Advances in Space Weather using GNSS in Asia over the past decade

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United Nation International Meeting on the applications of GNSS, Vienna 5-9 December 2022

OUTLINE

Introduction : ionospheric effects on GNSS signal

Regular plasma irregularities using S_4 and ROTI index

Climatology of Ionosphere using TEC data

Effects of Geomagnetic storms

- TEC
- ROTI index

THE IONOSPHERE

The ionosphere is a ionized layer around the Earth (from ~ 50 km up to 800 km).

The ionosphere is the largest source of perturbations for <u>GNSS</u>

Ionospheric electric currents are at the origin of variations of the Earth's magnetic field and Ground Induced Electric Currents (GIC)

Regular and irregular variations

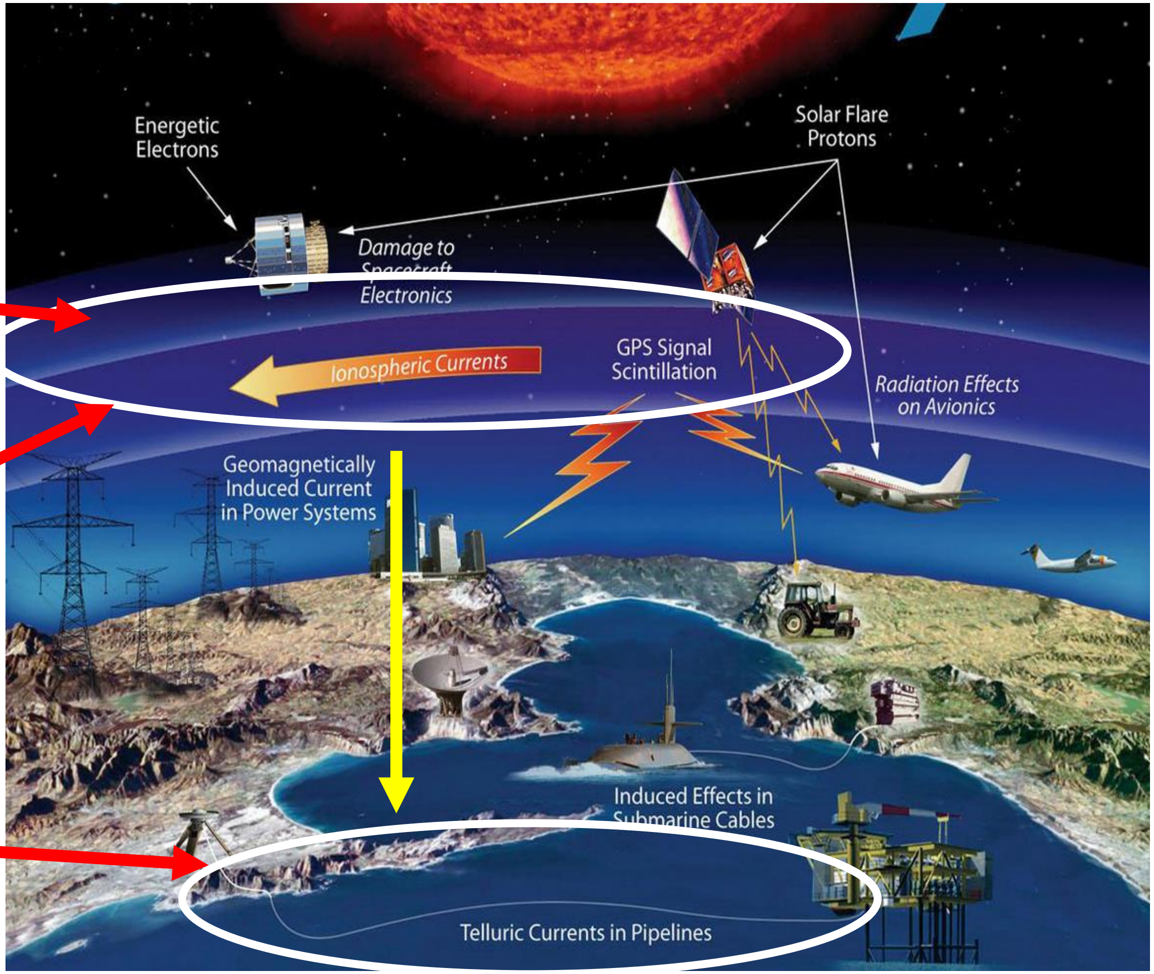
1) Ionization

Propagation of electromagnetic Waves

2) Ionospheric Electric current

3) Variations of the Earth's magnetic field and GIC

Nasa website



Effects of the ionosphere on propagation (TEC)

–Reduction of the phase path length (with respect to propagation in vacuum)

$$\Delta P_\phi = P_\phi - L = \int_L (n-1)\,ds$$

$$n = 1 - a\frac{N_e}{f^2}$$

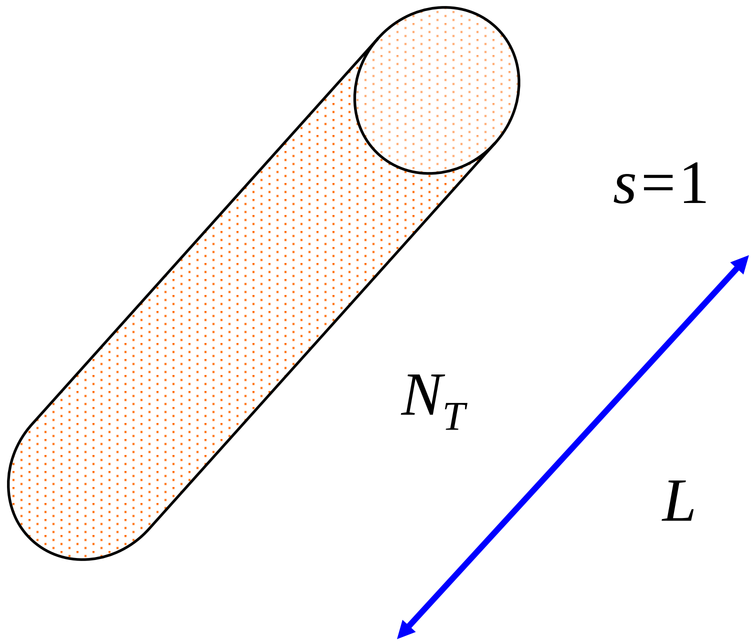
$$\Delta P_\phi = -\frac{a}{f^2}\int_L N_e\,ds$$

$$\Delta P_\phi = -a\frac{N_T}{f^2}$$

Phase path lenght : Distance that a wave needs to propagate in a vacuum to have the same total phase shift (φ)

– **Total Electron Content** (TEC)

$$N_T = \int_L N_e\,dl$$

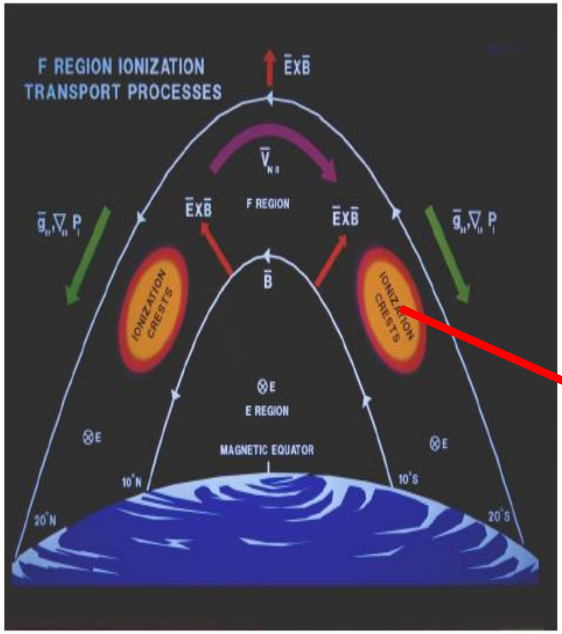


1 TECU = 10^{16} electron/m^2

Scintillations a regular phenomenon

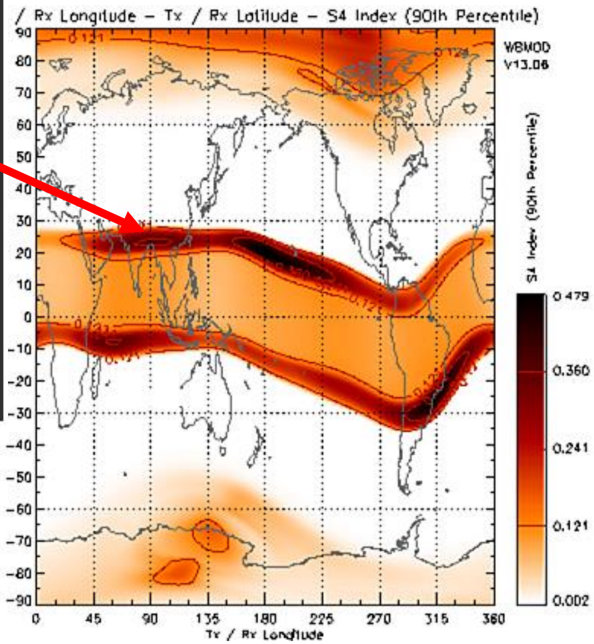
Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere **Physical Process : Instabilities in Plasma**

At the magnetic equator the Earth's magnetic field is horizontal



Equatorial Fountain
EIA

$$S_4 = \sqrt{\frac{<I^2> - <I>^2}{<I>^2}}$$



Scintillation index at GPS L1 (1575.42 MHz) assuming constant local time 23.00 at all longitudes(from http://www.sws.bom.gov.au)

During the daytime the east–west electric field and the north–south geomagnetic field produce the lift of plasma in E ionospheric region by **vertical E X B drift**. At higher altitudes in F region, the plasma diffuses downward along the geomagnetic field lines into both hemispheres under the influence of gravity and pressure gradients, this produces the EIA which is characterized by an electron density trough at the magnetic equator, and two crests of enhanced electron density at about ±15° magnetic latitude

PLASMA IRREGULARITIES

S4 -> fluctuations of the GPS power signal

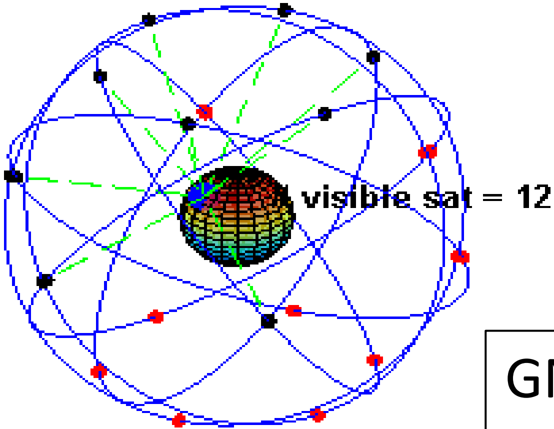
$$I = \frac{A^2}{2} \qquad s4 = \sqrt{\frac{<I^2> - <I>^2}{<I>^2}}$$

ROTI Index

$$\mathbf{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60 \qquad \mathbf{roti} = \sqrt{\langle \mathbf{rot}^2 \rangle - \langle \mathbf{rot} \rangle^2}$$

Training on daily global positioning system GPS data , Coordinates a monthly magazine on positioning, navigation and beyond, http://www.mycoordinates.org, **Volume XIII, Issue 03, March 2017** ***(****Amory-Mazaudier, Rolland Fleury, Sharafat Gadimova, Abderrahmane Touzani)*
Software of Rolland Fleury on www.girgea.org

During Solar Disturbances the propagation of electromagnetic waves is disturbed by changes in ionization => GNSS is affected
Global Navigation Satellite System (GPS, GLONASS, GALILEO, IRNSS, BIEDOU etc...)



GNSS is used for many applications of the daily life: car guidance, civil aviation, agriculture geography, epidemiology etc ....

