Observational and analytical simulation study of rapid co-seismic ionospheric disturbances during strong earthquakes

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The ionosphere hosts co-seismic ionospheric disturbances (CID or ionoquakes) during earthquakes due to Seismo-Atmosphere-Ionosphere (SAI) coupling. This phenomenon involves seismic vibrations at the Earth's surface triggering coupled energetics into the atmosphere and ionosphere in the form of various atmospheric/plasma waves. Ionoquake detection from Doppler radars, Total-Electron-Content (TEC) measurements from Global Navigation Satellite System (GNSS) receivers, and magnetometers have revealed ionoquakes as potential candidates for monitoring earthquake energetics in space. The continuous coverage provided by GNSS networks around the globe has made it possible to monitor disturbances in TEC around seismic faults with high spatial/temporal resolutions and to detect ionoquakes unambiguously. However, one of the unresolved issues in ionospheric seismology is the early detection of near-field ionoquakes, in less than 8 minutes from the earthquake onset.

In this study, we demonstrate that large earthquakes can generate ionoquakes that are detectable as early as 400 seconds after the earthquake onset and 250-430 seconds after the peak vertical ground velocity, based on GNSS-TEC data and using the SAI-analytical (SAI-ANA) simulation code. The SAI-ANA code was recently developed to simulate the SAI coupling, starting from the analytical solution of the equations used by Kherani et al. (2016) to model atmospheric gravity waves (AGWs) and their interaction with the ionosphere. This study is also the first to reveal the rapid arrival of gravity waves at ionospheric heights and the development of ionoquakes in less than 7 minutes from the start of the earthquake. Additionally, it is the first simulation to capture the occurrence of rapid ionoquakes within a simulation time of 1 minute, significantly faster than their development and detection within 8 minutes.