Reply

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In their comment on Nicholls et al. (1991, hereafter NPC), Pandya et al. (1993, hereafter PDB) more accurately evaluate the expression obtained by NPC for a prescribed heat source in a semi-infinite region. Their figure for vertical velocity shows that the compensating subsidence is significantly less in magnitude than the corresponding one shown in NPC. The purpose of NPC's study was to qualitatively demonstrate the characteristics of the gravity wave modes induced by a heat source or sink and to draw attention to some similarities between linear hydrostatic solutions and results of more complex numerical cloud model simulations. The analytic linear hydrostatic rigid-lid solution was only meant as a starting point, from which a systematic evaluation of the importance of effects such as nonlinearality, upward propagation of gravity wave energy, etc., could be made, by seeing how their inclusion modified the solution. Indeed, PDB use the hydrostatic rigid-lid solution as a benchmark for evaluating the importance of nonhydrostatic effects. However, the rigid-lid solution itself was not expected to give more than a very qualitative idea of the response to heat release in the real atmosphere. Although the compensating subsidence shown in Fig. 1 of PDB is considerably weaker in magnitude than the rigid-lid solution (Fig. 3 of NPC), it is worth noting that it is distributed over a broader region. The net downward displacement at $x = 100$ km and $z = 5$ km must be very similar for both cases, since the adiabatic warming at this location is almost identical. Therefore, in this respect there is a similarity between the rigid-lid solution and the semi-infinite region solution.

As pointed out by PDB, the shorter wavelength modes are associated with larger amplitude low-level vertical velocities for the semi-infinite region. Both NPC and PDB discuss the upward propagation of gravity wave energy and the resulting weakening in amplitude of low-level anomalies. However, it would be useful to obtain a more quantitative description of this process. This may not be straightforward in a purely analytical framework. One problem is that a factor of $gc_vp'/(c_pp_0)$ is neglected from the vertical momentum equation used in NPC and PDB, in order to obtain an analytic solution, which should be retained for deep vertical scales (Dutton and Fichtl 1969). Furthermore, even for the anelastic system of equations, an approximation has to be made in order to obtain a wave energy equation (Dutton and Fichtl 1969). If sound waves are not eliminated from the governing system of equations, an energy equation can be obtained without the need for the approximation (Eckart 1960). Therefore, an accurate analysis of wave energy propagation might benefit from the use of a fully compressible numerical model.

In summary, PDB extend the results presented in NPC by showing how nonhydrostatic effects modify the rigid-lid solution, formulating a better method for evaluating the solution for a semi-infinite region and pointing out some interesting aspects of this solution.

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