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Final Progress Report for NASA

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Grant Title: Wave Driven Exothermic Heating in the Mesopause Region

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Summary of Completed Project

A full-wave propagation model was developed that describes the propagation of gravity waves from the Earth's surface to the upper boundary, which can be placed anywhere between 150 and 500 km altitude. The model includes a realistic background atmosphere, and includes the effects of mean horizontal winds and their vertical shears, mean vertical temperature gradients, the eddy and molecular diffusion of heat and momentum, and the effects of ion-drag.

This model solves five coupled second-order differential equations (continuity, momentum, and energy) in the vertical coordinate to derive the perturbation variables u', v', w' (horizontal and vertical velocity components), T' (temperature) and p' (pressure). The upper boundary can be automatically selected based on tests using the radiation condition at the upper boundary, wherein the height is increased until the wave is experiencing severe dissipation at the upper boundary, ensuring that substantial absorption occurs for any waves reflected from the upper boundary.

The determination of wave amplitude is a key requirement of wave energetics. Therefore, the full-wave model has been applied to airglow observations in order to determine wave amplitudes as a function of altitude. This was accomplished by using the full-wave model output to drive a chemistry perturbation module that describes minor species perturbations and the resulting airglow perturbations. The full-wave output was multiplied by an altitude-independent factor such that the modeled and observed relative airglow intensity perturbations were equal. The effects of mean winds were included in these studies, and found to be the most important model input affecting the calculations (being more important than the choice of eddy diffusion profiles and chemical kinetic coefficients). In one study [*Hickey et al.*, 1997a] these winds could not be well estimated from the measurements, whereas in the second study [*Hickey et al.*, 1997b] the mean winds were well defined with a sodium wind-temperature lidar.

A simple wave saturation algorithm using the Lindzen approach has been included in the full-wave model, and also a scale-dependent, self-consistent diffusion algorithm was also developed and incorporated into the full-wave model. However, uncertainties associated with saturation effects have been found not to be as important as those associated with uncertainties in the mean winds.

Using our WKB model of gravity wave propagation coupled to the OH chemistry of the mesopause region we have shown that gravity waves will affect the chemical exothermic heating that occurs in the mesopause region [*Hickey and Walterscheid*, 1994]. In fact, we showed that large amplitude gravity waves can significantly mitigate the time-averaged chemical exothermic heating, thereby impacting the heat budget of the region.

We developed a 2-D, time-dependent, fully non-linear chemistry model to explore the chemical exothermic heating further. The model solves the basic equations of continuity including the effects of diffusion. The model incorporates both the $O(^1S)$ and OH chemistry, the latter including six minor species. The 2-D model solves these equations using a time-splitting technique, wherein both the global Newton method and a Lax-Wendroff method are used to advance the solutions in time. The 2-D model is forced by output from the full-wave model. We prescribe a forcing frequency as well as an envelope in the time domain that allows us to turn the forcing wave on and off again after a suitable duration of time. The complete envelope is Fourier analyzed and the frequency spectrum is truncated to allow us to simulate the time variation of the forcing with a manageable number of frequency components. We sum these steady-state components (each derived from the full-wave model) and weight them according to the previously derived spectrum. Additionally, we ensure that the wave forcing does not induce a second-order Stokes Drift by setting the Eulerian mean velocity to zero at every grid point at every time step. This work is still under development at no cost to this grant with the help of Ms. Marilyn Wellman, who is completing her Physics MS Degree.

Presentations and Publications

This grant led to numerous presentations (some invited at international meetings) and publications. A complete list follows.

Publications.

Hickey, M. P., M. J. Taylor, and C. S. Gardner, Full-wave modeling of small-scale gravity waves using ALOHA-93 $O(^1S)$ images and coincident Na wind/temperature lidar measurements, *J. Geophys. Res., in press*, 1997b.

Hickey, M. P., R. L. Walterscheid, M. J. Taylor, W. Ward, G. Schubert, Q. Zhou, F. Garcia, M. C. Kelley, and G. G. Shepherd, A numerical calculation of gravity waves imaged over Arecibo during the 10-day January 1993 campaign, *J. Geophys. Res.,102*, 11,475-11,489, 1997a.

Hickey, M. P., and J. M. C. Plane, A chemical-dynamical model of wave-driven sodium fluctuations, *Geophys. Res. Lett., 22*, 2861, 1995.

Hickey, M. P., and R. L. Walterscheid, Wave-modified mean exothermic heating in the mesopause region, *Geophys. Res. Lett., 21*, 2413, 1994.

Presentations.

Hickey, M. P., P. G. Richards, R. L. Walterscheid, and M. Wellman, A 2-D, time-dependent, nonlinear model of gravity wave-driven fluctuations in the OI 557.7 nm nightglow, *to be presented at AGU Fall Meeting, San Francisco,* 1997.

Hickey, M. P., and P. G. Richards, Time-dependent, nonlinear modeling of gravity wave-driven fluctuations in the $O(^1S)$ nightglow, *EOS Trans., 77, no. 46, F547,* 1996.

Hickey, M. P., Gravity wave dynamics in the mesopause region and related effects, (invited), *EOS Trans., 77, no. 22, W110*, 1996a.

Hickey, M. P., Gravity wave effects in the mesopause region, (invited), 12th Australian Institute of Physics Congress, Tasmania, 1996b.

Hickey, M. P., R. L. Walterscheid and G. Schubert, The propagation and dissipation of gravity waves in the terrestrial atmosphere: Full-wave versus WKB models, *EOS Trans., 76, no. 46, F436,* 1995.

Hickey, M. P., R. L. Walterscheid and G. Schubert, A numerical model of gravity wave propagation in an inhomogeneous atmosphere, *EOS Trans., 75, no. 44,* 508, 1994.