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Observation and modeling of tsunami-generated gravity waves in the earth's upper atmosphere

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LONG-TERM GOALS

The long-term goal for Dr. Vadas is to determine the response of the thermosphere from $z=200-300$ km to gravity waves (GWs) excited by realistically-modeled ocean tsunami.

OBJECTIVES

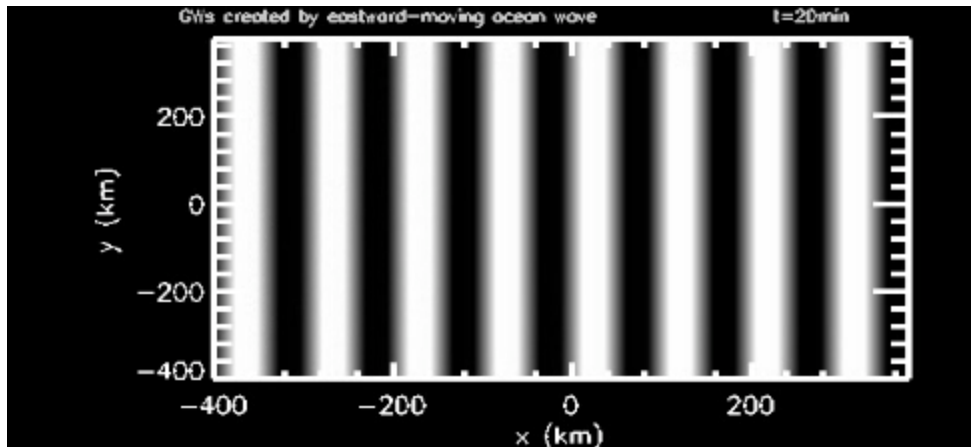
Our objectives are to build a compatible set of models which 1) calculate the atmospheric GWs excited by an ocean tsunami, 2) propagate these GWs into the thermosphere, and 3) reconstruct the GW field in the thermosphere (e.g., neutral wind, density and temperature perturbations caused by the GWs) as a function of space and time at altitudes of $z=200-300$ km. These perturbations will then be given to Dr. Makela to calculate the 630 nm airglow response to these GWs.

APPROACH

Our approach to solving this problem is to derive analytically the Fourier-Laplace compressible solutions to gravity waves (GWs) excited by fast-moving ocean waves, program these solutions into a fortran-90 model, input these excited GWs into our ray trace model, ray trace these GWs (from various locations and times) into an idealized atmosphere, reconstruct the GW field there using existing code, compare the reconstructed solutions with the exact analytic solutions for an isothermal, windless, non-viscous background atmosphere, and determine the factor needed in order to accurately normalize the GW amplitudes. We will then apply our models to several observed tsunamis (e.g., Tohoku). We will Fourier-decompose a given tsunami as a sum of plane ocean waves. We will then ray trace the GWs excited by each wave through a realistic background atmosphere (which includes variable wind, temperature and viscosity), and reconstruct the GW solution in the thermosphere. We will then add the solutions linearly to obtain the total solution. Using this approach, we will be able to calculate the total GW solution in the thermosphere generated by each tsunami.

