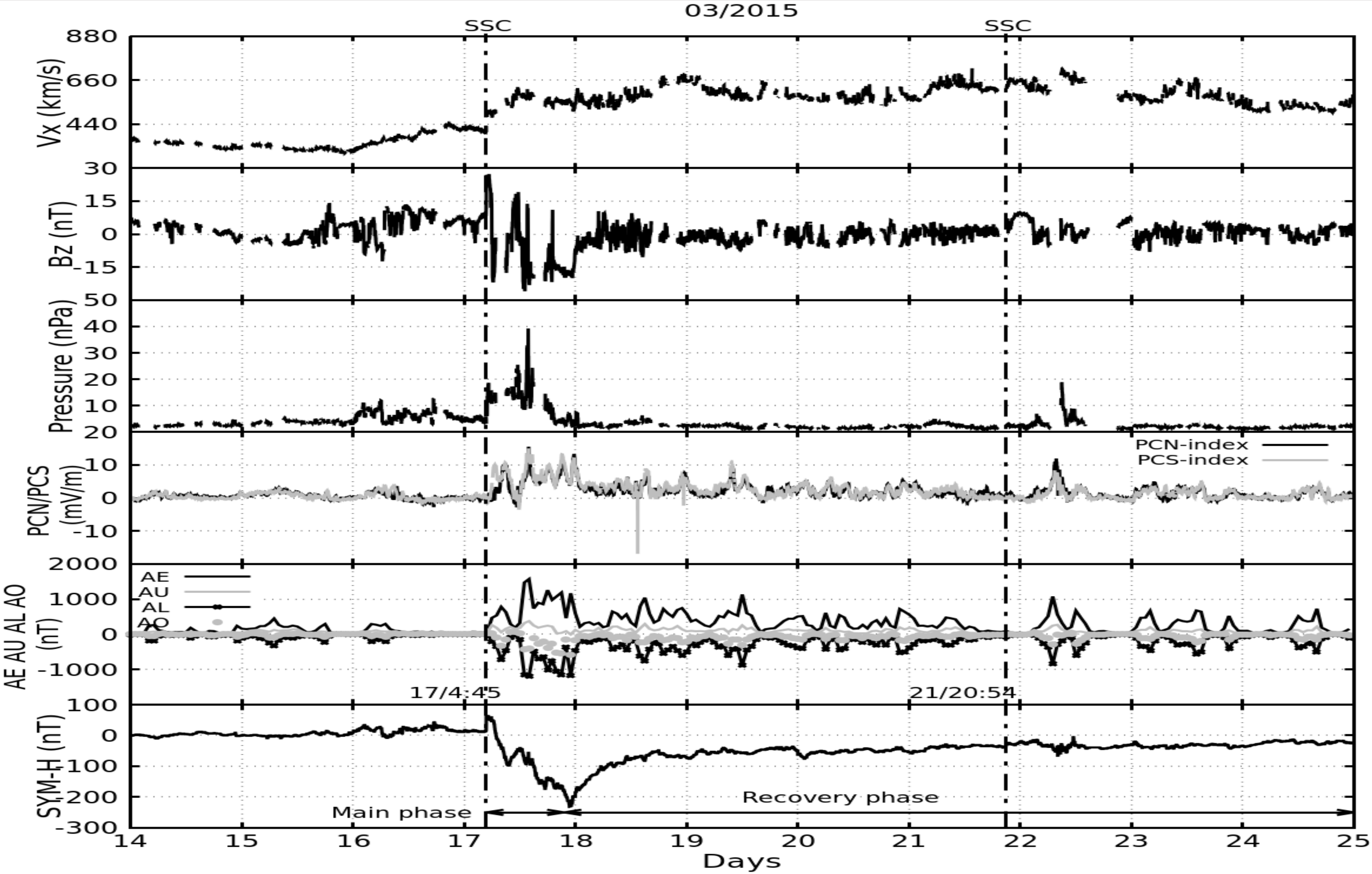
- IRI-2016 shows a small deviation from GPS-TEC (~ 10% - 20 %), while the NN model perfectly matches with GPS-TEC.

Prediction of VTEC using ANN

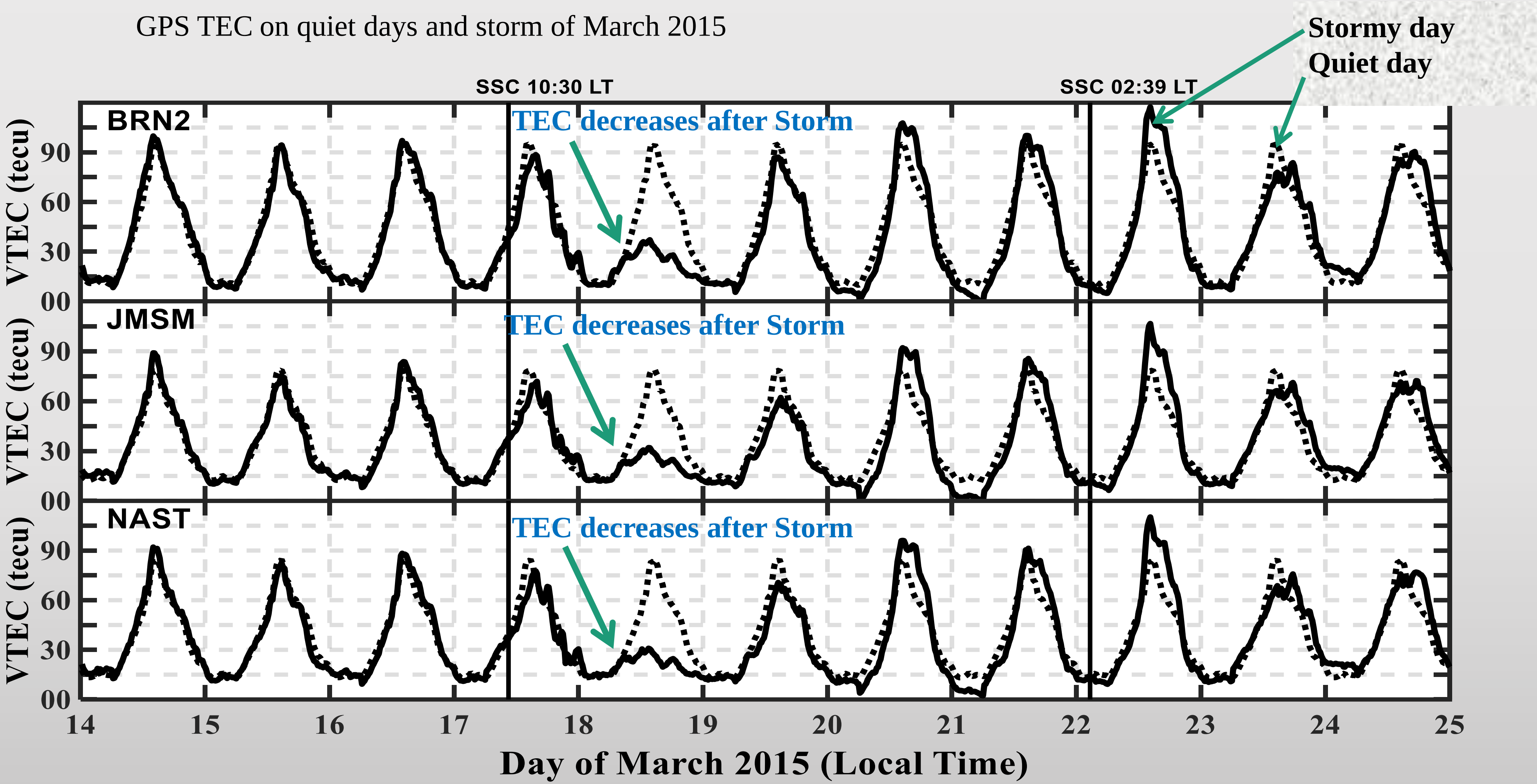


- Intensity of the VTEC varied from black (low) to yellow (high). It is maximum from DOY 70 to 240 and also showed higher VTEC in the day than during morning and night.

