United Nations/Mongolia Workshop on the Applications of Global Navigation Satellite Systems

IONOSPHERE TEC ANOMALIES OVER MONGOLIA AS DETECTED BY GPS OBSERVATIONS

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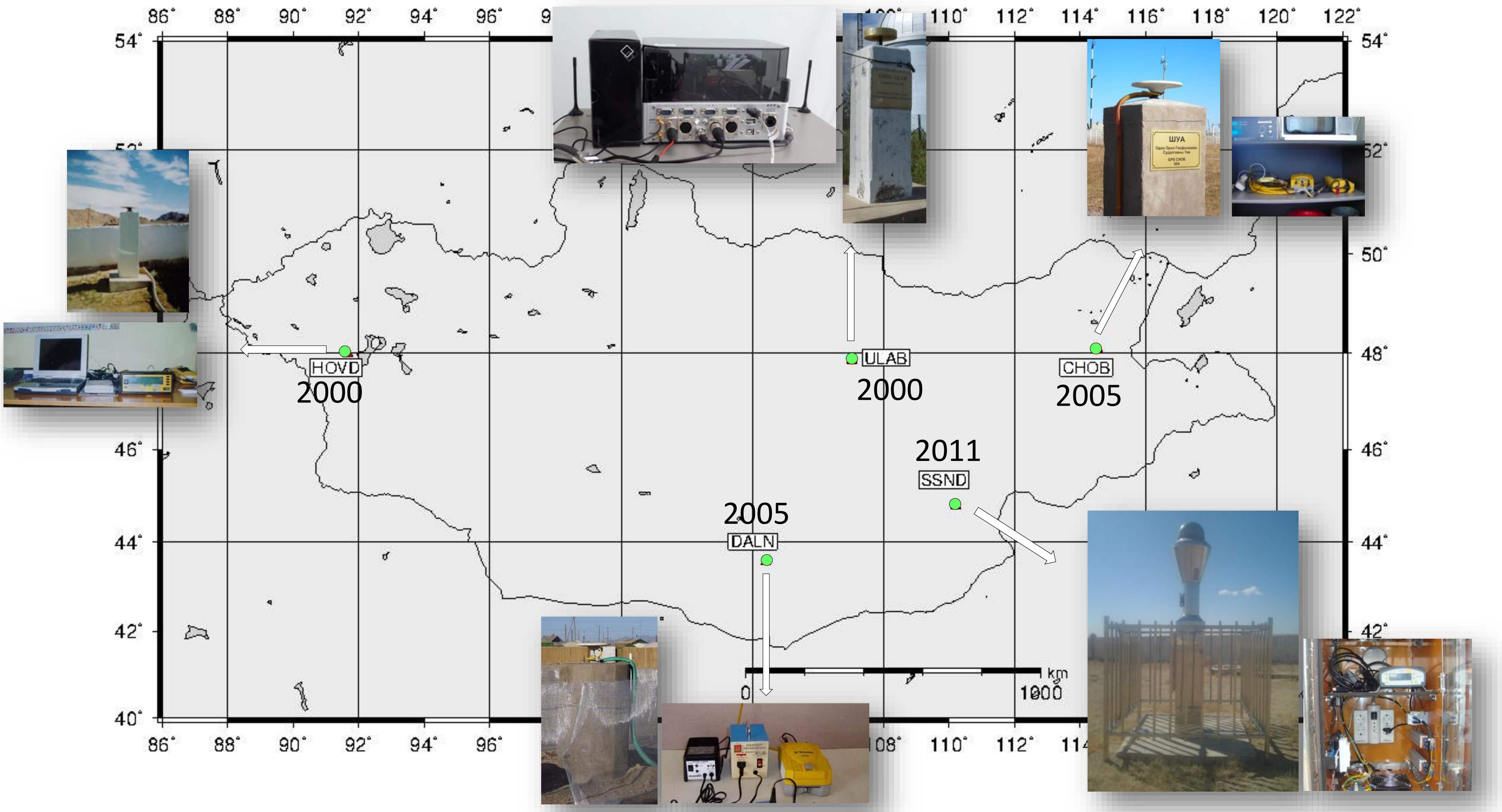
OUTLINE

- Introduction
- Ionosphere effects on GPS geodetic measurements – noise to information
- General variability of the ionosphere TEC over Mongolia (2008-2019 TEC data CGPS stations)
  - Variations and Anomalies
  - Seasonal, semiannual and annual
  - Storm-induced
  - Seismic
- Summary

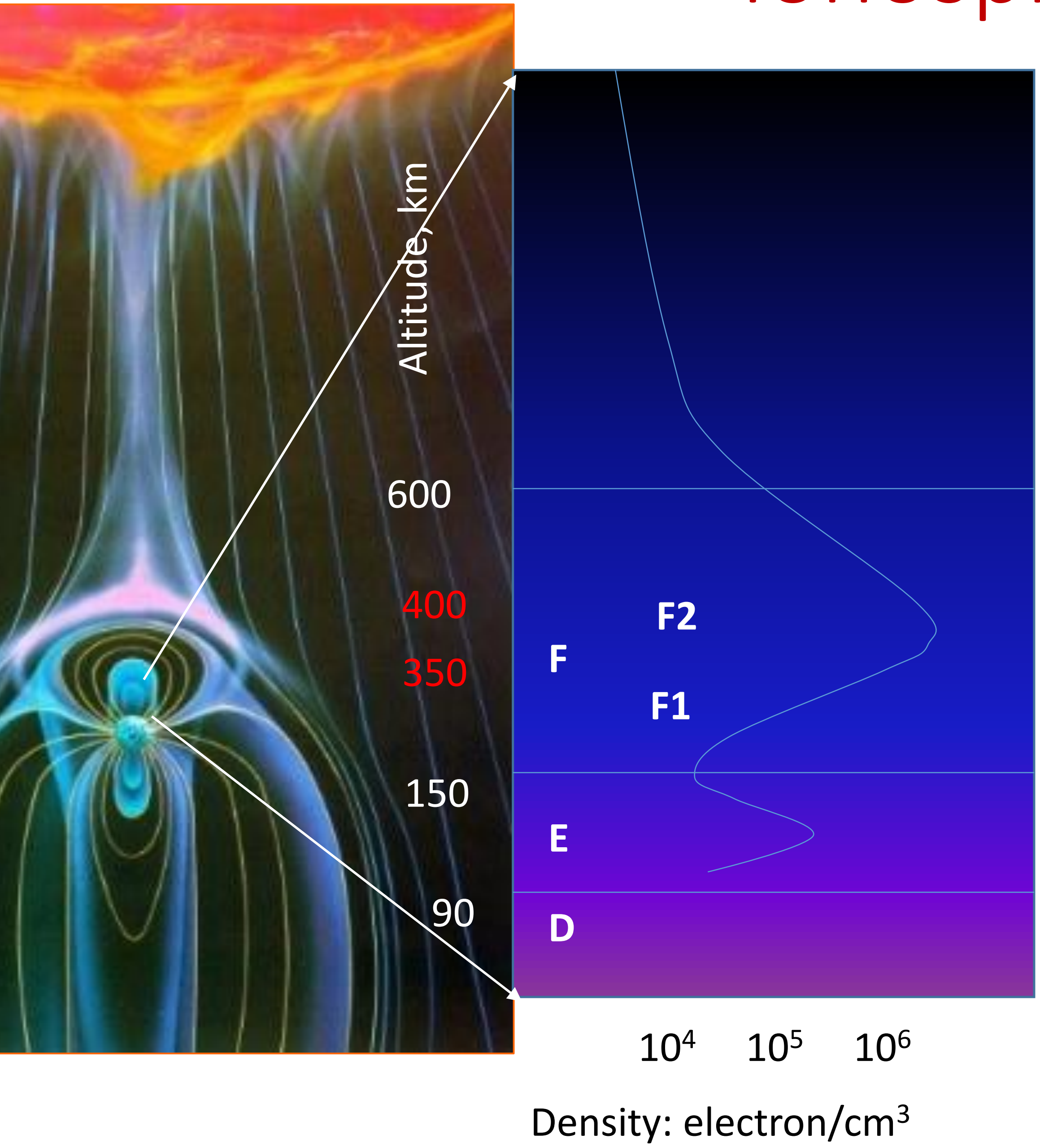
Astronomical Observatory of Mongolia

Solar flares, Sun prominences, corona, Solar burst, Solar ultra-violet radiation with radiometer, Ionosphere Total Electron Content

GPS stations of the Astronomical Observatory (AO)

