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Multi-instrument study on the Great American Solar Eclipse

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A solar eclipse (SE) is a celestial phenomenon that occurs when the Moon passes between the Earth and the Sun, partially or completely blocking sunlight. SE, rare and occurring once every 1.5 years, offer a unique opportunity to study the Sun-Earth interaction, focusing on atmospheric and ionospheric responses to sudden radiation reductions. The D-region of the ionosphere, the lowest layer, is sensitive to solar ultraviolet flux and plays a crucial role in propagating Very Low Frequency (VLF) signals through the Earth-ionosphere waveguide.

This study investigates the Great North American Solar Eclipse (GNASE) on 8 April 2024, ionospheric responses using a multi-instrumental approach, incorporating globally distributed GNSS data, VLF observations, INTERMAGNET geomagnetic measurements, and satellite-based datasets including COSMIC-2 and Swarm missions. The different GPS stations with PRN6, INTRAMAGNET, and VLF stations (transmitter and receivers) passing the eclipse path are depicted in Figure 1. On 8 April 2024, the reduction in solar irradiance led to decreased ionization rates in the D-region, increasing the effective reflection height. This caused a significant drop in both the amplitude and phase of the received VLF signals. We analysed signals from three VLF transmitters—NAA, NML, and NLK—received at five stations along a Great Circle Path (GCP), which intersected the eclipse path nearly perpendicularly.

In addition to VLF analysis, we examined the temporal variations of the X, Y, and Z components of the geomagnetic field recorded at 5 INTERMAGNET [1] stations. Compared to a quiet reference day, the SE produced the strongest disturbances in the X-component, typically lasting between 120 and 200 minutes.

GNSS-derived Total Electron Content (TEC) data show a clear depletion in the ionosphere during the eclipse, with reductions exceeding 10 TECU at certain locations. The extent of TEC degradation was found to vary spatially across GNASE. Additionally, wave-like structures associated with atmospheric gravity waves (AGWs)[2] were identified in the F-region ionosphere. The study found periodic waves with 20–45-minute durations, resembling sunrise terminator-induced AGWs, with longer periods in the F-region of eclipse-induced AGWs, based on FFT and wavelet analysis. Satellite observations further support these findings. COSMIC-2 occultation data showed a maximum vertical electron density depletion of 43%, while Swarm-A satellite electron density profiles were significantly reduced compared to reference values.

In summary, the total solar eclipse of 8 April 2024 offered a rare opportunity to study the ionospheric response across multiple altitudes and dimensions. This comprehensive analysis enhances our understanding of solar eclipse-induced ionospheric dynamics and contributes to ongoing efforts in space weather modelling and prediction.

References
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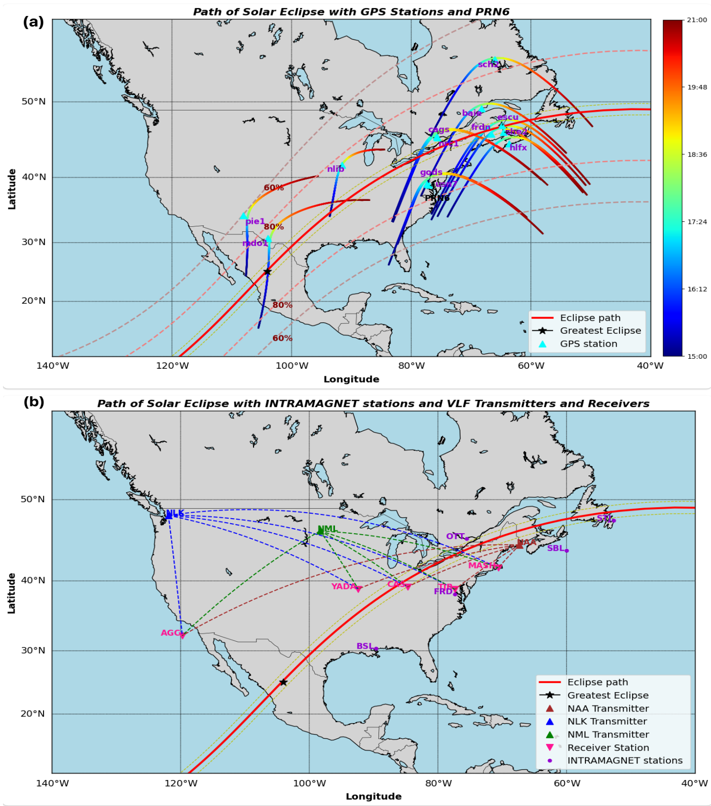

Fig. 1: Path of solar eclipse with different GPS stations (a), INTRAMAGNET and VLF stations (b)