Super Intense Geomagnetic Storms March 2015

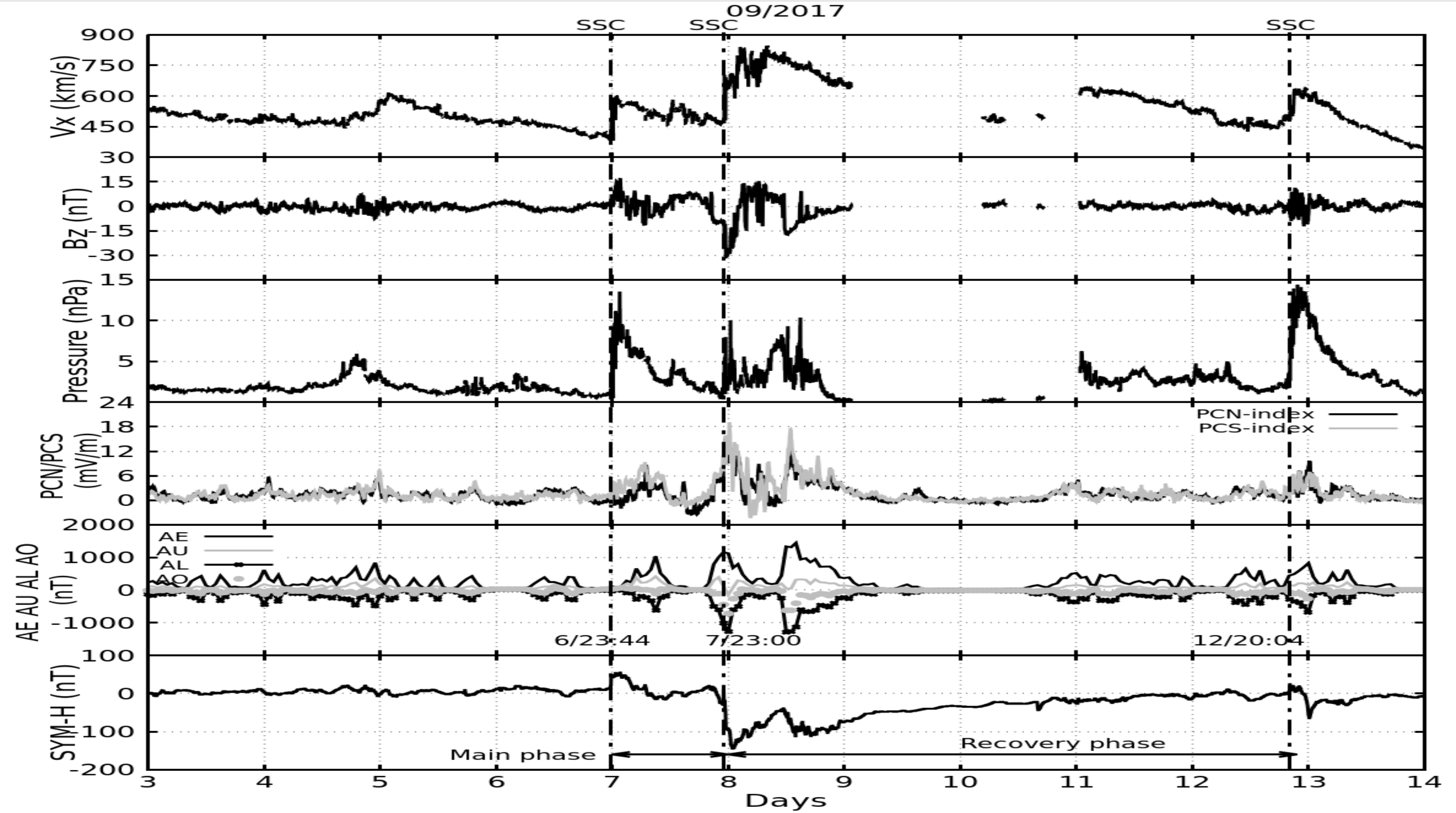


TEC Signature During Super Intense Geomagnetic Storms



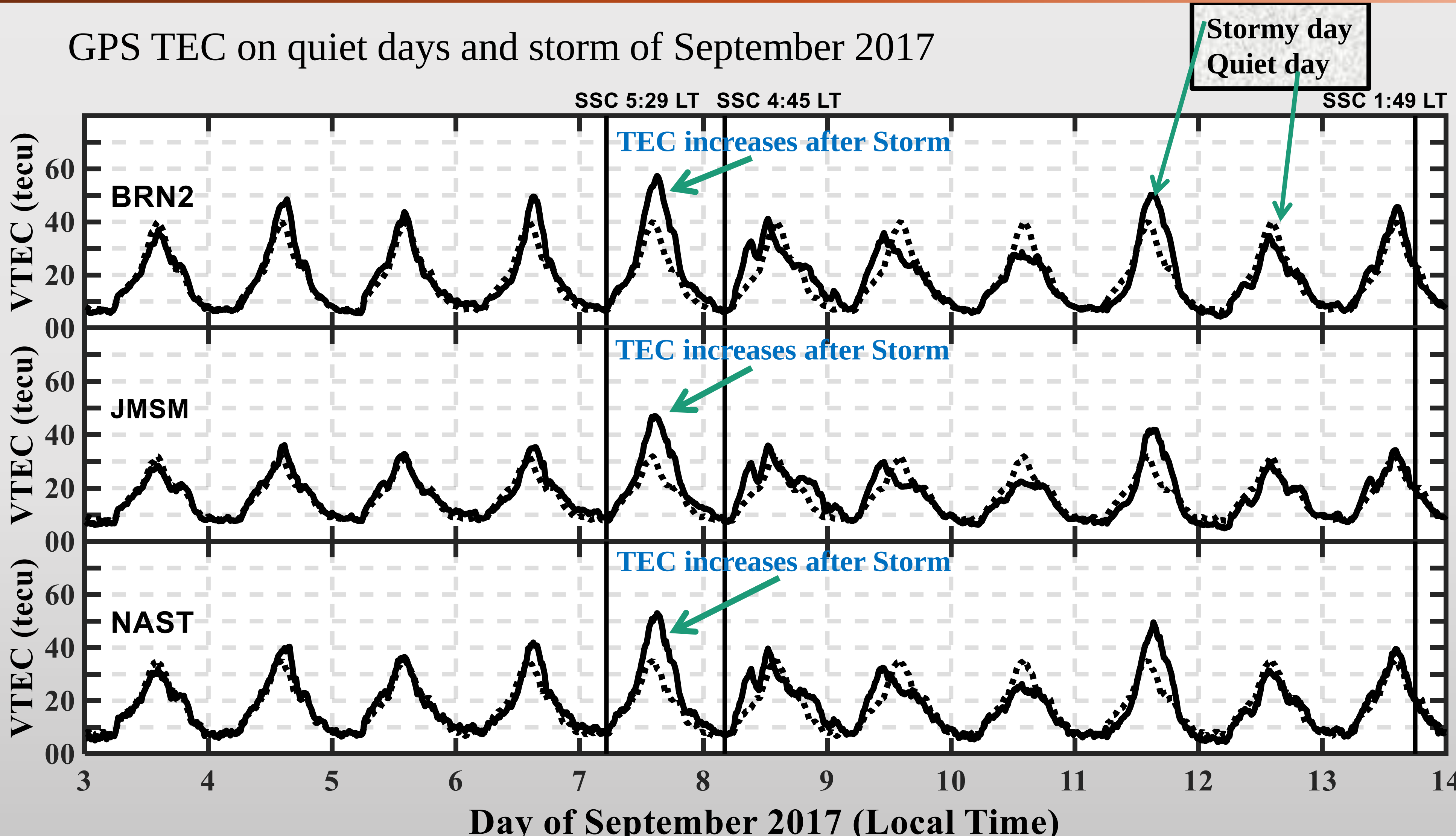
The main phase lies on 17 March and VTEC decreases after storm (negative ionospheric storm)

