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Nonlinear Propagation of Infrasound from Large Explosions

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Atmospheric explosions release immense quantities of infrasound energy that can be detected at receivers located from hundreds to thousands of kilometers from the origin. This has led to the deployment of a global 60-station network of micro-barometer arrays to aid in nuclear explosion monitoring. Current methods of estimating the radiated source energy from remote recordings of infrasound signals use simplified empirical source-yield relations that account for stratospheric winds along the source-receiver path. These formulations apply only to direct and stratospherically ducted arrivals. More recently, considerable progress has been made in applying numerical modeling techniques to develop more accurate source-yield formulations for realistic sound and wind speed profiles. However, these methods assume linear infrasound propagation along the travel path even though nonlinear effects – which arise when the amplitude of the acoustic pressure perturbation is a finite fraction of the ambient atmospheric pressure - are known to significantly alter infrasound frequencies, velocities and amplitudes, and thus can affect derived source yield estimates.
For realistic atmospheric profiles, nonlinearity can be significant both in the vicinity of a large explosive source as well as at much greater distances. Within the stratosphere, nonlinearity may arise at caustics created by ducting; in the thermosphere, nonlinearity may arise due to very low ambient pressures at high altitudes. In this study, the effects of nonlinearity on infrasound signal amplitudes and frequencies are simulated using a nonlinear finite difference, time-domain (FDTD) method. The key features that allow for accurate and efficient nonlinear synthesis of infrasound propagation through realistic media are that 1) it includes for atmospheric viscosity, and 2) the environmental models are constrained to have axial symmetry, yielding solutions relevant to a point source in a fully 3D model with rotational invariance. This detail is important, in that nonlinear effects depend on acoustic amplitudes, which decrease much more slowly in two dimensions than in three. In this way, direct comparisons can be made of linear and nonlinear propagation through realistic media, allowing for a careful examination of the extent to which nonlinearity plays a role in stratospheric returns, in thermospheric returns, and in infrasound penetration into zones of silence. Side-by-side comparisons of linear and nonlinear propagation through realistic representations of the atmosphere are shown for two simple models. The first is a near-field model in which the sound speed decreases with amplitude, creating a shadow zone near the source. The second is a realistic ambient sound speed profile that extends to 130 km altitude, so that both stratospheric and thermospheric returns are modeled. The results show that thermospheric returns are affected by nonlinearity even for relatively low source amplitudes. Thus more work is required to develop source-yield estimates, particularly for thermospheric returns.