ROLE OF GNSS IN THE SPACE WEATHER RESEARCH

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

Helsinki, 23-27 October 2023

outlines

- Introduction : UN Projects
- Use of GNSS for Science
- Capacity building in Africa
- Capacity building in Asia
- Conclusion

United Nations Space Science Initiative [1991-2012]

- 1992-1994: IEEY International Equatorial Electrojet Year – IAGA

worldwide study

- 1995 : GIRGEA – scientific network Europe Africa
- Since 2006 : GIRGEAA Europe Africa Asia

www.girgea.org

- 2005-2009: IHY International Heliophysical Year

Geophysics → Heliophysics

- 2010-2012 : ISWI International Space Weather Initiative

Science → daily life

- Since 2012 : ISWI network in United Nations

www.secretariat.org

77 National coordinators

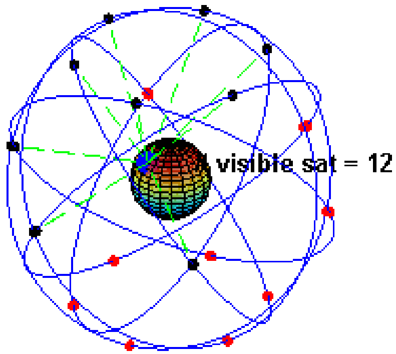
Amory-Mazaudier, C., S. Radicella, P. Doherty, S. Gadimova, R. Fleury, B. Nava, E. Anas, M. Petitdidier, Y. Migoya-Orué, K. Alazo, and K. Shiokawa, Development of research capacities in space weather: A successful international cooperation, J. Space Weather Space Clim. 2021, **11**, 28, Published by EDP Sciences 2021, https://doi.org/10.1051/swsc/2021006

ISWI network: http://www.iswi-secretariat.org

1. Distribution of scientific tools
2. Training schools / GNSS and Physics of the Sun Earth's System
3. PhD => position in the country
4. Curricula in Universities

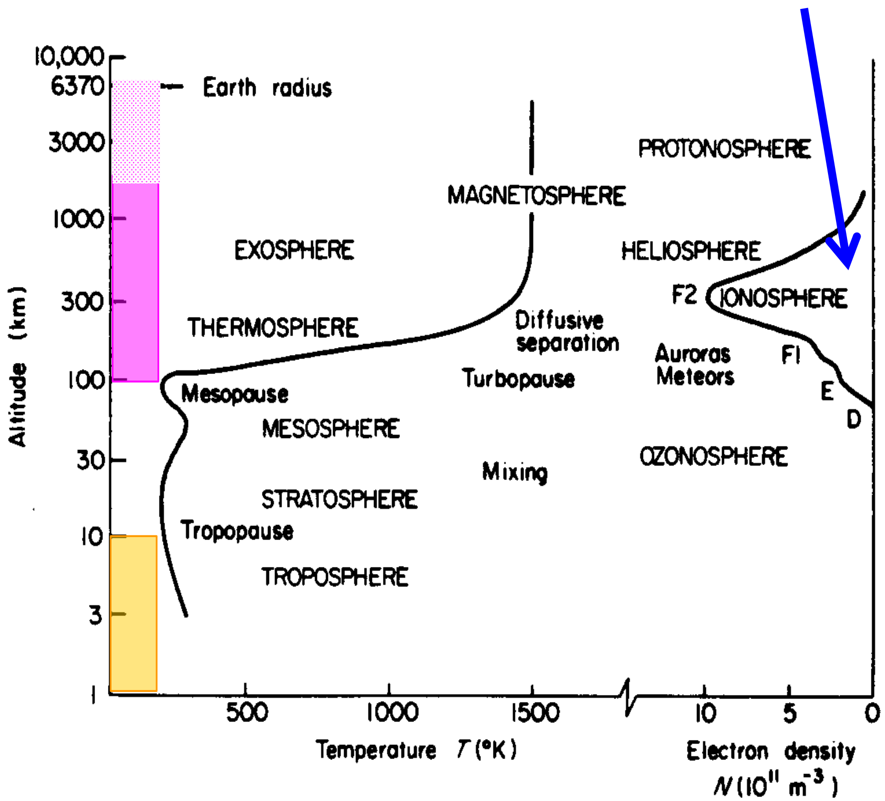
Use of GNSS for SCIENCE

The satellite signal is modified by ionosphere and troposphere



TEC

Total electron content



LAYERS

> 600 km EXOSPHERE
few collisions, Particles follow balistic orbit

80-600 km THERMOSPHERE
Ionization by the solar X-EUV radiation **IONOSPHERE**

30-80 km MESOSPHERE
Absorption of the radiation UV by the ozone layer

11-30 km STRATOSPHERE
Turbulence

0-11 km TROPOSPHERE
Meteorological phenomena

SPACE WEATHER EVENTS IN IONOSPHERE

The ionosphere is the largest source of perturbations for GNSS

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

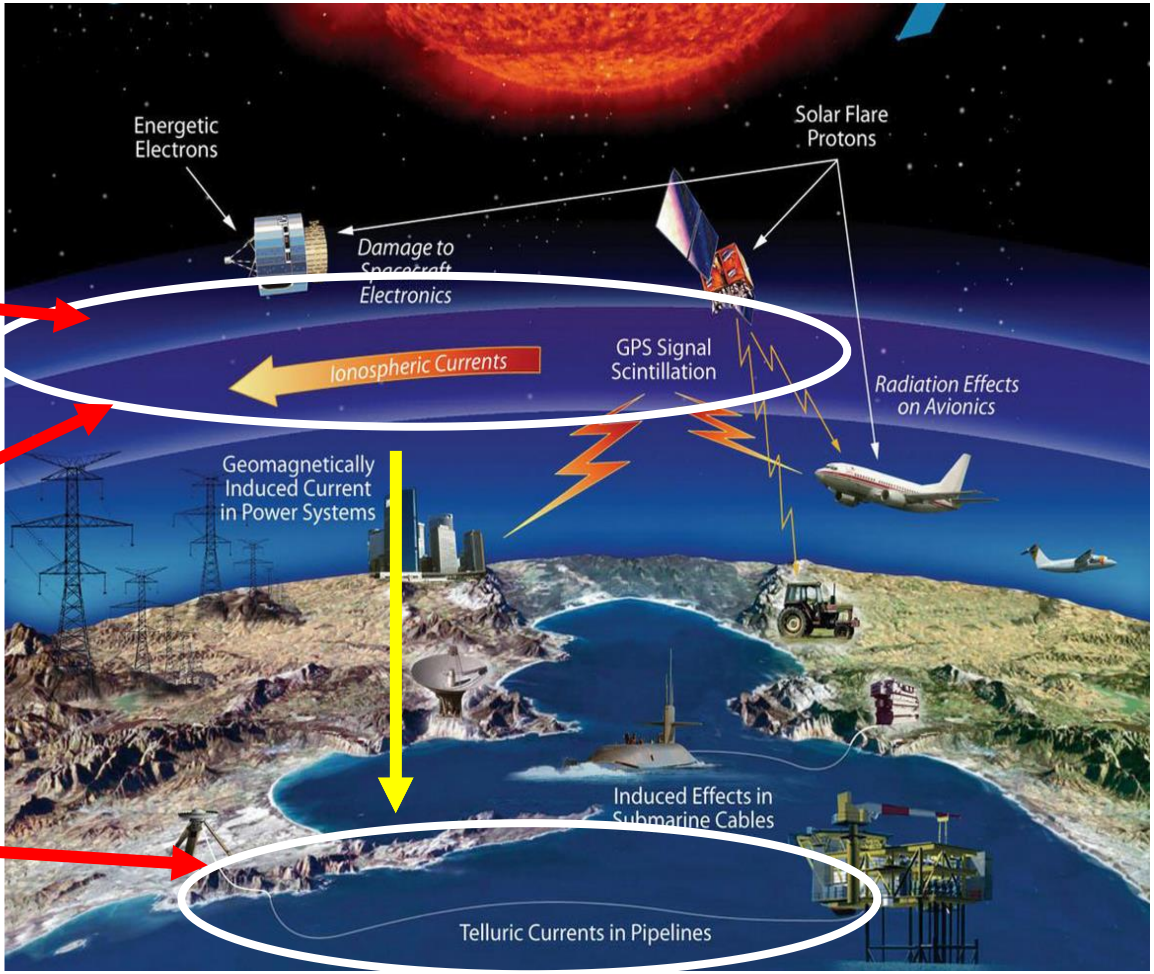
1) Ionization

Propagation of electromagnetic Waves

2) Ionospheric Electric current

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

Nasa website



AT EQUATOR : scintillations a regular phenomenon

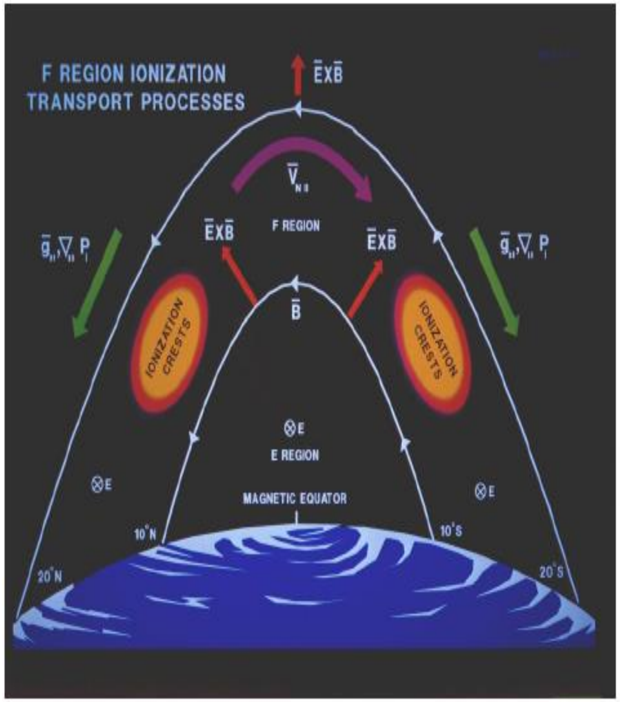
Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere **: Plasma Instabilities**