Super Intense Geomagnetic Storms September 2017



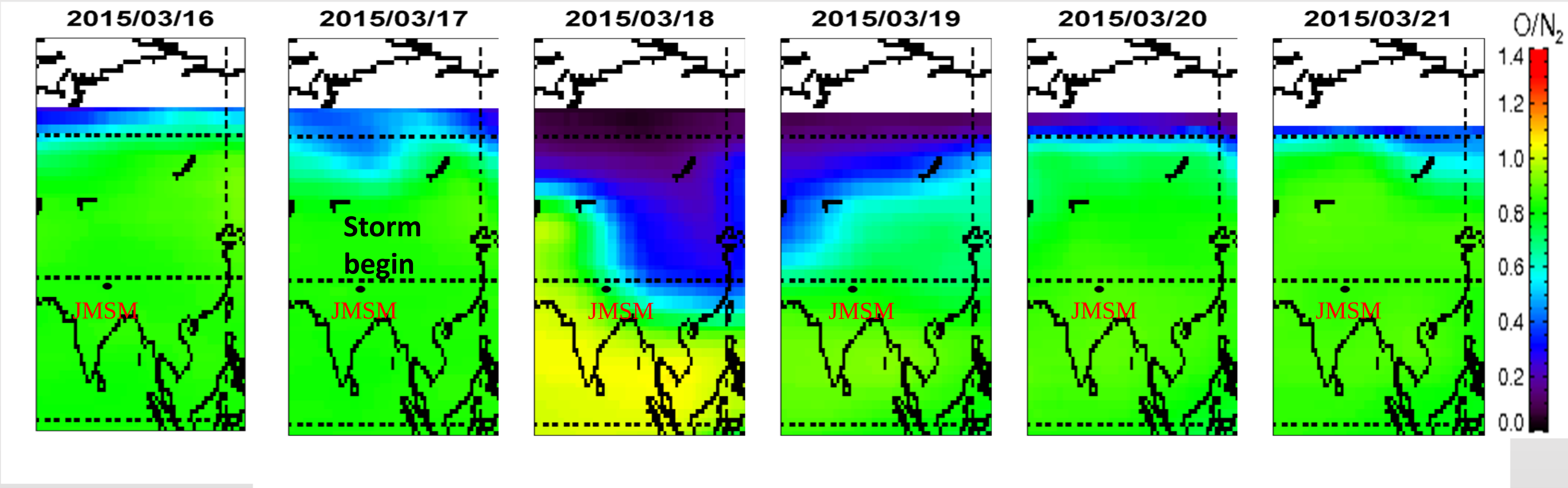
TEC Signature During Super Intense Geomagnetic Storms

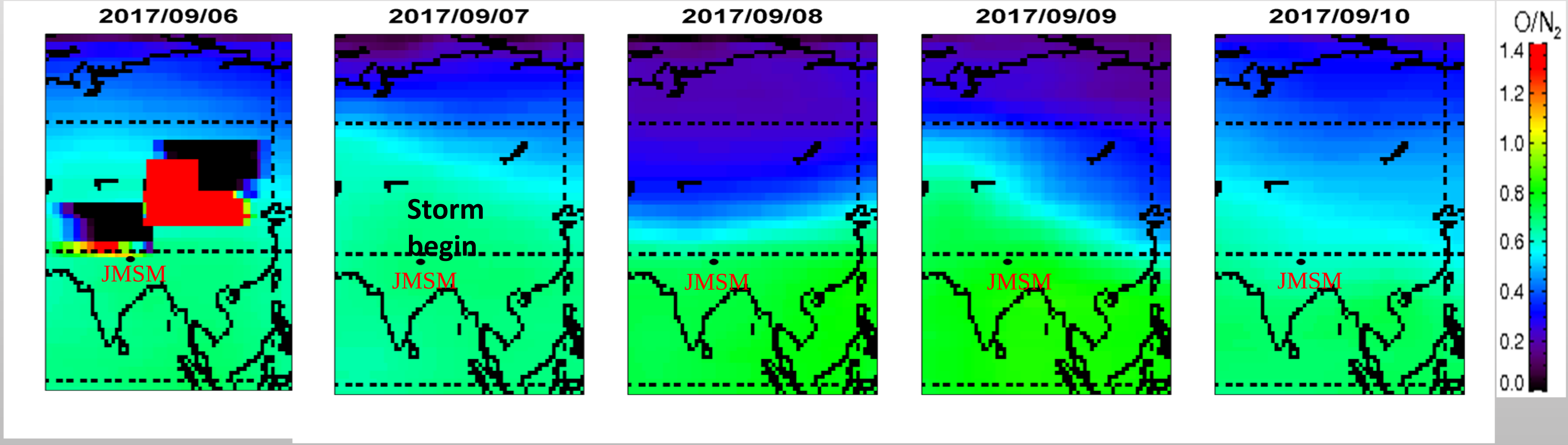
GPS TEC on quiet days and storm of September 2017



