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Peculiarities of the Propagation of Supersonic Seismic Waves to the Upper Atmosphere.

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Seismic waves generated before and after earthquakes produce vertical and horizontal motion of the Earth's surface. The perturbations can propagate upwards and produce variations and oscillations of atmospheric characteristics at different altitudes. One of the mechanisms of such ionospheric perturbations is propagation of acoustic-gravity waves (AGWs) in the atmosphere caused by seismic excitations at the ground surface. The main difficulties in such explanation are high phase speeds of surface seismic waves, much exceeding the sound speed in the atmosphere near the ground. The strongest ground seismic waves are the surface Rayleigh waves, having phase speeds 3 - 4 km/s (sometimes up to 10 km/s). Traditional theory of atmospheric AGWs predicts that such supersonic excitation should produce not propagating, but trapped (or evanescent) gravity wave modes with amplitudes exponentially decaying with altitude. This can raise questions about the importance of seismic-excited supersonic waves in the formation of ionospheric disturbances.

In the present study, we use the recently developed nonlinear numerical Whole-altitude Acoustic-Gravity Wave Model (WAGWM) to simulate propagation of supersonic wave modes from the ground to the upper atmosphere. The WAGWM is a three-dimensional model and uses the plain geometry. It calculates atmospheric velocity components and deviations of temperature, pressure, and density from their background values. Gavrilov and Kshevetskii (2014) described the set of used nonlinear three-dimensional equations of continuity, motion and heat balance. At the upper boundary $z = 500$ km we assume zero vertical velocity and zero vertical gradients of the other wave parameters. In the present research, we made calculations in rectangle region of the atmosphere and assume horizontal periodicity of wave solutions. Variations of vertical velocity produced by propagating seismic waves at the Earth's surface serve to force the waves in the model.

Calculations show that activating the surface plane wave forcing generates an initial acoustic pulse, which in 5 – 10 min reaches altitudes 100 – 200 km. After dissipation of this acoustic pulse, a transition to a quasi-stationary system of propagating waves occurs (see Gavrilov and Kshevetskii 2014). Simulated distributions of wave temperature perturbations for spectral modes with infrasound frequencies at time 2 hr after activating the surface seismic wave forcing with horizontal phase speed of 1 km/s show their propagation with the wave fronts inclined in the directions opposite to the direction of horizontal phase speed, which corresponds to upward infrasound phase propagation.

Spectral components corresponding to gravity wave frequencies are trapped in the lower and middle atmosphere with quasi-vertical wave fronts. Above altitudes 150 – 200 km, the gravity wave fronts become inclined to the horizon, which shows that the waves become propagating vertically. This means that the energy of supersonic seismic waves can penetrate to ionospheric altitudes, where the respective AGW modes become propagating and may produce travelling ionospheric disturbances (TIDs).

Reference: Gavrilov N. M. and S. P. Kshevetskii, Numerical modeling of the propagation of nonlinear acoustic-gravity waves in the middle and upper atmosphere. Izvestiya, Atmospheric and Oceanic Physics, 2014, Vol. 50, No. 1, pp. 66–72.