S_4 and ROTI indices derived from GNSS data

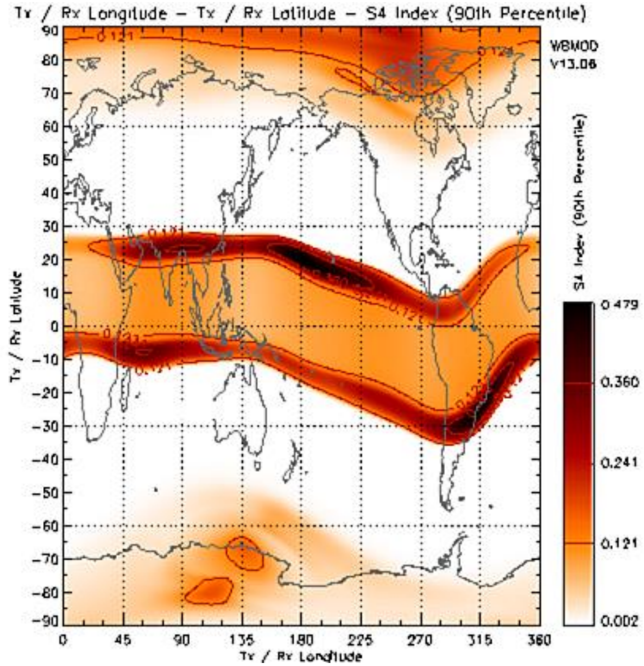
$$S_4 = \sqrt{\frac{<I^2> - <I>^2}{<I>^2}}$$

I : intensity of the signal

$$\mathbf{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$



Equatorial Fountain

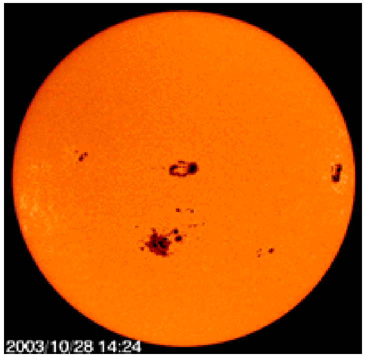


Scintillation index at GPS L1 (1575.42 MHz) assuming constant local time 23.00 at all longitudes (from http://www.sws.bom.gov.au)

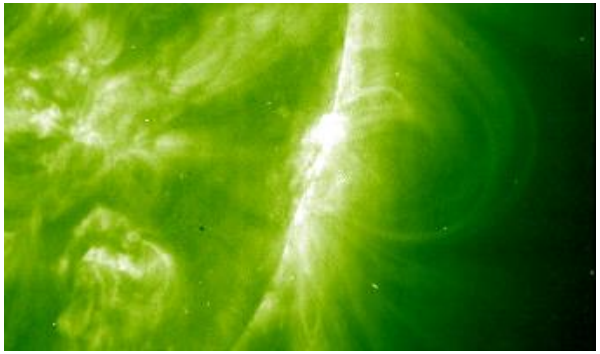
GLOBAL APPROACH OF OF THE SUN-EARTH SYSTEM

Electromagnetic emissions and particles [some large scale phenomena]

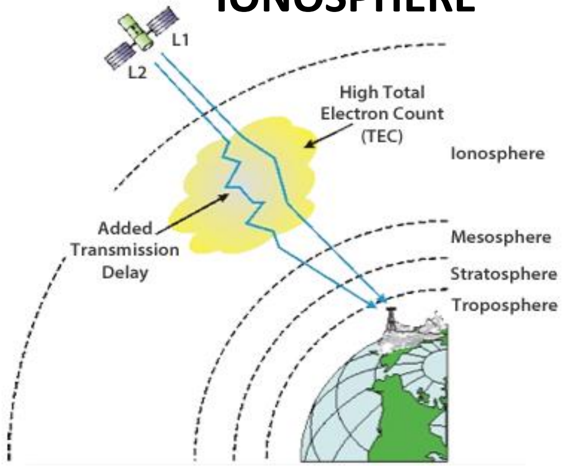
Sunspots

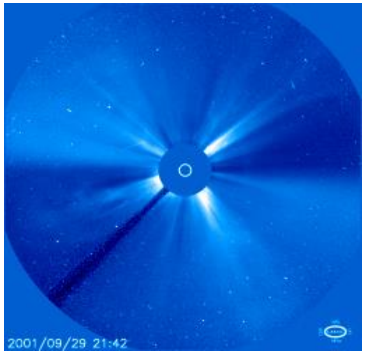


Big solar flare of November 2003



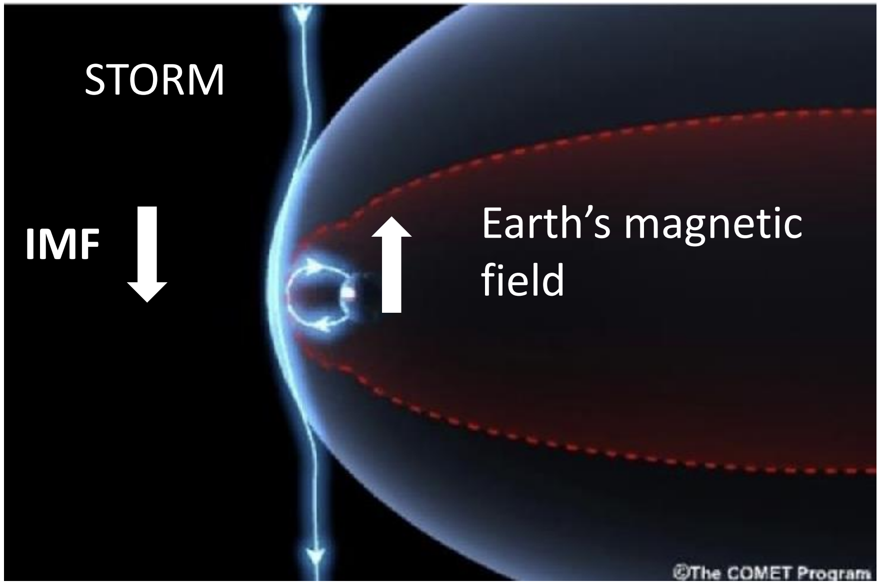
IONOSPHERE

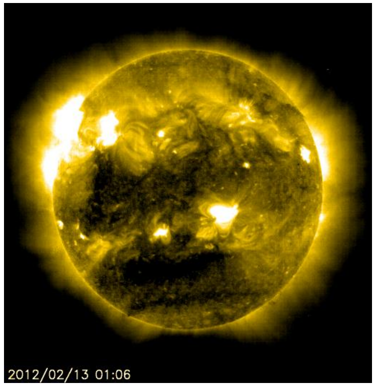




CME: Coronal Mass Ejection
Magnetic cloud
Billions of tons of solar mass

MAGNETOSPHERE





Coronal hole
HSSW –CIR
High speed solar wind

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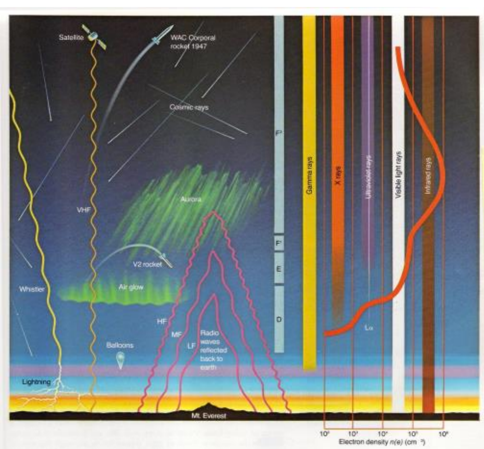
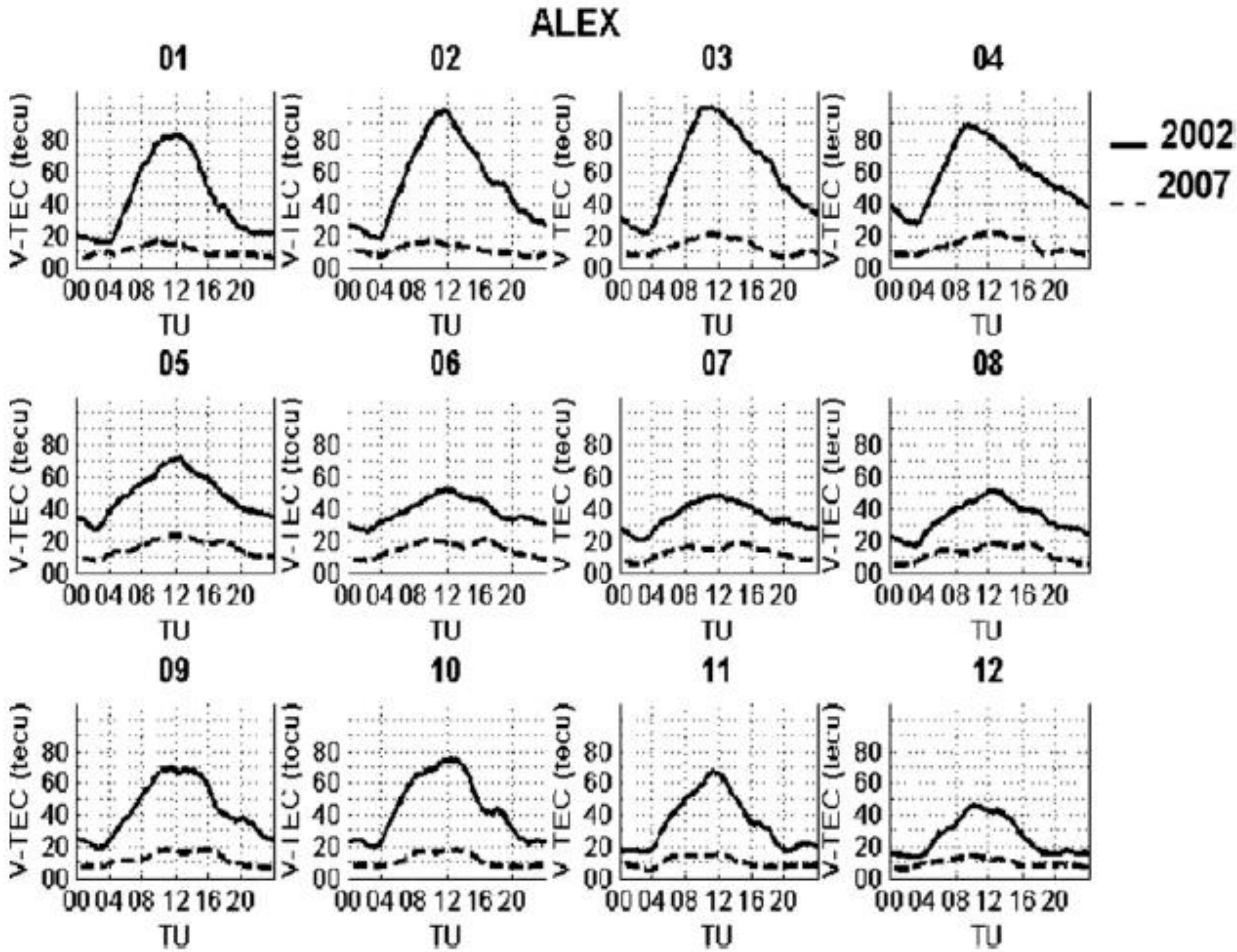
EGYPT Diurnal variations of VTEC for 2 years 2002 and 2007