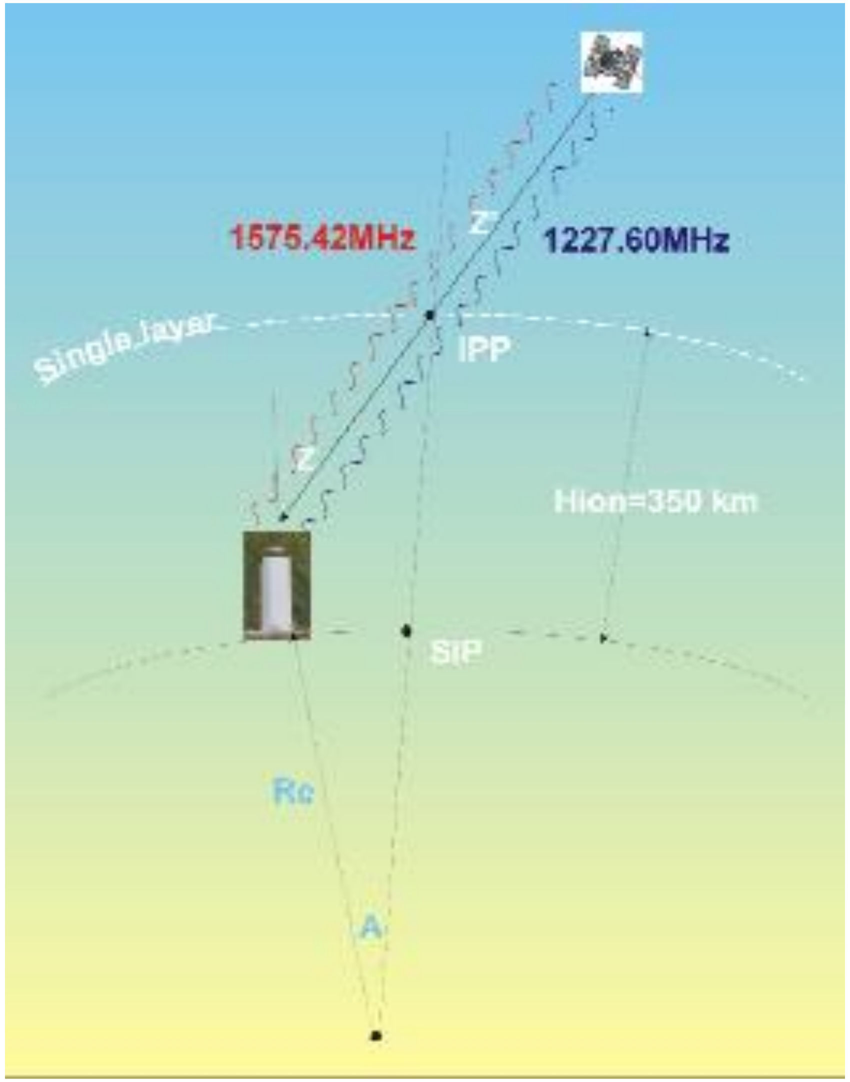


Ionosphere and the Sun



- Ionosphere is the ionized plasma layer of the upper atmosphere surrounding the Earth at ~60-1000 km
- The main density: 350-400 km (F2 layer)
- The main cause of the ionization – Sun EUV radiation and X-ray
- Spatial and temporal variation (geographical location, season, solar cycle and geomagnetic activity)
- Dispersive nature 1Hz < signal travel dependent of frequency

Ionosphere and GNSS signal propagation



- GPS signal f1=1227.6MHz, f2=1575.4 MHz
- Signal delay: low frequency – high delay (GPS L2 delay > L1)
- Delay is proportional to the density of free electrons along the ray path
- $\int_r^s N_e \, ds = \mathrm{STEC}$
- Ne – electron density (electron/m^2)
- S – signal travel path
  - 1 TECU delay:
  - L1 - 0.163 m, L2 - 0.267 m
  - 1TECU =10^{16}el/m^2

TEC retrieval from GPS observations

$$TEC_p = \frac{1}{40.3}\left[\frac{f_1^2 \cdot f_2^2}{f_1^2 - f_2^2}\right](P_1 - P_2 + b^s - b^r)$$

$$TEC_\Phi = \frac{1}{40.3}\left[\frac{f_1^2 \cdot f_2^2}{f_1^2 - f_2^2}\right](L_1 \cdot \lambda_1 - L_2 \cdot \lambda_2 + B^s - B^r)$$

$$VTEC = STEC(cosz')$$

$$z' = arcsin\left[\frac{R_e}{R_e + h_{ion}}\sin(z)\right], \qquad R_e = 6371km,$$

$$h_{ion} = 350\ km$$

(1) calculating the difference between pseudo-ranges and carrier phases

(2) repair cycle slips

(3) Phase TEC leveling by pseudorange TEC

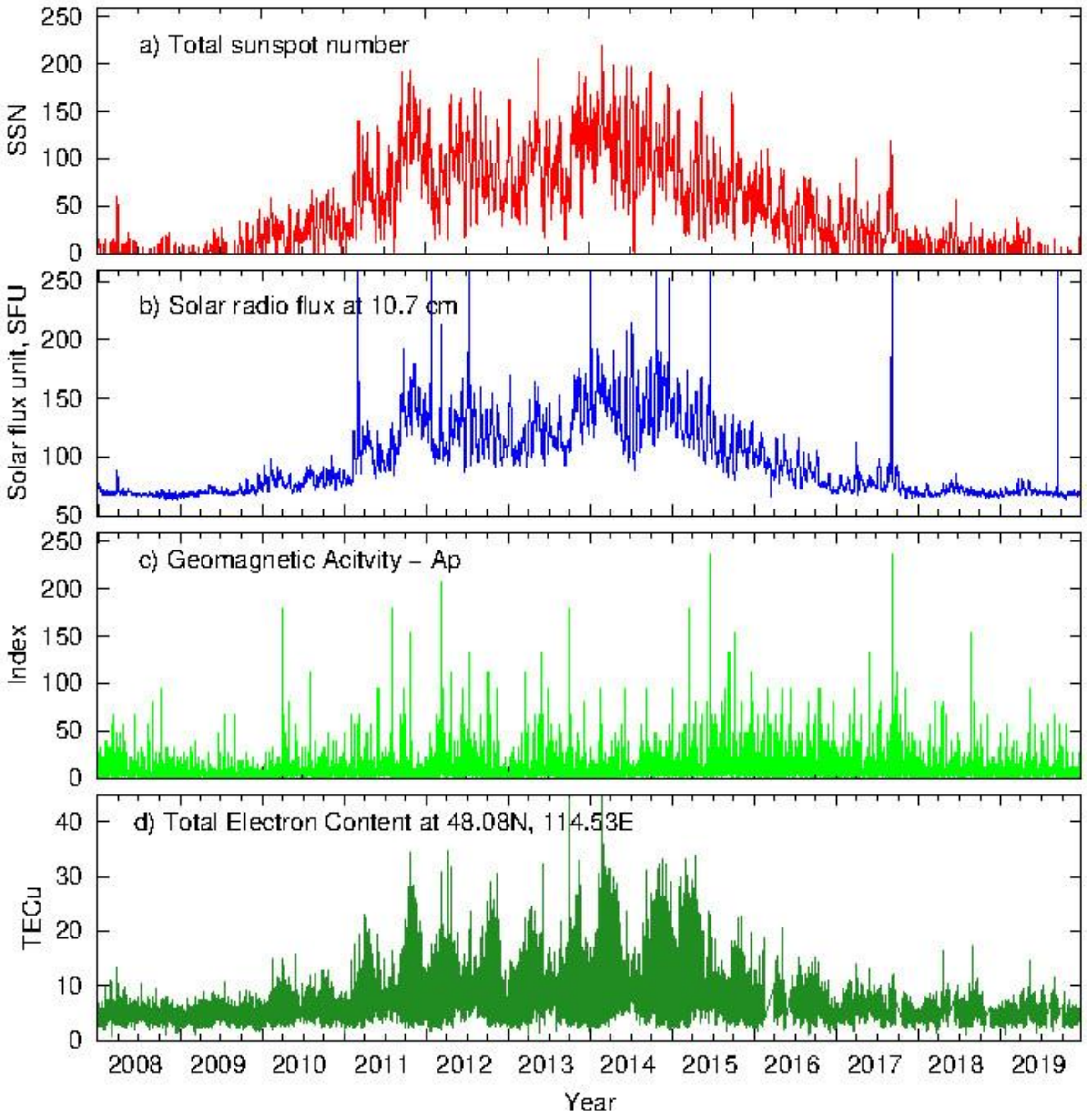
(4) removal of the satellite and receiver biases (DCB-differential code biases);

(5) projecting slant TEC to the vertical direction using the mapping function of the single layer model

