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The ionospheric response to geomagnetic storm of 23-24 April 2023 over Southern Africa

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ABSTRACT

The Earth's ionosphere responds to perturbations caused by solar activities such as coronal mass ejections (CMEs), solar flares, coronal hole high-speed streams, corotating interactive regions, and solar energetic particles. This study will focus on the ionospheric response to a geomagnetic storm that occurred on April 23rd to 24th, 2023. The key ionospheric parameters such as the critical frequency of the F2 layer (f0F2) and the Total Electron Content (TEC) are analyzed over South African stations located in Hermanus (19.22°E, 34.42°S) and Grahamstown (33.31°S, 26.52°E). The disturbance storm time (Dst) index reached a minimum of -180 nT with a maximum planetary K index (Kp) of 8. The Hermanus and Grahamstown stations both experienced a significant decrease in the f0F2 and TEC during the storm period. This distinct decrease is an indication of the negative ionospheric storm effect.

INTRODUCTION

Variations of the Earth's magnetic field under the influence of solar activity such as solar flares, fast solar wind speed and CMEs causes space disturbances in the ionosphere. This occurs when various magnitude of Sun's energy interacts with the magnetosphere during magnetic reconnection. A CME erupted over the central south of the solar disk on the 21st of April as shown by figure 1. An arrival of the CME was observed from the 23rd to 24th of April 2023 resulting in a strong geomagnetic storm (Kp=8). This study analyses the impact on the ionosphere caused by the CME-driven geomagnetic storm

