EGU25-10846, updated on 06 May 2025
https://doi.org/10.5194/egusphere-egu25-10846
EGU General Assembly 2025

Experimental data and models for radio diagnostics of extreme impacts “from below” on ionospheric space weather: LOFAR data on ionospheric acoustic-range perturbations caused by Hunga-Tonga volcano eruption.

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The 2022 Hunga Tonga Volcano Eruption (HTVE) had unprecedented impacts on atmospheric space weather. It provided a clear example of how space weather may be impacted by influences both “from above” (e.g. the solar wind, geo-magnetic storms) and “from below” (e.g. powerful volcanoes, hurricanes, earthquakes). Manifestations of unprecedented geophysical effects from HTVE were an acoustic wave that circled the Earth several times, the formation of strong ionospheric plasma bubbles and plasma depletion. An important method for diagnosing ionospheric space weather is ionospheric radio scintillation (IS). The purpose of this work is data analysis, modelling and interpretation of radio scintillation data of ionospheric effects from HTVE using the Low-Frequency Array (LOFAR), supported by observations from the European Space Agency’s Swarm mission and other geophysical instruments. Specifically, LOFAR observed TIDs in the ionospheric plasma over the Europe, which, based on typical velocities and pulse widths (on the order of 10 s), are interpreted as the effect of waves generated as a result of the HTVE. The physical modelling carried out corresponds to a picture corresponding to the penetration of Lamb waves into ionospheric altitudes, with their source being a pressure pulse associated with HTVE. Moreover, the corresponding physical explanation, based on the modelling carried out, is given from two points of view: (1) acoustic mode and (2) acoustic impulse representations. (1) Modes with periods of about 12 min were studied. It turned out that such frequencies correspond to a number of eigenmodes of Lamb waves which, accounting for attenuation, travelled thousands of km from the source to the observation site and having a finite/non-zero excitation efficiency (velocity value) near the Earth’s surface. At the same time, the acoustic field of such waves is concentrated at the heights of the altitude region of the E region of the ionosphere. (2) It has been shown that a pressure pulse with a duration of about 10 s in the lower atmosphere effectively penetrates to the heights of the E region of the ionosphere, its acoustic field is concentrated in the E region and it tends to propagate in the horizontal direction, exciting the E region. An analytical

algorithm is proposed to determine the response of the ionosphere to the corresponding acoustic pulse, and a method of complex geometric optics is presented, which makes it possible to simulate the scattering of high-frequency (HF) electromagnetic waves (EMW) in the LOFAR (MHz) range. In general, the observations, estimates and numerical simulations confirm the effect of pulsed impact on the ionosphere of acoustic waves penetrating to ionospheric heights at distances of many thousands of kilometres from the source associated with HTVE and causing the scattering of HF EMW detected by the LOFAR radio telescope. The above-mentioned model is under development now. Its appropriate application will allow us to study and interpret other effects of acoustic waves from a source associated with HTVE and develop further the methods for radio diagnostics of ionospheric space weather.