Ionospheric variations

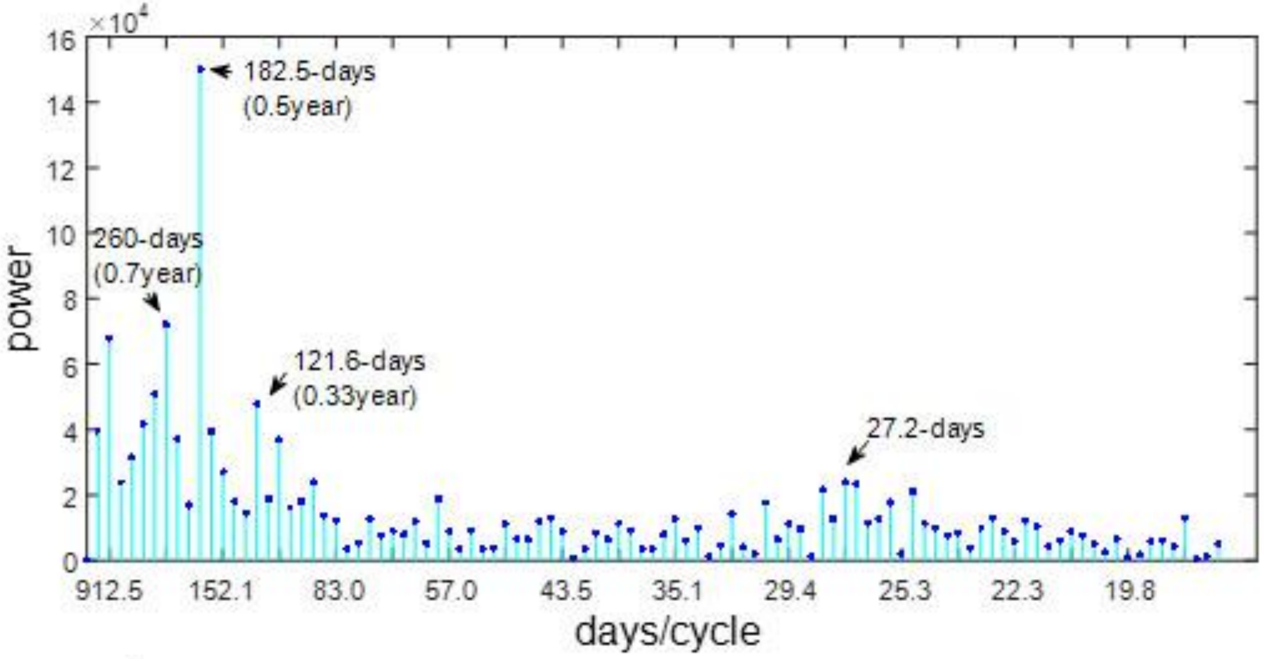
- Regular
  - diurnal, seasonal and solar cycle: *periodic -predictable*
- Irregular
  - extreme solar flare, solar wind, coronal mass ejection, geomagnetic disturbances, earthquakes and volcanic eruptions: *sudden – not predictable*
- Anomaly - Ionosphere fluctuations caused from space weather and geophysical phenomenon
- Detection (deviation from the background) – mean, median
  - Elevation cut-off angle to 40°

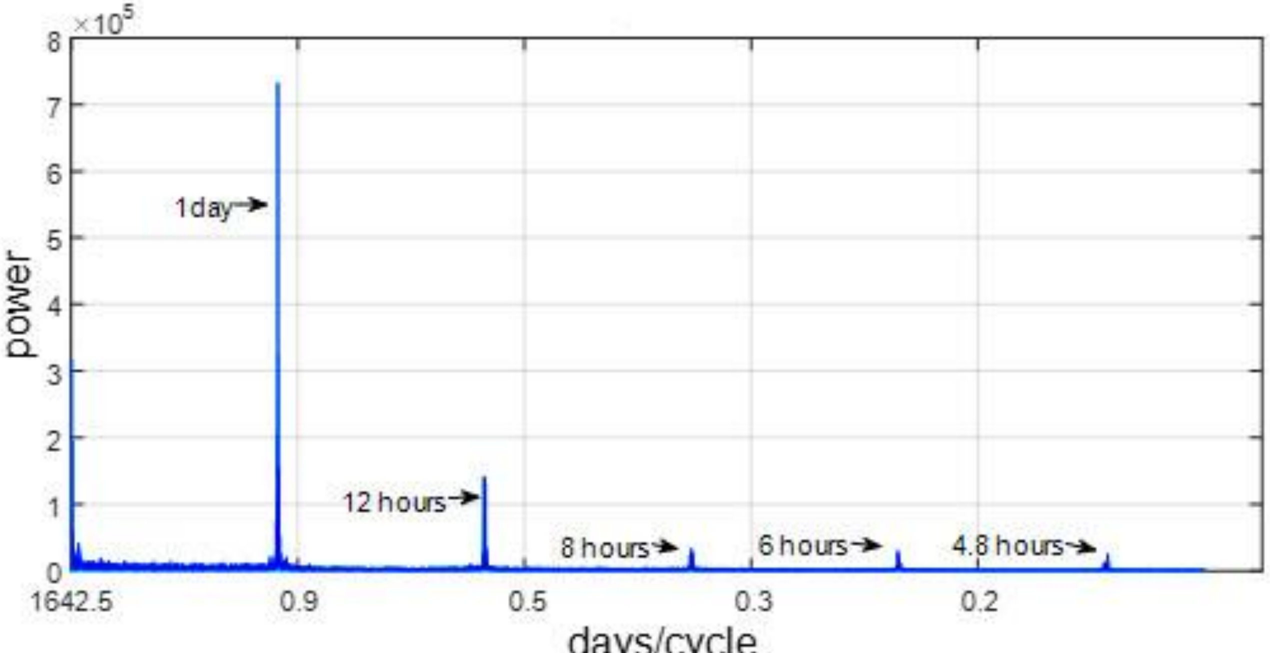
Mid-latitude Ionosphere variability. Solar cycle variation



- Data on solar activity from 2008 to 2019.
- (a) Monthly mean sunspot number from WDC-SILSO, Royal Observatory of Belgium (http://www.sidc.be/silso/datafiles)
- (b) daily solar flux from NOAA (http://lasp.colorado.edu/lisird/data/penticton_radio_flux/
- (c) Geomagnetic activity indices Ap (ftp://ftp.gfz-potsdam.de/pub/home/obs/)
- (d) vertical TEC data from CHOB GPS station (48.08N,114.53E)