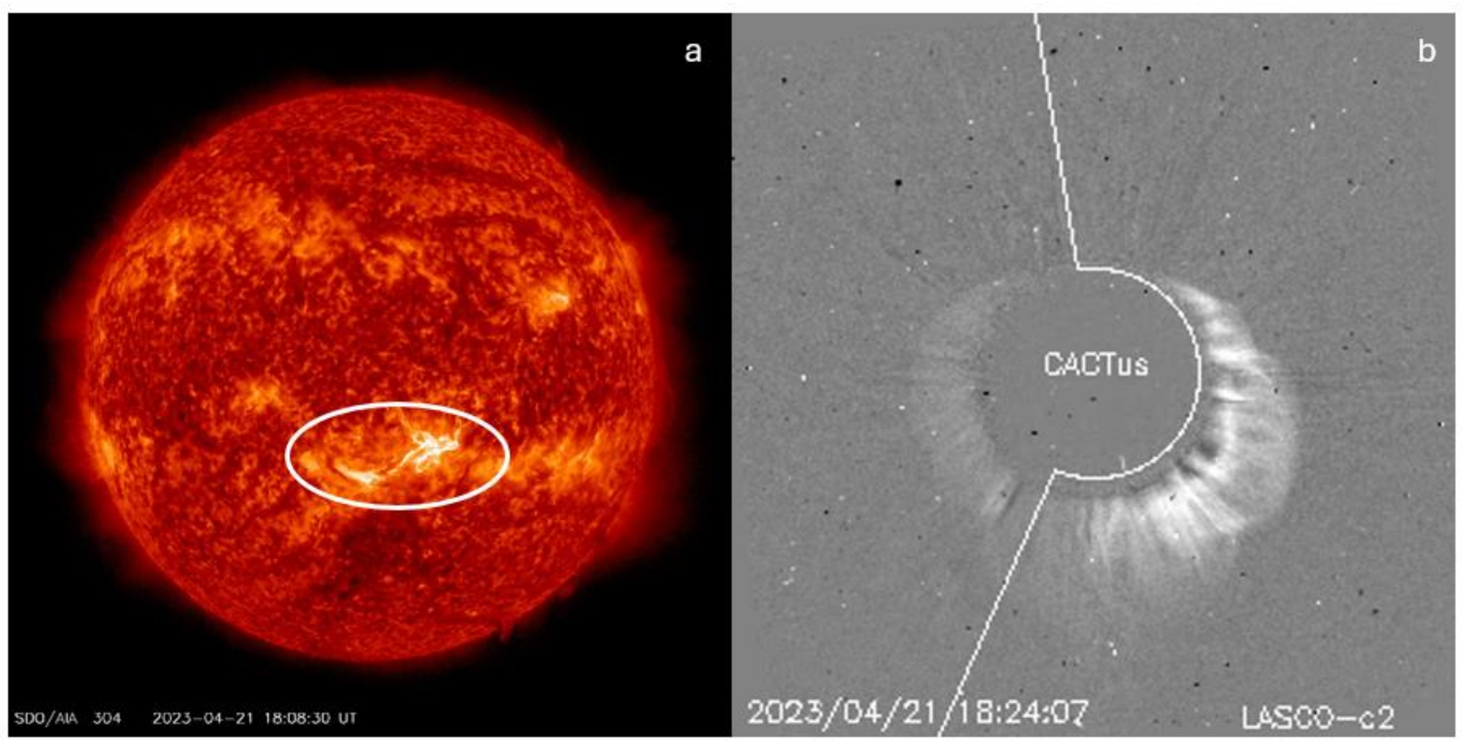

Figure 1: SDO/AIA 304 image displaying the filament eruption/dimming SDO | Solar Dynamics Observatory (nasa.gov). (b)CME Cactus coronagraph showing the CME eruption on the 21 April 2023.

DATA SOURCES

- Planetary K (Kp) and Dst indices are extracted from postdam website Kp Index - Kp index (gfz-potsdam.de) and Kyoto https://wdc.kugi.kyoto-u.ac.jp/
- GPS and Ionosonde instruments were used to gather Total Electron Content (TEC) data from observations made over Grahamstown (33.31°S, 26.52°E) and Hermanus (19.22°E, 34.42°S).
- GPS TEC observations in South Africa between latitudes 40°S to 20°S and longitudes 15°E to 35°E.

IONOSPHERIC RESPONSE

The Disturbance Storm Time (Dst) index classifies storm intensity as severe when − 200 nT< Dst≤− 100 nT (Le et al., 2013), coinciding with a maximum Kp index of 8. The main phase of the storm transpired on the 23-24 April, was characterized by a swift drop in Dst to the value of -180 nT succeeded by a gradual recovery that commenced on April 25th.