Daily life

GNSS is a valuable tool for various research concerning the Earth's environment: Space Weather, plate tectonics, atmosphere etc...
We focus on Space Weather and mainly on TEC, S4 and ROTI parameters, concerning ionosphere.
We will only present some effects of the sun on the ionosphere.
the GNSS technique makes it possible to approach many new fields of research in different countries

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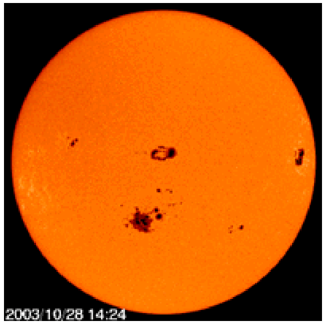
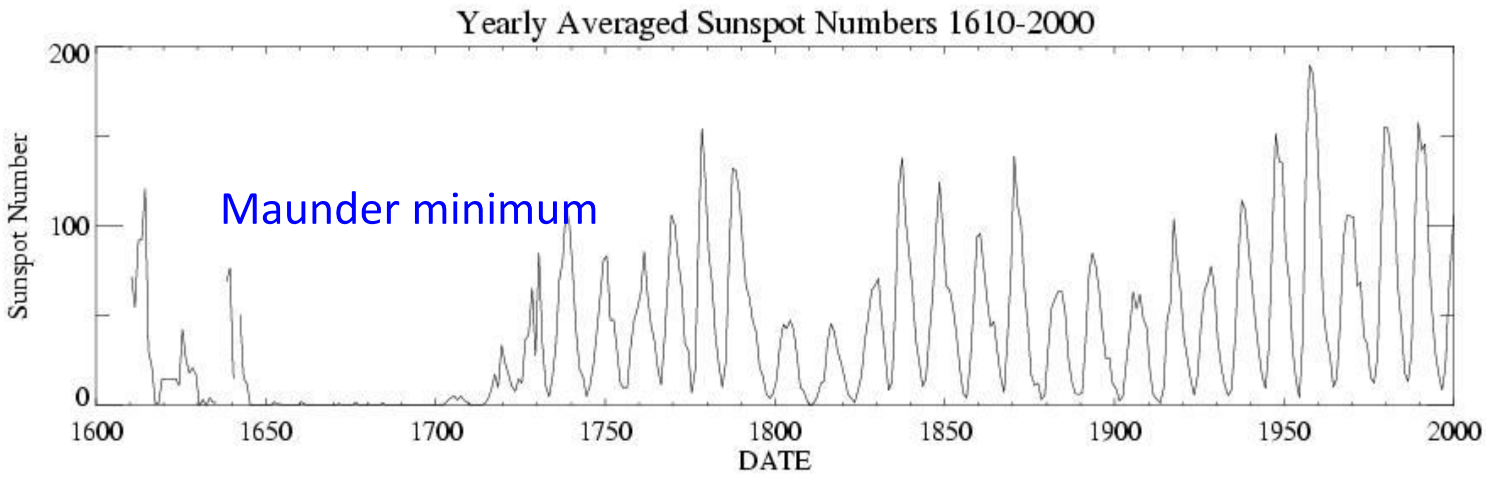
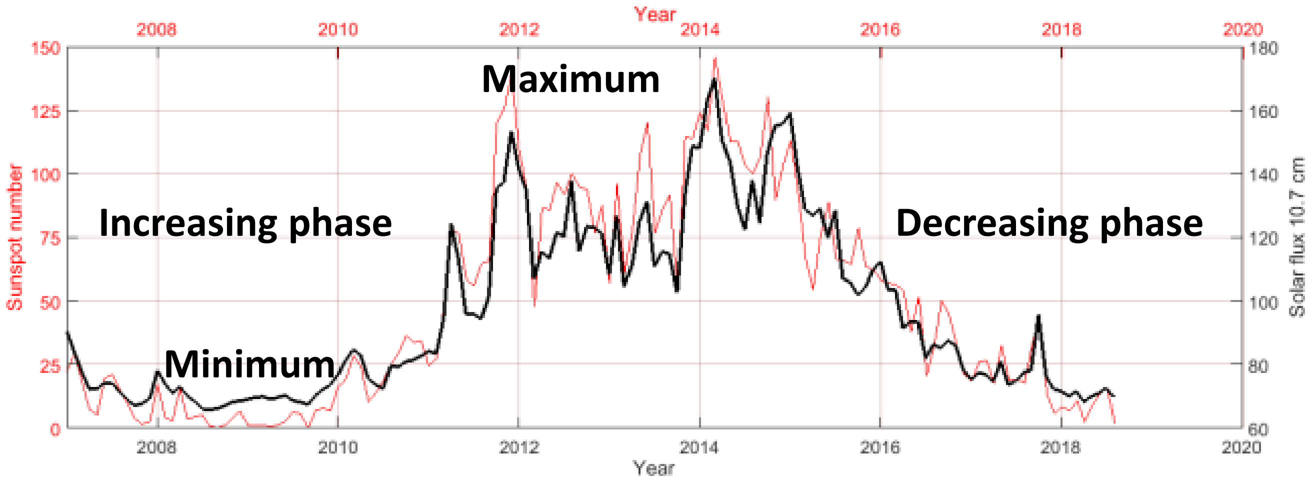
PHYSICS

Solar electromagnetic emissions/ Sunspot cycles

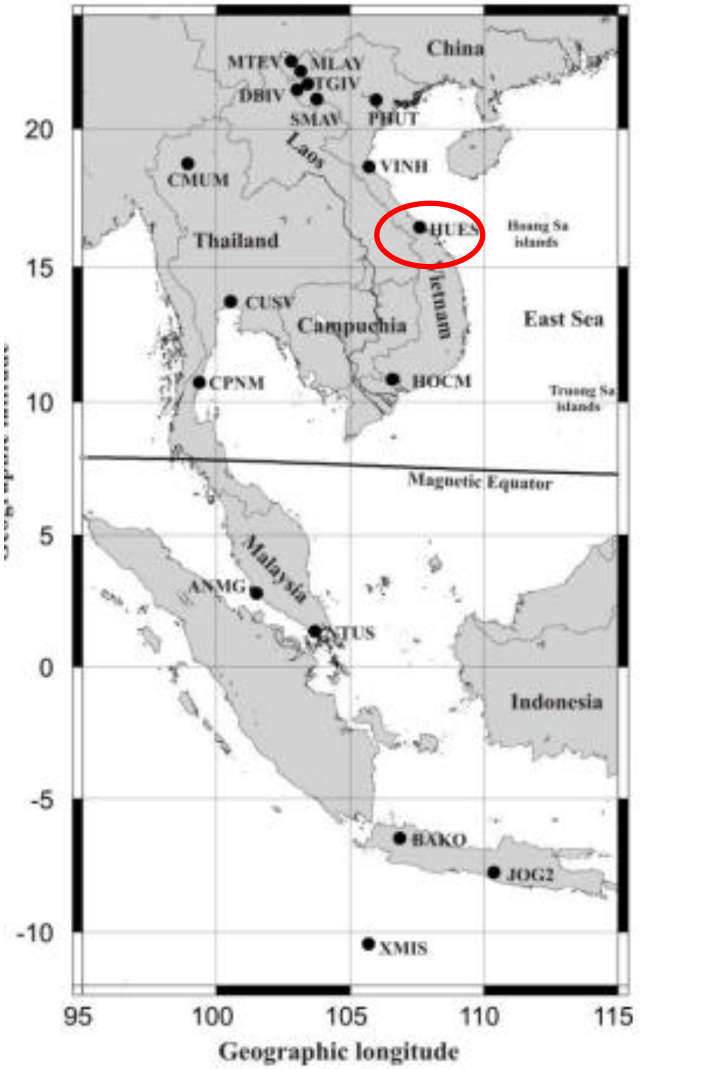




Solar cycle 24

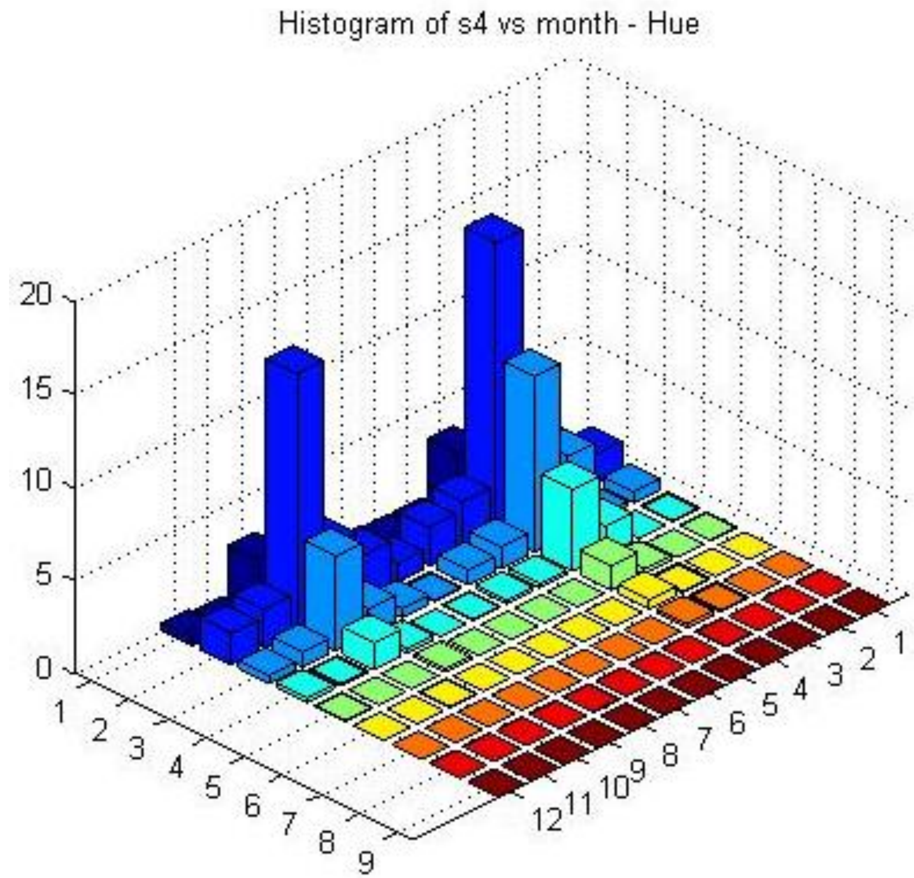


Scintillation index S4 observed at Hue (Vietnam) from 2006 to 2008 -> fluctuations of the GPS power signal



Distribution of GPS receivers in Vietnam
And adjacent region

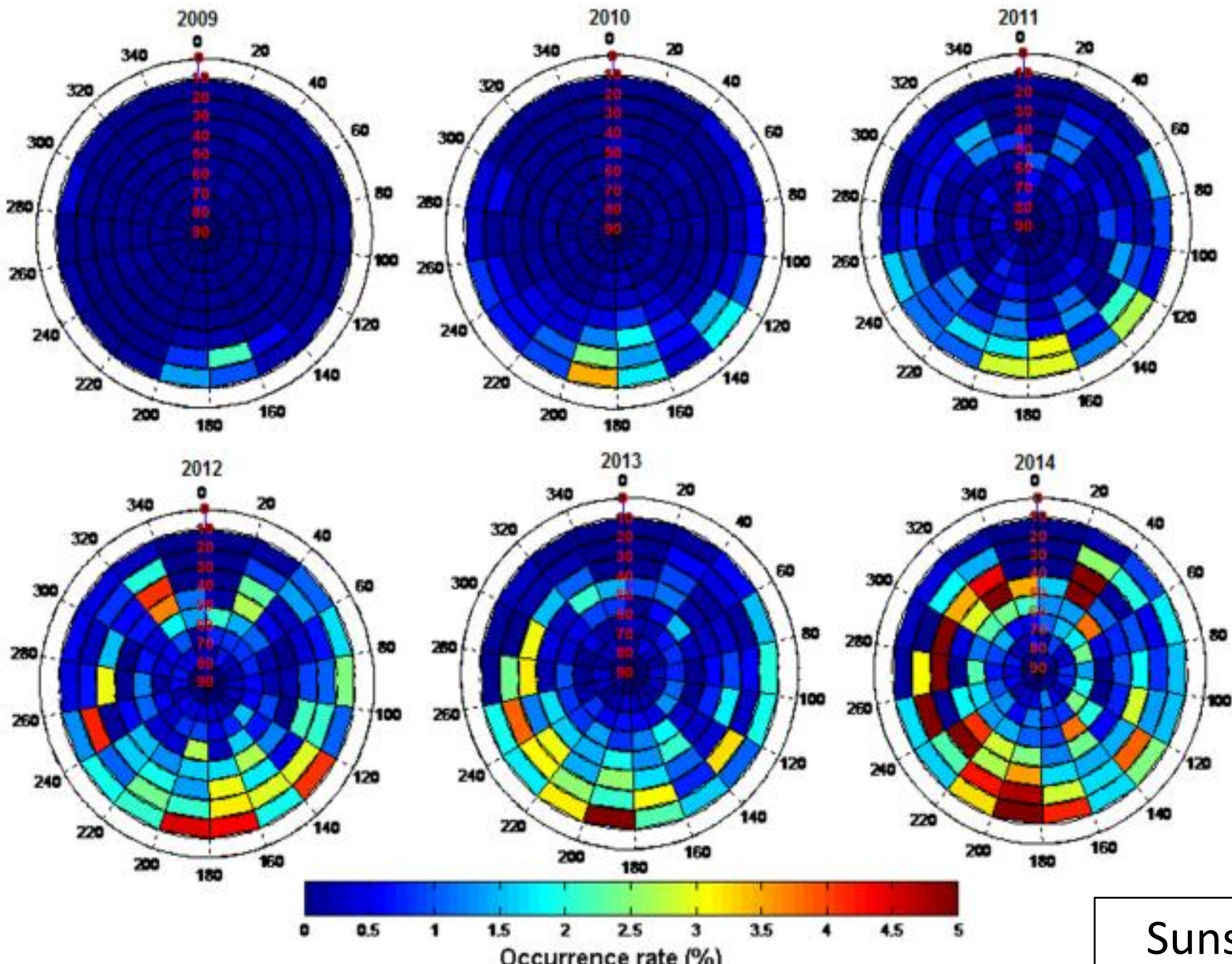
$$I = \frac{A^2}{2} \qquad s4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

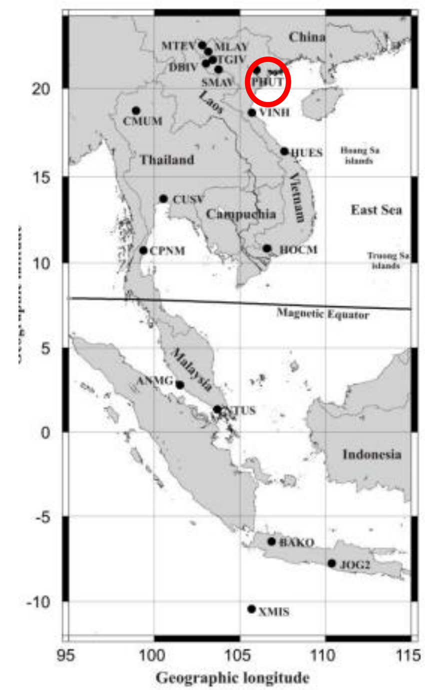


Seasonal variations: equinox maximum

The directional distribution of scintillations observed from PHUT station during 2009–2014.