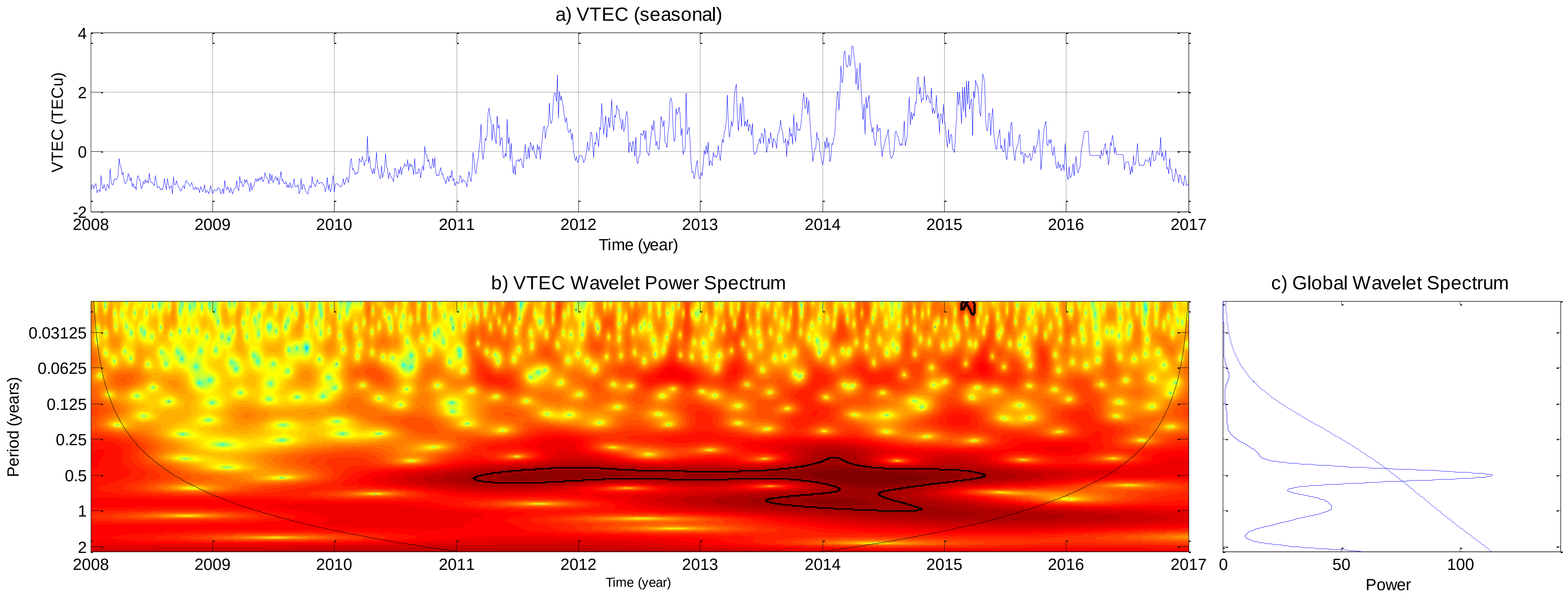
Regular variations





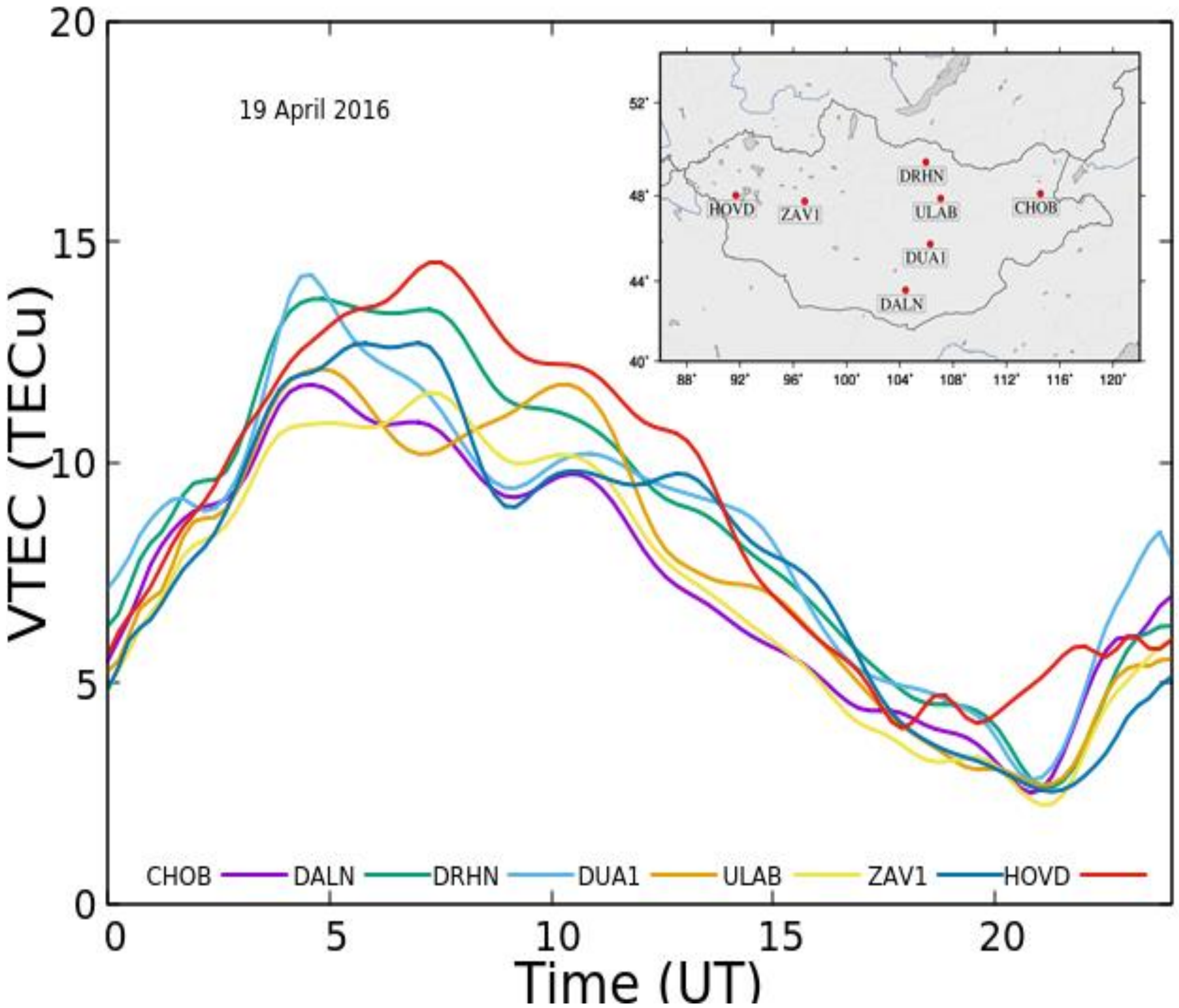
- Spectral Fourier and Wavelet analysis
- CHOB-GPS TEC 8-hour averaged data for 2008-2017
  - 260 days
  - 182.5 days
  - 121.6 days
  - 27.2 days
  - 1 day
  - 12 hours

Periodic variations (Wavelet transform)



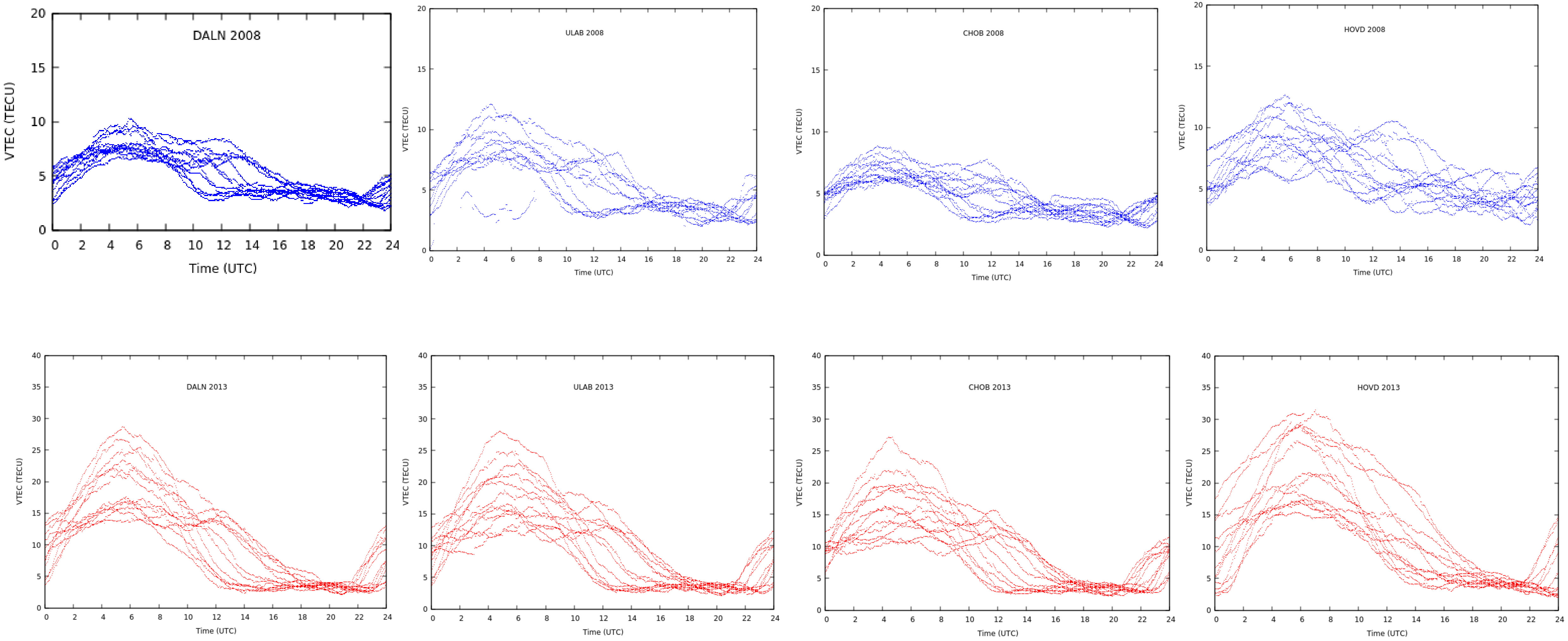
- The major significant period: semi-annual and annual cycles

Diurnal Variation



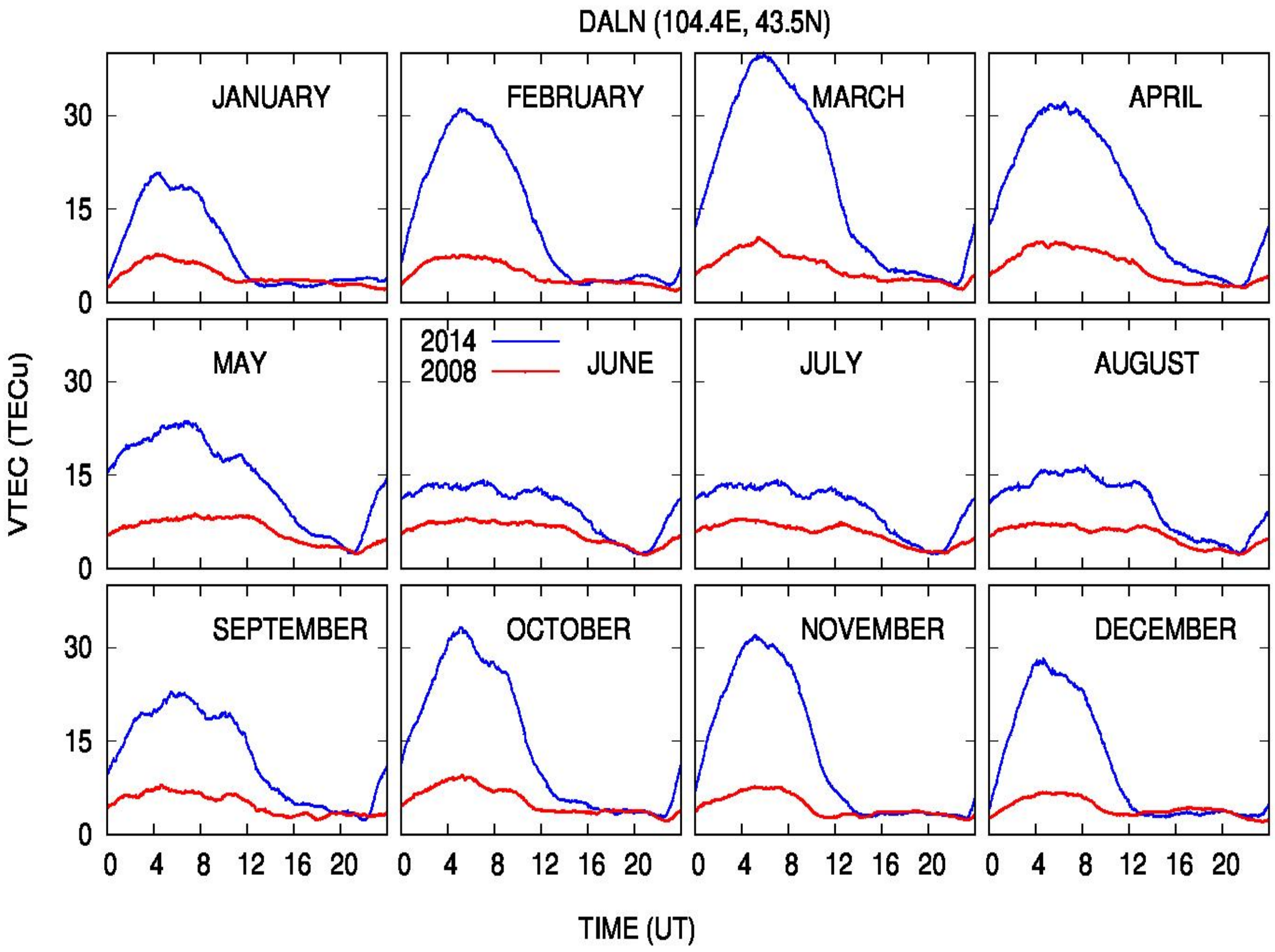
- Due to Sun movements across the sky, ionization depends on the Sun's zenith angle
- Diurnal variation from hourly mean (2016)
  - Peak at ~13LT (UTC+8h) with TEC value of 10-15 TECU
  - Kp=1 quiet condition, of descending 2016 of Solar cycle, of equinox month
  - Obvious two peaks
  - Daytime anomaly
  - Typical behavior of mid-latitude ionopshere
- Seasonal, solar activity variation