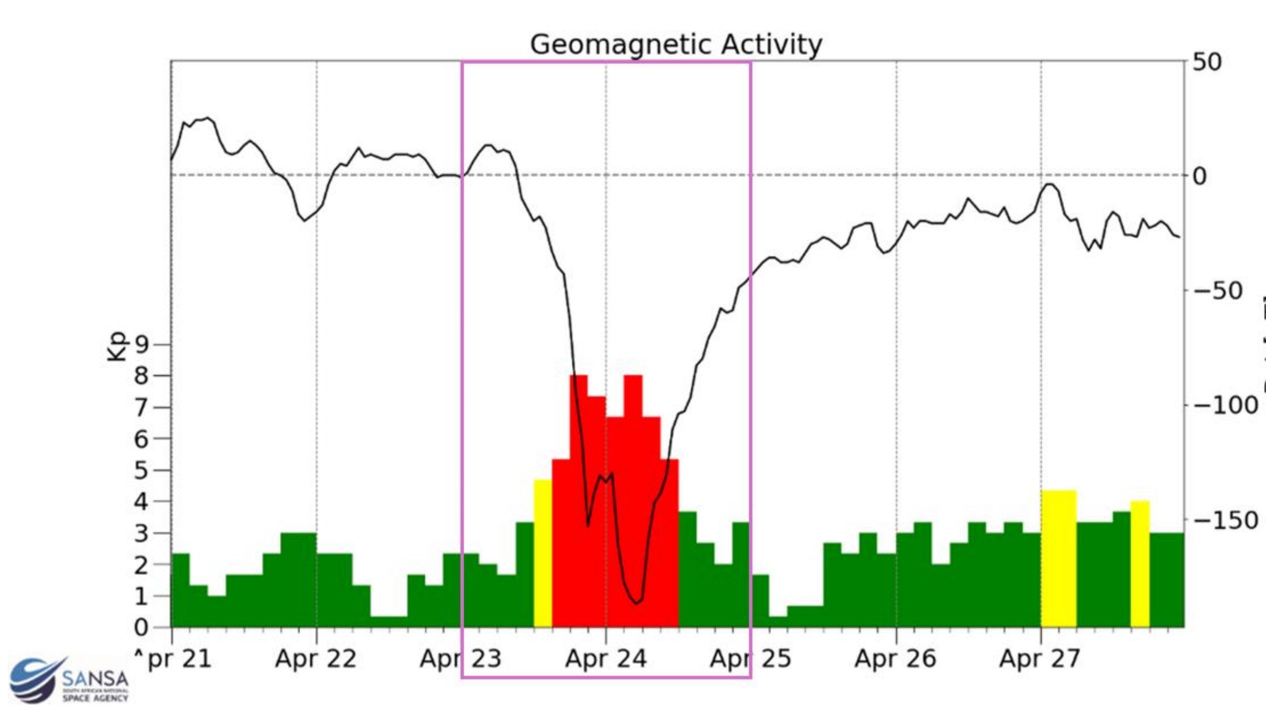

Figure 2: Dst and Kp indices for 21-27 April 2023.

The critical frequency of the F2 layer (f0F2) represents the highest frequency that can be reflected by the ionosphere, typically measured using an ionosonde instrument. During the storm, the ionogram observational data indicated instances of radio wave signal absorption, or radio blackout as shown in figure 3 b. and d. This is usually associated with solar flares, but no significant flares were observed during the period of study.

Habarulema et al., (2024) concludes that the absence of HF echoes during the storm was due to ionospheric tilting, characteristic of a negative storm effect. Figure 3 a. and c. shows the signal traces of f0F2 on a quiet day with no geomagnetic storms or solar flares.