2002 : maximum of sunspot cycle 23, 2007 : minimum of sunspot cycle 23

Study of ionosphere made in all the countries with GPS receivers



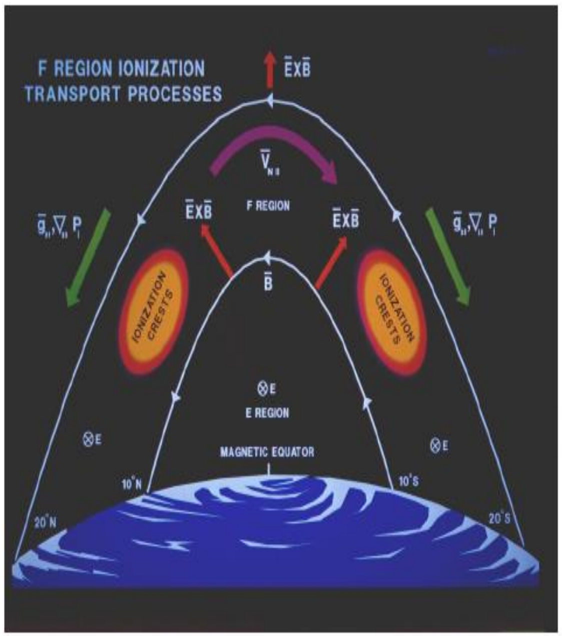
Regular Solar Radiations
UV, EUV, X rays

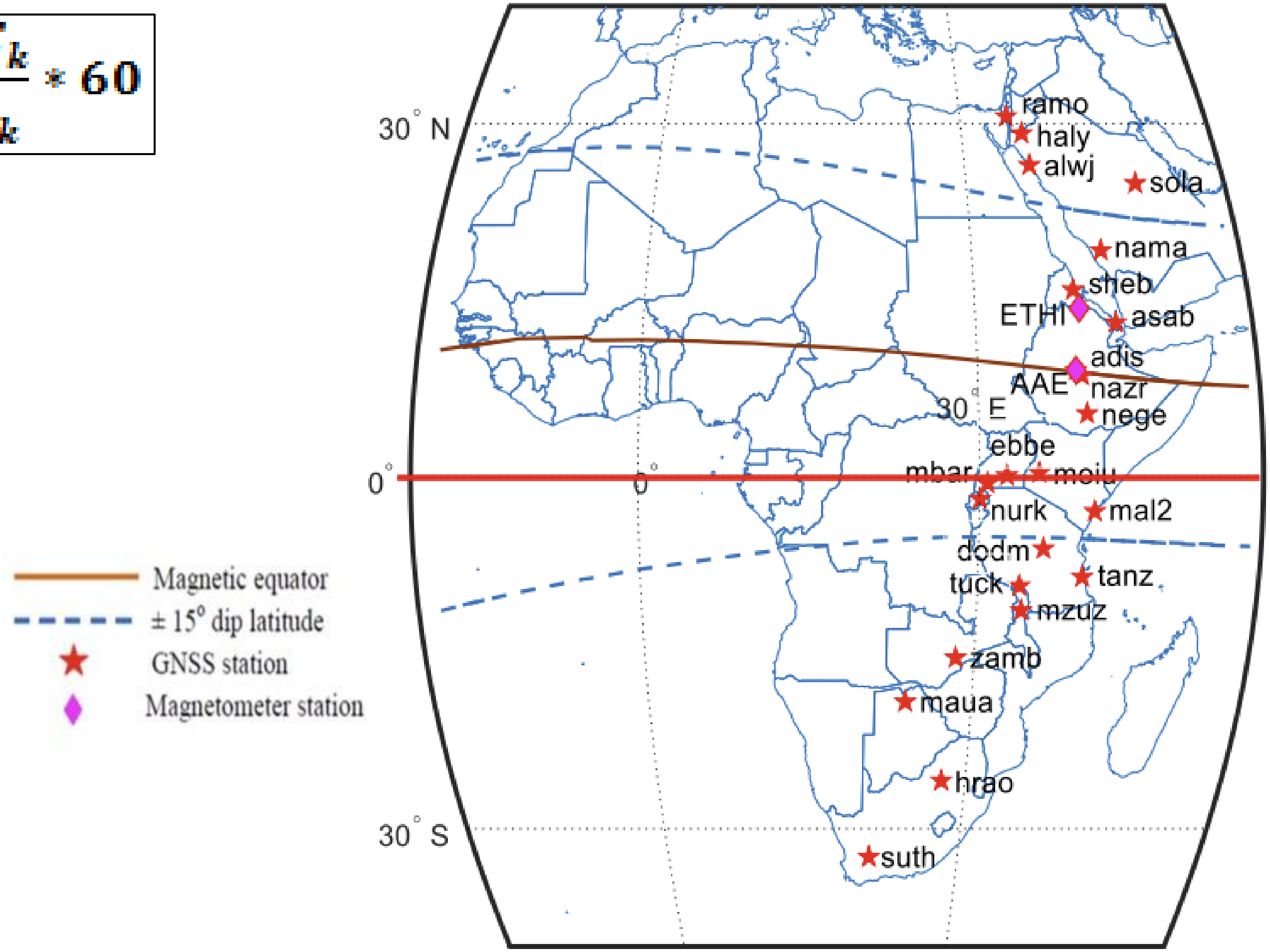


Shimeis, A., C. Amory-Mazaudier, R.Fleury ,A.M. Mahrous,A. F.Hassan, 2014, Transient Variations of Vertical Total Electron Content over Some African Stations from 2002 to 2012, Advances in Space Research 54, 2159-2171

STUDY of IONOSPHERIC IRREGULARITIES IN EAST AFRICA using the ROTI index derived from the TEC

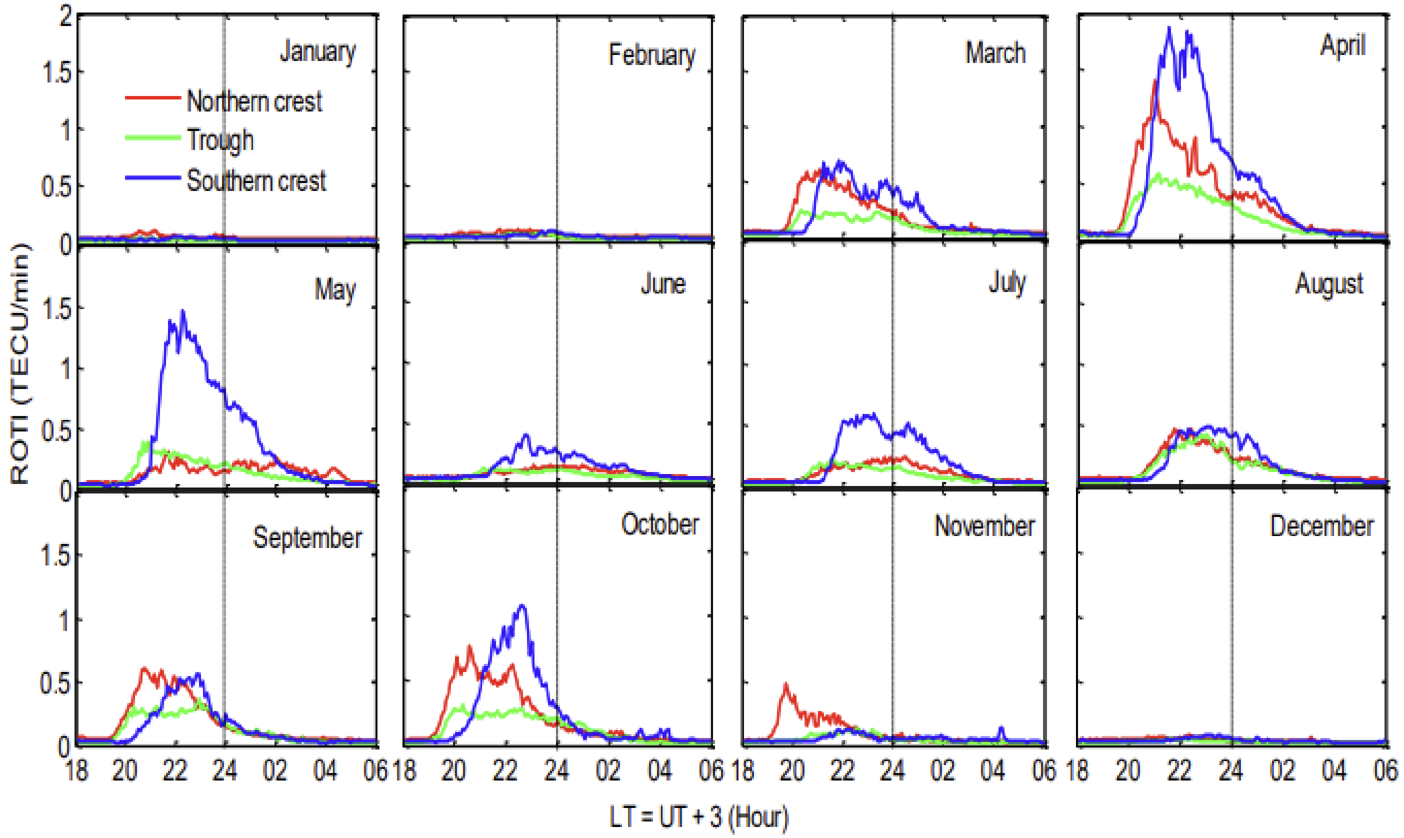
$$\mathbf{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$