Diurnal variation



Hourly monthly median for 4 CGPS stations
During the low Solar cycle (2008) and high Solar cycle (2013) phases

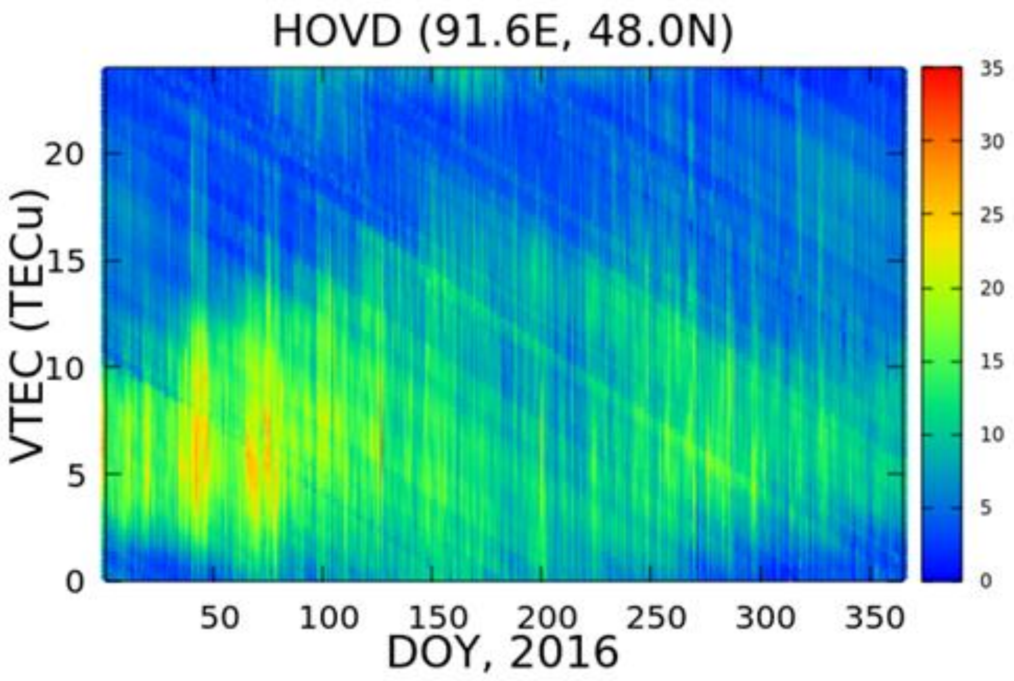
Seasonal variation

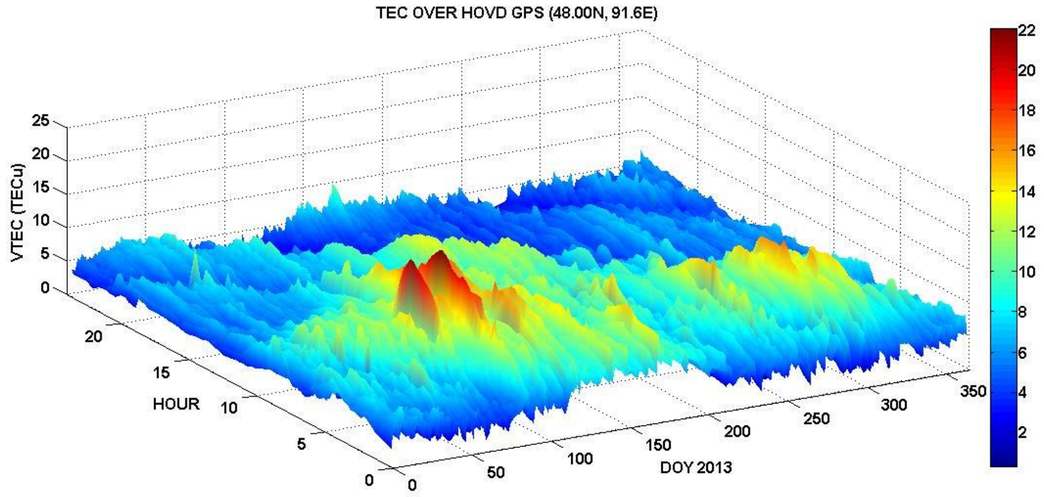


Annual or non-seasonal anomaly: December solstices are significantly greater than those in June solstices

- Seasonal variation is associated with the revolution of the Earth around Sun
- Equinoctial months
  - spring-March, April, May
  - Fall-September, October, November
- Solstice months
  - Summer (June, July, August)
  - Winter (December, January, February)
- Winter or seasonal anomaly: ionization is greater in winter than in summer by day, but the anomaly disappears at night, NmF2 being greater in summer than in winter.

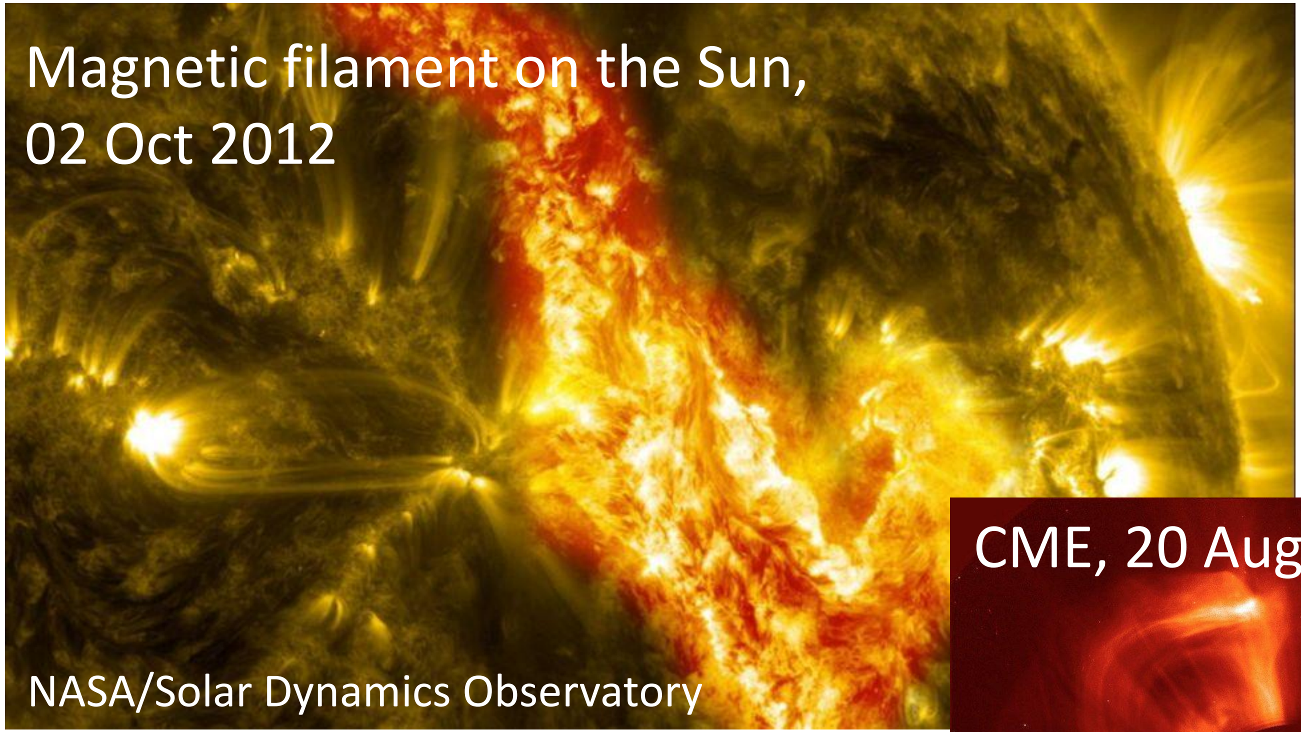
Semiannual variation



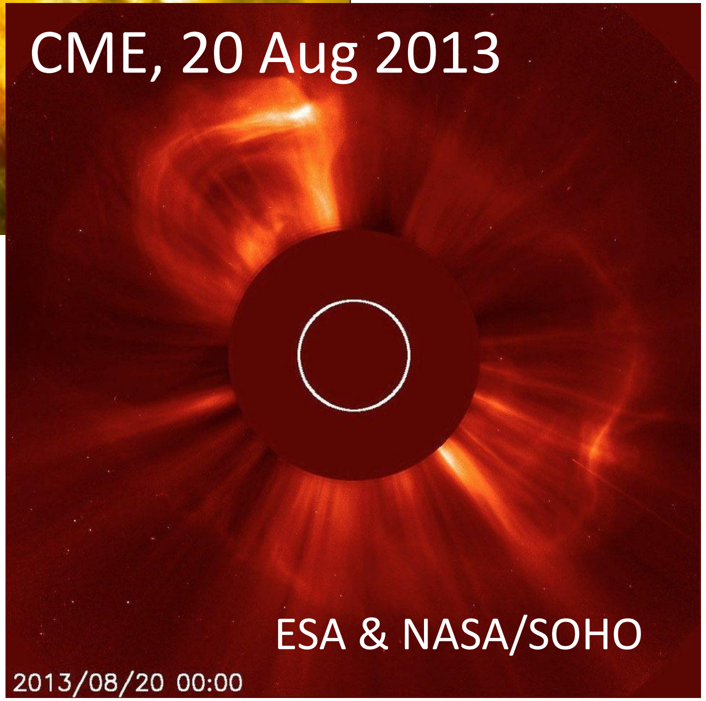


- Ionization maxima in equinoxes and minima in solstices
- Semiannual anomaly: ionization is greater at equinox than at solstice
- the ionization among the two equinoxes exhibits higher plasma densities in March equinox than in September equinox solstice

