Comments on “Use of Ducting Theory in an Observed Case of Gravity Waves”

F. MARTIN RALPH
NOAA/ERL/Environmental Technology Laboratory, Boulder, Colorado
29 October 1996 and 19 February 1997

1. Introduction

Monserrat and Thorpe (1996, hereafter referred to as MT96) used a matrix eigenvalue method to explore gravity wave ducting, including the effects of shear in the layer between the ground and a gravity wave’s critical layer. They tested their technique under idealized conditions and then applied it to wind and temperature profiles measured during an observed gravity wave event documented earlier by Monserrat and Thorpe (1992). The fastest of the diagnosed modes matched the observed ground-relative phase speed and were non-dispersive, as was observed. The key conclusion that the wave was ducted was supported by the fact that the ducting criteria of Lindzen and Tung (1976) were met, the vertical profile of the Scorer parameter was consistent with wave propagation within the duct, and the vertical structure revealed from the eigenvalue method matched the structure expected for a ducted mode in which the vertical velocity approaches zero near a critical level. Although the MT96 exploration of wave ducting depends on interpretations of the vertical structure to eliminate some predicted modes from consideration, no observations of the vertical structure were available from their experiment for comparison. While this significant limitation has traditionally been viewed as inevitable in studies of ducted gravity waves because no direct method of observing their vertical structure was available, such measurements do now exist (Ramamurthy et al. 1990; Koch et al. 1993; Ralph et al. 1993). These include an observation that closely matches the structure predicted by MT96 in a separate but similar event (Ralph et al. 1993).

The goal of this comment is to perform a comparison, which is absent from MT96, between the waves they studied and the event documented by Ralph et al. (1993). This comparison strengthens key conclusions in MT96 by providing some verification of their predicted vertical structure in a phenomenon for which such direct observational verification had not yet been demonstrated.

2. Comparison of the vertical structure predicted by MT96 with that observed in a similar case

Figure 1a, which is reproduced from MT96, shows the vertical structure of the neutral mode with the longest wavelength that has a phase speed matching the observed phase speed. This structure represents a neutral eigenmode determined by applying the matrix method to a vertical sounding closest to the time the waves were observed (Monserrat and Thorpe 1992). Although the actual amplitude of the vertical motion remains arbitrary in this method, the structure clearly contains an antinode near 1.5 km and nodes at the surface and at 3.2 km, very near the base of the critical layer (as defined here by the layer with wave-parallel wind speed within 1.5 m s\(^{-1}\) of the observed phase speed). A second, weaker vertical velocity maximum extends upward into the broad critical layer.

Ralph et al. (1993) used direct measurements of vertical air motions made by a 50-MHz clear-air Doppler radar (wind profiler) to document a similar mesoscale gravity wave’s vertical structure (Fig. 1b). The radar sampled every 1–3 min with 750-m vertical spacing. Pressure and wind measurements from a nine-station surface mesonetwork determined the wave period and phase velocity, and serial rawinsonde ascents (seven over a 12-h period) allowed for a uniquely complete assessment of the ducting criteria of Lindzen and Tung (1976). The observed conditions, including the vertical structure, were found to be consistent with the conclusion that the wave was ducted. The most distinct features of the observed vertical structure (Fig. 1b) are a node at roughly 4.5 km and two antinodes near 2.7 km and 5.5 km. Although no vertical velocity data were available below 1.8 km, a node is also inferred near the surface. Uncertainty is present in the vertical positions of the nodes and antinodes due to the 750-m vertical sampling. The wave amplitude before bandpass filtering
was roughly 50 cm s$^{-1}$ at the antinode. Based on the observed vertical motions, horizontal wind profile, temperature profile, and ground-relative wave phase velocity, it was shown that the wave should have produced a surface pressure perturbation of about 2 hPa, which compared favorably with the observed 1.6-hPa peak-to-peak amplitude. This provided an independent cross-check of the measured vertical structure.