VIETNAM





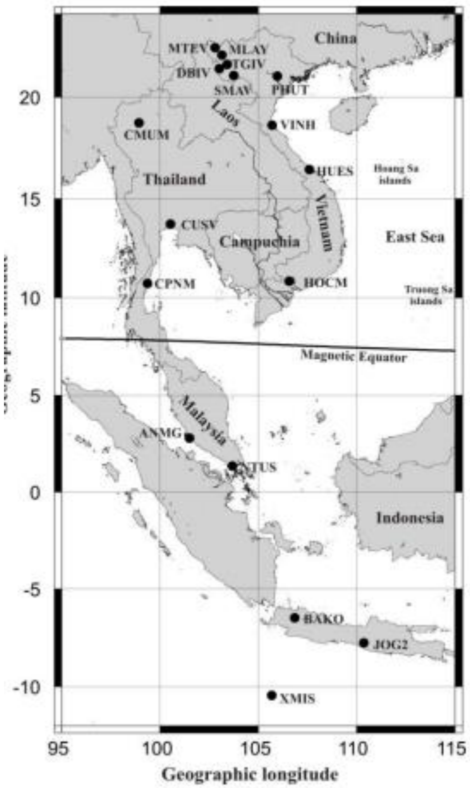
Sunspot cycle Maximum
2012,2013,2014

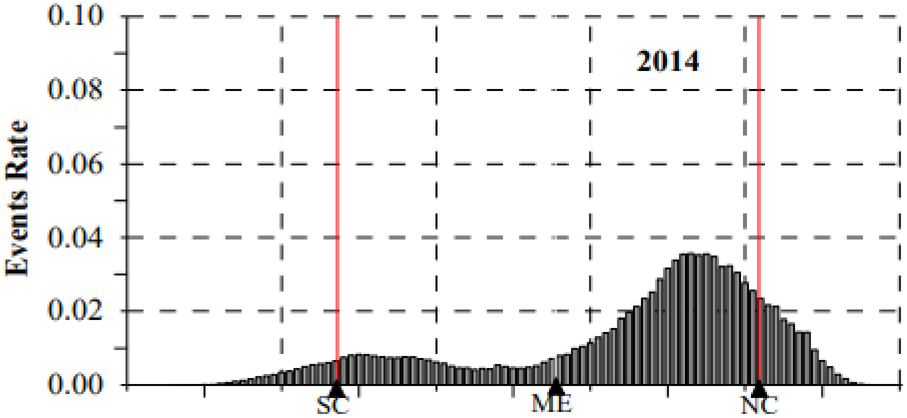
Tran Thi L., M. Le Huy et al.,Climatology of ionospheric scintillation over the Vietnam low-latitude region for the period 2006-2014, Advances in Space Res. http://dx.doi.org/10.1016/j.asr.2017.05.005.

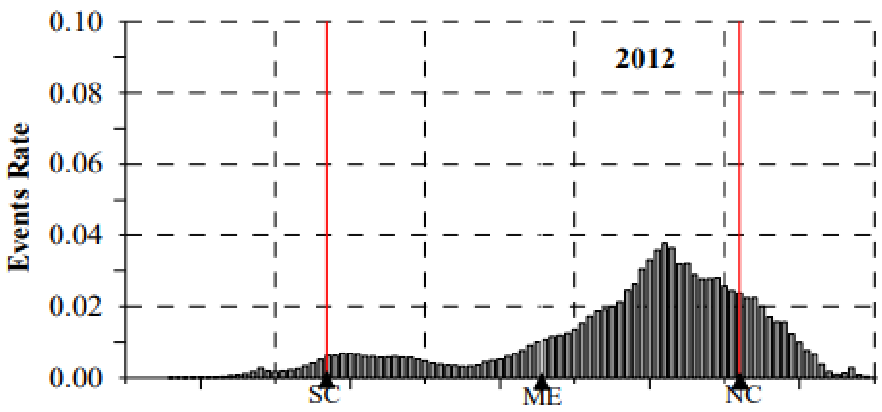
Statistics of ionospheric irregularities (ROTI≥0.5) along geographic latitude during the period 2008-2018.

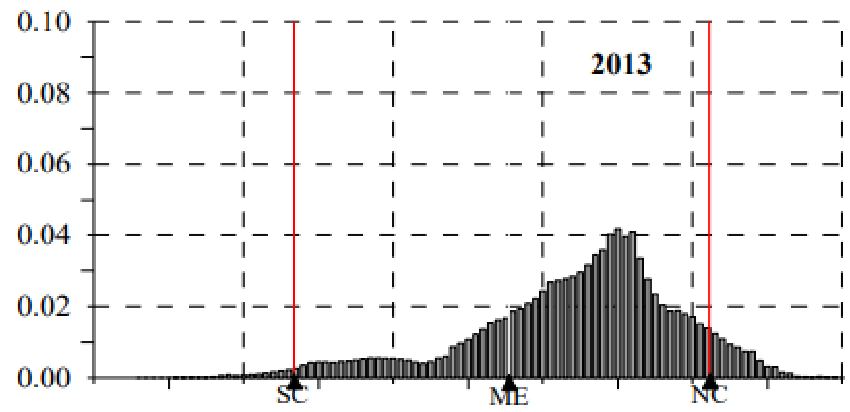
Phase maximum of sunspot cycle 24

ASIAN SECTOR



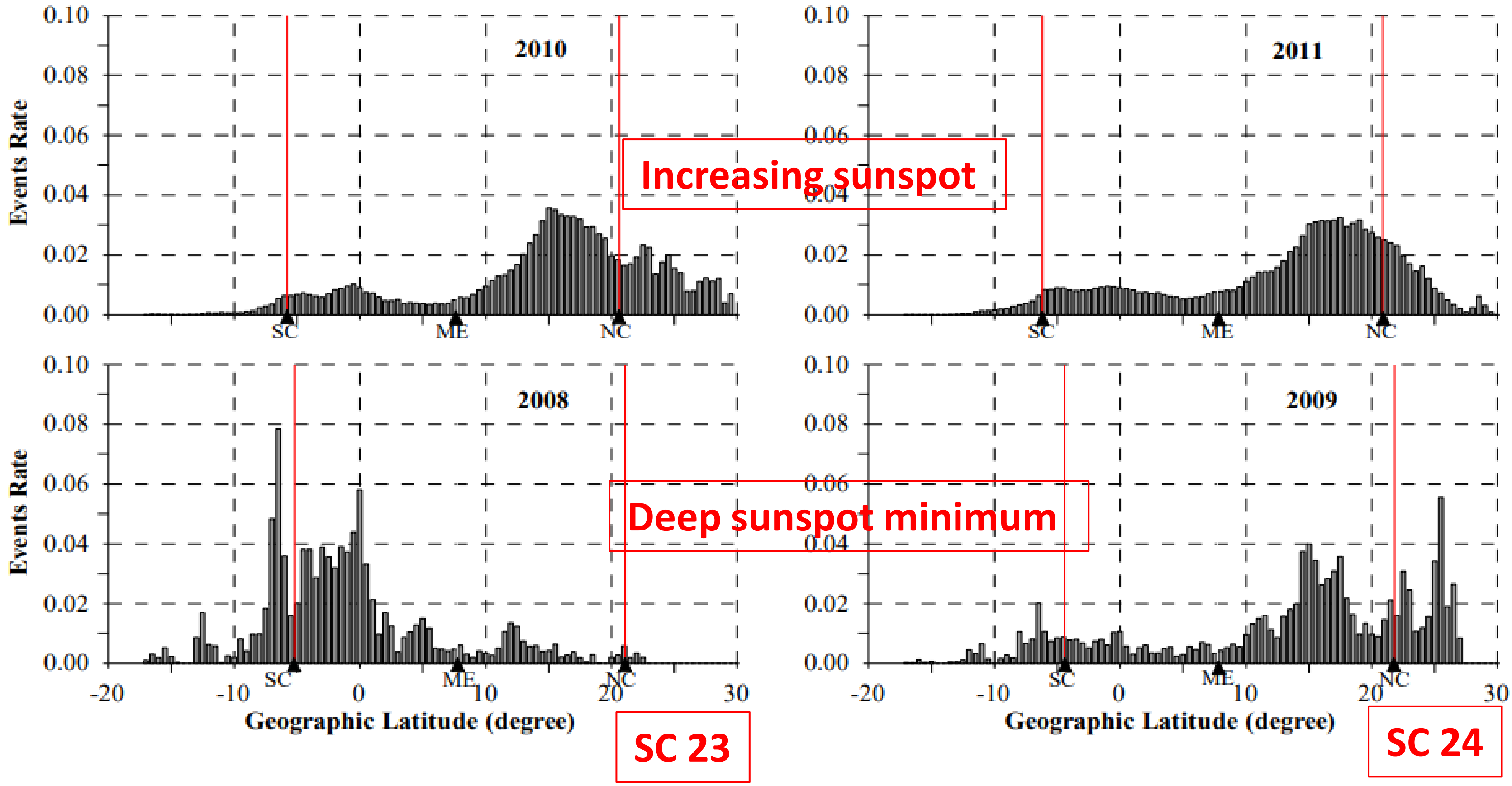






Dung Nguyen Thanh et al., https://doi.org/10.15625/2615-9783/16502

Statistics of ionospheric irregularities (ROTI≥0.5) along geographic latitude during the period 2008-2018. ME: magnetic equatorial; SC: southern crest; NC: northern crest **ASIAN SECTOR**

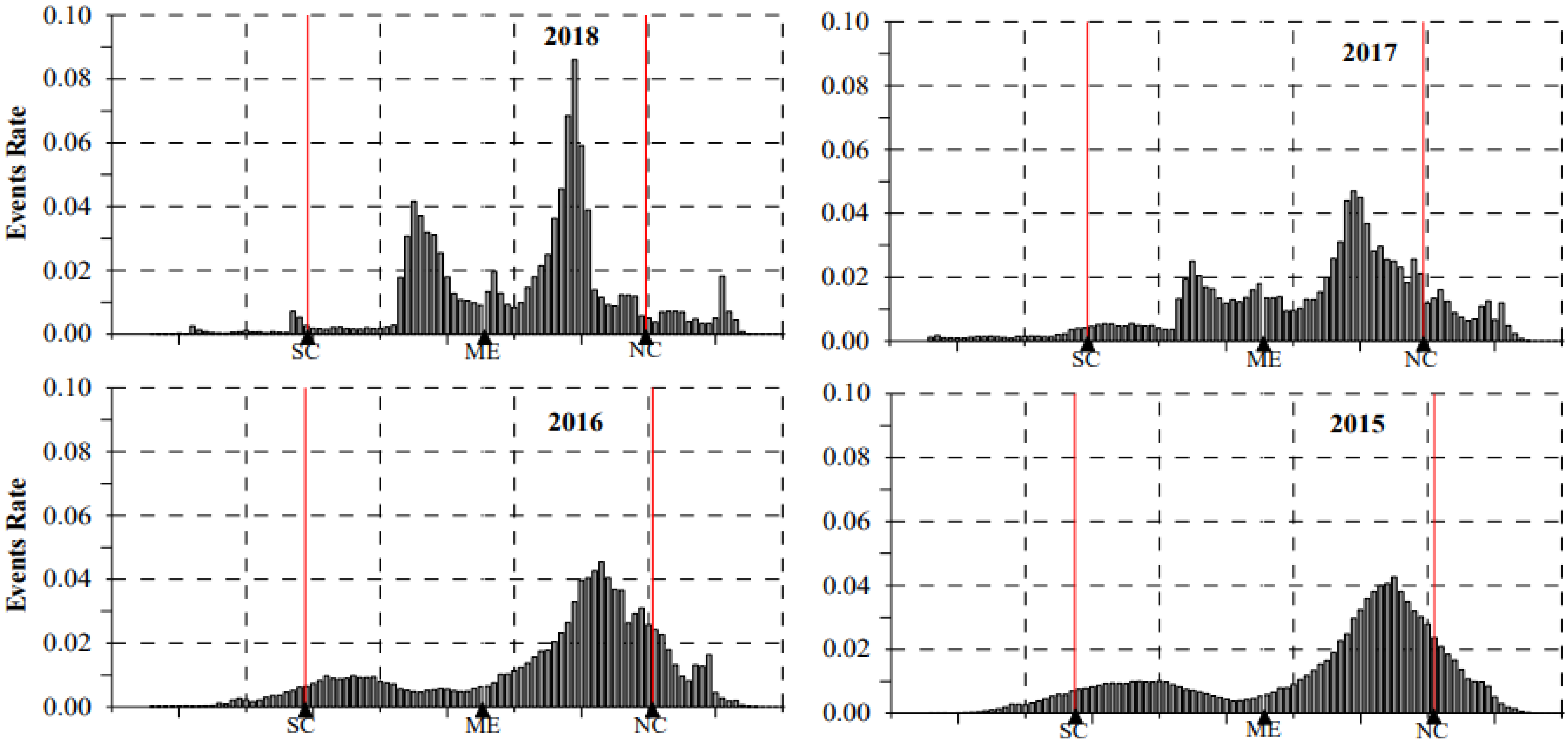


Dung Nguyen Thanh, Minh Le Huy, Christine Amory-Mazaudier, Rolland Fleury, Susumu Saito, Thang Nguyen Chien, Hong Pham Thi Thu, Thanh Le Truong, Mai Nguyen Thi, Characterization of ionospheric irregularities over Vietnam and adjacent region for the 2008-2018 period, Vietnam Journal of Earth Sciences, 1-20, https://doi.org/10.15625/2615-9783/16502

Statistics of ionospheric irregularities (ROTI≥0.5) along geographic latitude during the period 2008-2018. ME: magnetic equatorial; SC: southern crest; NC: northern crest