WORK COMPLETED

As discussed in our last annual report, we derived analytically the Fourier-Laplace compressible solutions to GWs excited by a steady-state plane ocean wave in year 1. (A tsunami can be decomposed as a Fourier sum of plane ocean waves.) Those analytic solutions were successfully derived, and were implemented into a fortran-90 code. However, we found after running the model and plotting the results that we would not be able to determine the GW normalization factor needed for ray tracing because of infinite reflections of the GWs off the boundaries. This rendered those solutions unusable for our approach. In year 2, we proceeded to derive the analytic Fourier-Laplace compressible solutions to GWs excited by a plane ocean wave multiplied by an envelope having a finite duration in time. Physically, this represents a localized ocean wave with only a few peaks in time. We set up the five f-plane fluid equations with a localized periodic vertical body force at the ocean surface. This force models the displacement of air directly above a localized ocean wave packet or tsunami. We then linearized these equations, and solved them using standard Fourier-Laplace techniques (e.g., Vadas and Fritts, JAS, 2001; Vadas, JGR, 2013). We finished this derivation during the summer of 2014, and programmed the solutions into our fortran-90 code. We showed how we can reproduce a moving ocean wave using two of these solutions by having one solution 90 degrees out of phase with the other. We then created a simple movie showing the GWs excited by a plane ocean wave (see a sample screen shot below), and presented it to Dr. Makela at the COSPAR meeting in Moscow in August 2014. The advantage of this new solution is that 1) this localized ocean wave packet better-represents a tsunami, which possibly eliminates the need to Fourier sum many solutions to obtain the total tsunami solution, and 2) using this solution, it will be possible (and straightforward) to normalize the GW amplitudes for input into the ray trace model, because there will not be an infinite number of GW reflections from the boundaries because the force duration is finite.



Recently, we modified our ray trace code to input the ocean wave GW excitation solutions discussed above. We then began experimenting with “sprinkling” GWs at various locations and times at the ocean surface in order to determine the best way to reconstruct the GW field at higher altitudes after ray tracing. We also modified the subroutine which reconstructs the GW field in order to take into account the different requirements needed for the ocean wave excitation mechanism. Via experimentation, we found that when the GW frequency approaches the forcing frequency (or approaches the sum/difference with the envelope frequency), our compressible solutions “blow up”. This is similar to previous results (e.g., Vadas and Fritts, JAS, 2001), and will be rectified via deriving special solutions in these limits.

RESULTS

From the new compressible ocean wave excitation solutions, we have found that a moving ocean wave packet excites GWs with four fundamentally different frequencies. The first frequency is the same as that of the moving ocean wave. This “fundamental frequency” is the only frequency which has been modeled previously in the literature. The second and third frequencies are the sum and difference frequencies, respectively, of the plane ocean wave and the wave packet envelope frequencies. The fourth “frequency” is actually a spectrum of frequencies centered on the “characteristic frequency” determined by plugging the spatial scales of the ocean wave into the GW dispersion relation. Note that the second through fourth frequencies have not been previously modeled in the literature, but may be quite important. Because GWs with frequencies that do not equal the fundamental tsunami frequency have been observed in the 630 nm airglow emission, it is possible that one or more of these second through fourth GW frequencies may explain these additional waves in the observations. Thus, these new solutions may be quite important for understanding the complexity seen in the 630-nm observations.

WORK IN PROGRESS

We are currently working on deriving the special solutions that occur when the GW frequency approaches the plane ocean wave frequency or approaches the sum/difference with the envelope frequency. Afterward, we will program these special solutions into our GW excitation model. We will then resume ray tracing the “sprinkled” excited GWs to higher altitudes in a windless, isothermal, and non-viscous background atmosphere. Once we determine a “sprinkling” mechanism that compares well with the exact solutions, we will determine the normalization factor needed to convert the ray traced solutions to the exact solution. We will then ray trace these GWs through more-realistic background atmospheres which include variable temperature, wind, and viscosity. We will do this for different ocean wave propagation angles, and will give the results to Dr. Makela. We will also begin modeling the GWs excited by the dominant plane ocean waves in the Tohoku tsunami when the tsunami is 500-1000 km north of Hawaii. We are scheduled to present this work as a poster at the fall AGU meeting in San Francisco (December 2014).

IMPACT/APPLICATIONS

Because we are building a more realistic set of GW excitation and propagation models, our GW solutions may provide a much better understanding of how tsunamis affect the 630 nm airglow emission. This would greatly enhance our ability to detect tsunamis in the 630 nm airglow layer and in the ionosphere in general.

RELATED PROJECTS

Not at this time.

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