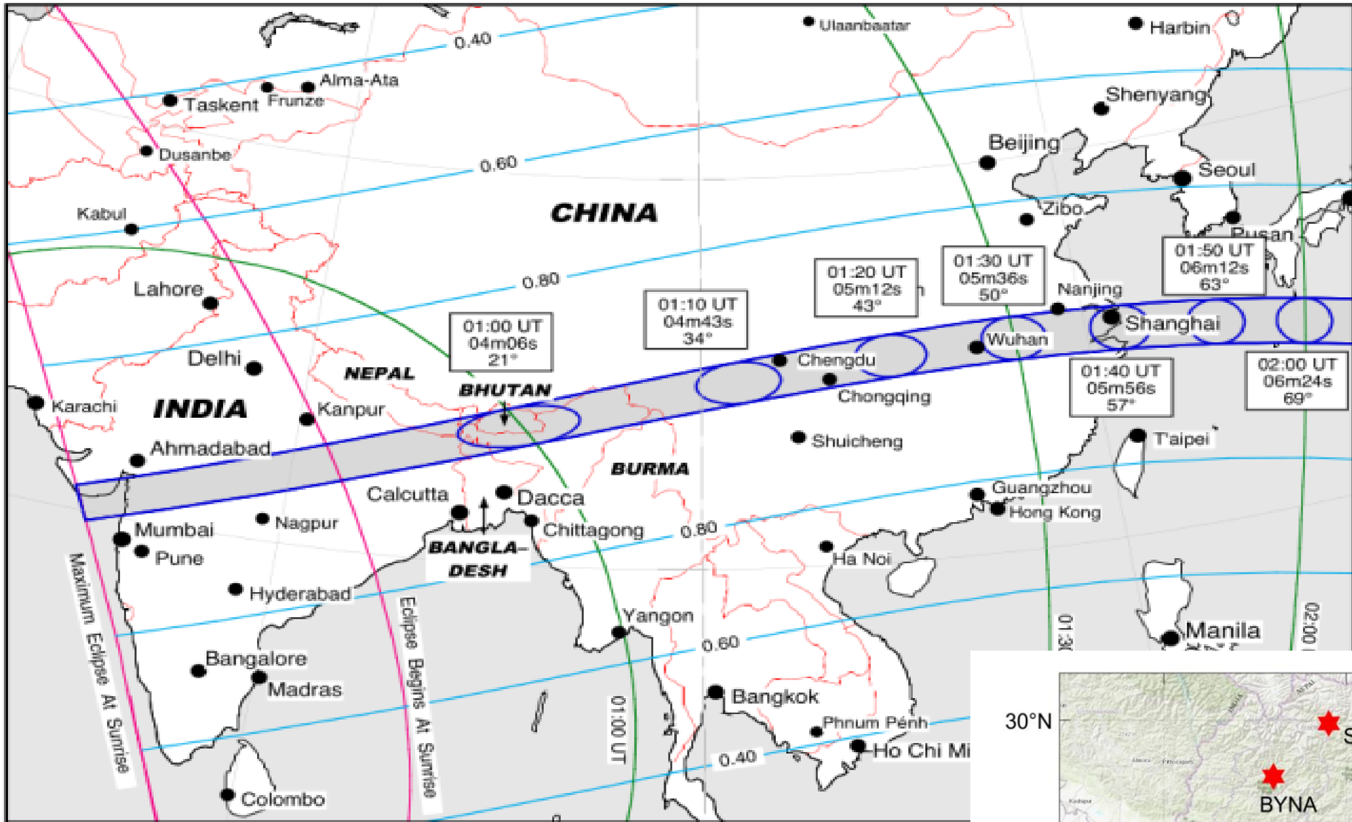
The main phase lies on 7 September and VTEC increases after storm (positive ionospheric storm).