Amaechi, P.A., E.O. Oyeyemi, A.O. Akala, E.O. Falayi, M. Kaab, Z. Benkhaldoun, C. Amory-Mazaudier, Quiet-time ionospheric irregularities over the African Equatorial Ionization Anomaly (EIA) region, Radio Science, 55, e2020RS007077. https://doi.org/10.1029/2020RS007077

Asymmetry between the Northern and Southern crests of the EIA due to the configuration between the magnetic equator and the geographic equator (influence of the neutral wind)



Monthly mean variation of quiet time irregularities over Northern crest (red line), trough (green line) and Southern crest (blue line), in 2013 (figure 5 of Amaechi et al., 2020)

8 PhD => 1993-2000

10 PhD => 2001-2010

After IHY [use of GPS]

55 PhD => 2011-2023


Senegal -2009


Côte d'Ivoire -2016


Morocco-2016


Côte d'Ivoire 2007

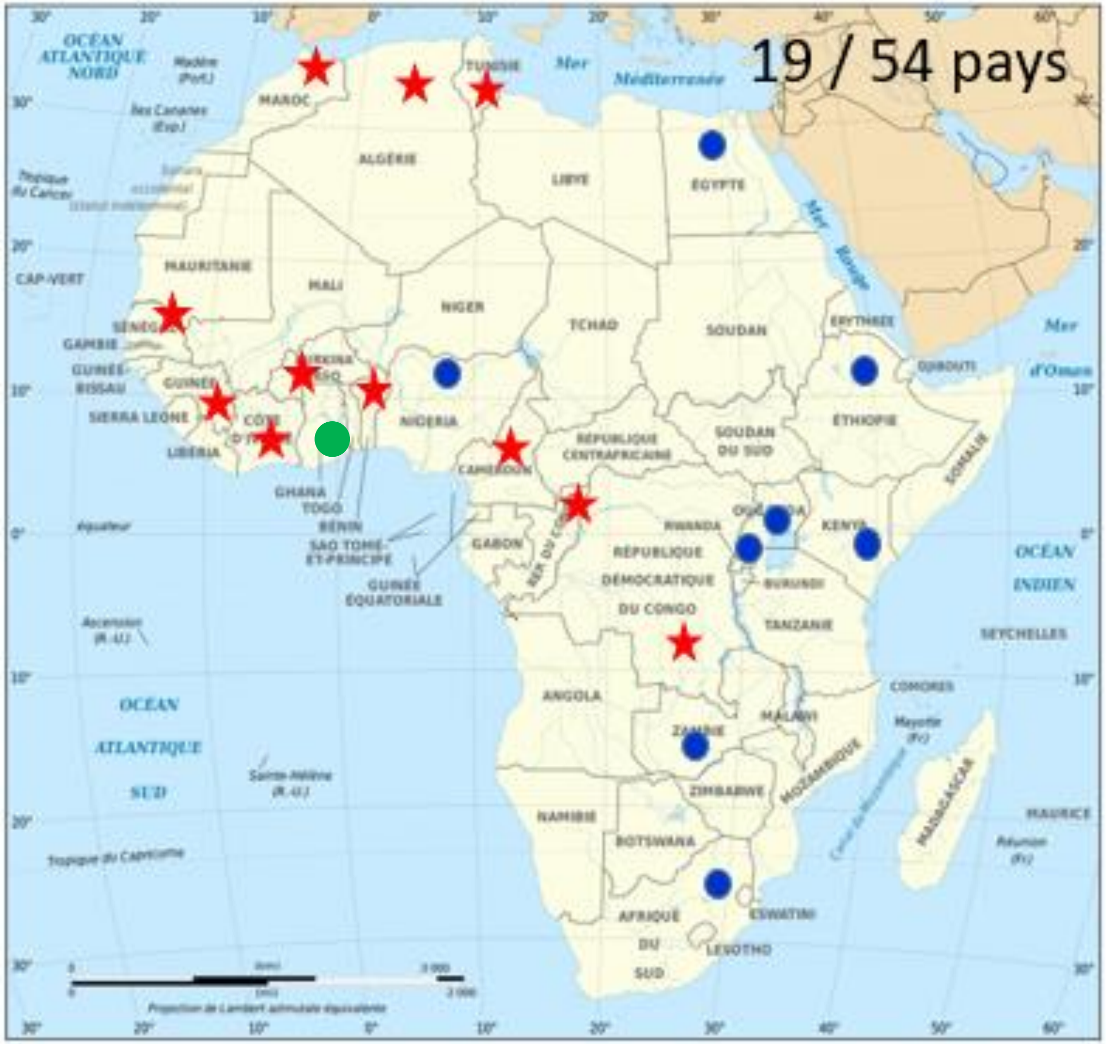
Burkina Faso-2012


Algeria -2017

Tunisia-2017


Cameroon-2018


DRC-2016



20/54 countries

Total PhD in Space weather in Africa since IHY ~100

ISWI Coordinator for Africa B. Rabiu from Nigeria

Algeria, Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Guinea, Kenya, Morocco, Nigeria, Uganda, Republic of Congo, Republic Democratic of Congo, Rwanda, Senegal, South-Africa, Tunisia, Zambia

+ Ghana, Tchad

outlines

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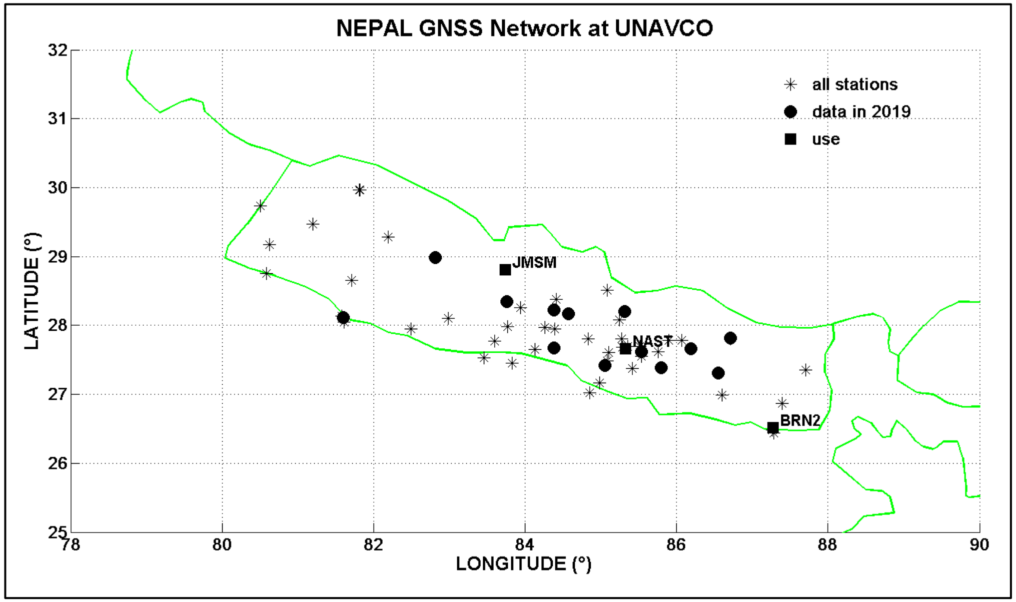
NEPAL / CAPACITY BUILDING/SPACE WEATHER