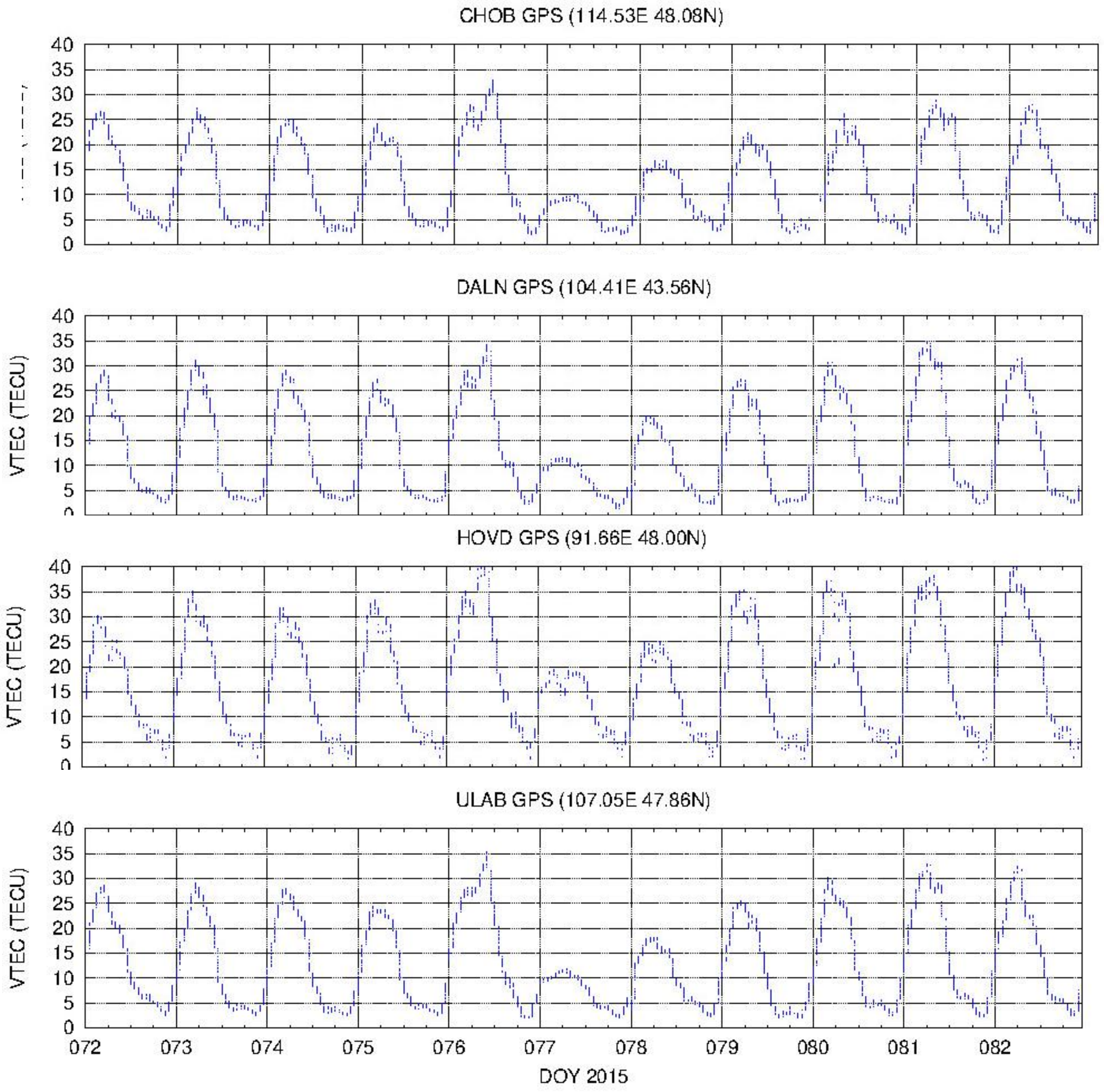
Solar active phenomenon



- Coronal mass ejection (CME)
- Solar flare
- Solar burst

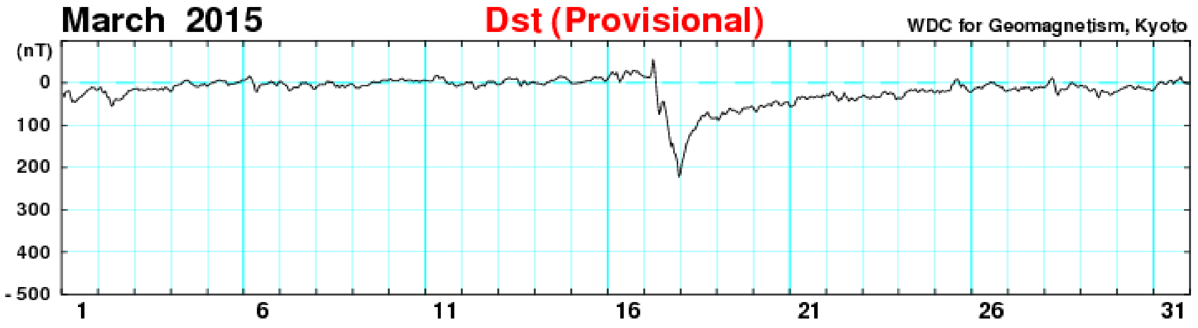


Flare activity class
X

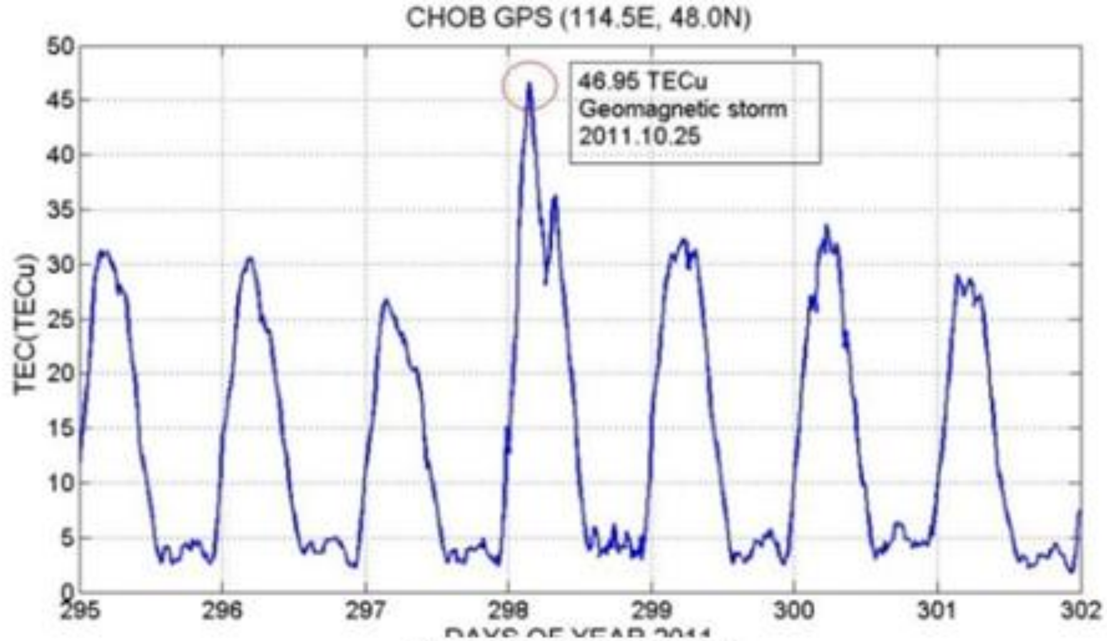


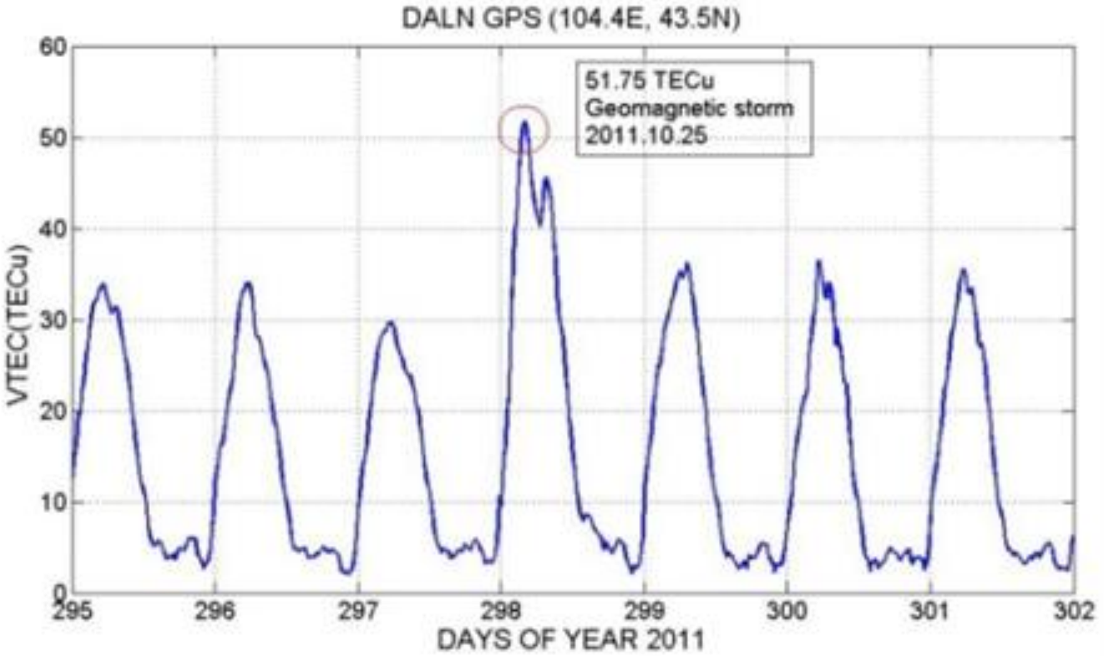
Storm-induced anomaly (17 March 2015)

- St. Patrick's day – 17 March 2015 originated from Solar storm of 15 March 2015 at 2:10 UTC a partial halo coronal mass ejection (CME)
- Flare C9.1
- Series of radio bursts type of II/IV
- Dst = -223nT
- Doy 76 -17March increase 35-40TECU
- Doy 77 -18March decrease 10-20 TECU