Thermosphere O/N_2 Ratio during Geomagnetic Storms



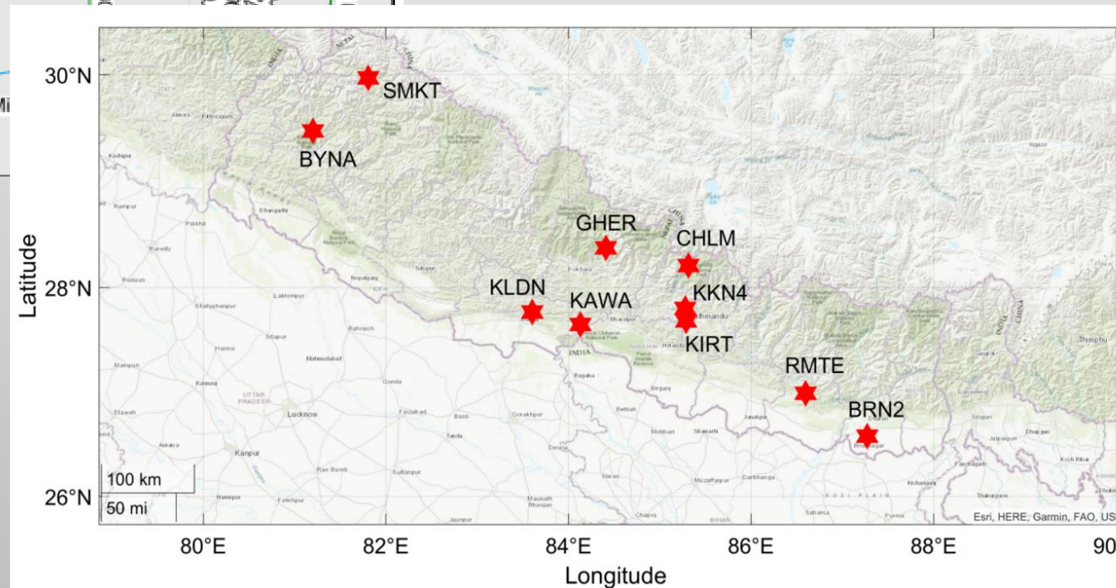


Ionospheric Anomaly due to Solar Eclipse



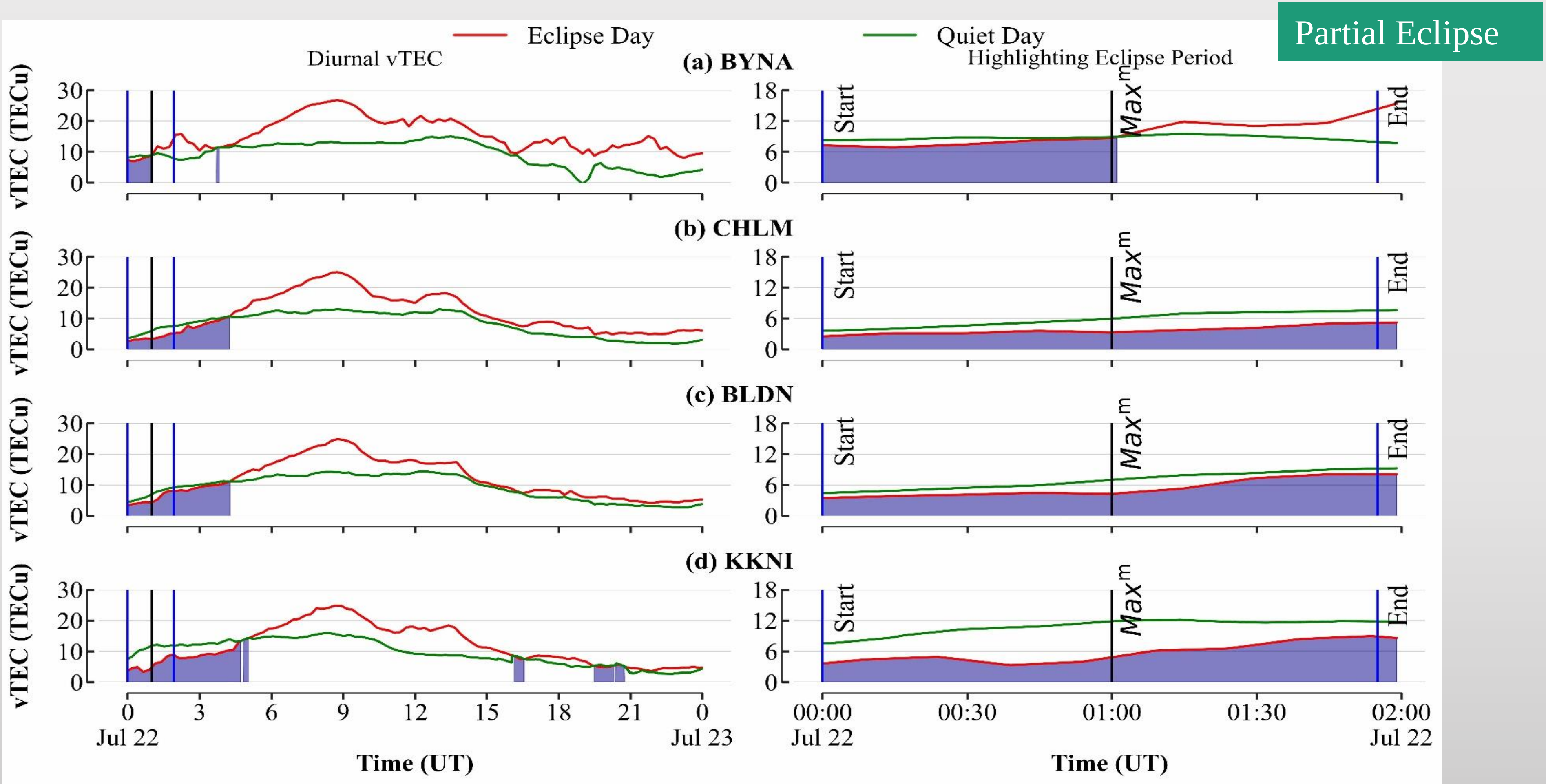
Path of 22 July 2009 solar eclipse through Asia.

It was the longest solar eclipse of the twenty-first century, lasting 6 minutes and 39 seconds.



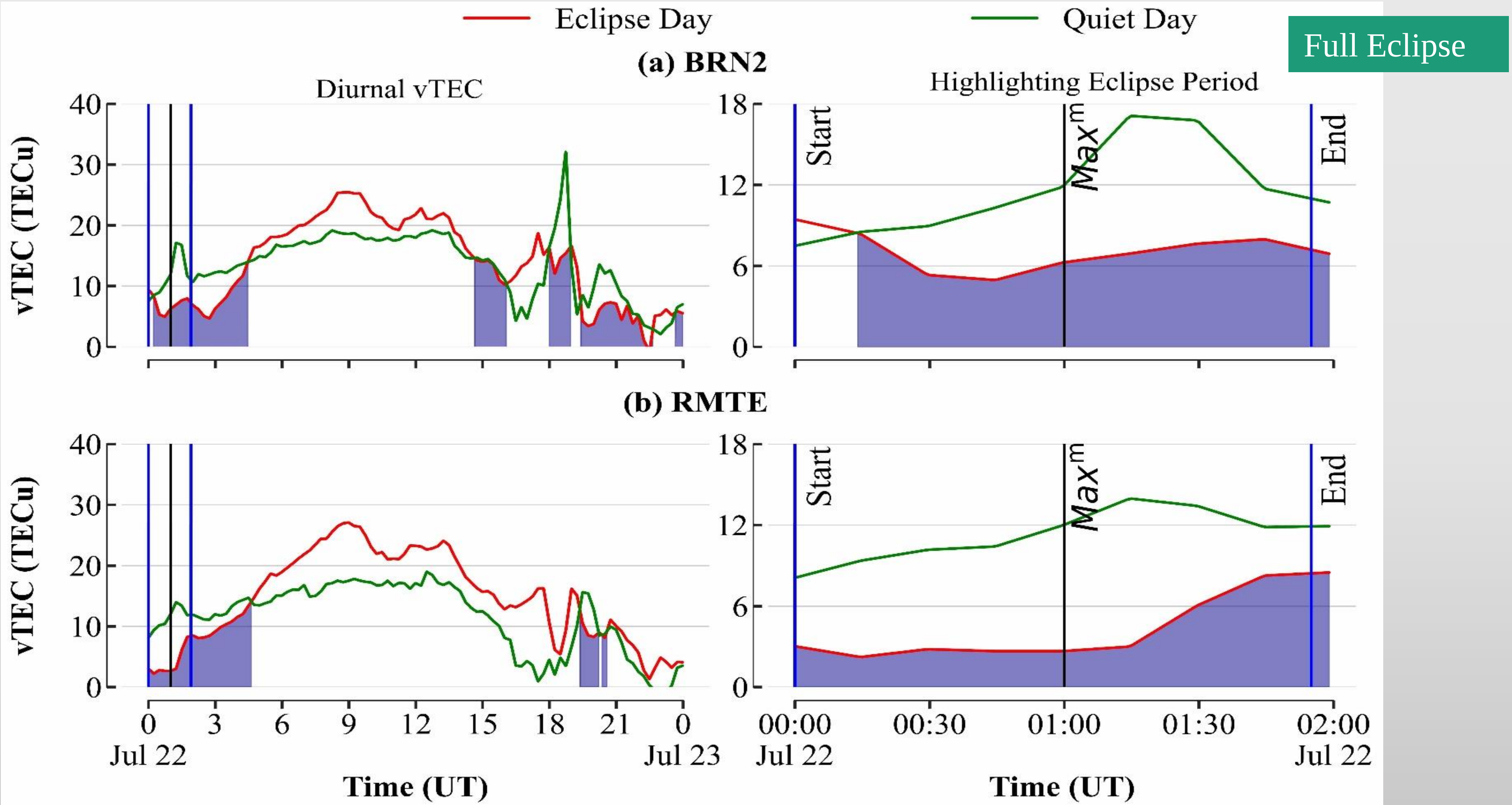
GPS receiver stations around solar eclipse path

Ionospheric Anomaly due to Solar Eclipse



- The left panel displays the variance in TEC at the four GPS sites during the solar eclipse and a comparison with TEC on the quietest days.
- The variance between the solid blue line from 0:00 to 2:00 UT is displayed in the right panel.

