EgSA
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Egyptian Space Agency

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Session 7: Space Weather Research

Impact and Mitigation of Space Weather Effects on GNSS Receiver Performance

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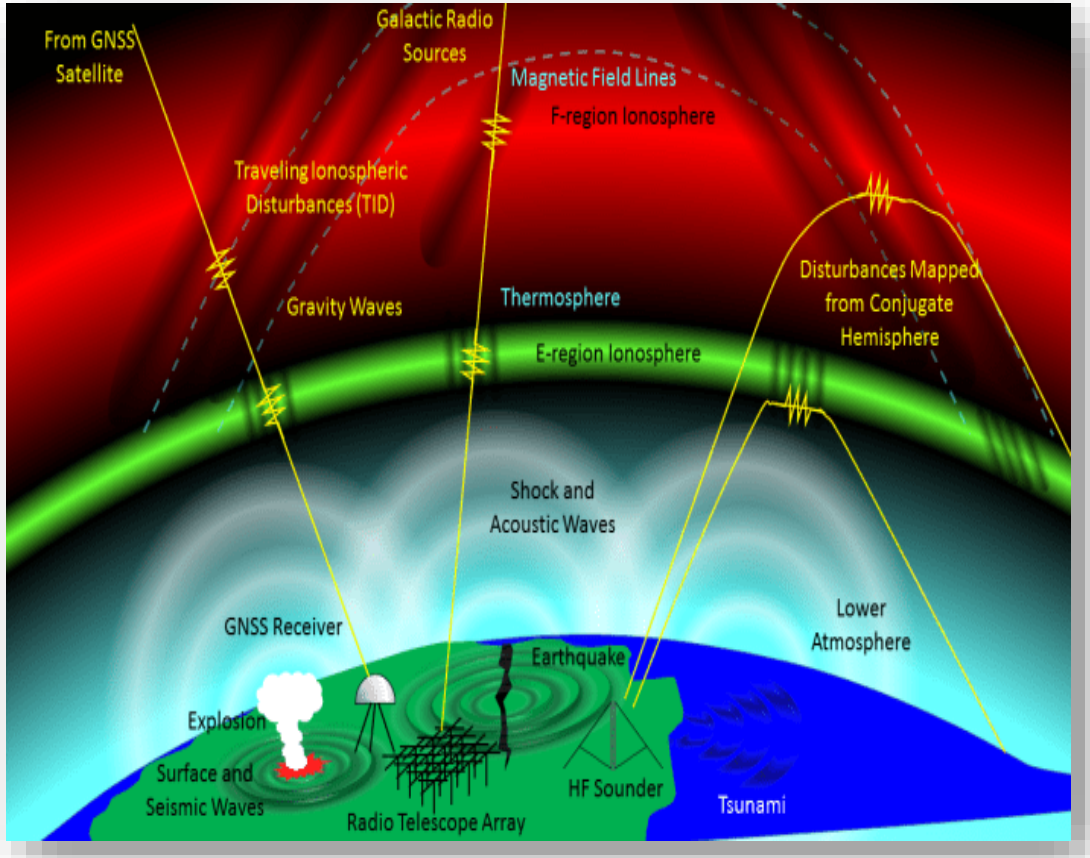
Introduction

- The ionosphere is defined as the region of the upper atmosphere where radio signal propagation is affected by charged particles.
- The ionosphere is highly variable in space and time.
- The ionosphere acts as a refractive medium for radio signals
- The index of refraction depends on the amount of ionization.



Credit: Huang et al. [2019], F

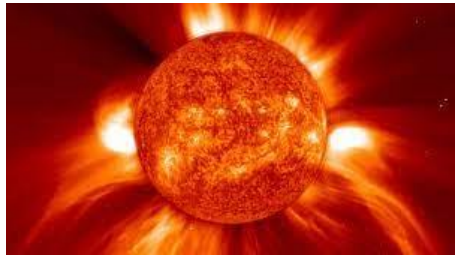
GNSS Users

1. Aviation.
2. Maritime.
3. Agriculture.
4. Defense.
5. Mining.
6. Surveying, Construction.
7. Land and mineral surveys, geophysics.
8. Science (ionospheric, timing, engineering).
9. Natural Resource Management.
10. Managing the Local Environment.