Comparing Figs. 1a and 1b reveals how similar the observed structure from Ralph et al. (1993) is to the structure predicted by MT96 for their case. Both show a wave contained primarily below the base of the critical layer, with a node near the bottom of the critical layer (within approximately one range gate in Ralph et al. 1993) and a weaker antinode within the lowest portion of the critical layer. Indications of these features are also found in the predictions of vertical structure in studies by Koch et al. (1993) and Ferretti et al. (1988), although Ferretti et al. (1988) also predicted a second node and third antinode below the critical level.

To assess the applicability of the results from Ralph et al. (1993) to the MT96 case, it is important to determine whether the events were similar in other ways as well. The wave packet observed by Monserrat and Thorpe (1992) and used in MT96 had wavelengths from 20 to 90 km, periods of 10–60 min, ground-relative phase speeds of 29 m s$^{-1}$, and peak-to-peak pressure amplitudes of 1.5–2.5 hPa. The wave documented by Ralph et al. (1993) had a wavelength of 76 ± 11 km, a period of 90 ± 5 min, a ground-relative phase speed of 14.8 ± 1.8 m s$^{-1}$ (based on three independent methods of estimating phase speed), and 1.6-hPa peak-to-peak amplitude. Although the ground-relative phase speeds and wave periods differed substantially between the two cases, the wavelengths and amplitudes were similar.

The background static stability profiles were also similar in that there was a relatively stable layer in the lowest 2–3 km, capped by a layer of much weaker static stability above that. While the static stability within the duct was nearly the same in both cases, the stable layer was deeper in MT96, which contributed to the greater phase speed in MT96. The vertical profiles of the horizontal wind parallel to the direction of wave propagation in each case contain a region of rather uniform vertical shear, which MT96 concluded was a significant feature, capped by a layer of very weak shear above 3–4 km. This is highlighted in Fig. 2, using one of three wind soundings during the wave passage from Ralph et al. (1993). (The two other soundings also contain a sheared lower layer and a critical layer above.) In both studies the upper layer of weak shear also corresponds approximately to the phase speed of the gravity wave and thus represents a vertically broad critical layer. Although it has not yet been explored, the presence of this broad critical layer in both events suggests that the broadness may be important in wave ducting.

While deep convection was present in the Ralph et al. (1993) case, none was present in the MT96 event. Thus the similarities between the wave structures documented in each case suggest that deep convection is not a prerequisite for the development and propagation of such mesoscale ducted gravity waves. The concept that gravity waves and latent heating within a storm can
create confusingly similar signatures in time series of surface pressure was explored recently by Browning and Kreiss (1997) using idealized and numerical simulation techniques. They also concluded that noise in wind profiler measurements makes observations of gravity waves very difficult with such instruments, a conclusion that runs counter to the results described here and to other wind profiler studies of gravity waves.

3. Conclusions

Although MT96 present a compelling argument that the event they studied was a ducted wave, their study lacked observation of the wave’s vertical structure, a shortcoming characteristic of most studies of mesoscale ducted gravity waves. However, observations by Ralph et al. (1993) provide unique documentation of this vertical structure that could have been used to compare with the MT96 predicted structure. Although the studies are based on different events, the key wave parameters of amplitude and horizontal wavelength are similar, as is the presence of a vertically broad critical layer, strong vertical shear within the duct, and a statically stable lower troposphere. The remarkable similarities between the MT96 predicted vertical structure and the observed vertical structure give more credence to the predicted structure than has been possible in other studies and thus would have been useful for MT96 to describe. The point of this comment has been to highlight those similarities and thus to illustrate the satisfying convergence of observations and theory 20 years after the ducting criteria were first clearly elucidated by Lindzen and Tung (1976).

Acknowledgments. Reviews by Drs. Ola Persson and Earl Gossard are appreciated. I also wish to thank Drs. Sebastian Monserrat and Alan Thorpe for agreeing with the contents of this comment.

REFERENCES


