Analysis of Ionospheric Electron Density Responses to Geomagnetic Storm Using Radio Occultation Data

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Background

- Geomagnetic storms are disturbances to the Earth's magnetosphere caused by variation in solar winds.
- Solar flares and Coronal Mass Ejections often cause geomagnetic storms by releasing energy and plasma into space
- The strength of a geomagnetic storm can be measured by two scales: Kp and Dst (Disturbance storm time).
- Depending on the strength of a geomagnetic storm, satellites, GPS/navigation, and radio communication may be negatively affected
- Total Electron Content (TEC) can be derived from GNSS signal delay between a GNSS transmitter and a receiver and can help determine the ionospheric response to a geomagnetic storm

Objectives

- Develop code to plot solar wind, geomagnetic, and ionospheric conditions before, during, and after a storm event from NASA OMNI data and LEO PlanetiQ satellite RO data using Python
- Utilize the Kp and Dst indices to determine the occurrence of a geomagnetic storm
- Analyze how TEC across the globe changes during a geomagnetic storm

Results

- Analyzed TEC changes as a result of the January geomagnetic storm
- Successfully plotted OMNI and LEO satellite data using Python

Observations of Jan. 21-22 Severe Geomagnetic Storm Event

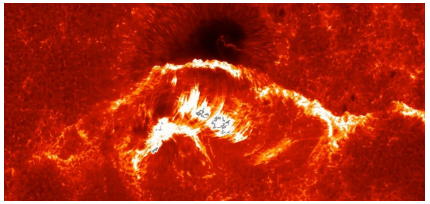


Figure 1. Solar optical telescope picture of a solar flare from the January event.
Source: https://starlust.org/powerful-x-1-9-class-solar-flare-on-january-18-triggers-radio-blackouts-across-the-americas/

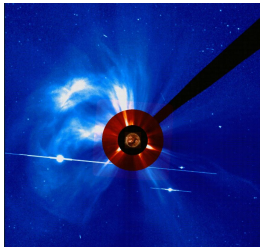


Figure 2. Image of a Coronal Mass Ejection (CME) leaving the Sun during the January event.
Source: https://www.esa.int/ESA_Multimedia/Images/2026/01/Coronal_Mass_Ejection_erupts_from_the_Sun_on_18_January_2026



Figure 3. Photograph of an aurora caused by the January event
Source: https://www.news18.com/photogallery/world/solar-storm-2026-incredible-aurora-images-from-around-the-world-ws-l-9846069.html

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January Geomagnetic Storm Overview

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Storm Details

- On January 18, an X-class solar flare was detected and was followed by a CME that traveled toward Earth
- High energy particles near Earth reached peak intensity one day later and reached an S4 level (severe).
- The following geomagnetic storm was labelled as G4 and could have negatively impacted technology such GPS, radio communication, and satellites.

January Storm Event from OMNI Data

- Kp and Dst help measure the strength of a geomagnetic storm.
- The Kp index measures global geomagnetic activity (averaged from 13 mid latitude magnetometer readings). The scale ranges from 0 to 9 (8=G4/Severe & 9=G5/Extreme)
- The Dst index (disturbance storm time) averages the reading of 4 magnetometer stations, measuring the horizontal magnetic field depression. It is measured in units of nano teslas (nT), with a value of -100 to -250 nT indicating an intense storm and a value < -250 nT indicating a super storm
- The Kp value from the OMNI data was between 1 and 4 (considered inactive) before 1/19/26, increased the next day (~8.5), and stayed elevated (~6-7.5) until 1/22/26.
- Before 1/19/26, Dst values stagnated at ~0 nT, dropped to ~-240nT on 1/20/26 and later increased to -40nT.

