EFFECTS OF TSUNAMIS ON THE UPPER ATMOSPHERE

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ABSTRACT

Following the early suggestion of Peltier and Hines [1], it is now generally accepted that tsunamis can excite acoustic-gravity waves, and that these waves can propagate to the upper atmosphere. Because of the decrease of atmospheric density with increasing altitude, conservation of wave energy causes the wave disturbance amplitudes to increase with increasing altitude. At high altitudes molecular diffusion (viscosity and thermal conduction) increases, and the dissipation rate becomes large enough to offset this amplitude growth, and at greater heights the wave amplitudes diminish considerably [2].

The acoustic-gravity waves reaching the F-region ionosphere may cause significant ionospheric perturbations (traveling ionospheric disturbances, or TIDs) with resulting disturbances in the total electron content (TEC). Perturbations in the TEC associated with tsunamis have been measured using GPS measurements [3], and shown to have amplitudes ranging from a few percent to tens of percent of the mean TEC. Numerical models have been used to simulate the interaction of gravity waves with the ionospheric plasma, exploring the dependence of the ionospheric response to the wave parameters (period, speed, propagation direction) [4] and to the orientation of the geomagnetic field [5, 6]. The ionospheric response has been found to be smallest for zonal propagation at low latitudes, but at middle and high latitudes the response is less dependent on the direction of wave propagation.

Atmospheric gravity waves generated by tsunamis can also interact with chemically active species in the upper atmosphere, thereby producing perturbations in the airglow [7]. Some affected airglow emissions include the FUV OI 1356Å, and the visible 6300Å. These airglow fluctuations represent another means to measure tsunami effects in the upper atmosphere.

Acoustic-gravity waves are also able to transport energy and momentum to the upper atmosphere. When gravity waves dissipate they deposit their momentum in the mean flow [8], while also driving a downward sensible heat flux [9]. Simulations [10] show that the thermal effects of tsunami generated gravity waves are quite modest. However, the simulations suggest that the momentum forcing associated with one event was extremely large, with an acceleration of ~ 150 m/s occurring during a one hour period for the thermosphere between ~ 200 km and 300 km altitude.

In this paper the ionospheric perturbations are simulated using a new version of our full-wave model. Prior to this the calculations were simplified considerably by using various approximations. These included neglecting partial ion pressure gradients, neglecting the effect of gravity in the ion momentum equations, and also neglecting ion diffusion in the ion momentum equations and in the ion continuity equations. These are good approximations for application to the E-region ionosphere. In order to better describe the response of the F-region ionosphere to gravity waves, we have developed a new model, briefly discussed next.

In our new version of the full-wave model, instead of calculating the ionospheric response after-the-fact (that is, after solving the Navier-Stokes equations for the neutral gas perturbations), the ionospheric response is calculated self-consistently. To do so, the ion (and electron) perturbations are solved simultaneously with the neutral perturbations. The numerical procedure involves increasing the number of coupled differential equations beyond their current value (a total of 5, which includes 1 continuity, 1 energy, and 3 momentum equations describing the neutral gas) to at least 10 (accounting for the additional effects of just a single O^+ ion). As the number of ions is increased, the number of equations is increased accordingly. A standard numerical procedure is used to solve these differential equations subject to specified boundary conditions.

In this paper we discuss the effects of tsunami-generated atmospheric gravity waves on the thermosphere and on the F-region ionosphere. The ionospheric perturbations obtained with the improved full-wave model are discussed and compared to our previous simulations and are also applied to more recent observations of total electron content associated with tsunami events. These observations allow us to constrain the amplitudes in the model, and hence allow us to better determine the forcing effects of the waves on the mean state (both thermal and momentum). Implications for future studies are discussed.

REFERENCES

[1] W. R. Peltier and C. O. Hines, "On the possible detection of tsunamis by a monitoring of the ionosphere", J. Geophys. Res., vol. 81, pp. 1995-2000, 1976.

[2] M. L. V. Pitteway and C. O. Hines, "The viscous damping of atmospheric gravity waves", Can. J. Phys., vol. 41, pp. 1935, 1963.

[3] J. Artru, V. Ducic, H. Kanamori, P. Logonné, and M. Murakami, "Ionospheric detection of gravity waves induced by tsunamis", *Geophys. J. Int*., vol. 160, pp. 840-848, 2005.

[4] M. P. Hickey, G. Schubert, and R. L. Walterscheid, "The Propagation of Tsunami-Driven Gravity Waves into the Thermosphere and Ionosphere", *J. Geophys. Res.,* vol. *114*, A08304, doi:10.1029/2009JA014105, 2009a.

[5] G. Occhipinti, P. Lognonne, E. A. Kherani, and H. Hebert, "Three-dimensional waveform modeling of ionospheric signature induced by the 2004 Sumatra tsunami", *Geophys. Res. Lett*., vol. 33, L20104, doi:10.1029/2006GL026865, 2006.

[6] G. Occhipinti, E. A. Kherani, and P. Lognonne, "Geomagnetic dependence of ionospheric disturbances induced by tsunamigenic internal gravity waves", *Geophys. J. Int*., vol. 173, pp. 753-765, 2008.

[7] M. P. Hickey , G. Schubert, and R. L. Walterscheid, "Atmospheric airglow fluctuations due to a tsunami-driven gravity wave disturbance", *J. Geophys. Res., submitted*, 2009b.

[8] R. S. Lindzen, "Turbulence and stress owing to gravity wave and tidal breakdown", *J. Geophys. Res*., vol. 86, pp. 9707-9714, 1981.

[9] R. L. Walterscheid, "Dynamical cooling induced by dissipating gravity waves", *Geophys. Res. Lett*., vol. 8, no. 12, pp. 1235-1238, 1981.

[10] M. P. Hickey, R. L. Walterscheid, and G. Schubert, "Effects of a major tsunami on the energetics and dynamics of the thermosphere", *J. Geophys. Res., submitted*, 2009c.