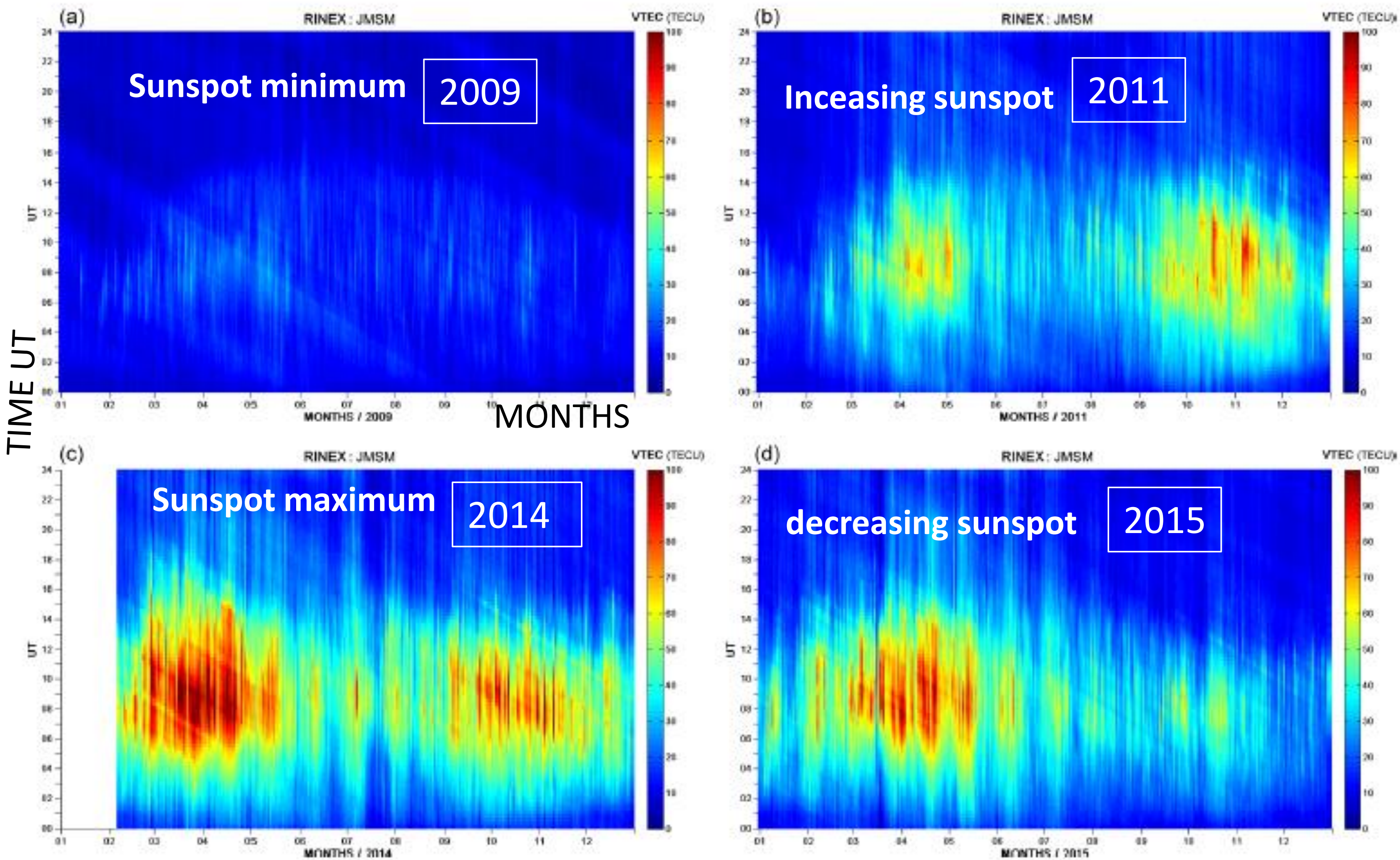
PhD of D. Pandit on September 23,2022

Super substorms related signatures at middle and low latitudes ionosphere.

School organized by ICTP- September 2019

Station GPS JOMSON (JMSM)

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.

TEAM of RESEARCH at KATHMANDOU/NEPAL

Professor Narayan CHAPAGAIN
Tribhuvan University, Amrit Campus, Thamel,

Dr Rolland FLEURY
National school Telecom

SENIOR SCIENTISTS

Dr Christine AMORY-MAZAUDIER
Sorbonne Universités

Dr. Binod ADHIKARI Lecturer and Research Coordinator St. Xavier's College, Maitighar

Drabindra PANDIT

Basudev GHIMIRE

2 PhD Students of the Institute of Science and Technology ,Tribhuvan University. and Lecturers : St. Xavier's College,

In NEPAL => Invitation to publish in the Journal Coordinates

GNSS

Space Weather, from the Sun to the Earth, the key role of GNSS

The goal of this paper is to give a clear view of the Sun Earth relationships that are complex. The phenomena acting at large scales and essentially related to dynamic and electromagnetic physical processes have been addressed. Besides physics, the work done to develop the training in Space Weather by focusing on Global Navigation Satellite Systems has also been presented. We present this paper as a series in two parts. In this issue the focus is on physics of the relationships Sun, Earth and Meteorology of Space. In March issue, GNSS training and capacity building would be discussed

Dr Christine Amory-Mazaudier
Senior Scientist, University Pierre and Marie Curie and Staff Associate at ICTP. Recently awarded Marcel Nicolet Medal for her work in Space Weather

Dr Rolland Fleury
Associate Professor, Microwave Department of the 'IMT Atlantique' School of Engineering, Brest campus, France

Sharafat Gadimova
Programme Officer, the United Nations Office for Outer Space Affairs, leads the organization of the activities on GNSS and the development of the International Committee on Global Navigation Satellite Systems

Professor Abderrahmane Touzani
Director, African Regional Centre for Space Science and Technology Education - in French Language (CRASTE-LF), Rabat, Morocco was Professor in University Mohammed V, Rabat, Morocco

This paper presents a study made for the Seminar on Space Weather and its effects on GNSS held in conjunction with United Nations/Nepal workshop on the applications of GNSS held in Kathmandu, 6 to 12 December 2016. The Seminar focused on cross-cutting area, in particular resiliency, the ability to depend on space systems and the ability to respond to the impact of events such as adverse space weather.

The aim is to give an outline of the Space Weather and its effects on GNSS receivers, and this in relation to the international organizations in charge of the harmonization of the various GNSS systems.

This article is composed of 3 parts: Part I: Physics of the relationships Sun Earth and Meteorology of Space, Part II: GNSS teaching and parameters that can be deduced from GNSS receivers, Part III: Building capacity of developing countries in using GNSS technology for sustainable development

From the Sun to the Earth, Space Weather and its effects

Emissions from the Sun

The sun is our star and it influences the terrestrial environment according to different channels,

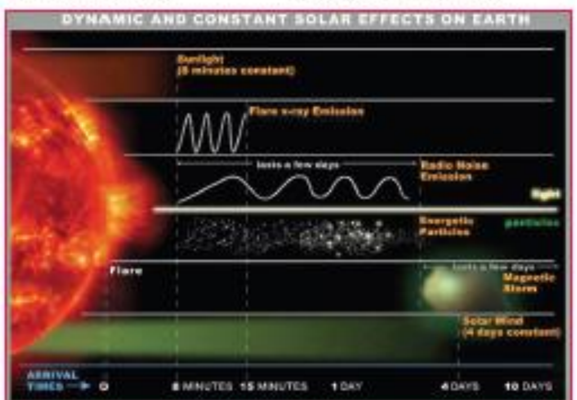


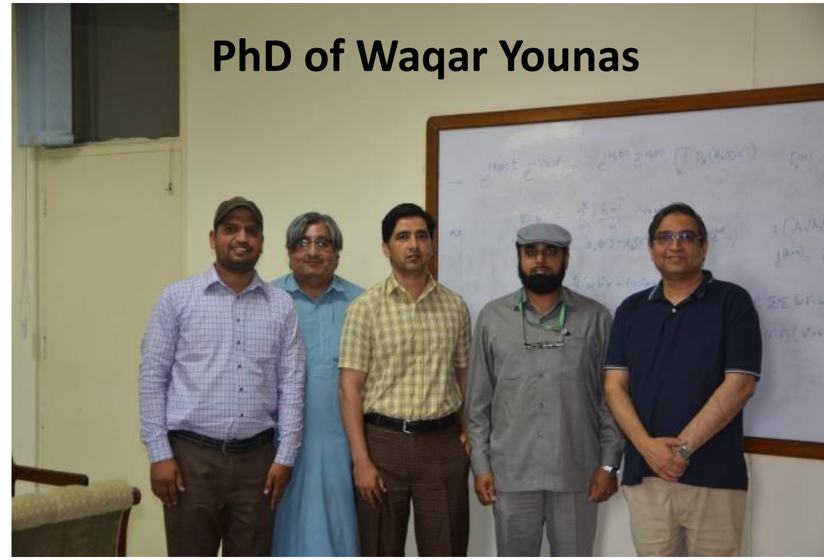
Figure 1.1: https://www.nasa.gov/sites/default/files/thumbnails/image/faq26.jpg

Amory-Mazaudier, C., R. Fleury, S. Gadimova, A. Touzani (Feb.2017), Space Weather, from the Sun to Earth, the key role of Global Navigation Satellite Systems, **Part I : From the Sun to the Earth, Space Weather and its effects,** Coordinates a monthly magazine on positioning, navigation and beyond, http://www.mycoordinates.org

Amory-Mazaudier, C., R. Fleury, S. Gadimova, A. Touzani (March 2017), Space Weather from the sun to the Earth, the key role of Global Navigation Satellite Systems- **Part II: Training on daily global positioning system GPS data** Coordinates a monthly magazine on positioning, navigation and beyond, http://www.mycoordinates.org,

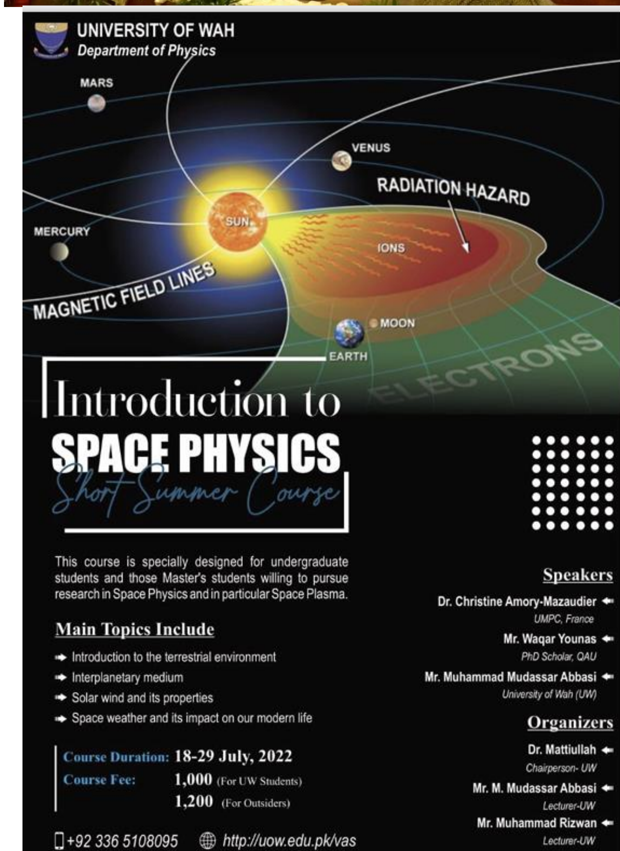
Software of Fleury free on the web

PAKISTAN/CAPACITY BUILDING



PhD , May 31 2023, Quaid-I-Azam University, Islamabad

Title :Ionospheric and magnetic changes induced by space weather at low-and-mid-latitudes."