ASIAN SECTOR

Decreasing phase of sunspot cycle 24



Dung Nguyen Thanh et al., https://doi.org/10.15625/2615-9783/16502

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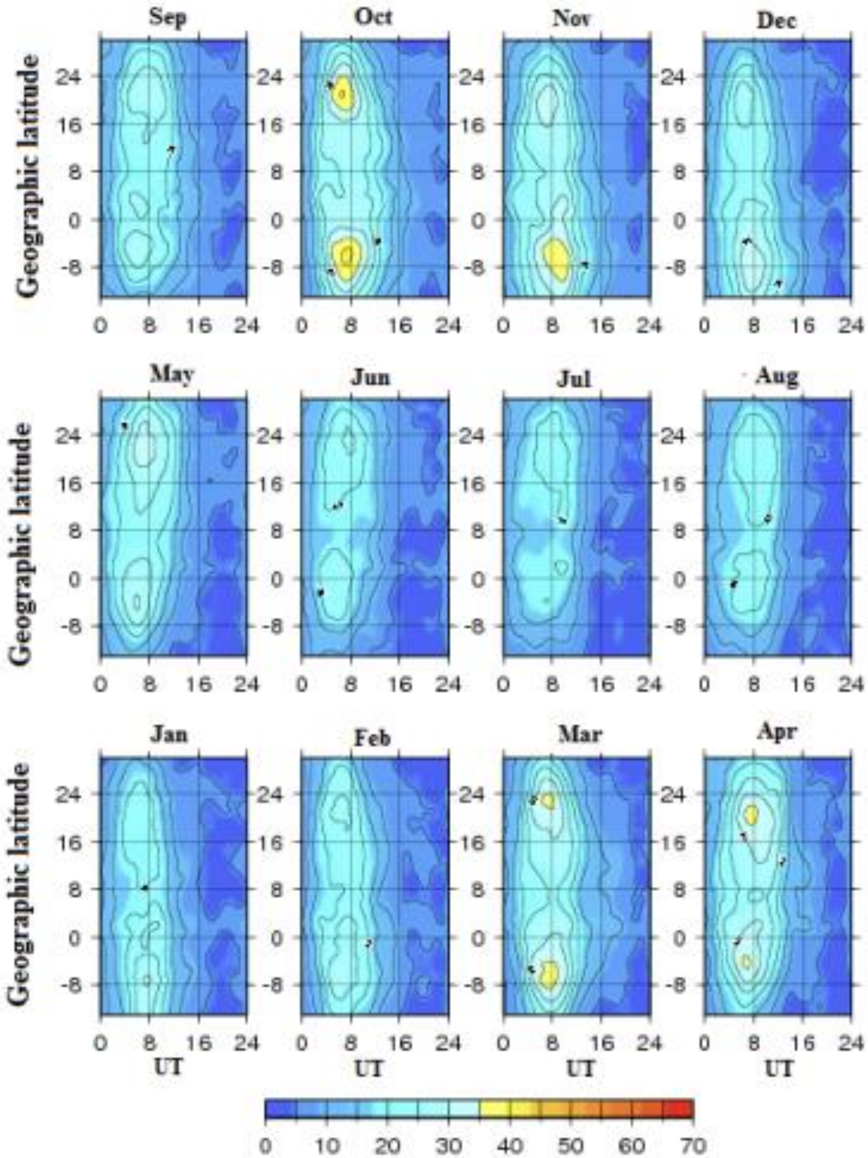
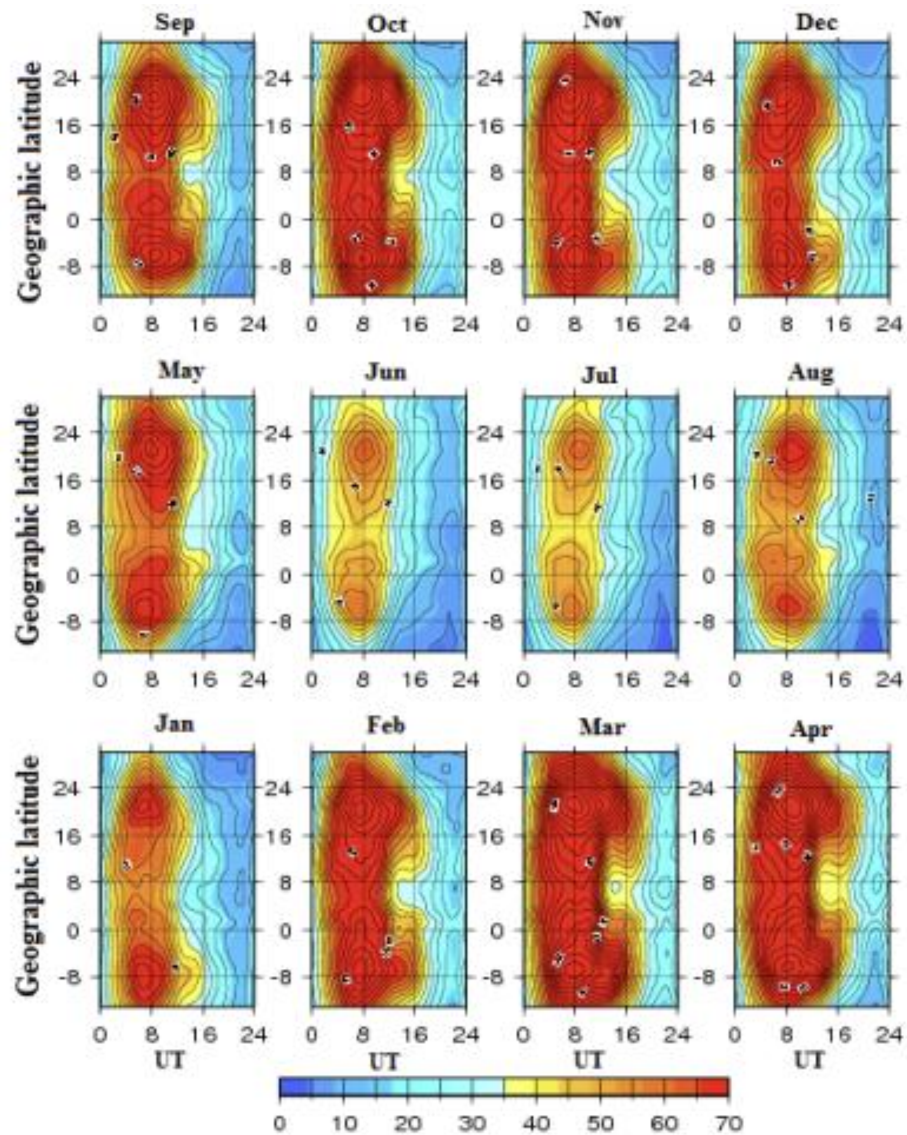
MAPS of Total Content Electron

Minimum sunspot cycle -2009

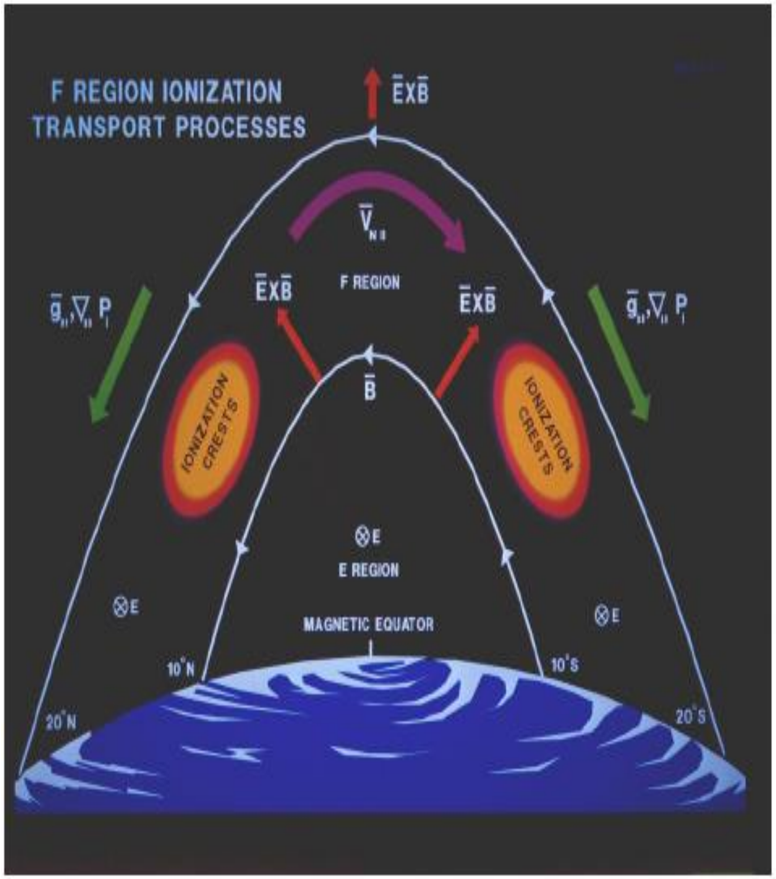


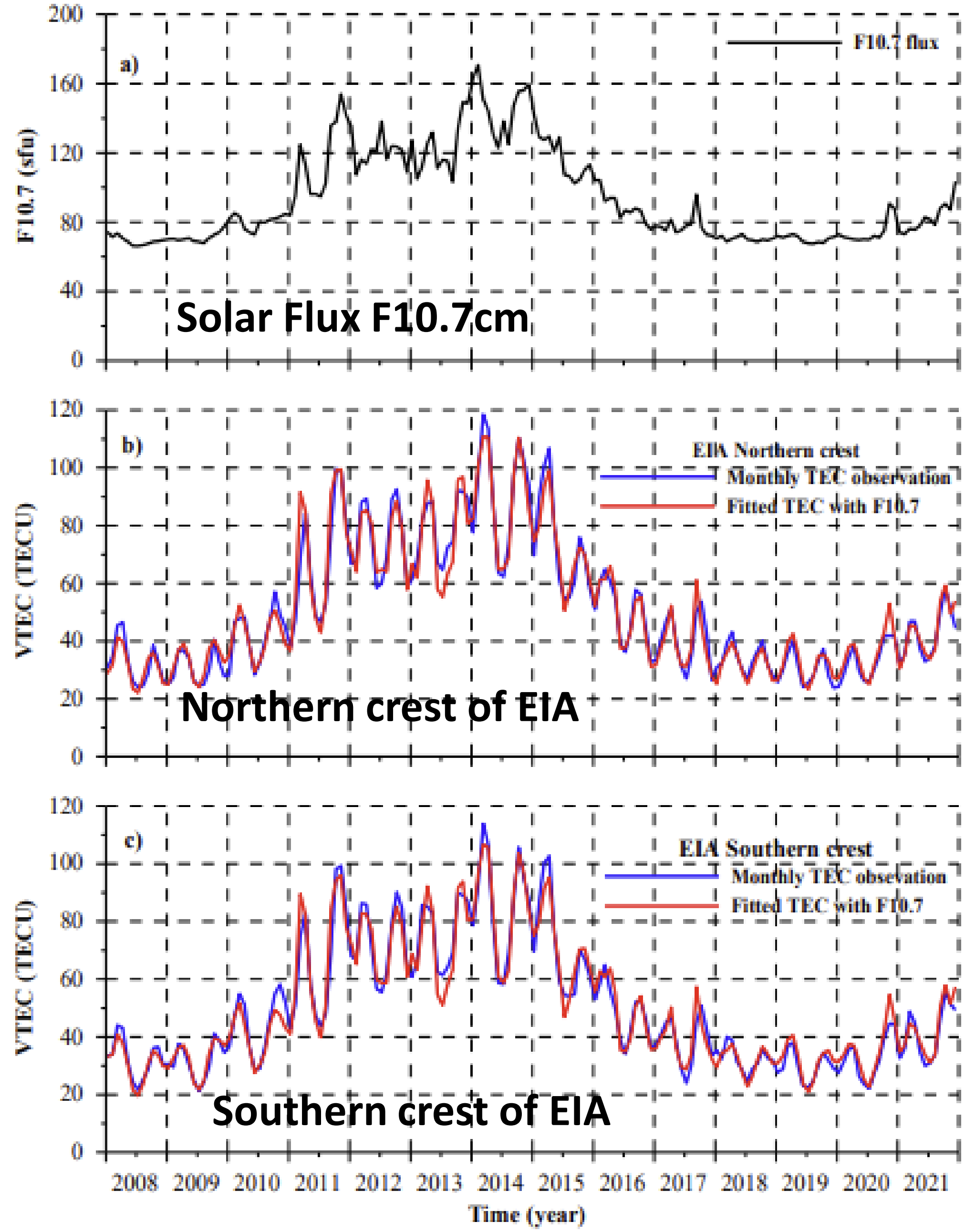
Maximum sunspot cycle-2014



Dung Nguyen Thanh, et al., Ionospheric quasi-biennial oscillation of the TEC amplitude of the equatorial ionization anomaly crests from continuous GPS data in the Southeast Asian region , Vietnam Journal of Earth Sciences, 1-18, https://doi.org/10.15625/2615-9783/17490