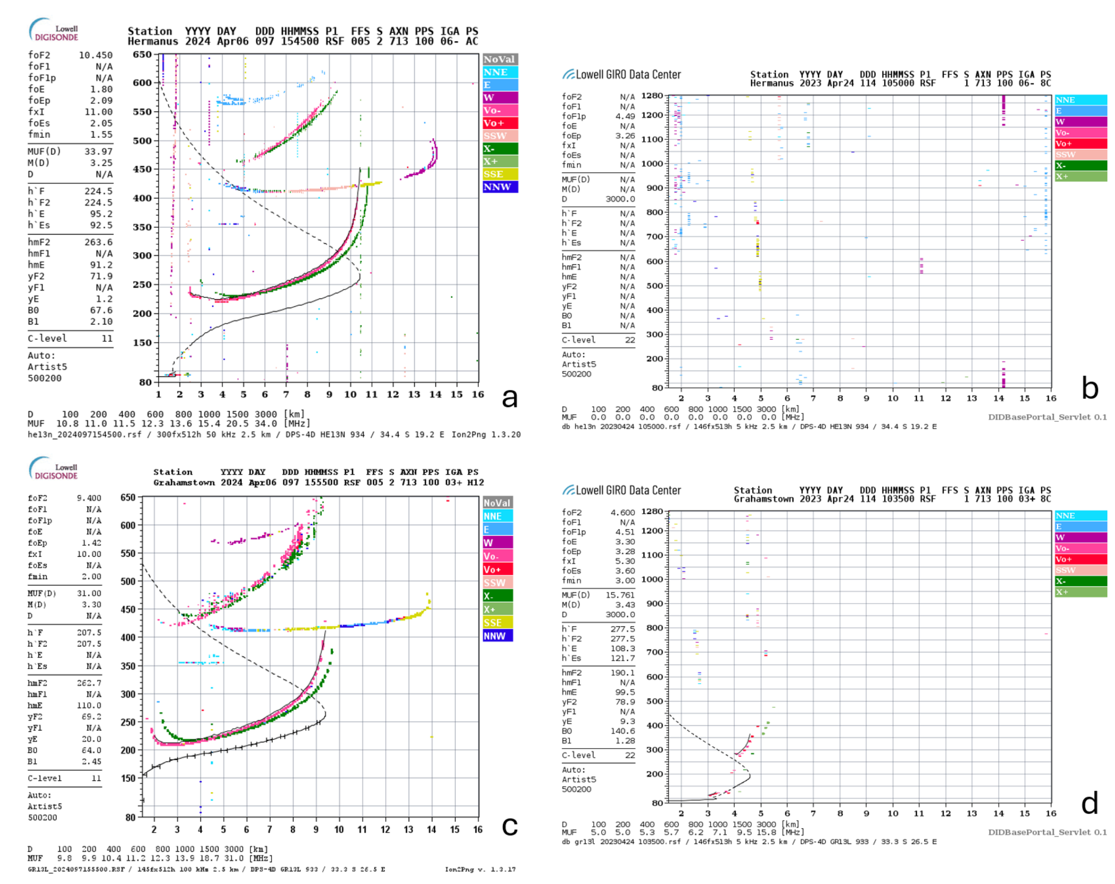

Figure 3: Example of ionograms showing f0F2 signal traces during local day time in South Africa over Hermanus (a. 06 April 2023; b. 24 April 2023) and Grahamstown (c. 06 April 2023; b. 24 April 2023) stations.

Figure 4a depicts the variation of TEC values across South Africa at 10:00 UT on a standard day, where values peaked at 50 TECU. The onset of the storm occurred later on the same day around 13:00 UT, specifically during the night of April 23rd. Conversely, Figure 4b illustrates a notable decrease, with TEC values dropping to 14 TEC at the same 10:00 UT time on April 24th. The significant depletion of electrons are clearly observed in figure 5 during the storm.