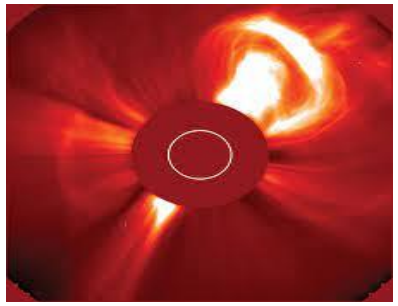
Space Weather Events

1. Solar Flare: arrives on Earth in minutes.

2. Solar Wind: arrives on Earth in 0.5h or several hours.

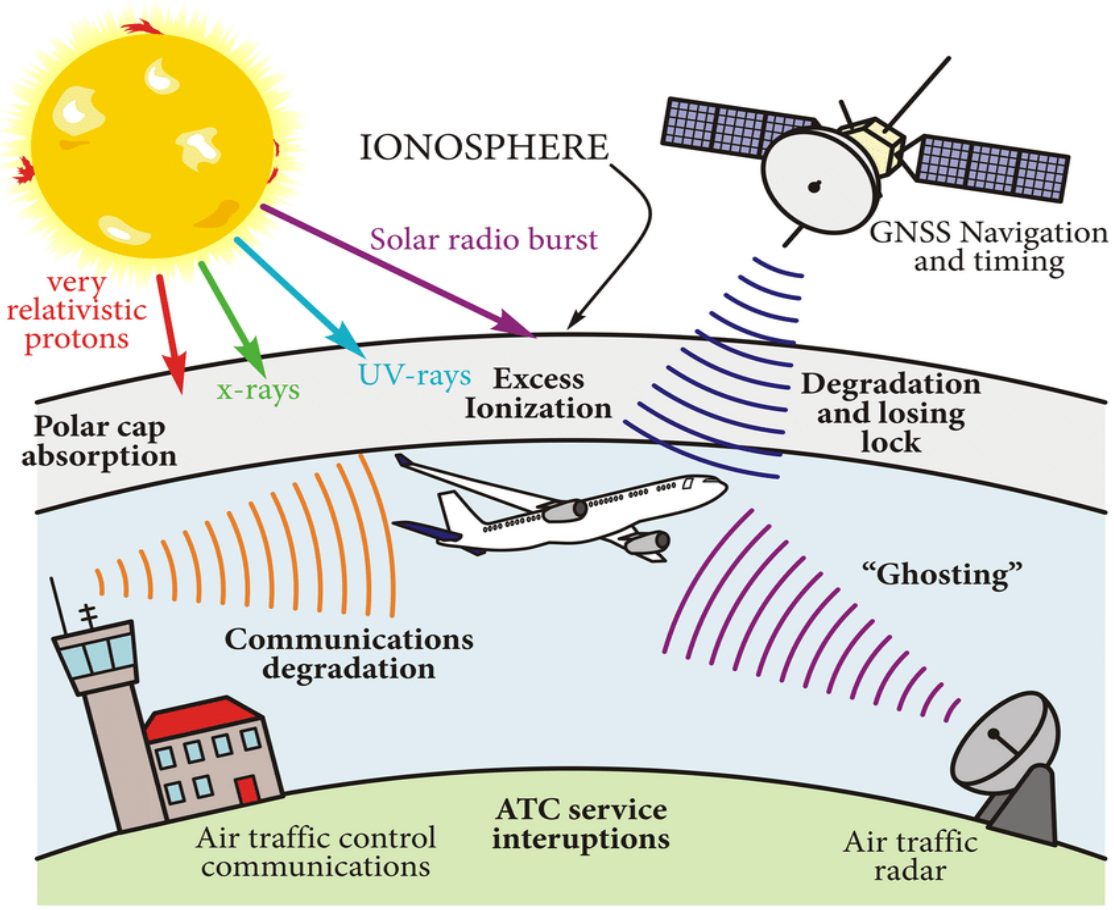


3. Coronal Mass Ejections (CME)s: arrive on Earth in hours or days.



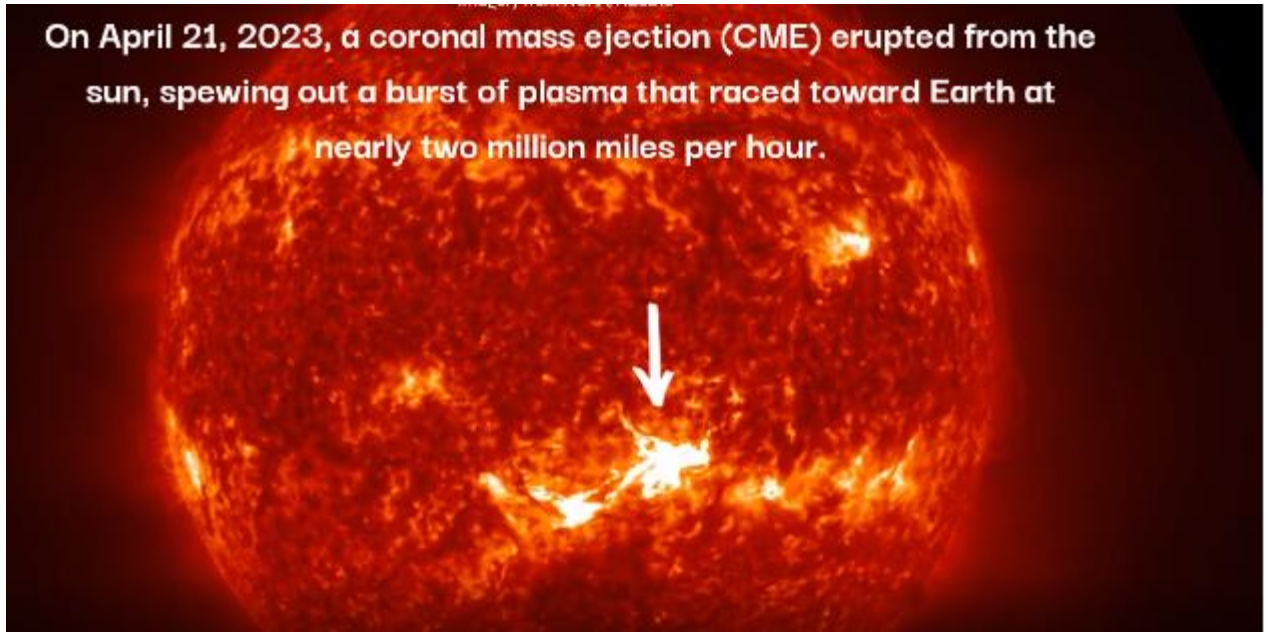
Three Major Space Weather Effects

1. Ionospheric Delay.
2. Ionospheric Scintillation.
3. Solar Radio Bursts.



Geomagnetic Storm from 22 – 27 April 2023

- On April 21, 2023, a coronal mass ejection (CME) occurred on the sun, resulting in the emission of a high-speed burst of plasma that traveled toward Earth at a velocity of approximately two million miles per hour. This event triggered a severe geomagnetic storm that attained level 4 out of 5 on NOAA's space weather G-scale. The storm reached its peak at 3:26 p.m. EDT on April 23.
- There is a Solar wind speed: of 660.9 km/sec, & a density: of 10.02 protons/cm3.



Material for Data

1. **Space Weather Data:**

   ✓To identify and characterize geomagnetic storms, we used the SYM, KP, and Bz geomagnetic indices from the OMNI database (https:/omniweb.gsfc.nasa.gov).

   ✓Please note that in this study we used geomagnetic indices as a marker of a storm, and did not aim at statistical analysis of ΔTEC.

1. **Total Electron Content Data:**

   ✓There are two data sources to study the signature and behaviour of the TEC Parameter: Egyptian GNSS Ground Stations & Madrigal Model.