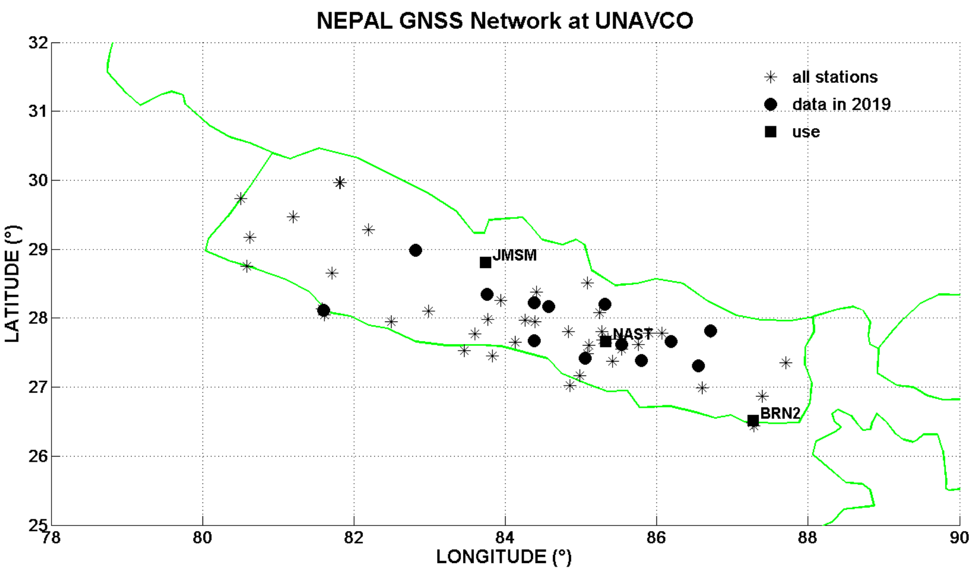
Equatorial Ionization Anomaly
Equatorial Fountain





Dung Nguyen Thanh, et al., Ionospheric quasi-biennial oscillation of the TEC amplitude of the equatorial ionization anomaly crests from continuous GPS data in the Southeast Asian region , Vietnam Journal of Earth Sciences, 1-18, https://doi.org/10.15625/2615-9783/17490

NEPAL / CAPACITY BUILDING/SPACE WEATHER



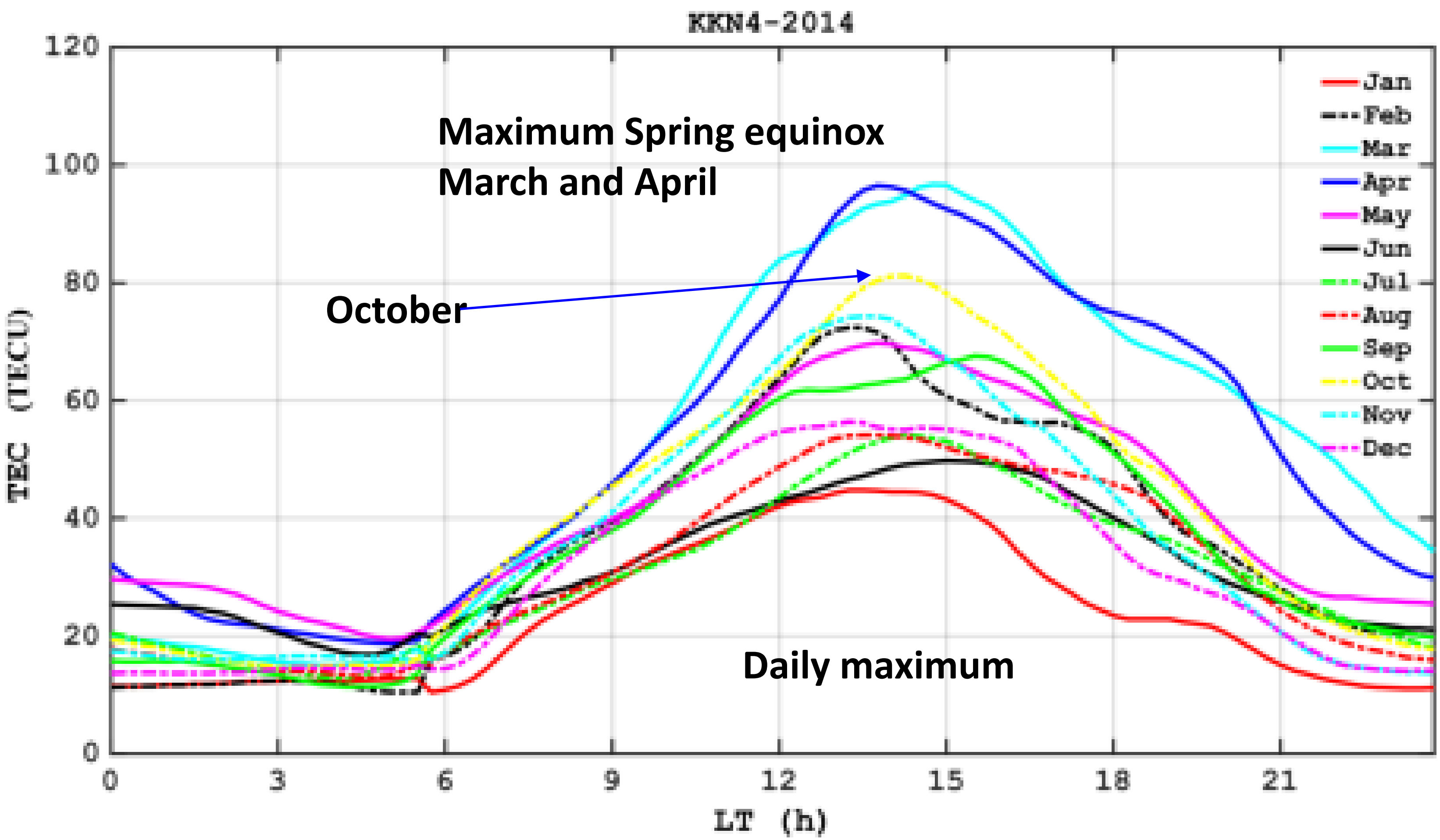
ICG workshop, December 2016

School organized by ICTP- September 2019

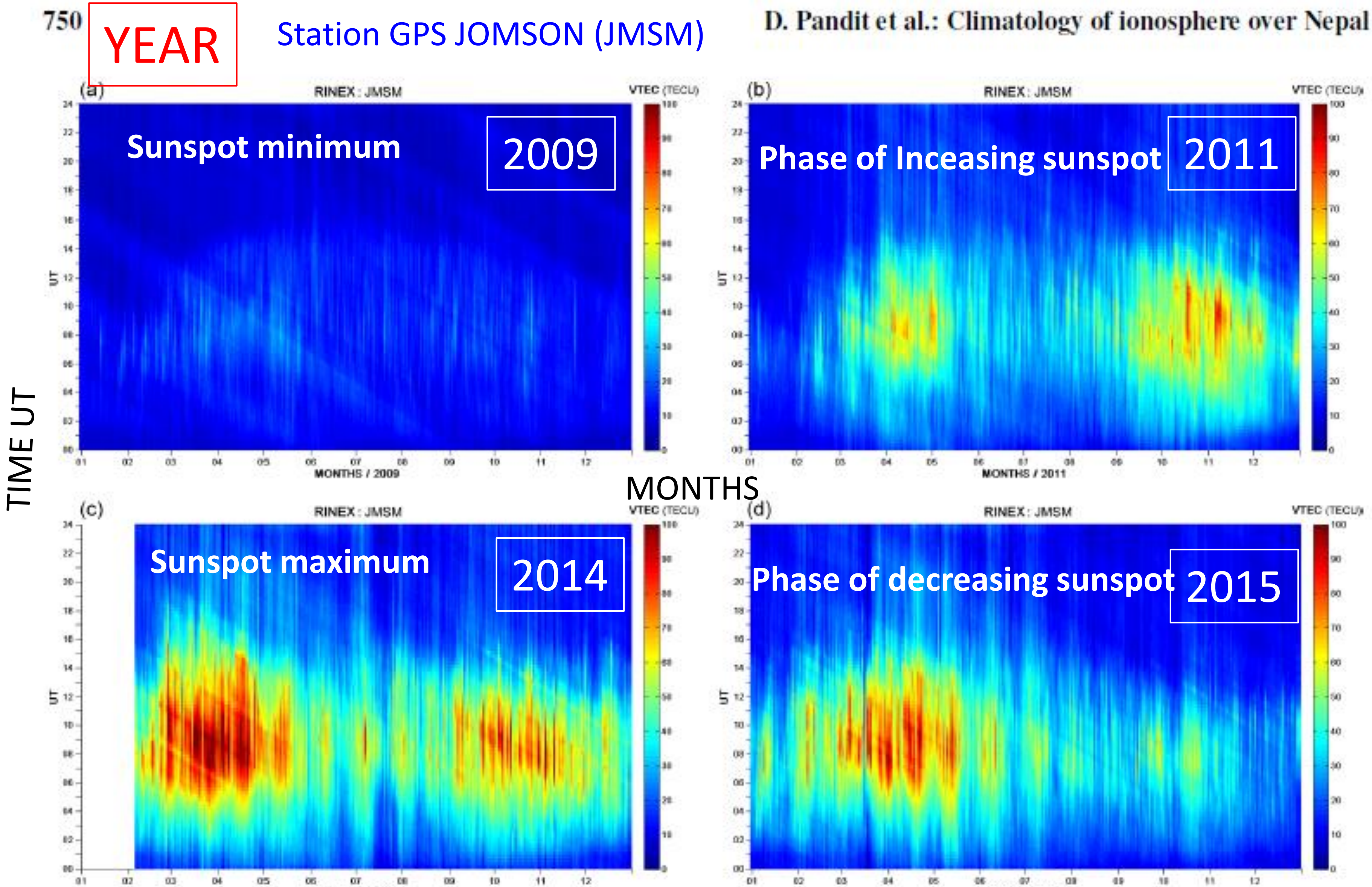
PhD of D. Pandit on September 23,2022

MONTHLY Variations

Monthly variation in vertical TEC in LT for 2014 at KKN4 station.

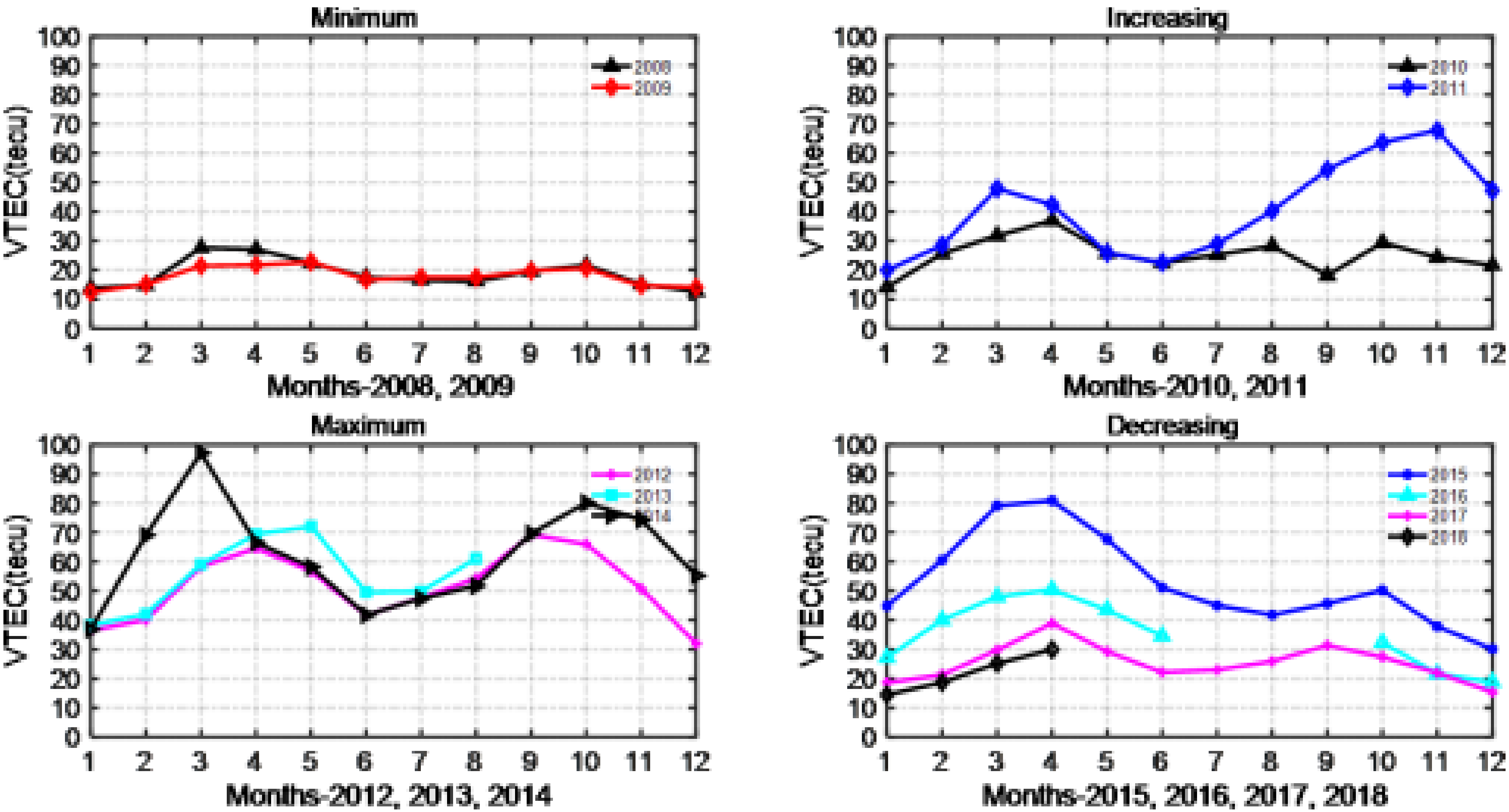


Pandit, D. B. Ghimire, C. Amory-Mazaudier, R. Fleury, N. P. Chapagain, B. Adhikari, Climatology of ionosphere over Nepal based on GPS TEC data from 2008 to 2018, Ann. Geophys., 39, 743–758, 2021 https://doi.org/10.5194/angeo-39-743-2021