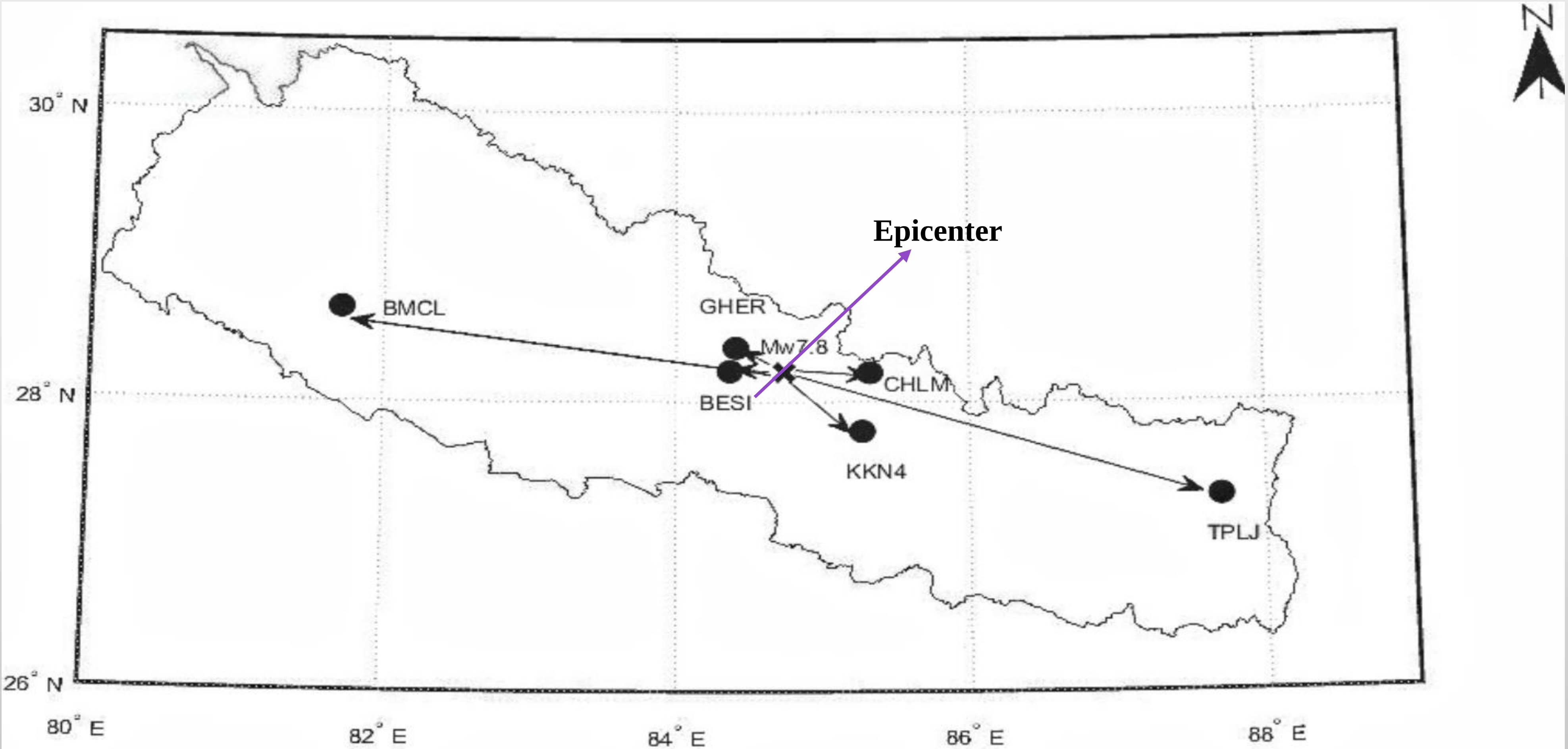
Ionospheric Anomaly due to Solar Eclipse



- The obscuration rate is strongly associated with the size of the reduction (*Founda et al., 2007*)
- The variance in TEC at the two GPS stations during the solar eclipse and a comparison with TEC on the quietest days (*Ghimire et al., 2022).*

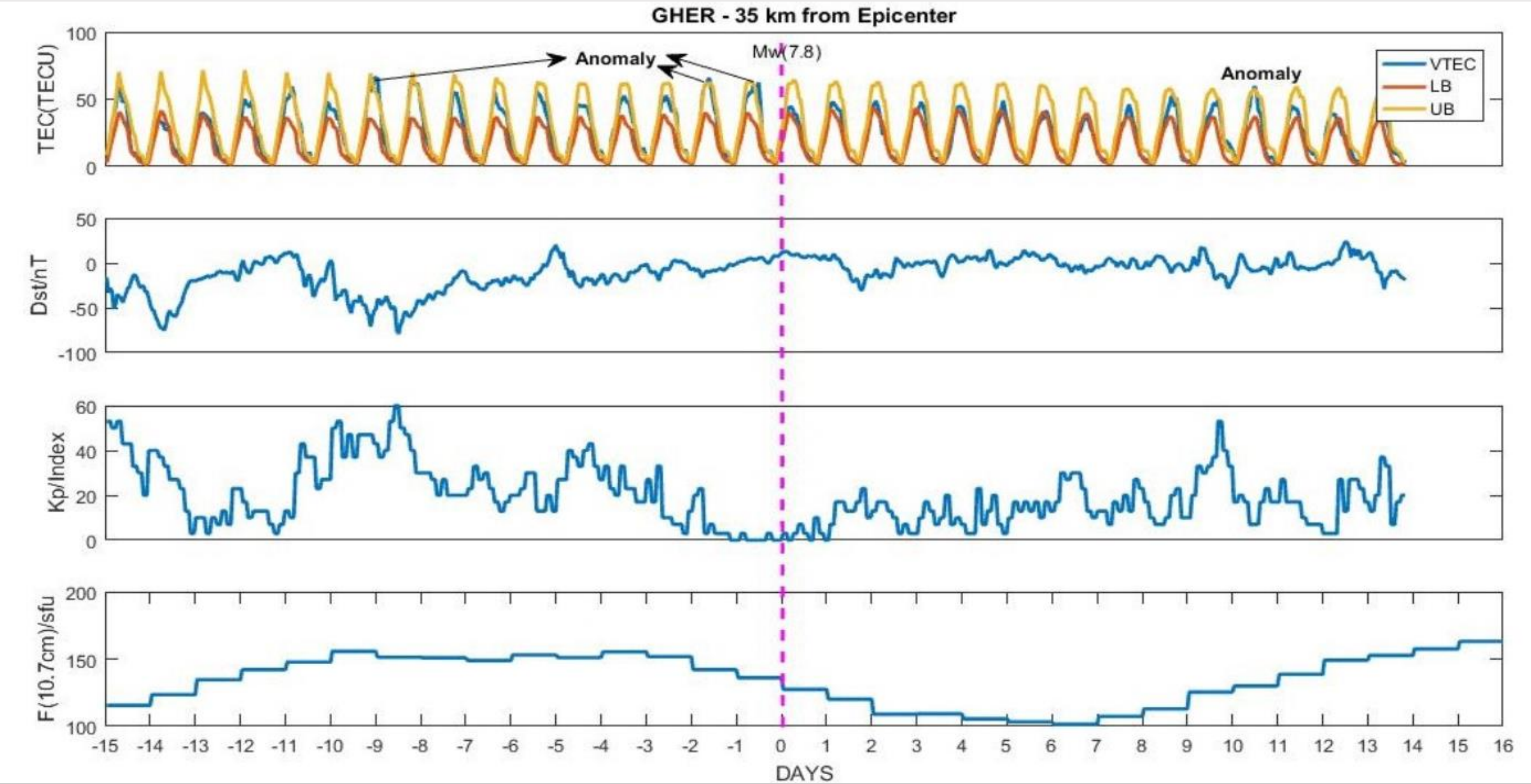
Ionospheric Anomaly due to Earthquake

Nepal Great Earthquake (M=7. 8) (25th April, 2015)