OMNI Data- Kp and DST- 1/17/26-1/27/26

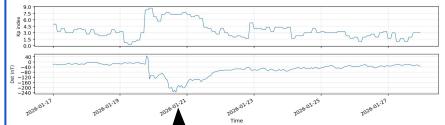


Figure 1. Line plo[illegible] Kp (top) and Dst (bottom) values from 1/17/26 to 1/27/26

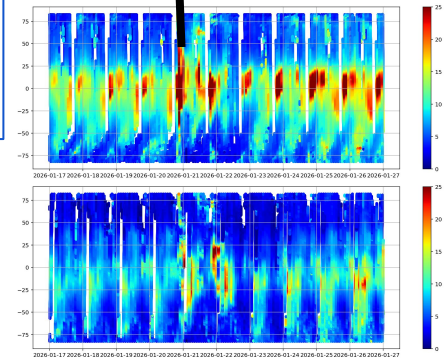


Figure 2. Graph of TEC values at different latitudes during the day (top) and night (bottom) from 1/17/26 to 1/27/26

TEC Data

- Total Electron Content (TEC) is the total number of electrons integrated between two points measured in TEC units/TECU (defined as 10^{16} electrons per m^2).
- GNSS-RO (GNSS Radio Occultation) data from PlanetiQ was used, where the signal changes between a satellite and receiver can be used to calculate electron density
- Daytime TEC values were higher than nighttime TEC at low to mid latitudes
- Equatorial Daytime TEC increased on 1/21/26 and stayed elevated

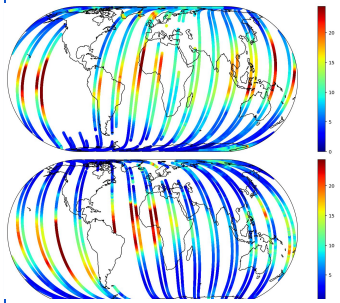


Figure 3. Overhead TEC arcs from LEO satellite data on 1/21/26 projected onto Earth during the day (top) and night (bottom).

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Interpretation and Discussion

Interpretation of the Data

- The Kp increase and Dst decrease from 1/19/26-1/21/26 occurs at approximately the same time as the daytime TEC increase (near the equator).
- This suggests that the January geomagnetic storm led to elevated TEC values and the potential to disrupt radio communication and GNSS navigation

Limitations

- The PlanetiQ satellite is Sun-synchronous with limited local time coverage.
- Only one storm's data was used, so general trends cannot be characterized (although the trend found agrees with known TEC changes caused by a geomagnetic storm).

Potential Future Work

- Map to geomagnetic coordinates instead of geographic coordinates (more accurate characterization for ionosphere)
- Utilize data from satellite systems with more local-time coverage to plot global data.
- Analyze data from multiple storms instead of one to draw larger scale conclusions

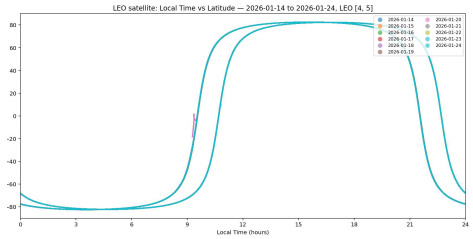


Figure 1. Latitude vs local time plot for the satellite system used during the January storm event.

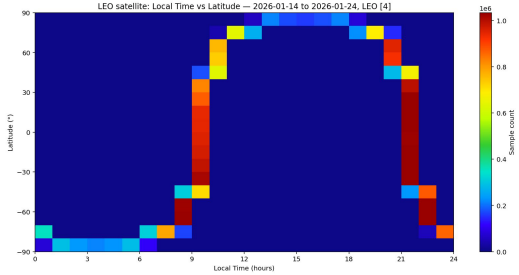


Figure 2. Color plot of one LEO satellite frequency (latitude vs local time, binned in 10° by 10°))

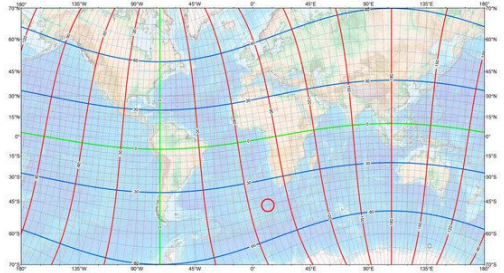


Figure 3. Photograph of geomagnetic coordinates. Source: https://www.mdpi.com/1424-8220/22/8/2954