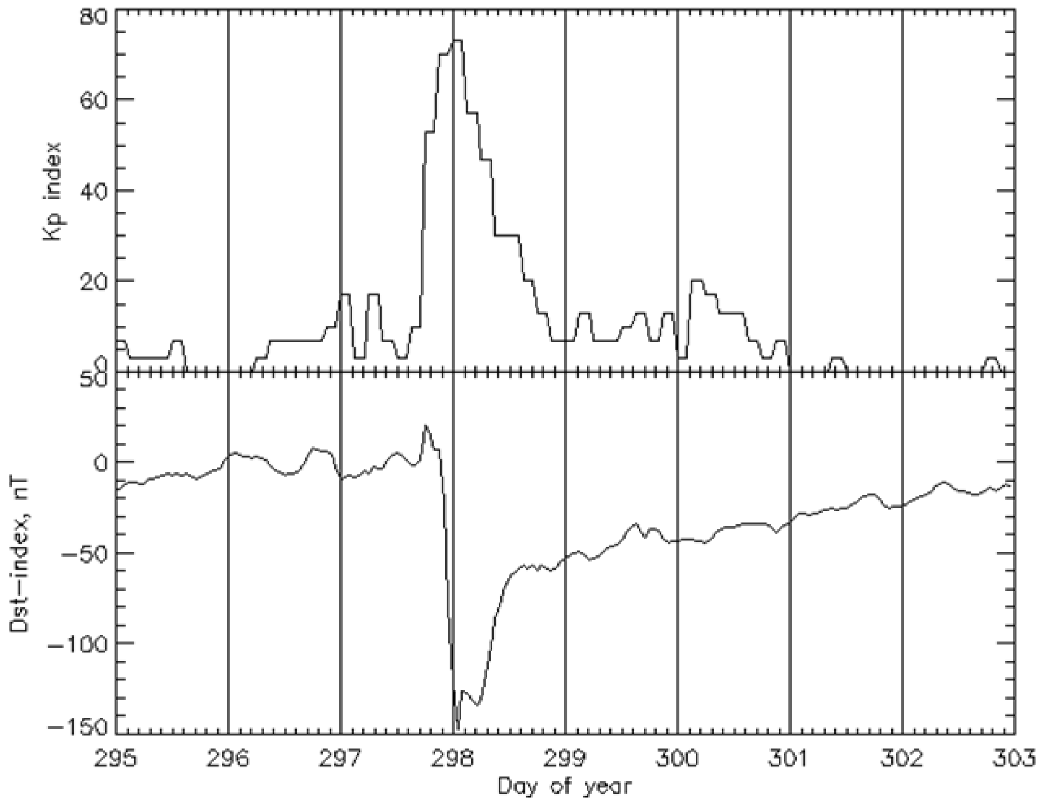


Geomagnetic activities

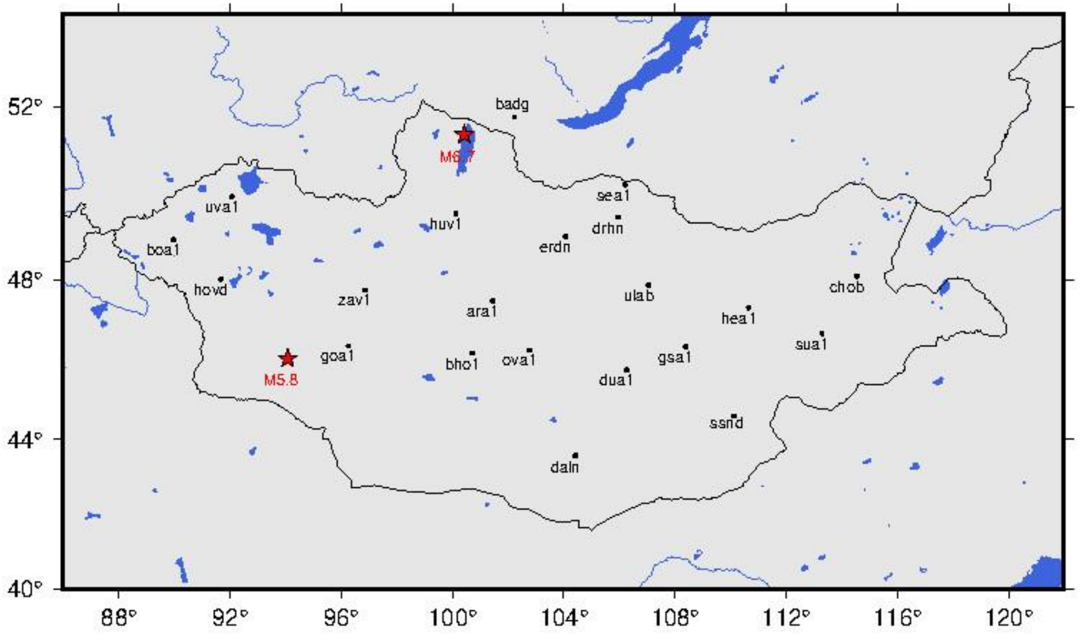




- Solar disturbances solar flares, CME
- 25 October 2011



Seismo-ionospheric anomalies



Two moderate to large EQ

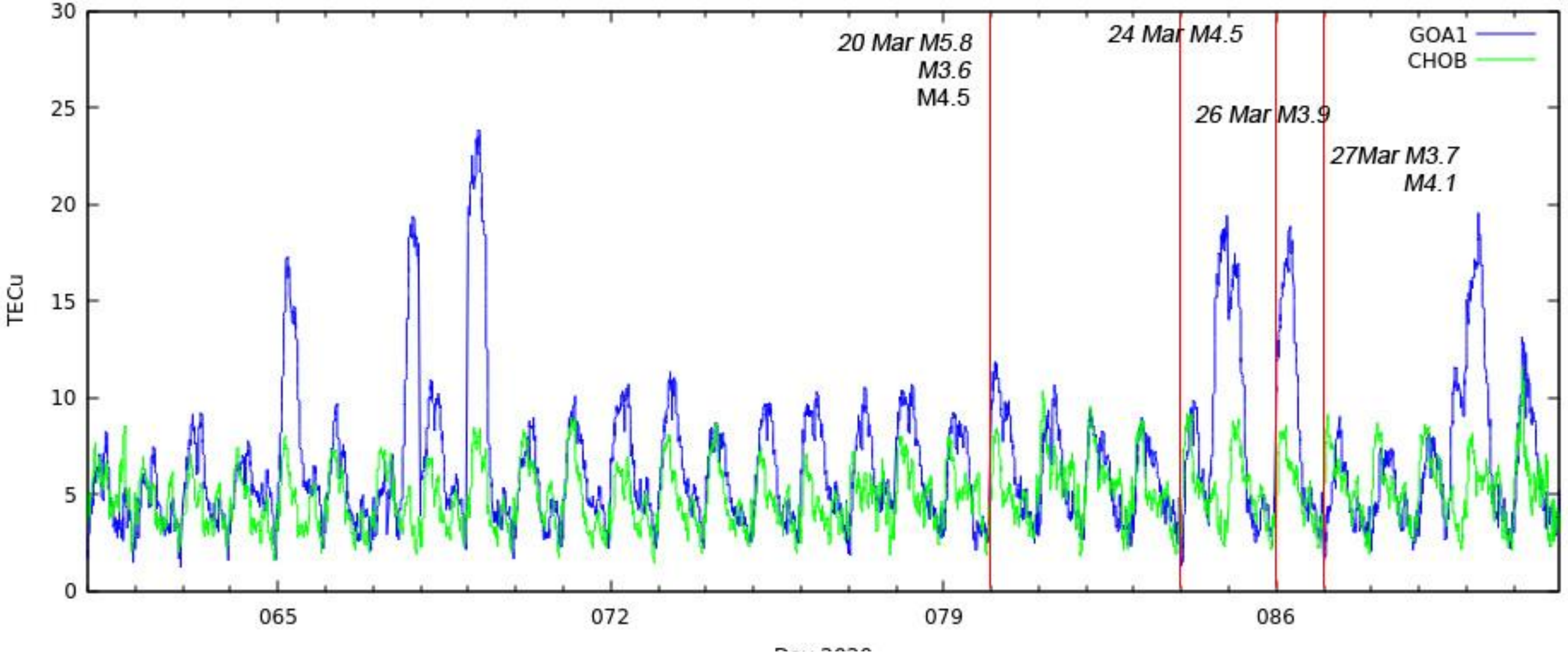
1. M5.8 Gobi Altay
2. M6.7 Hubsugul EQ

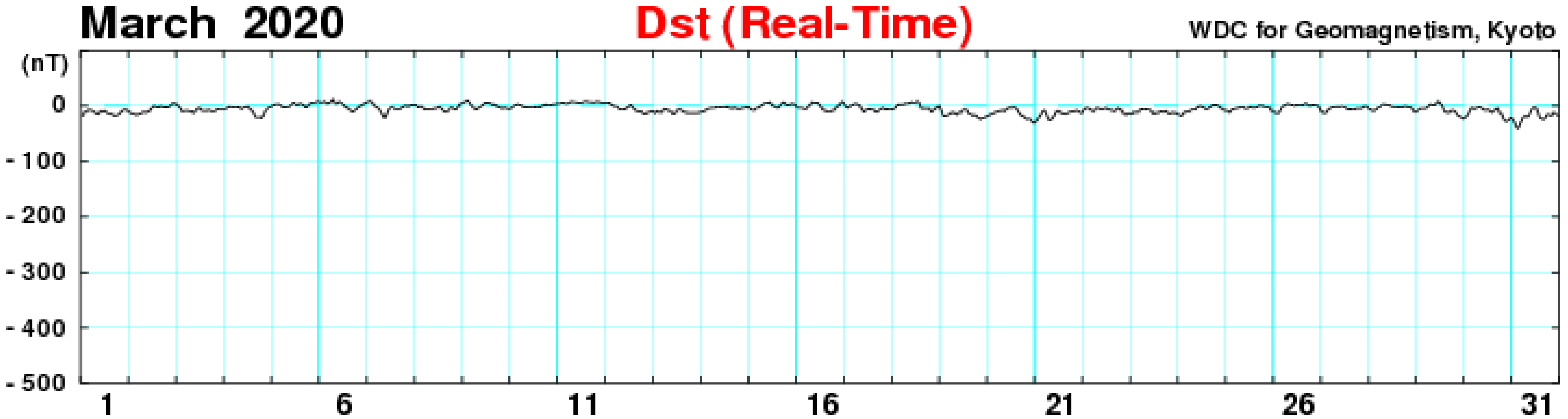
No	Location	Lon/Lat	Date	Magnitude, M	Depth, km	GPS station	ρ, km
1	Gobi-Altay	94.07E/46.06 N	20/03/2020	5.8	10	GOA1	312
2	Hubsugul	100.42E/51.38N 97.36E/52.34N	12/01/2021 21/02/2021	6.7 5.1	10 15.1	HUV1	760

- The radius of preparation zone is calculated (Dobrovolsky et al, 1979)
- $\rho = 10^{0.43M}$ km
- ρ – radius of preparation zone, M is earthquake magnitude