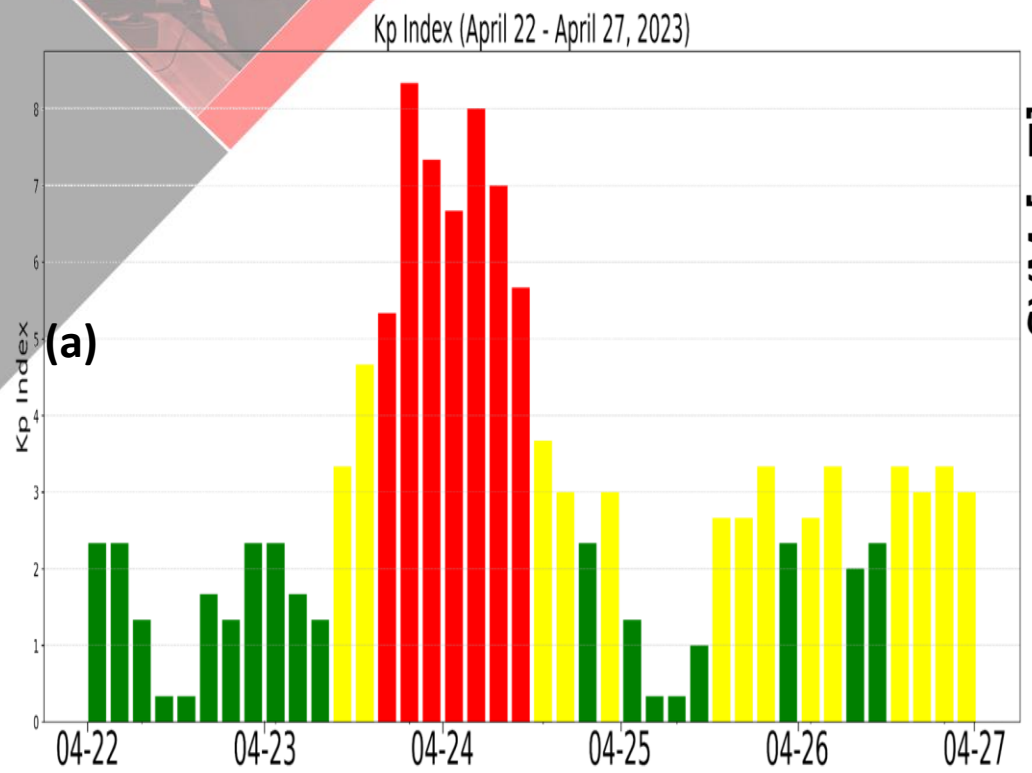
Results

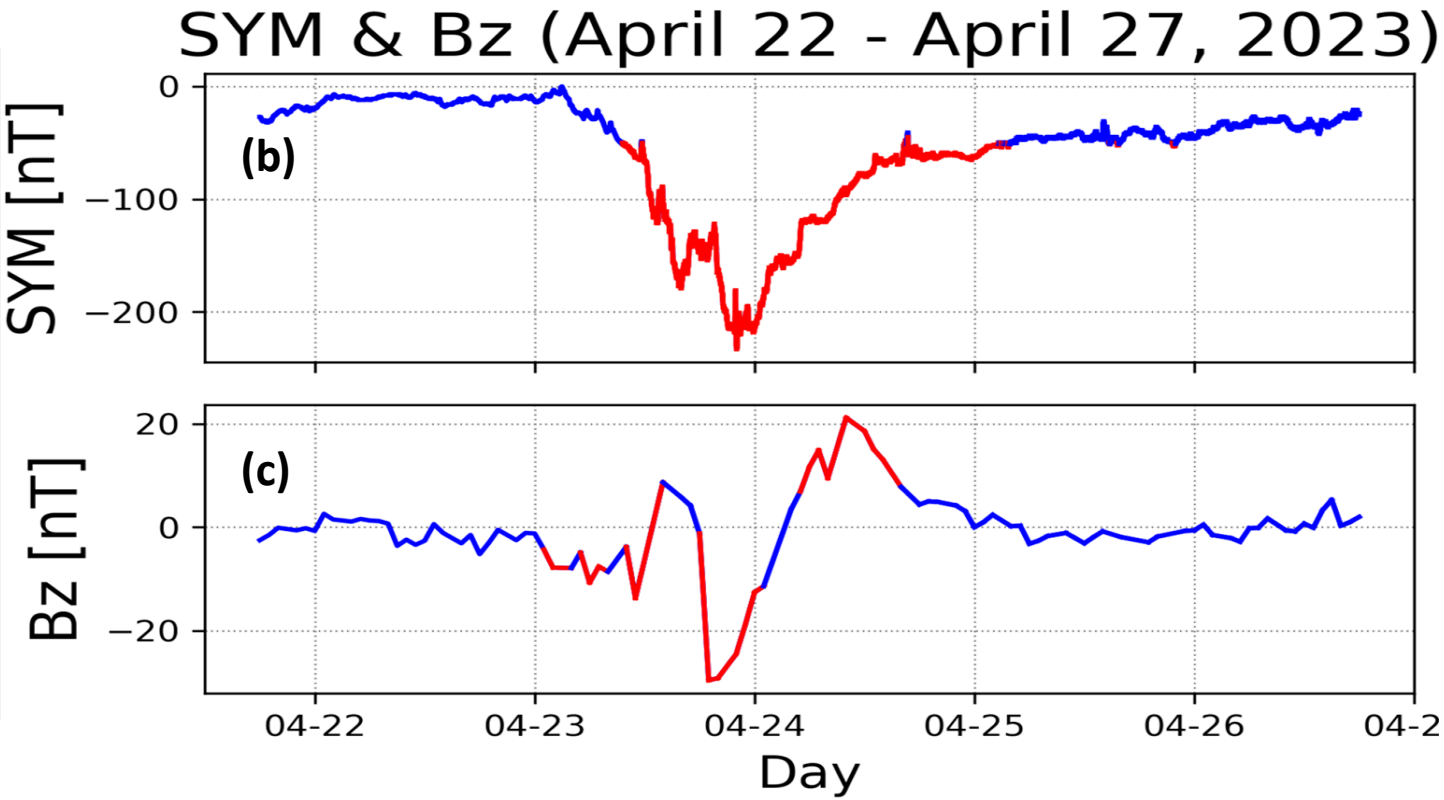
1. Geomagnetic Storm

- ✓ On April 21, 2023, a coronal mass ejection (CME) occurred on the sun, resulting in the emission of a high-speed burst of plasma that travelled toward Earth at a velocity of approximately two million miles per hour.
- ✓ This event triggered a severe geomagnetic storm that attained level 4 out of 5 on NOAA's space weather G-scale.
- ✓ The storm reached its peak at 3:26 p.m. EDT on April 23.
- ✓ The heightened solar radiation and associated geomagnetic storms can cause several adverse effects. For instance, they can disrupt power grids, radio signals, and communication systems on Earth.
- ✓ This recent event was the third severe geomagnetic storm (G4) since the onset of Solar Cycle 25 in 2019. The previous storms occurred on November 4, 2021, and March 24, 2023. NOAA's DSCOVR spacecraft helped to measure the elevated solar winds associated with these storms and provided data that informed the subsequent geomagnetic storm forecasts.
- ✓ These events can also interfere with satellite operations and GPS navigation capabilities. Astronauts in space are especially vulnerable as the radiation they are exposed to outside Earth's protective atmosphere can result in radiation poisoning or other severe health effects. Additionally, the storms may cause spectacular auroras on Earth.

Results

1. Geomagnetic Indices





These figures show Space weather indices for the storm of 22 to 26 |April 2023. Where (a) the planetary K index, (b) the SYM-H index is a high-time-resolution version of the original DST index, and (c) the Bz component of the magnetic field.

Results

2. Egyptian TEC Mapping

- ✓ After the analysis of the ionospheric data of the Madrigal Model & the Different Egyptian GNSS Ground Stations to characterize TEC values over Egypt from its regional 24h working receivers.
- ✓ Borders of the maps are from 24.5° to 38.5°E longitude and from 21° to 33°N latitude with 1h temporal resolution of day 22:26 April 2023.
- ✓ The following figures in the next slides show the ionosphere distribution over Egypt's country borders every 1 hour. Maps show near equal distribution of TEC over Egypt at all times of that day.
- ✓ The highest values of contour TEC values are calculated from real GPS observation not interpolated points.

