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Seismic ionospheric disturbances related to Chile-Illapel 2015 earthquake and tsunami observed by Swarm and ground GNSS stations

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The study investigates Swarm data including in-situ electron density (ED) measured by Langmuir Probes (LP) and total electron content (TEC) from precise orbit determination (POD) GNSS receivers in time of Chile-Illapel earthquake (EQ) and tsunami in 2015. The research is based on the symbiosis of Swarm data, ground GNSS data and seismic records combined with the information on EQs and tsunamis. The FFT-based filtering and short-term Fourier transform (STFT) analysis are used in detection of seismic ionospheric disturbances (SID) in ED from LP and POD TEC data. The classification of the spectral characteristics of disturbing along-track signals is supported by their simultaneous search in ground GNSS observations, which gives an opportunity for the validation of the spectral recognition. Ground GNSS data, due to several tens of satellites and thousands of stations, provide the only full spatiotemporal view on SIDs and enable the inspection of their spatial shapes, spatial relations and speeds. The location of dense ground GNSS networks is however limited to selected places. Swarm and other LEO satellite data, in turn, are globally distributed, but they are dense only along the orbital tracks. Therefore, 1D nature of Swarm along-track observations, fast satellite movement and limited chance for spatiotemporal correlation due to the non-repeating orbits, strongly require spectral analysis for better recognition of the signals. The detection of SIDs from along-track Swarm data is also complicated due to the variety of disturbing signals occurring in the ionosphere, and the spectral analysis is also crucial there. STFT spectral approach to along-track Swarm data gives an opportunity for distinguishing the signals of different origin. The analyses of Swarm data provide interesting observations of ionospheric disturbances not only directly related with the largest EQ events and tsunami, but also occurring during entire periods of enhanced seismic activity and at larger distances from EQ epicenter. The disturbing signals triggered by the largest EQs and tsunami were also observed. However their amplitude in the ionosphere is not always such dominating as the amplitude of some other, associated disturbances on the neighboring days. This difference in scale can suggest that the electron disturbances in the ionosphere are rather more generally related to the crustal motion and seismic activity, than solely correlated with large EQs.