CORONAL HOLE

GEOPHYSICS => HELIOPHYSICS

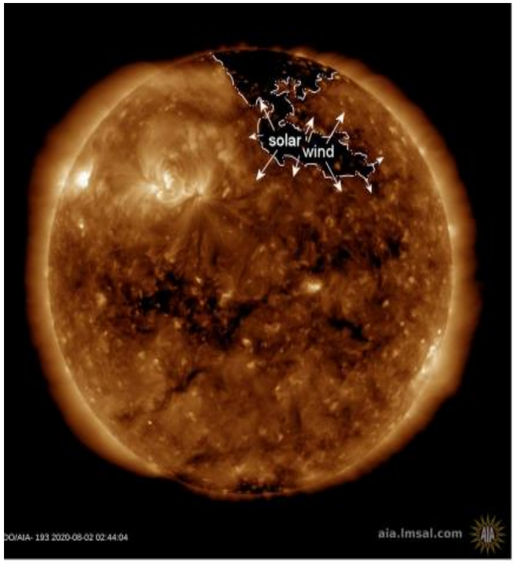
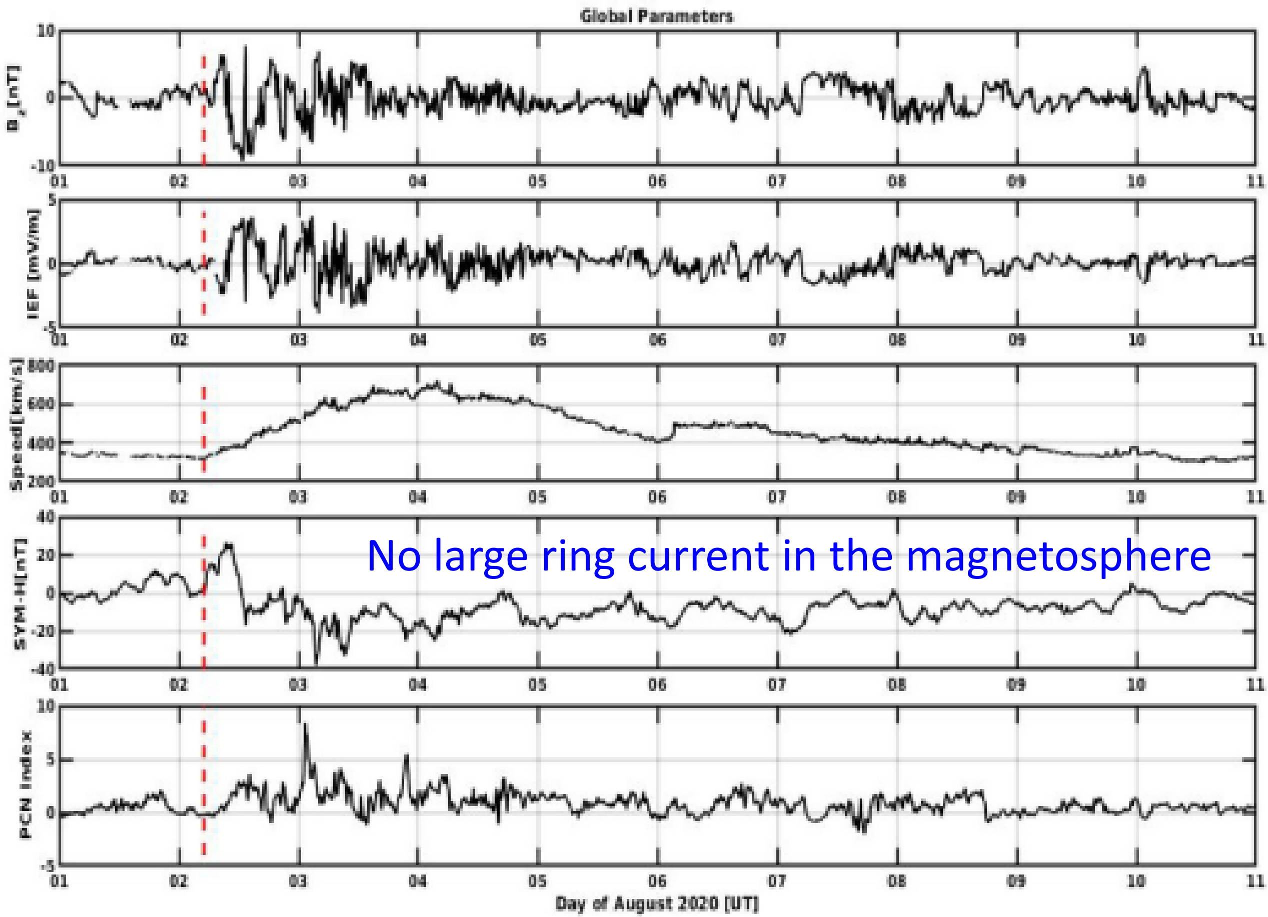


Figure 1. (a) Coronal hole in the northern part of sun as observed by AIA-193 on board Solar Dynamics Observatory (SDO) (Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams)

Figure 1.(b) Variations of interplanetary and geophysical parameters, from top to bottom, Bz component of interplanetary magnetic field, solar wind speed, pressure, and SYMH index from 01 August 2020–10 August 2020



Younas, W., Khan, M., Amory-Mazaudier, C., & Amaechi, P. O., Ionospheric response to the coronal hole activity of August 2020: A global multi-instrumental overview. Space Weather, 20, e2022SW003176. https://doi.org/10.1029/2022SW003176

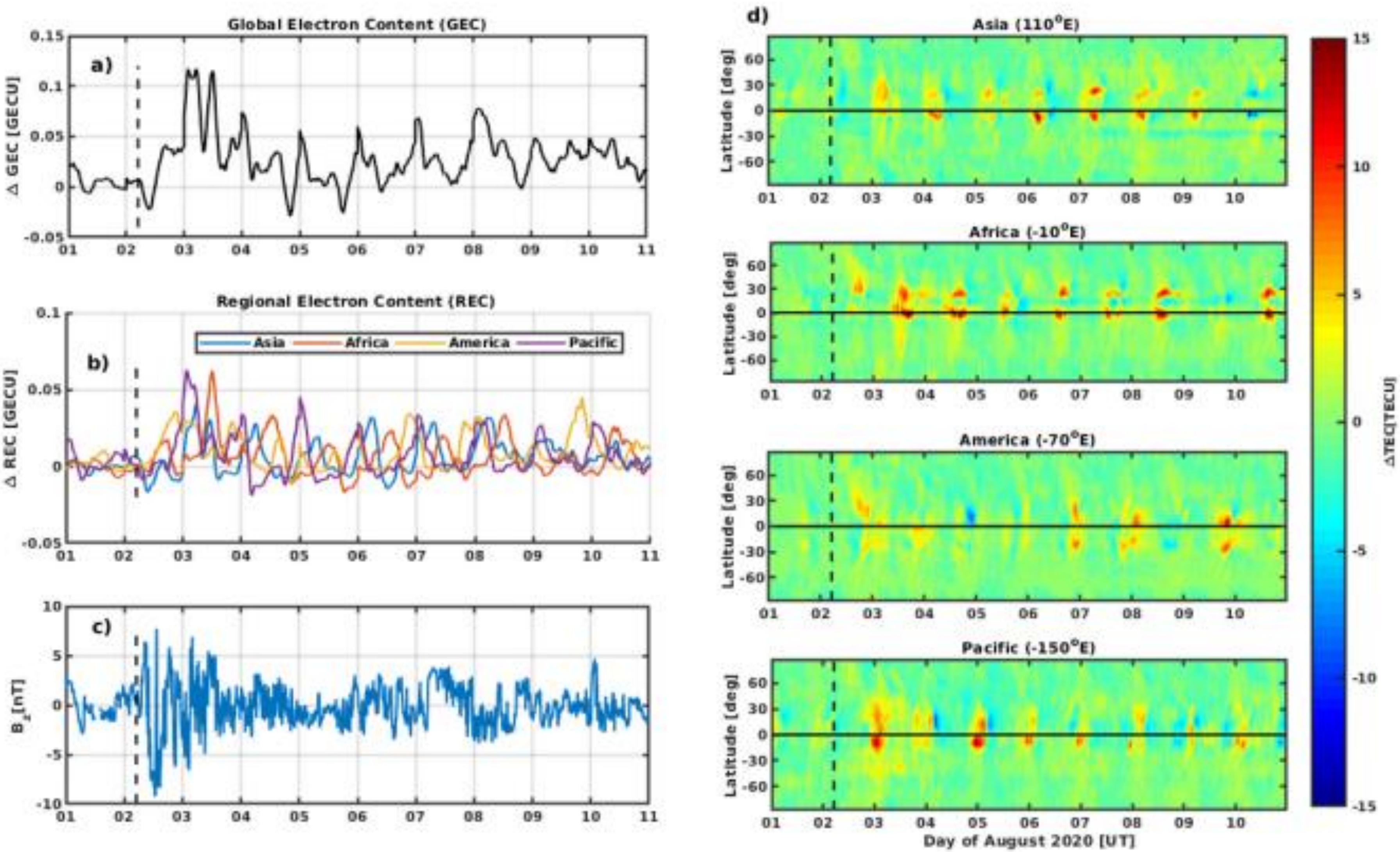
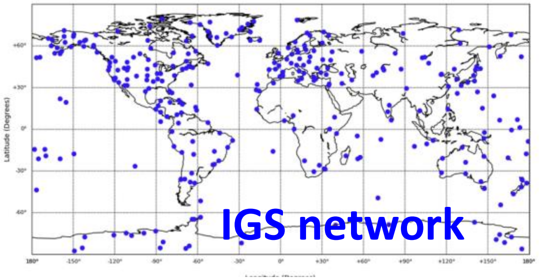
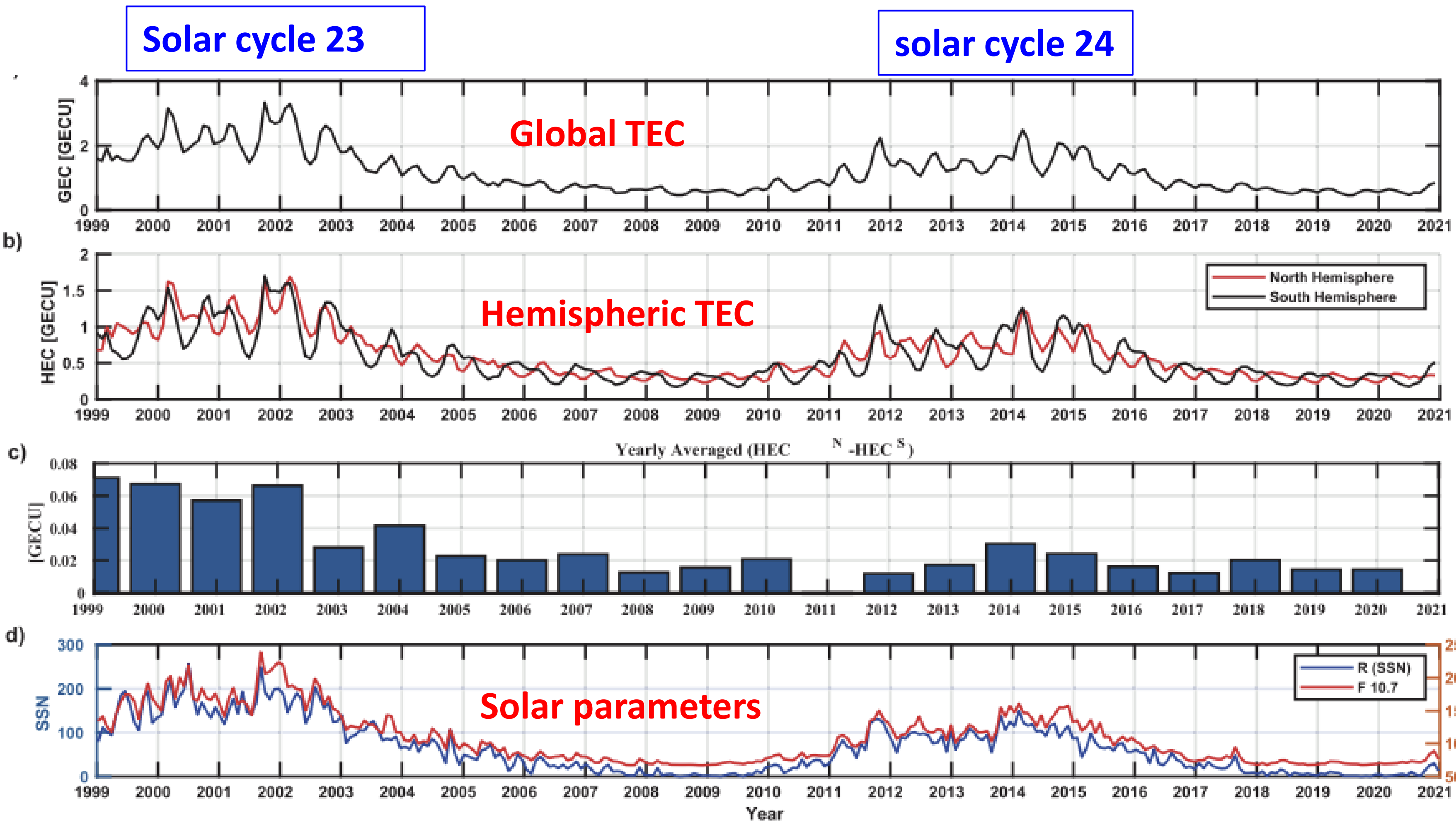


