Simulation of ionospheric responses driven by acoustic and gravity waves following inland earthquakes

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Total Electron Content (TEC) measurements, based on Global Navigational Satellite System (GNSS) signals, are a readily available and robust source of data for the investigation of ground-atmosphere-ionosphere coupling processes driven by natural and anthropogenic hazards (earthquakes, tsunamis, nuclear explosions etc.). They reveal many important aspects of acoustic and gravity wave (AGWs) dynamics in ionosphere triggered by seismic events [Komjathy, Radio Sci., 51, 2016]. In recent times, the possibility of incorporating TEC data into tsunami early-warning systems has attracted a lot of attention [Savastano, Nature, 7, 2017]. However, TEC, being an integrated measurement of electron density, provides information on electron responses to AGWs at mostly the bottom-side of the F layer of the ionosphere (~250-300 km), and relies on mutual geometry of AGWs and GNSS transmitter-receiver lines-of-sight. Thus, simulation case studies, spanning from Earth's surface to upper ionosphere, are necessary and important steps in the understanding of these geophysical phenomena.

Coupling processes involve different propagation media and interfaces in-between, spanning from Earth's interior to the upper levels of ionosphere. Our modeling approach is based on coupling of Earth's interior and ocean dynamics models with a nonlinear neutral atmospheric model for acoustic-gravity wave propagation, MAGIC, which is in turn coupled with a nonlinear ionospheric model, GEMINI, to simulate driven plasma disturbances, electric currents and geomagnetic field perturbations [Zettergren and Snively, JGR, 120, 2015]. Seismic wave propagation codes SPECFEM3D [Komatitsch and Vilotte, BSSA, 1998; Komatitsch and Tromp, GJI, 149, 2002] combined with kinematic slip models are used to simulate time-dependent surface displacements driven by large earthquakes. These surface displacements are then used to drive the MAGIC model as the time-dependent lower-boundary conditions.

Here, we present recent results of simulations of AGW dynamics from ground to thermosphere and resulting ionospheric airglow and plasma disturbance. Cases for two inland earthquakes, 2015 Mw 7.9 Gorkha (Nepal) and 2016 Mw 7.8 Kaikoura (New Zealand), that are similar in magnitude, but markedly different in terms of background atmosphere-ionosphere conditions and faulting dynamics, are investigated. In particular, the possibilities of retrieving earthquake source mechanisms, rupture directivity and areas of uplift and subsidence using GNSS TEC data are examined. We find that in both cases the direction of rupture propagation, arrest and re-activation can be constrained with certain precision based on atmospheric and ionospheric data. The regimes of propagation and nonlinear effects of AGWs are studied as at near-field regions, as for displacements driven by P, S and Rayleigh waves at far-field. Our results indicate the applicability of GNSS TEC data for investigating the coupling earthquake-atmosphere-ionosphere mechanisms, but also raises questions about previously reported conclusions.