Geophysical Research Abstracts
Vol. 19, EGU2017-11396, 2017
EGU General Assembly 2017

Acoustic and Gravity Waves at Finite Amplitude in the Mesosphere, Thermosphere, and Ionosphere Following Transient Forcing

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Acoustic waves (AWs, ∼1-4 minute periods) and gravity waves (GWs, ∼5-10s minute periods) are readily generated by transient forcing at Earth's surface or troposphere, and are routinely observed in the mesosphere, lower thermosphere, and ionosphere (MLTI). Observations include ground and space-based imaging of GWs via their perturbations to airglow layers [e.g., Taylor and Hapgood, PSS, 36(10), 1988, Akiya et al., GRL, 41(19), 2014] and detection of both AWs and GWs in ionospheric total electron content (TEC) [e.g., Nishioka et al., GRL, 40(21), 2013]. Of observational importance are waves that are spectrally coherent and that may persist over long periods of time, locally or over large horizontal or radial extents, due to reflection, ducting, and resonance. Specifically, mesospheric airglow data frequently reveal evidence for coherent ducted gravity waves with phase velocities ∼25-125 m/s and horizontal wavelengths ∼10s-100 km [e.g., Simkhada et al., Ann. Geophys., 27, 2009; Akiya et al., 2014]. Likewise, F-region ionospheric responses are dominated by gravity waves typically with higher phase velocities >100 m/s and larger scales >100 km, which may also be ducted, in addition to persistent acoustic waves with periods ∼3-4 minutes [e.g., Nishioka et al., 2013; Lay et al., JGR, 120(7), 2015] that are consistent with simulations of resonance from ground to thermosphere [e.g., Walterscheid et al., JGR, 108(A11), 2003; Matsumura et al., JASTP, 75-76, 2012].

Here, we investigate the effects of finite amplitude for acoustic and gravity waves generated by transient sources (with resulting spectra spanning ∼few-10s minute periods) and their observable signatures in the MLTI. A nonlinear, compressible, atmospheric dynamics model is used, and coupled with models for the responses of the mesospheric hydroxyl airglow layer and a self-consistent ionosphere [e.g., Snively, GRL, 40(17), 2013; Zettergren and Snively, JGR, 120(9), 2015]. We find that the dominant observable wave spectra in the ionosphere may, in many cases, be determined by linear processes associated with reflection, ducting, and resonance. However, we identify several scenarios where effects of nonlinearity may become detectable. Observable features include evolutions in the underlying wave spectra via steepening, formation of harmonics, or coupling with larger-scale waves or flows, in addition to nonlinear responses of the airglow or ionospheric systems through which the waves are observed. The interpretation and separation of linear and nonlinear features of AW and GW events, in the context of recent MLTI observations depicting otherwise coherent wave signatures following transient forcing, are demonstrated via simulation case studies.