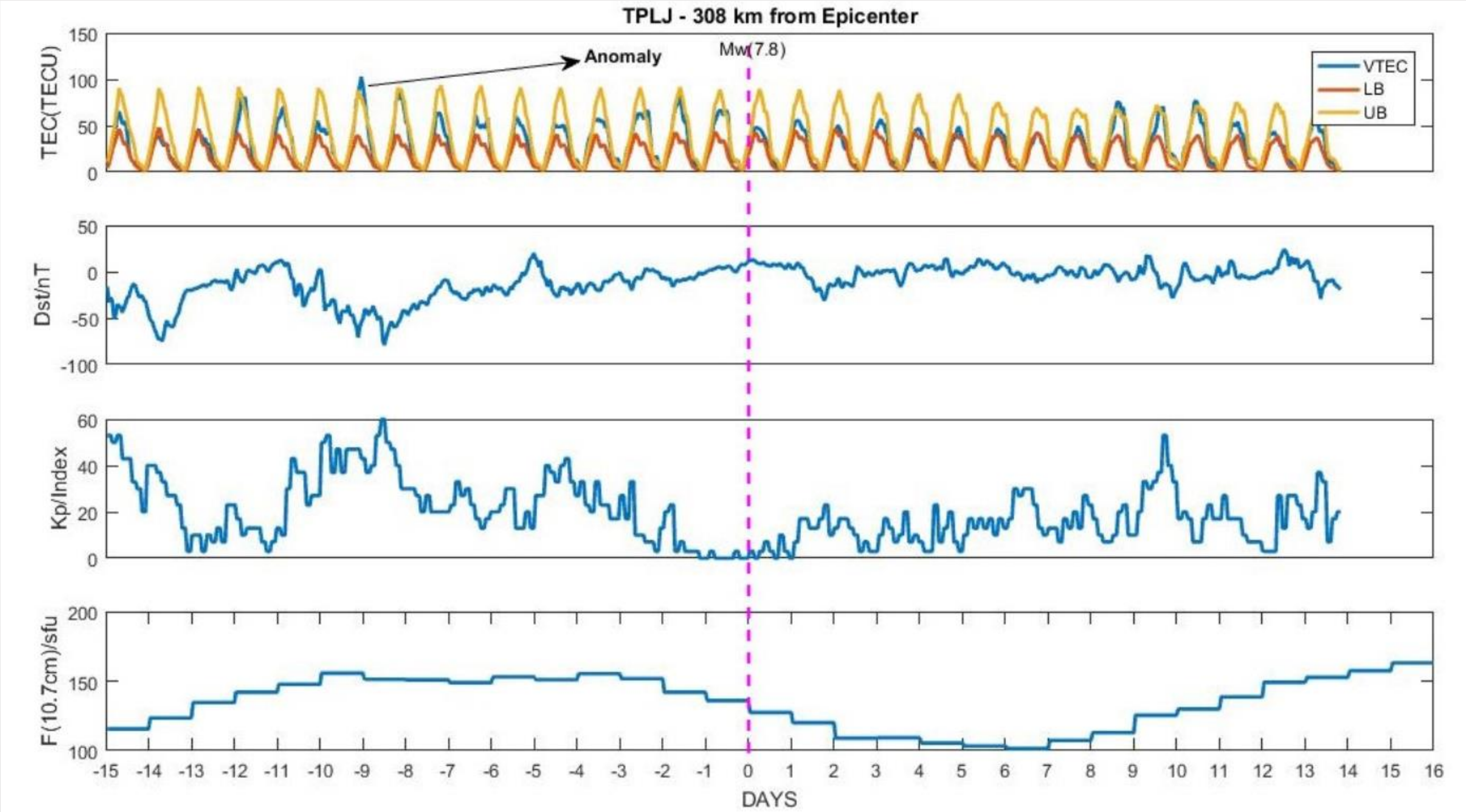
GPS Station and epicenter, Nepal *(Ghimire and Chapagain, 2022)*

Ionospheric Anomaly due to Earthquake



One, two and nine day before the earthquake event, 25th of April (GHER close to Epicenter). Similar result is obtained as CHLM, and BESI stations *(Ghimire and Chapagain, 2022)*.