Figure 2. (a) ΔGEC (b) ΔREC in four longitudinal sectors Asia, Africa, America, and Pacific (c) Bz component of interplanetary magnetic field and (d) ΔvTEC at fixed longitudes, from top to bottom, Asia, Africa, America, and Pacific during 01 August–10 August 202



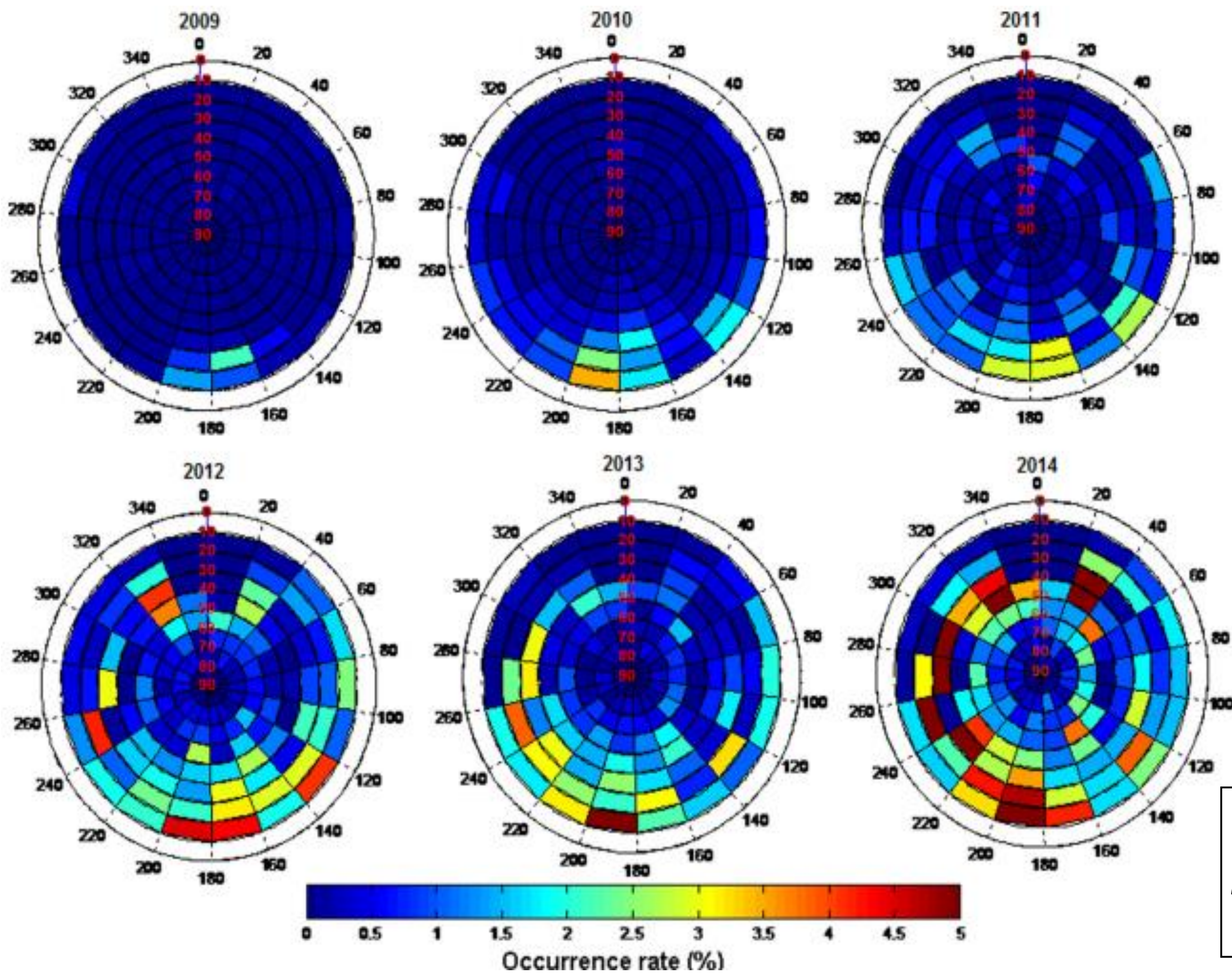
Climatology of global, hemispheric and regional electron content variations during the solar cycles 23 and 24

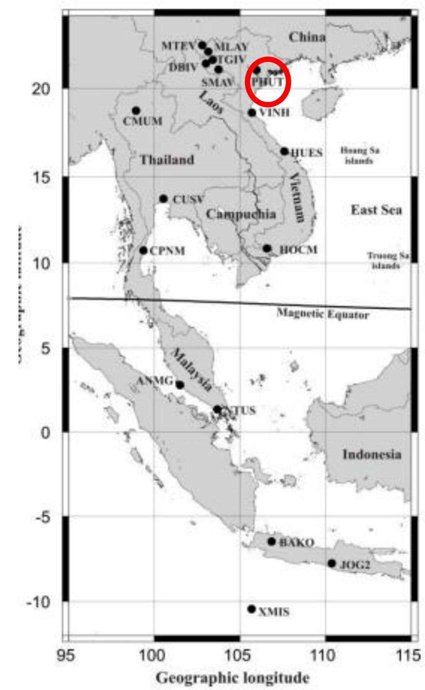


Younas, W., C. Amory-Mazaudier, Majid Khan, Paul O. Amaechi, Climatology of global hemispheric and regional electron content variations during the solar 23 and 24., Advances in Space Research, https://doi.org/10.1016/jasr.2022.07.029

VIETNAM

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

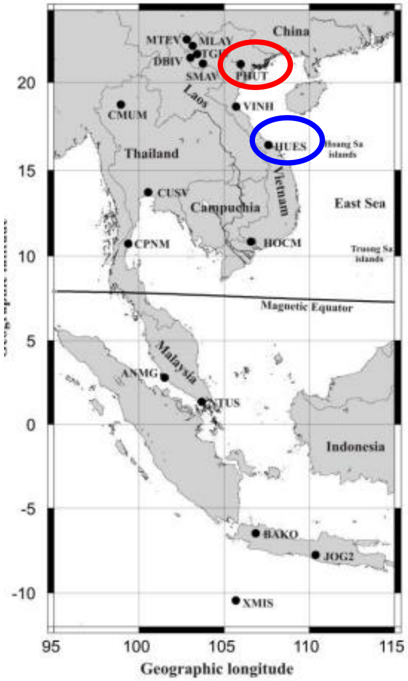




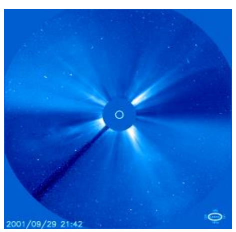
$$s4 = \sqrt{\frac{<I^2> - <I>^2}{<I>^2}}$$

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.