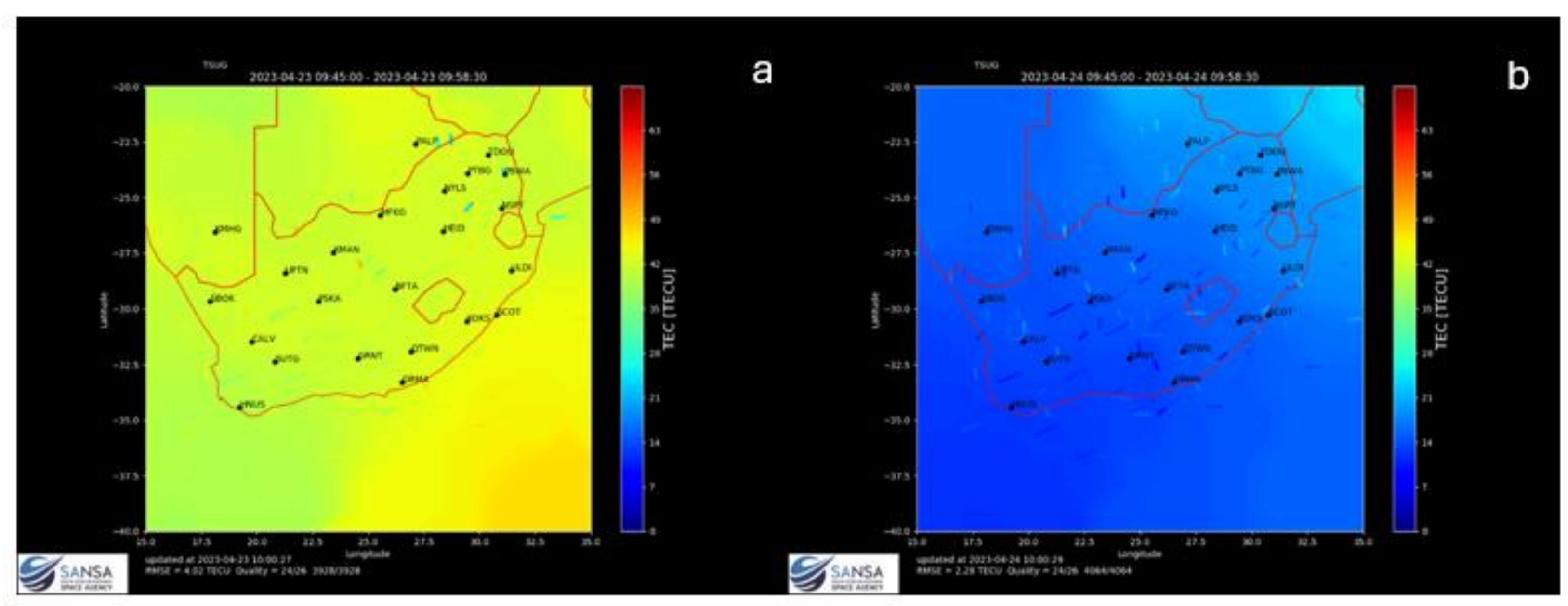

Figure 4: TEC maps days at 10:00 UT (a) 23 April 2023, (b) 24 April 2023.

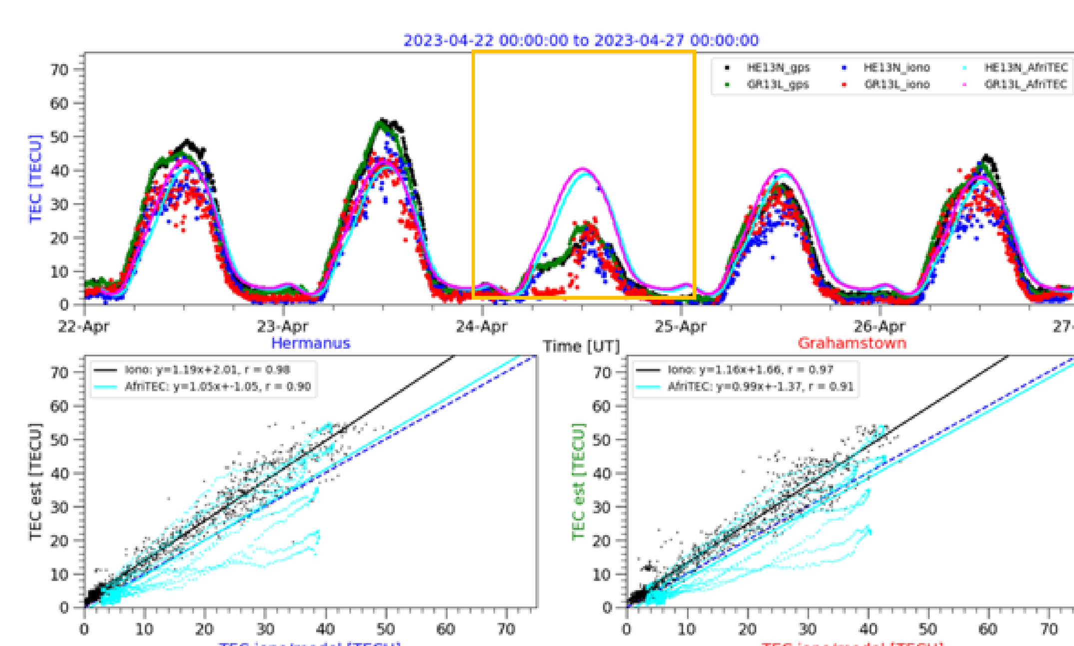

Figure 5: TEC estimates from the ionosondes, GPS and AfriTEC for 22-27 April 2023. Bottom left graph is the comparison for Hermanus, bottom right for Grahamstown. The magenta and cyan are the AfriTEC model.

SUMMARY AND CONCLUSION

The analysis of ionospheric parameters indicates a notable disruption in the ionosphere, characterized by decreases in TEC and the absence of HF echoes signals of the F2 layer. This significant depletion of electrons is known as the negative ionospheric storm effect.

ACKNOWLEDGMENT

- South African National Space Agency (SANSA) for providing ionosonde data and supporting all my travel expenses.
- Department of Science and Innovation (DSI) for supporting the implementation of SANSA projects and encourages international cooperation in space related activities.

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