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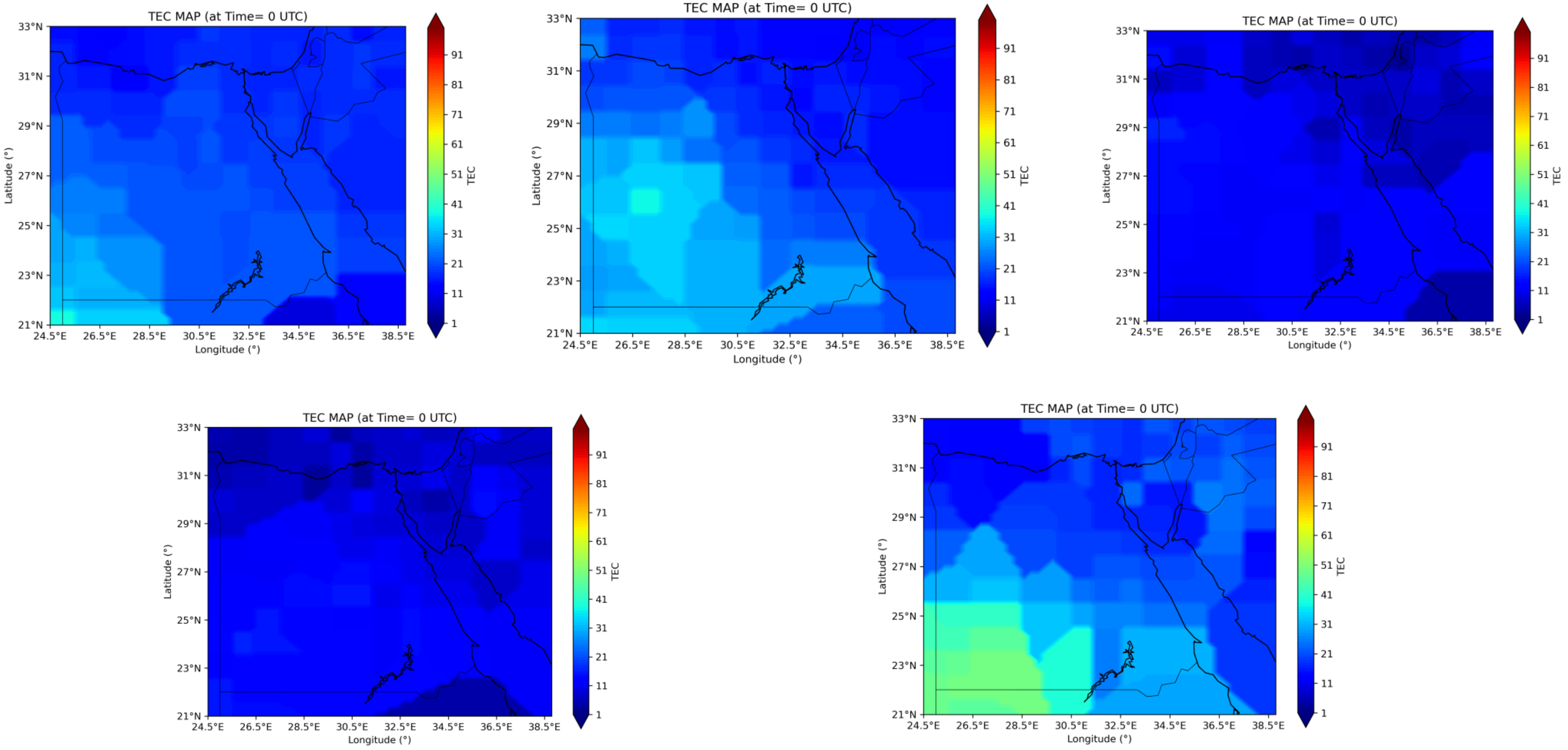
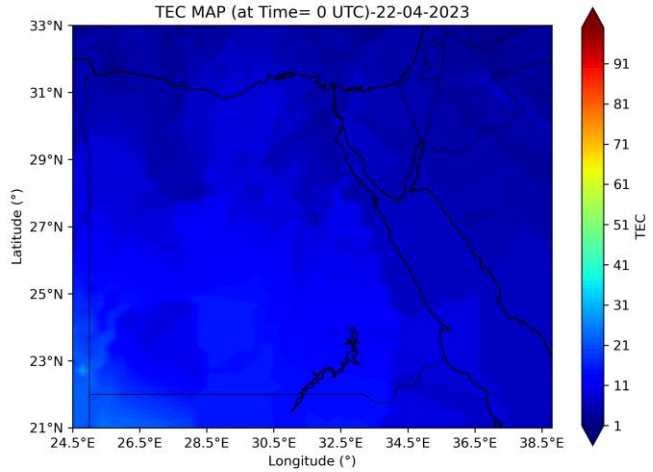
Results