S_4 and ROTI index during storm event in Vietnam



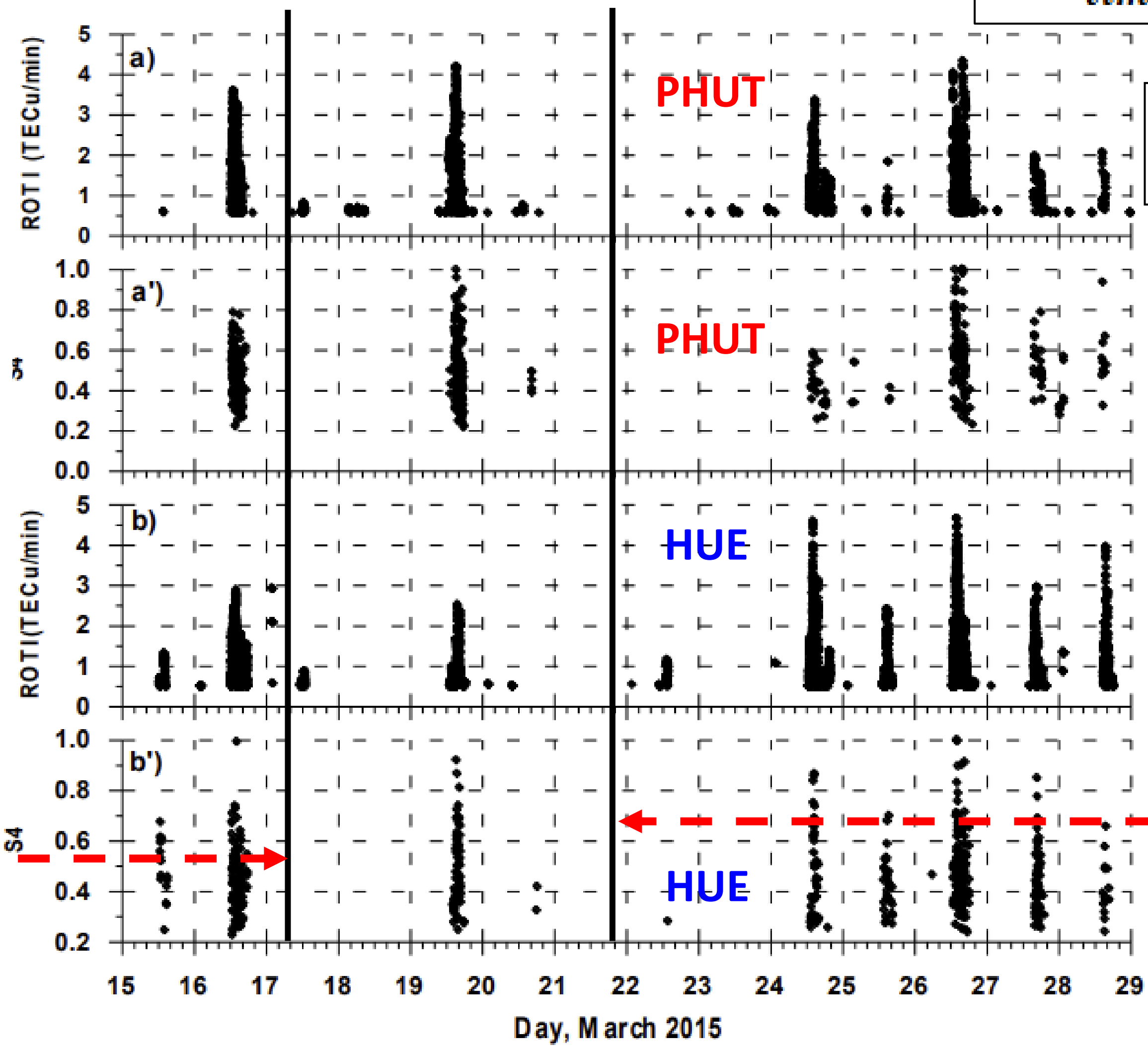
CME



STORM SSC
March 17, 04.45UT

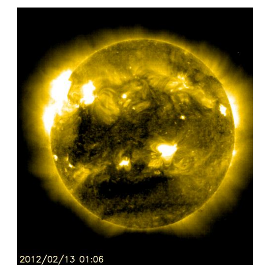
Vietnam Journal of Earth Sciences Vol 38 (3) 267-284

$$rot = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$



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

HSSW

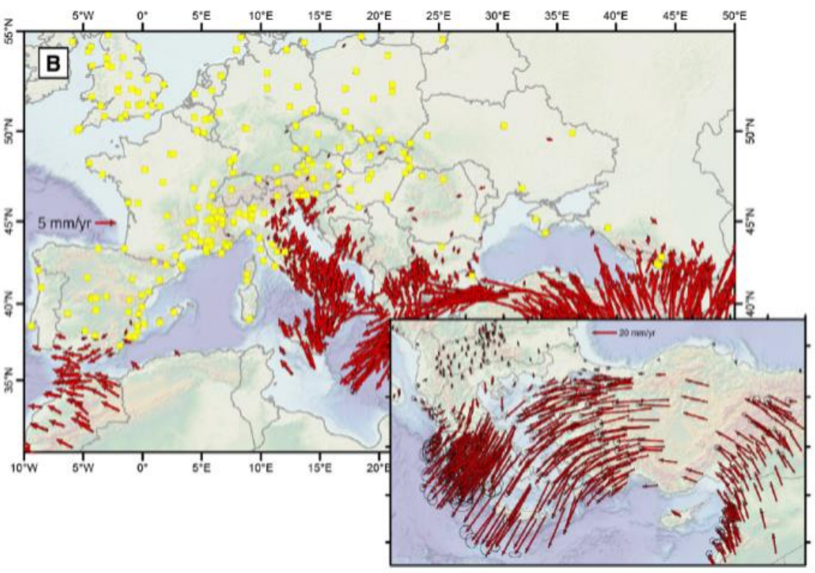


Arrival HSSW
March 21,
20.54UT

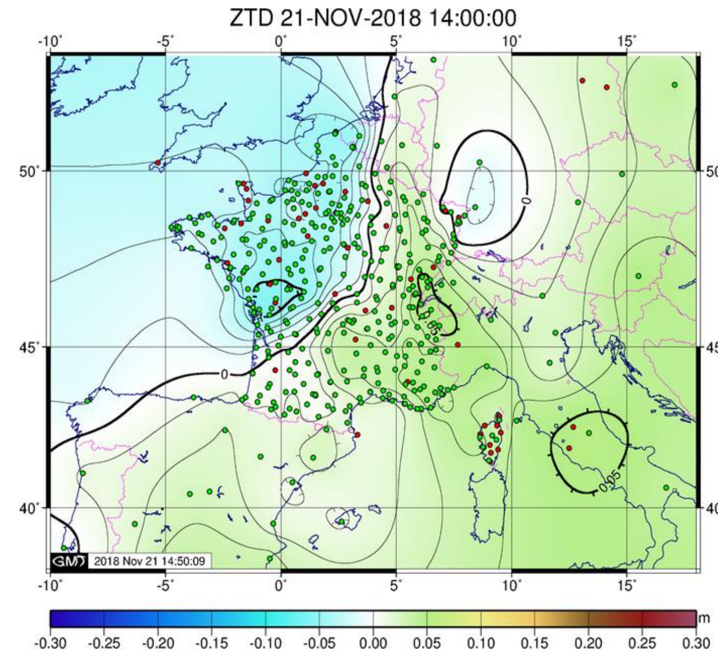
Le Huy Minh et al.,. TEC variations and ionospheric disturbances during the magnetic storm on March 2015 observed from continuous GPS data in the Southeast Asian region, *Vietnam J. Earth Sciences*, ISBN 0866-7187, **38(3)**, 287-305, https://doi:10.15625.0866-7187/38/3/8714

GNSS a universal tool for research and many applications in everyday life

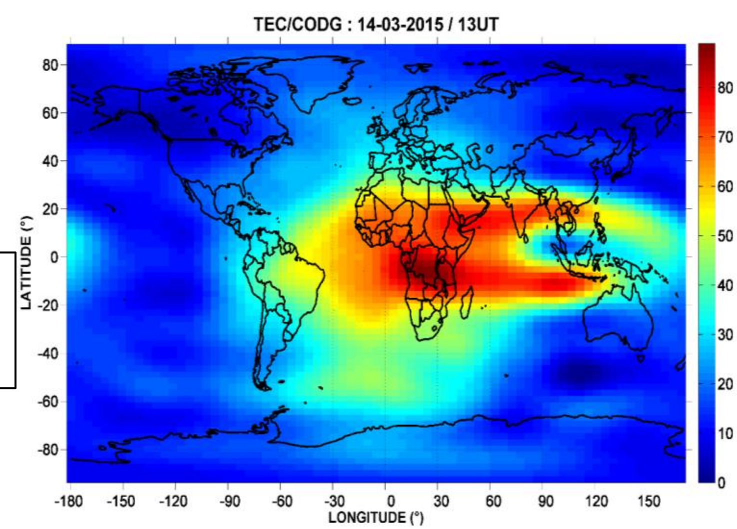
Nocquet (2012) GPS velocity field from the Euro Mediterranean region, relative to Eurasia. Yellow squares indicate velocities
below 1 mm/yr. The inset illustrates the westward movement of Anatolia relative to Eurasia.



ZTD values over France
on 21/11/2018 at 14: 00UT
Zenithal Hydrostatic Delay, ZHD



Post-processed ionospheric map of TEC from CODE on 14/03/2015 at 15UT



Figures and references in the paperAmory-Mazaudier, C. R. Fleury, F. Masson, S. Gadimova, E. Anas, Sun and Geosphere, Vol 14/1, pp. 71-79, 2019

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 (geomagnetic storm, solar flare, eclipse, earthquake, stratospheric warming, quasi biennal oscillation, hurricane, etc…)