(a–d) A two-dimensional (2D) variation in vertical TEC according to UT at the JMSM station for one of the years of the minimum (2009), ascending (2011), maximum (2014) and descending (2015) phases of solar cycle 24. Pandit, D et al. https://doi.org/10.5194/angeo-39-743-2021

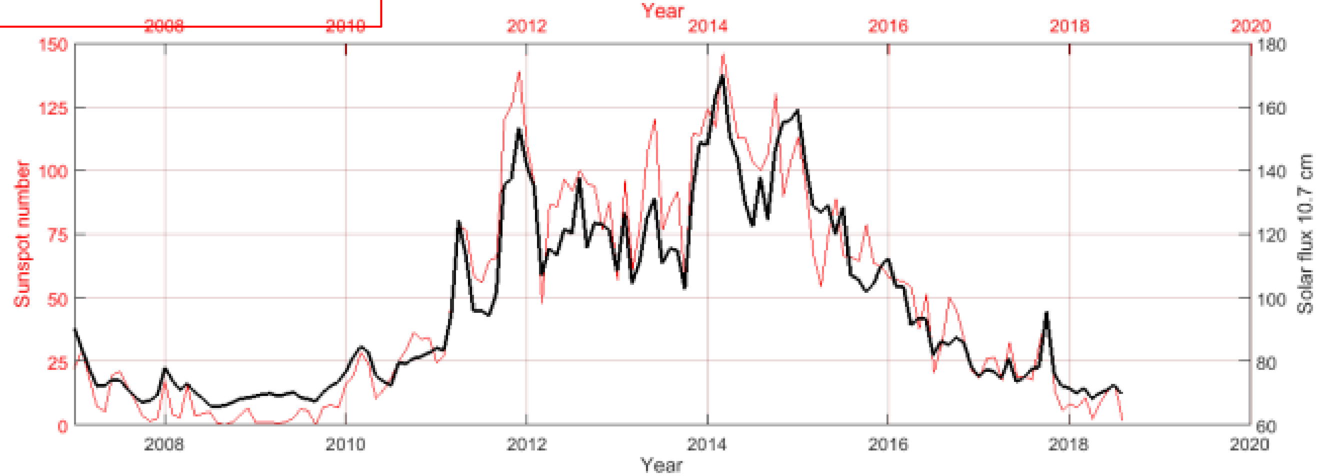
PHASES OF SUNSPOT CYCLE 24

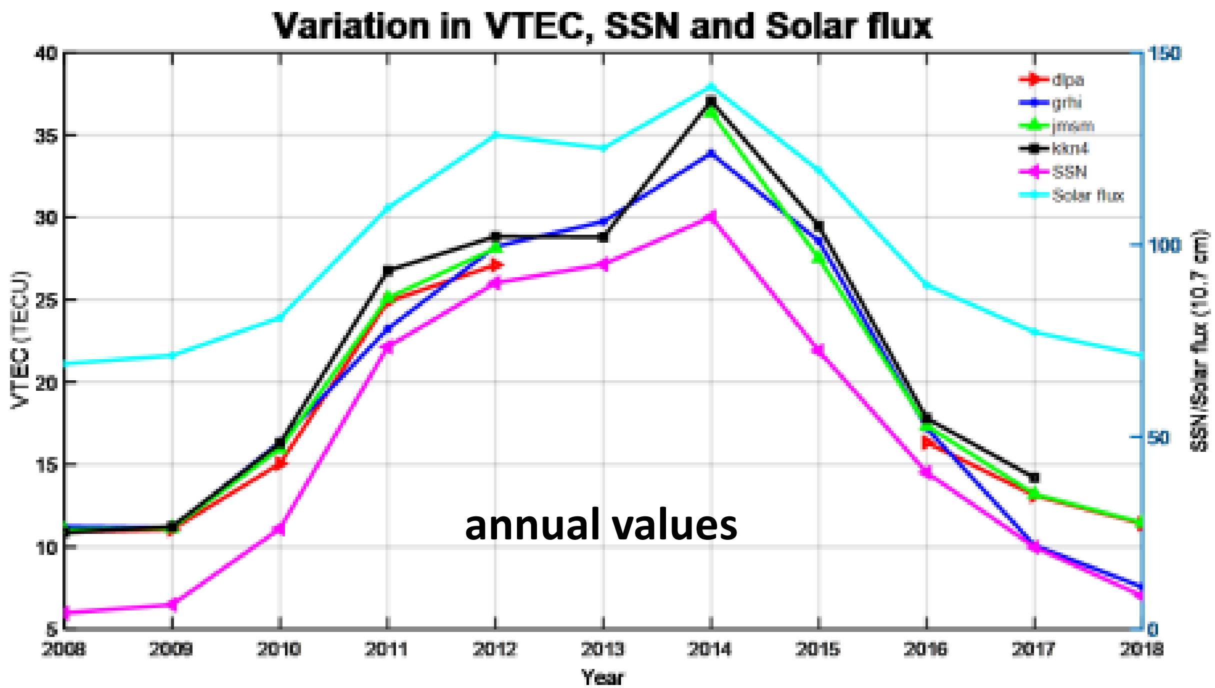


VTEC variability in GRHI station during minimum, increasing, maximum and decreasing phases of solar cycle 24

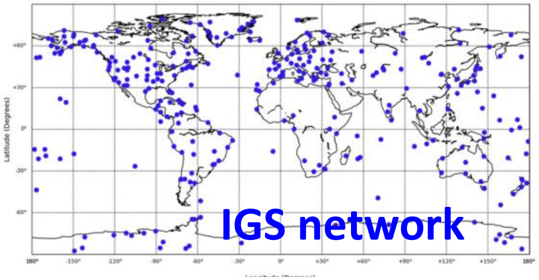
Pandit, D et al. https://doi.org/10.5194/angeo-39-743-2021

SUNSPOT CYCLE 24

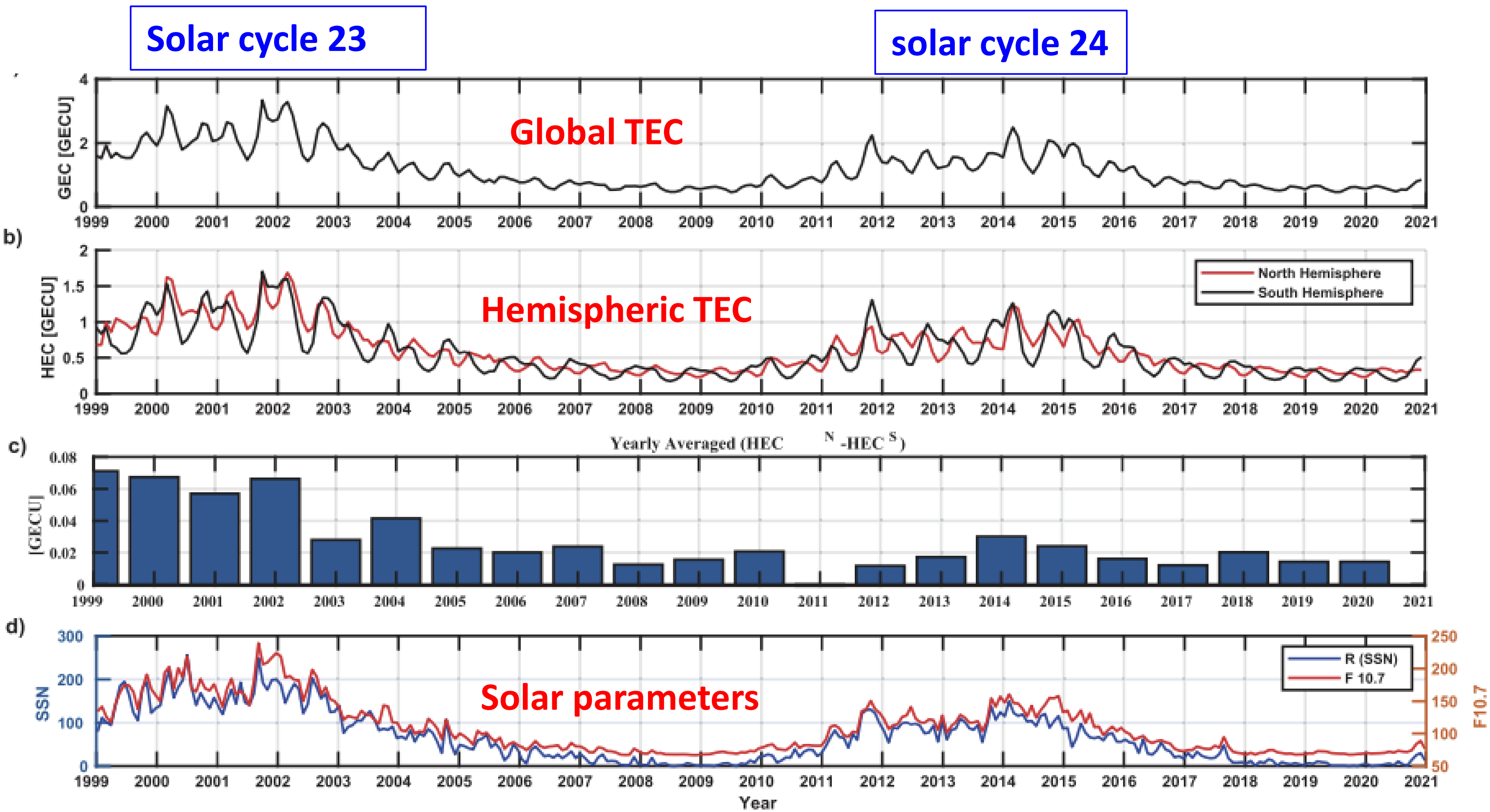




Pandit, D et al. https://doi.org/10.5194/angeo-39-743-2021



Climatology of global, hemispheric and regional electron content variations during the solar cycles 23 and 24



Younas, W., C. Amory-Mazaudier, Majid Khan, Paul O. Amaechi, Climatology of global hemispheric and regional electron content variations during the solar 23 and 24., Advances in Space Research, https://doi.org/10.1016/jasr.2022.07.029

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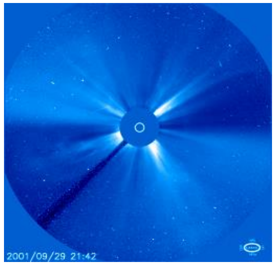
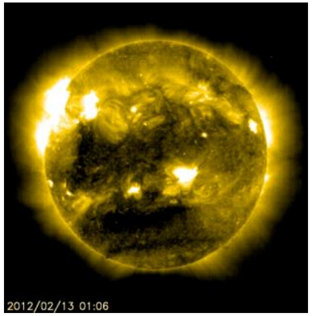


SOLAR EVENTS

Coronal Mass Ejection and Magnetic cloud

High Speed Solar Wind HSSW and CIR



If the Interplanetary Magnetic Field , IMF field is opposite to the terrestrial magnetic field, i.e directed toward the South, there is reconnection between the IMF and the Earth's magnetic field and **there is a magnetic storm**

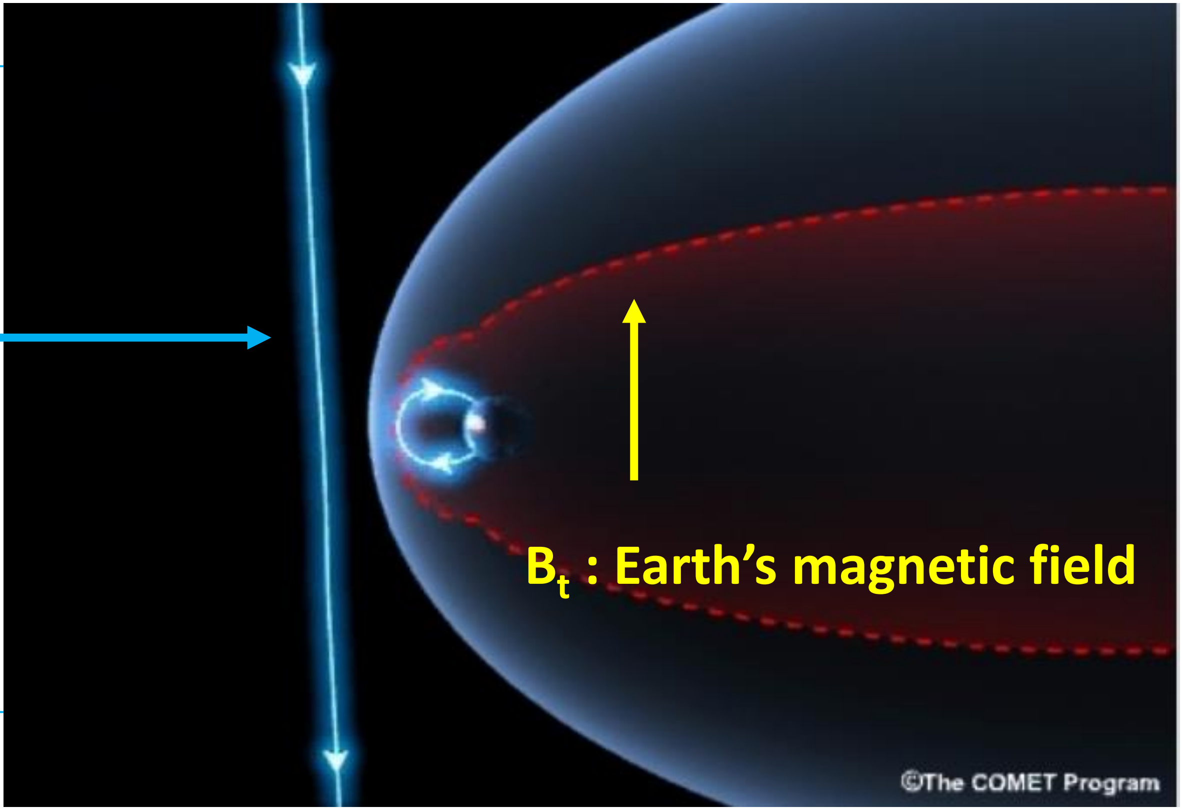
Key parameters for Space Weather

B_z IMF

Vs : solar wind speed

E_y=- V_x.B_z

Solar wind is a flow of particules emitted from the sun continuously



Solar wind – Magnetosphere Dynamo : E=VsxB movement is converted into electrical energy