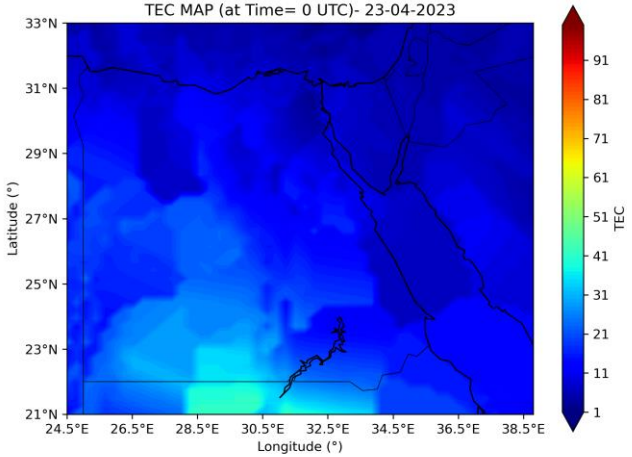
2. TEC Data from Madrigal Model from 22 to 26 April 2023

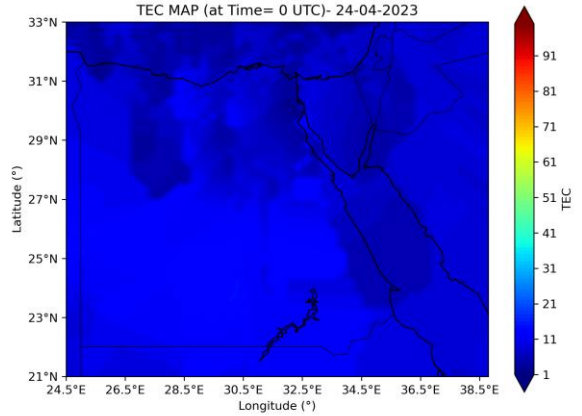


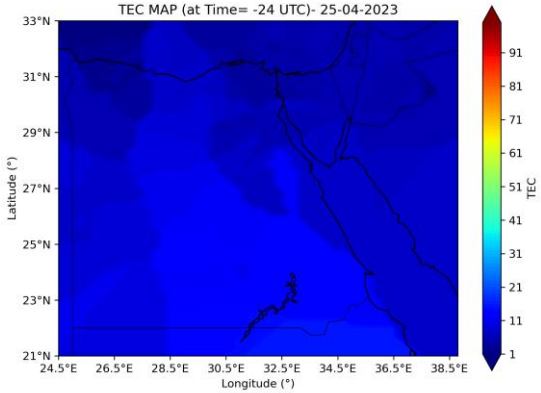
Results

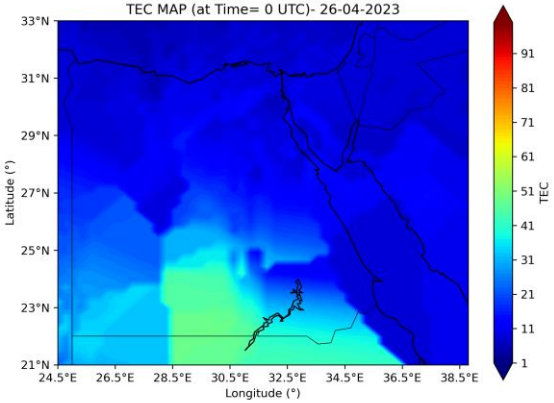
3. TEC Data from Different Egyptian GNSS Ground Stations from 22 to 26 April 2023











Conclusion

- Space weather can have adverse effects on technology, such as causing disturbances of Global Navigation Satellite Systems (GNSS). As space weather effects on GNSS cannot be mitigated, it is of vital importance to develop a method for space weather forecasting.
- Space weather effects on the signals transmitted by GNSS, such as GPS (Global Positioning System) and GLONASS (Global Navigation Satellite System), include the effect of ionospheric perturbations and solar radio bursts.
- Intense solar radio bursts occurring in the L-Band can impact the tracking performance of GNSS receivers located in the sunlit hemisphere of the Earth.
- A significant decrease in the GNSS signal carrier-to-noise ratio (C/N0) is observed, which can lead to the complete loss of lock on the satellite signals.
- High-precision GPS positioning on the entire sunlit side can be partially disrupted during solar radio bursts.
- Hence, solar radio bursts are potential threats to safety critical systems based on GNSS.
- Consequently monitoring these events is important for suitable warnings to be issued in support of related services and applications.
- In this study, a TEC mapping over Egypt was developed to monitor ionosphere changes with a 1 h temporal resolution based on dual-frequency GPS receivers.
- This response to the 22–26 April 2023. The ionospheric variations during the storms are also shown in the Madrigal Model & Different Egyptian GNSS Ground Stations during the third severe geomagnetic storm (G4) in Solar Cycle 25.


THANK YOU