M5.8 Gobi-Altai EQ, 20/03/2020

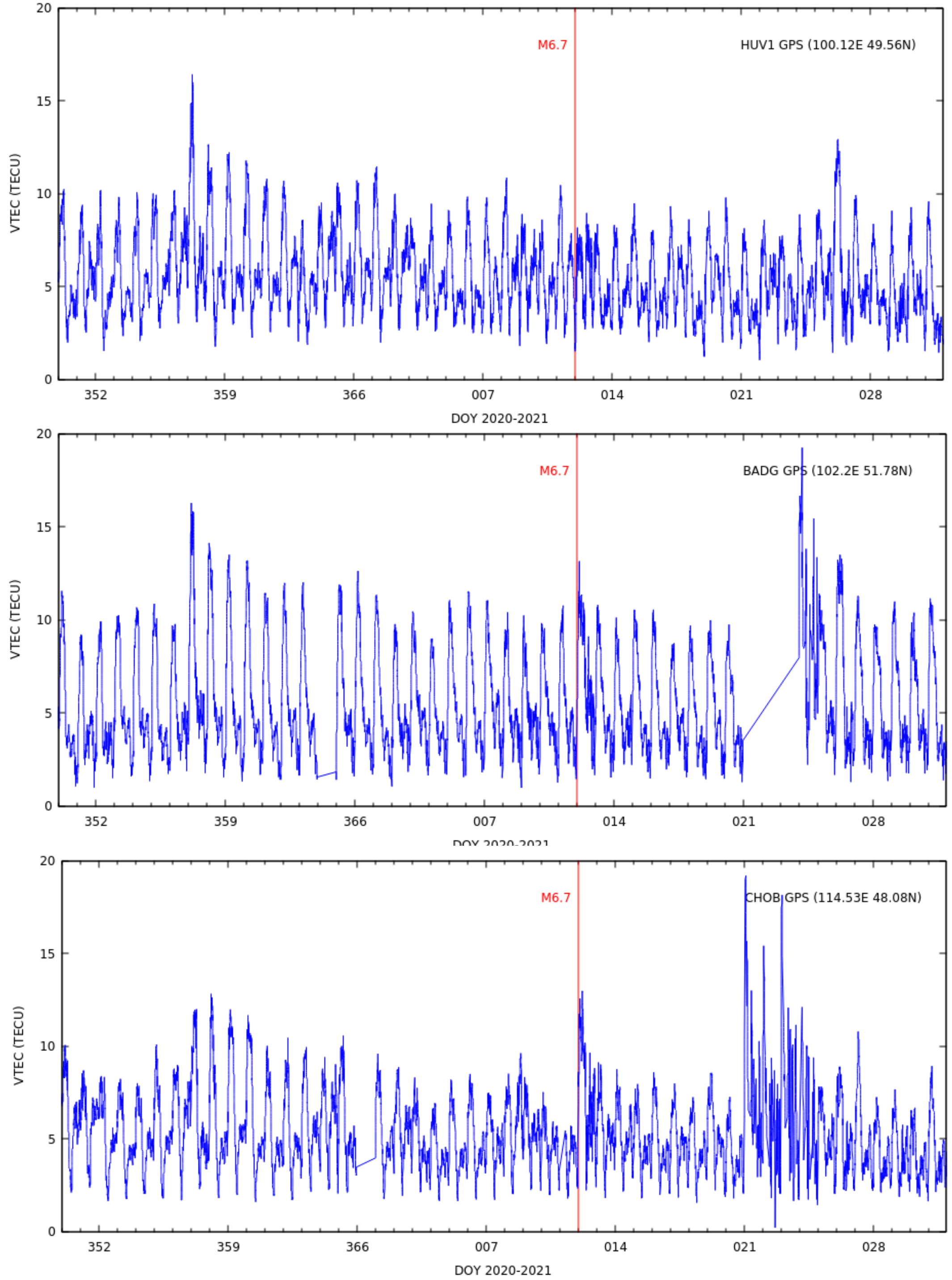
- 20/03/2020
  - 1M5.8
  - 11:14LT M3.6
  - 11:56LT M4.5
- 24/03/2020
  - M4.5
- 26/03/2020
  - M3.9
- 27/03/2020
  - M3.7, M4.1
- 02/04/2020
  - M3.9

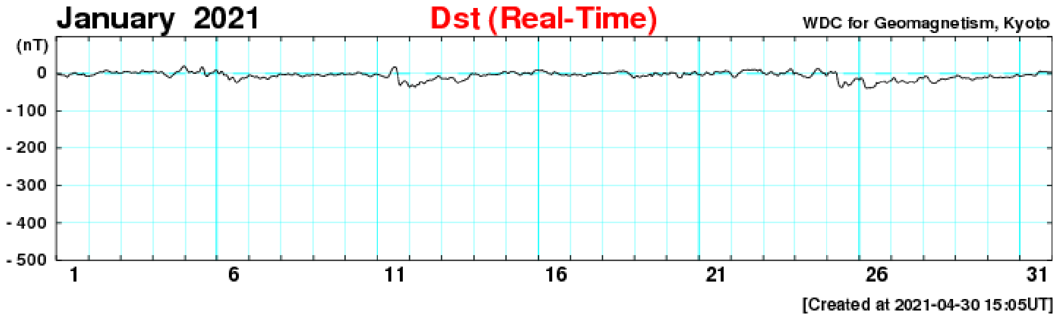




M6.7 Hubsugul 12/01/2021

- BADG IGS, HUV1, CHOB
- TEC enhancement prior to EQ on DOY 357





Summary

- Patterns of Ionosphere regular and irregular variations over Mongolia are presented in terms of the Total Electron Content derived from CGPS
- ionosphere over Mongolia has a general characteristics of mid-latitude ionosphere
- Solar and magnetic activities, and seismo-induced distrubances can also be detected