Coupling between high and low latitudes

There are many physical processes acting in aurora region

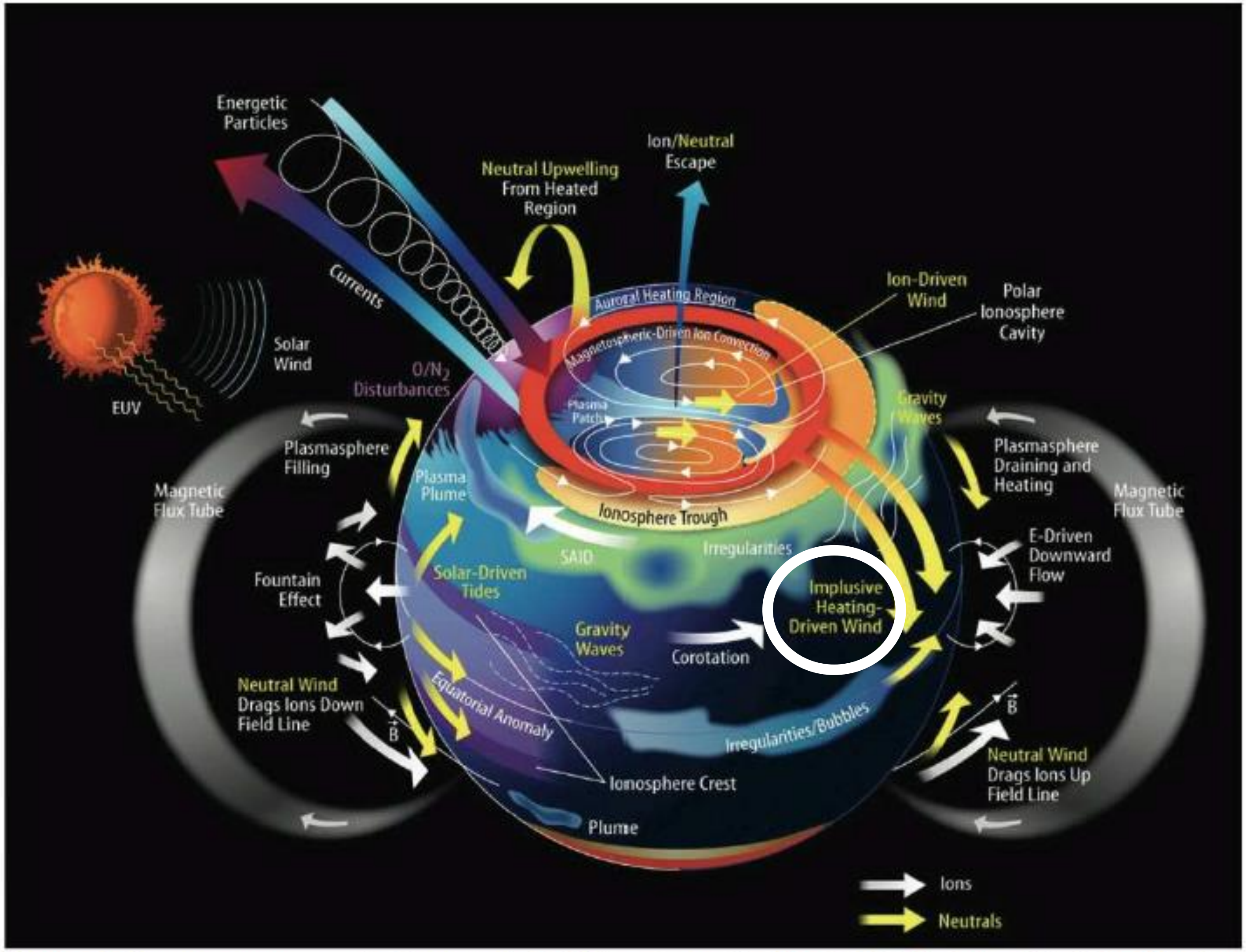


Figure 1. Known processes in the coupled MIT system. Credits: NASA's Scientific Visualization tps://svs.gsfc.nasa.gov/4641

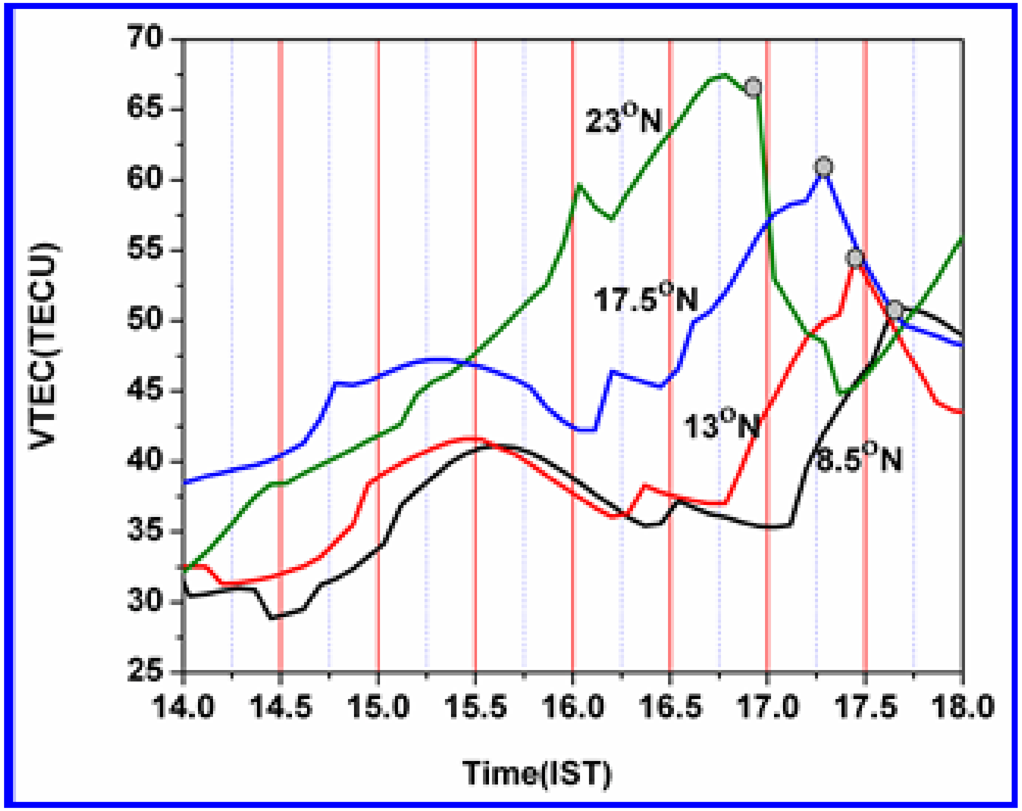
Thermal expansion of the atmosphere: Travelling Atmospheric disturbance (TAD's) => disturbed TEC [Theory Fuller Rowell et al., (1994), (1996)]

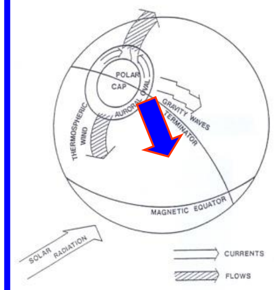
24/08/2005

SSC : 13.00 UT
Main Phase : 16 00 UT

INDIA
77-78°E meridian

V~750m/s



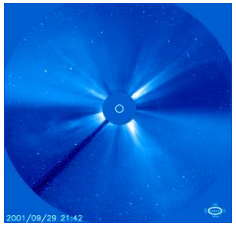


A time delay in the VTEC variations over the different latitudes indicates a propagation of TAD's Velocity 750m/s

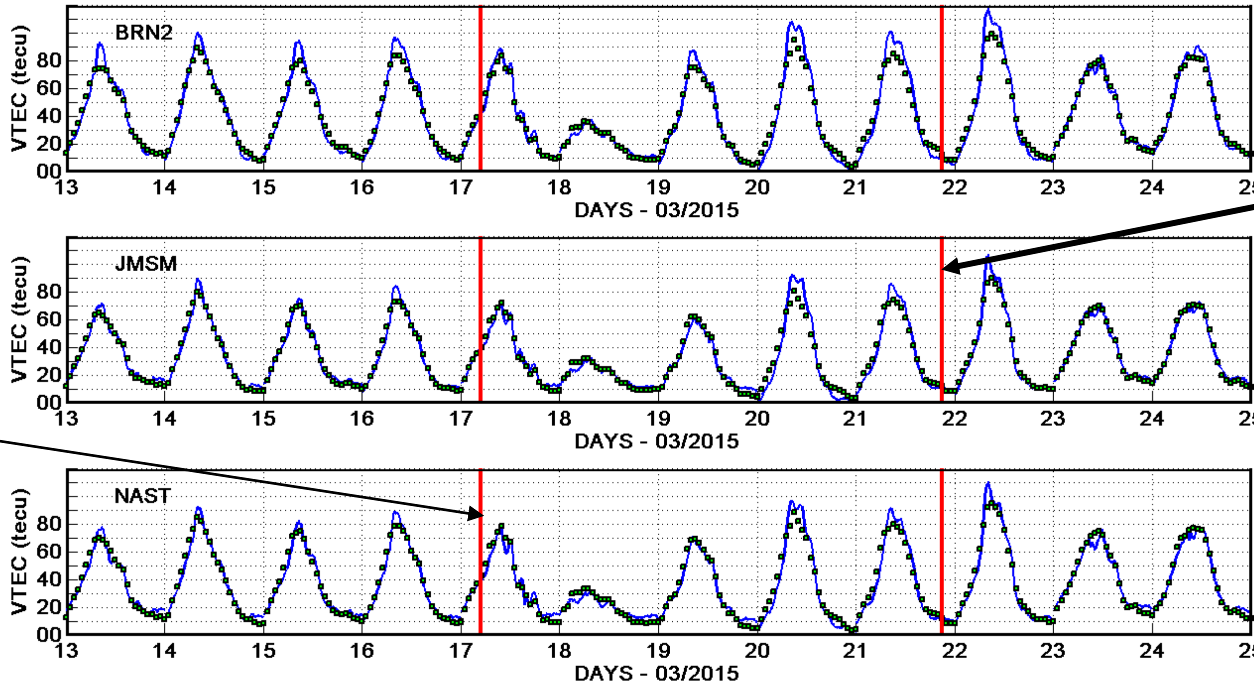
Sreeja et al., JGR vol 114, A12307, 2009

Variations of VTEC over NEPAL, during the period 14–24 March 2015, plotted using CODG TEC respectively.

