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Modeling of Upper Atmospheric Responses to Acoustic-Gravity Waves Generated by Earthquakes and Tsunamis

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Modeling of upper atmospheric responses to acoustic-gravity waves generated by earthquakes and tsunamis

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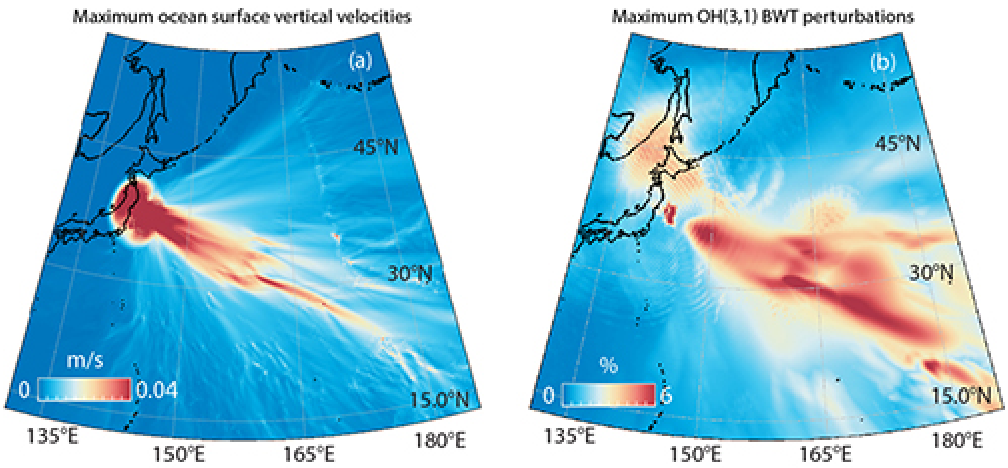
Recent studies have shown that upper atmospheric observations can be used to examine the properties of acoustic and gravity waves (AGWs) induced by natural hazards (NHs), including earthquakes and tsunamis (e.g., Komjathy et al., Radio Sci., 51, 2016). In addition to rapid processing, analysis, and retrieval of the AGW signals in data, the need remains to investigate a broad parameter space of atmospheric and ionospheric state observables for the robust constraint of coupled and nonlinear processes. Here, we present several earthquake/tsunami-atmosphere-ionosphere case studies that demonstrate the possibility to detect AGWs and constrain the characteristics of their sources. Direct numerical simulations of the triggering and wave dynamical processes, from Earth's interior to the exobase, are carried out based on coupled forward seismic wave and tsunami propagation models and our state-of-the-art nonlinear neutral atmosphere and ionosphere models MAGIC and GEMINI (Zettergren and Snively, JGR, 120, 2015).

We first demonstrate that ionospheric plasma responses to AGWs from large earthquakes include information about rupture evolutions, providing another independent dataset for the investigation of faulting processes (Inchin et al., JGR, 125, 4, 2020). At the same time, we highlight that remote sensing observables, such as total electron content (TEC), can be insensitive to some specifics of the rupturing process (and thus characteristics of induced AGWs) due to their integrated nature or inefficient geometry of observations to uncover those specifics, and should be used accordingly and with consideration of their geometry. Likewise, we demonstrate that ground-level magnetometer observations are readily sensitive to magnetic field disturbances from ionospheric dynamo effects, induced by coseismic AGWs generated over epicentral areas. These are readily measured at low cost, may also be incorporated to complement the analysis of earthquake-atmosphere-ionosphere coupled processes. Next, we show that in addition to ionospheric plasma responses, mesopause airglow (MA) transient imprints of coseismic and tsunamigenic AGWs are readily detectable with modern ground- and space-based imagers. We demonstrate that AGW-driven fluctuations in the MA, generated over near-epicentral areas, may be readily detectable 6 minutes after the earthquake, providing an important and independent data source to supplement early-warning systems, additionally uncovering specifics of rupturing processes (Inchin et al., JGR, 125, 6, 2020). The amplitudes of tsunamigenic AGWs and related fluctuations in

MA closely follow the dynamics of the tsunamis, uncovering their spatial and temporal evolutions (Inchin et al., JGR, 125, 12, 2020). In summary, comprehensive dynamical simulations reveal subsequent observable features of surface to atmosphere-ionosphere coupling, and new opportunities to diagnose hazard processes.



Field of simulated (a) absolute maximum vertical ocean surface velocities and (b) absolute maximum hydroxyl temperature perturbations.