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Ionospheric Total Electron Content (TEC) Anomalies as Earthquake Precursors: Unveiling the Geophysical Connection Leading to the 2023 Moroccan 6.8 Mw Earthquake

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Abstract: The study delves into the relationship between ionospheric total electron content (TEC) anomalies and seismic activity, with a focus on Morocco's 6.8 Mw earthquake on 8 September 2023, lying within a tectonically active region at the convergence of the African and Eurasian Plates. To enhance the reliability of our findings, we incorporate space weather conditions, utilizing indices (Dst, Kp, and F10.7) to pinpoint periods of stable space weather. This minimizes the possibility of erroneously attributing natural ionospheric fluctuations to seismic events. Notably, our TEC analysis unveils positive and negative anomalies, with some occurring up to a week before the earthquake. These anomalies, exceeding predefined thresholds, provide compelling evidence of significant deviations from typical ionospheric conditions. Spatial mapping techniques employing both station-specific vTEC data and pseudorandom noise codes (PRNs) from multiple global navigation satellite system (GNSS) stations highlight a strong correlation between ionospheric anomalies and the earthquake's epicenter. The integration of PRNs enhances coverage and sensitivity to subtle anomalies. Additionally, the analysis of satellite imagery and ground displacement data using Sentinel-1 confirms significant ground uplift of approximately 15 cm following the earthquake, shedding light on surface responses to seismic events. These findings underscore the potential of ionospheric science in advancing earthquake early warning systems and deepening our understanding of earthquake precursors, thus contributing to the mitigation of seismic event impacts and the protection of lives and infrastructure.

Keywords: Morocco earthquake; total electron content; ionospheric anomalies; PRNs; InSAR; LAIC

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1. Introduction

The study of seismic activity and its precursors has long been a subject of profound scientific interest and societal importance. Earthquakes, being natural disasters of considerable magnitude, have the potential to cause devastating consequences to both human life and infrastructure. Understanding the intricate processes leading to an earthquake is crucial for early warning systems and disaster preparedness. Traditional earthquake prediction methods primarily rely on monitoring geological and seismological parameters, such as ground deformation [1–3], strain accumulation [4,5], lineament analysis [6,7], and seismic activity [8]. However, recent advances in the field of ionospheric science have opened new avenues for earthquake forecasting, offering complementary insights into the complex processes that precede seismic events. One emerging area of research that holds promise in unraveling the mysteries of earthquake precursors is the analysis of ionospheric total electron content (TEC) anomalies [9–15]. This study explores the intriguing relationship between ionospheric TEC and seismic activity, focusing specifically on the North African region, with a primary emphasis on Morocco. Situated in a tectonically active zone