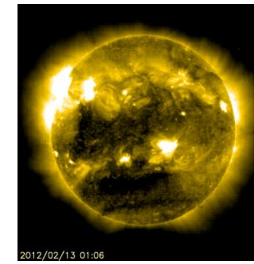
CME



STORM SSC
March 17,
04.45UT



HSSW



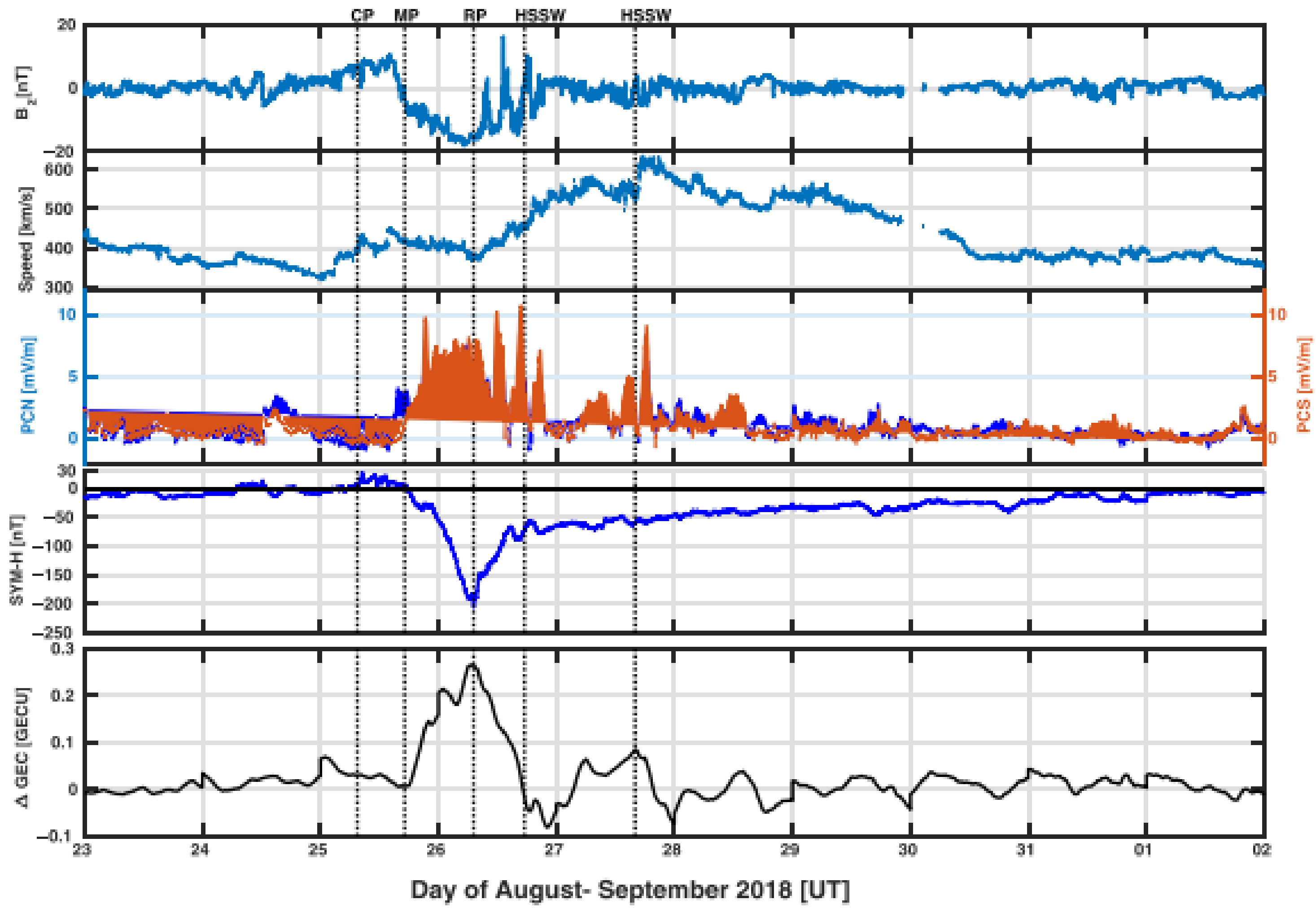
Arrival HSSW
March 21,
20.54UT

Days	BRN2		JMSM		NAST	
	RINEX-CODG	RINEX-IGSG	RINEX-CODG	RINEX-IGSG	RINEX-CODG	RINEX-IGSG
14	10	10	9	10	6	9
15	11	13	11	7	13	13
16	13	16	16	16	10	11
17	4	5	2	2	-4	-4
18	-3	-2	0	1	-3	-3
19	-1	-5	-1	0	-3	-4
20	12	19	10	21	7	19
21	3	8	3	8	12	13
22	19	19	16	17	10	14
23	7	8	-3	-2	1	1
24	-10	-7	1	1	-3	-4

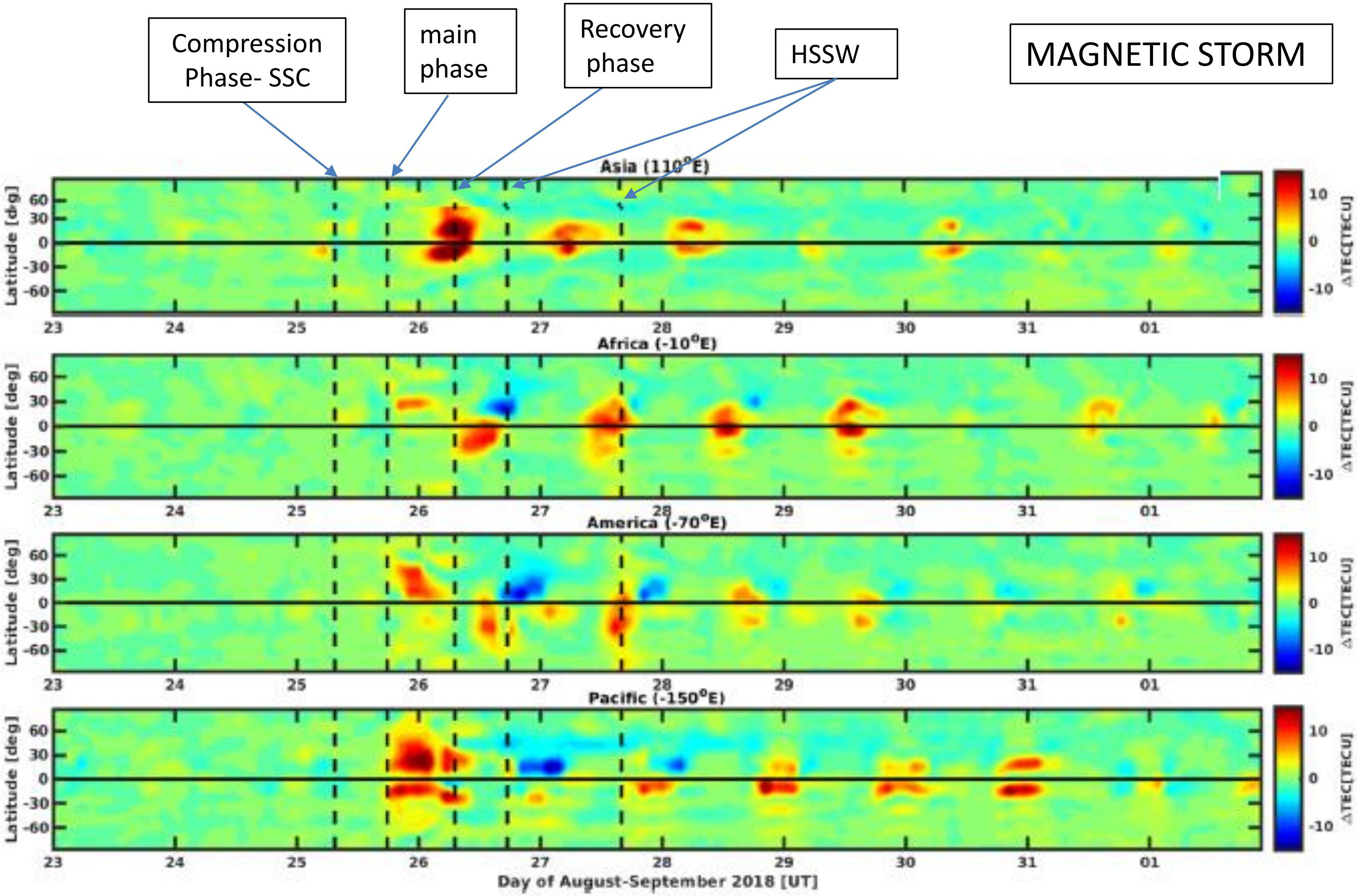
Comparison with GIM maps provided by CODE: CODG http://aiuws.unibe.ch/ionosphere/ and IGSG.

Pandit, D. et al., VTEC Observations of Intense Geomagnetic Storms above Nepal: Comparison with Satellite Data CODE and IGSG Models in Indian J Phys https://doi.org/10.1007/s12648-022-02441-w

Global parameters, from 23 August to 1 September: (from top to bottom) the Bz component of IMF in nanotesla, the solar wind speed in km/s, the SYM-H index in nanotesla, polar cap indices in mV/m, and GEC in GECU **[PAKISTAN]**



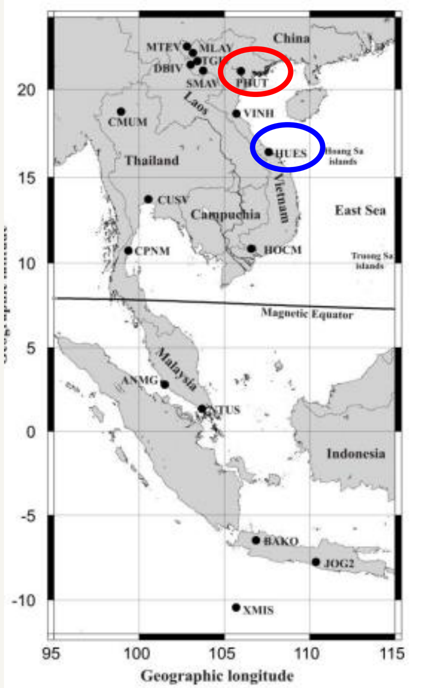
Younas, W. C., C. Amory-Mazaudier, M. Khan, R. Fleury, Ionospheric and Magnetic signatures of a Space Weather event on 25-29 August 2018 : CME and HSSSWs, , Journal of Geophysical Research: Space Physics, 125, e2020JA027981. https://doi.org/10.1029/2020JA027981

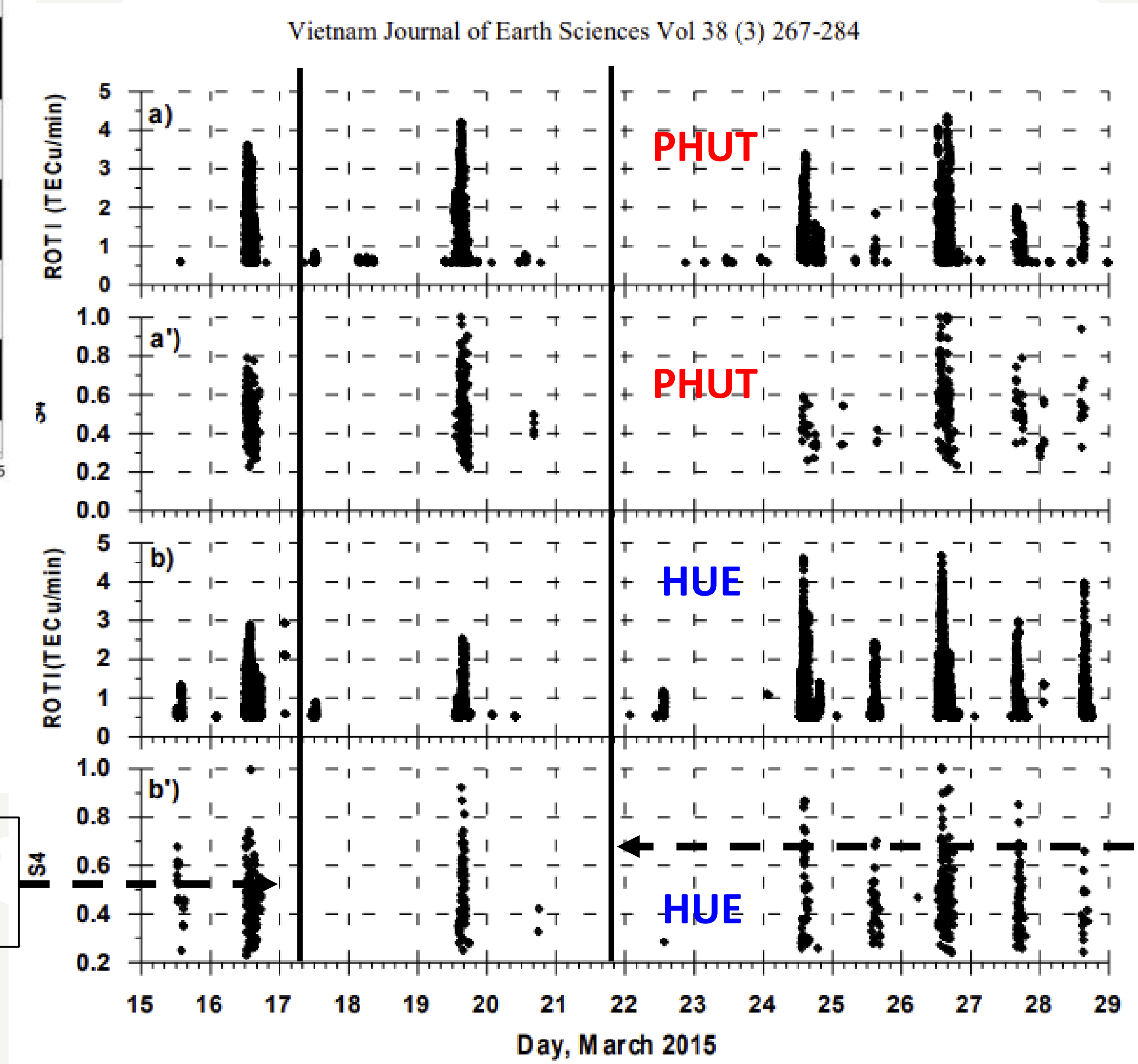


VTEC is influenced by PPEF, DDEF and Thermal expansion of atmosphere

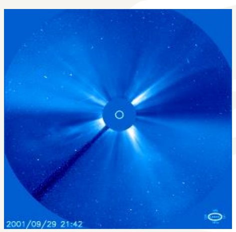
Younas,W et al., Journal of Geophysical Research, Space Physics, 125, e2020JA027981. https://doi.org/10.1029/2020JA027981

S_4 and ROTI index in Vietnam

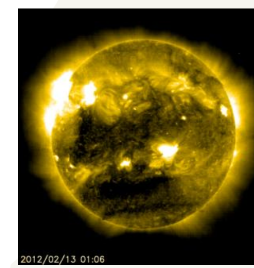




CME



HSSW



STORM SSC
March 17, 04.45UT

Arrival HSSW
March 21,
20.54UT

Le Huy Minh et al.,. TEC variations and ionospheric disturbances during the magnetic storm on March 2015 observed from continuous GPS data in the Southeast Asian region, *Vietnam J. Earth Sciences*, ISBN 0866-7187, **38(3)**, 287-305, https://doi:10.15625.0866-7187/38/3/8714

CONCLUSION

The use of the GNSS technique has allowed the development of studies on the ionosphere in countries where the ionosphere was not studied for lack of scientific tools.

These studies carried out within the framework of the IHY 2007-2009) and ISWI (2010-2012) projects integrating a systemic approach of the Sun-Earth system have enabled the emergence of pioneers in the discipline of Space Weather in many countries.

These students had new data that led them to publish in the best journals, to have a position in their country and to be recognized internationally.

The strength of the GNSS technique is that it works continuously and it can capture all the variations of ionospheric ionization due to different physical phenomena and therefore study their impacts on ionosphere (solar flare, eclipse, earthquake, SW, QBO, hurricane, etc…)