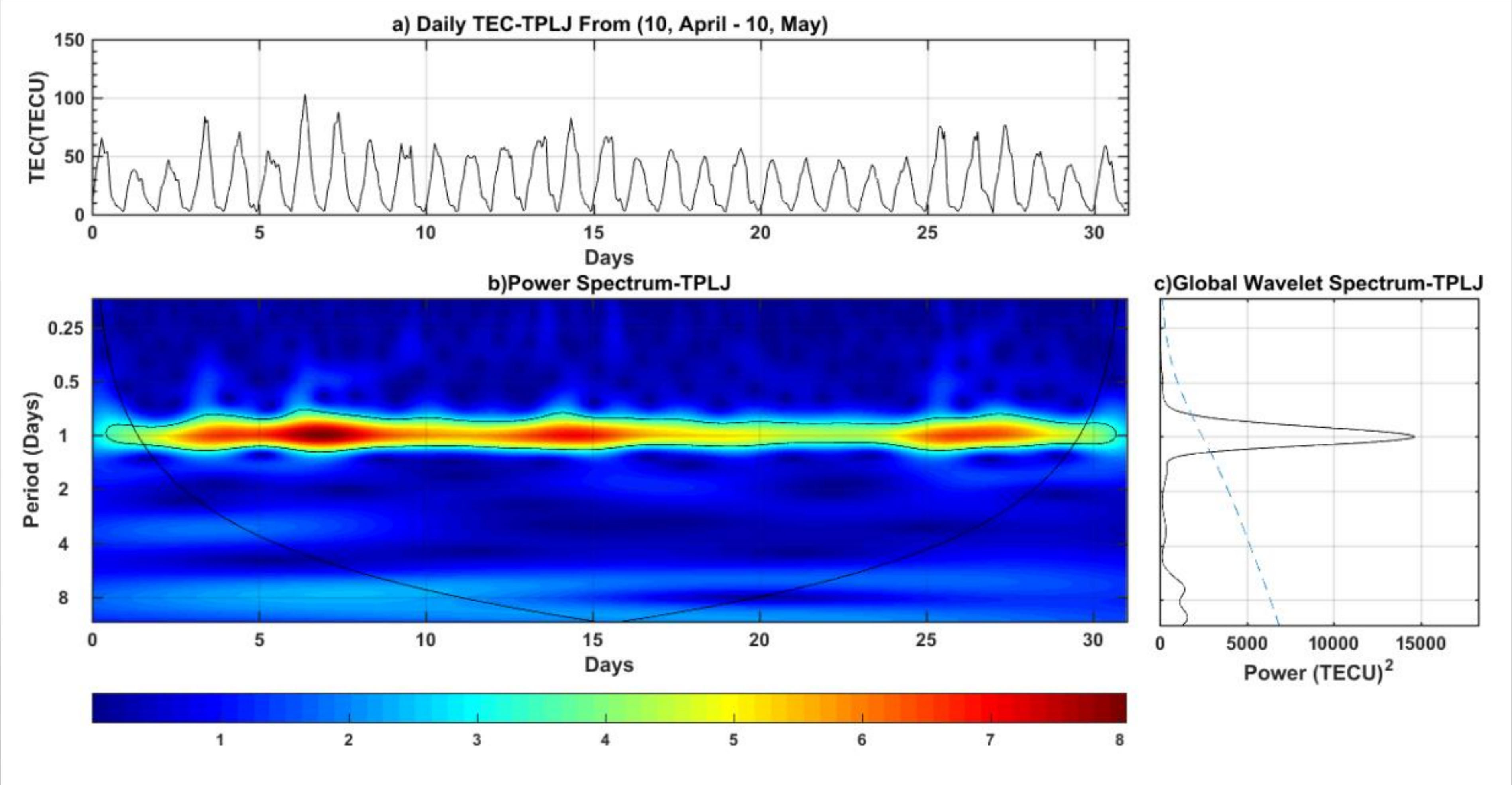
Ionospheric Anomaly due to Earthquake



9 day before the earthquake, 25th of April (from TPLJ station far from epicenter), and Similar for BMLC station. *(Ghimire and Chapagain, 2022).*

Ionospheric Anomaly due to Earthquake

Nepal earthquake of (M=7. 8) (25th April, 2015)



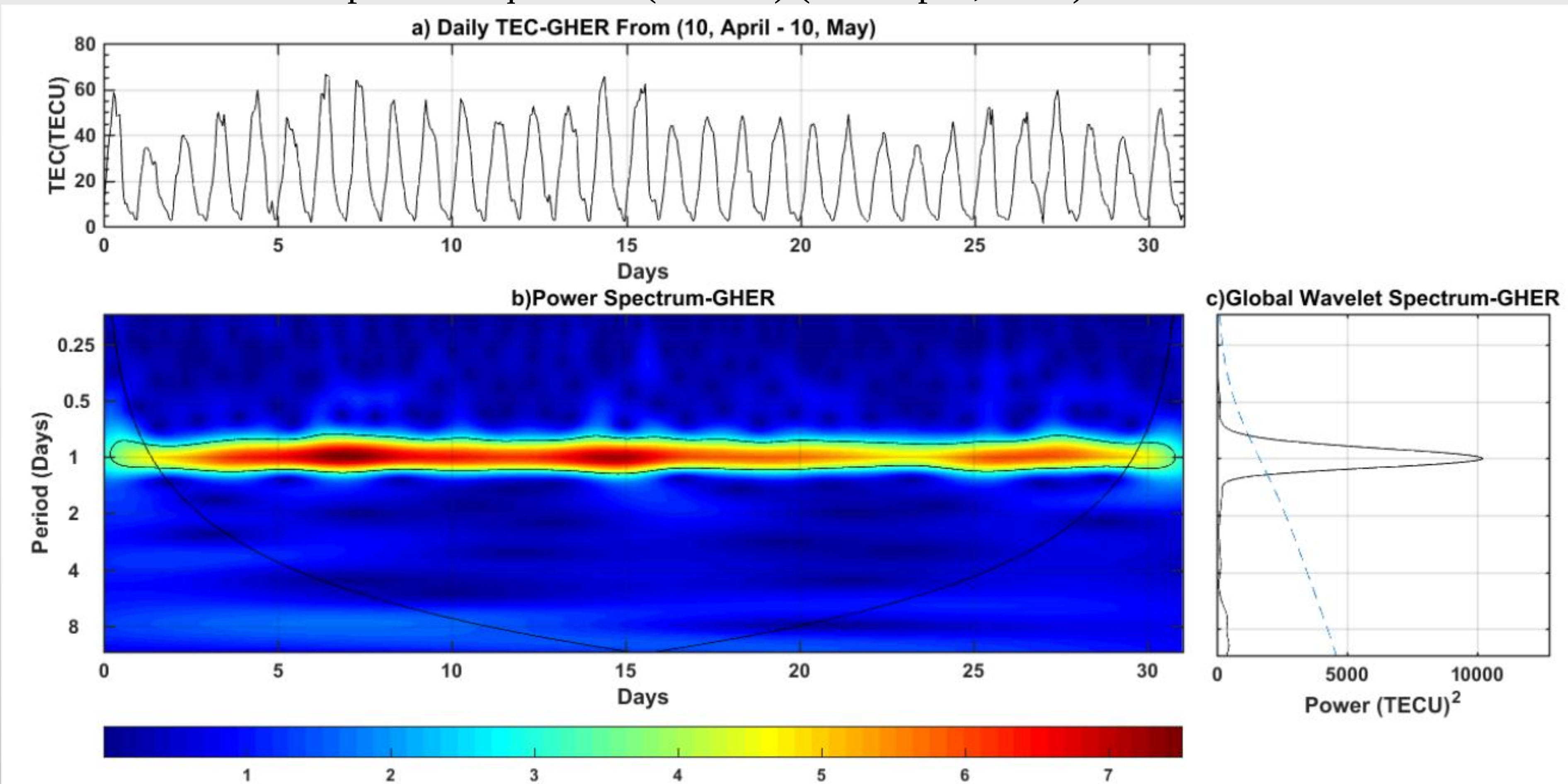
a)VTEC distribution recorded at TPLJ station 15 days before and after Nepal earthquake

b) Wavelet power spectrum with the different color bar

c) Global wavelet spectrum with main periodicity

Ionospheric Anomaly due to Earthquake

Nepal earthquake of (M=7. 8) (25th April, 2015)



a)VTEC distribution recorded at GHER station 15 days before and after Nepal earthquake
b) Wavelet power spectrum with the different color bar
c) Global wavelet spectrum with main periodicity (*Ghimire and Chapagain, 2022*).

Summary

- The maximum values of TEC were mostly observed around noon and afternoon showing pre- dawn minimum and steep rise in the morning and then gradual decrease after sunset.
- The high values of TEC were observed in spring (March, April, and May) and the lowest was in Winter (December –February).
- The IRI-TEC model and Artificial Neural Network (ANN) model (better) can be used to predict ionospheric TEC and these models can be used for the long-term analysis of the ionosphere.
- Negative ionospheric storm is identified during storm of March 2015, while positive ionospheric storm is noticed during storm of September 2017.
- During solar eclipse, 2 stations exhibiting a considerable reduction of >5 TECU and the other 8 stations with a reduction of 1-5 TECU as the eclipse reduced the movement of photoionization in the ionosphere.
- The notable anomalies were seen before one and nine days (April 16 and 24) of earthquake event (April 25) in stations near the epicenter, indicating that the VTEC anomaly may be pre-curser of earthquake.

Thank you.