ATMOSPHERIC GRAVITY WAVES: OBSERVATIONS AND THEORY

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Abstract

Theoretical and observational aspects of gravity wave motions within the lower and middle atmosphere are addressed in this thesis. The opening chapter provides a non-technical review of these waves in atmospheric settings, giving particular emphasis to the important role these waves play in a variety of fluid-dynamical processes in geophysics and astrophysics. Chapter 2 sets forth selected aspects of the theory of atmospheric gravity waves which are drawn from in later chapters.

Remaining chapters comprise the body of the research work. Arguments are developed in Chapter 3 which advise care in the analysis of small-scale atmospheric fluctuations. If one assumes that these perturbations are produced by gravity waves, in almost all cases a spectrum of many waves exists, and it is shown that analysis based on monochromatic premises can produce (and has produced) misleading results. Furthermore, there is currently debate as to whether atmospheric fluctuations are indeed due to gravity waves, or whether quasi two-dimensional turbulence (also known as vortical modes) produces most of the variance. Experimental assessment of these two theories has centred on comparing the power spectra of these fluctuating fields with the separate spectral predictions of gravity-wave and vortical-mode theory. However, observations also imply that these spectra must be nonstationary, and simulations reveal that experimental spectra can be distorted from the stationary theoretical predictions, making comparisons with theory ineffectual. A non-spectral statistic is developed to provide more stationary experimental evaluations of the competing theories.

In Chapter 4, this newly-developed theoretical test is applied to time series of atmospheric wind velocities measured in the lower atmosphere (2–12km height range) with a VHF radar system. The analysis reveals that these fluctuations are consistent with gravity waves, and inconsistent with quasi-two-dimensional turbulence. These observations were conducted during the passage of cold fronts, and strong correlations between these frontal passages and bursts in gravity-wave energy are presented and analyzed.

It was argued in the previous two chapters that distortion of gravity-wave frequency spectra at mesospheric heights (60–90km) should not be severe, and this is assessed experimentally in Chapter 5 by spectrally analyzing a large base of wind data from this region, as measured with an HF radar system. The observations confirm that distortions are not significant, and in the process some important characteristics of the wave field at these heights are brought to light.

Upper-stratospheric heights (20–60km) cannot be probed by radar, and so information on gravity

wave characteristics here is limited. However, rockets have probed this region for many years from a number of sites around the world, and these data are analyzed in Chapter 6 for evidence of gravity wave motions. New and important information on seasonal variations in the amplitudes and propagation directions of gravity waves are obtained, and the significance of some of these new findings is discussed.

These observations, together with others performed elsewhere, have now resolved some basic features of gravity waves in the middle atmosphere. Surprisingly, many of these characteristics have yet to be explained. In Chapter 7, simple ideas are developed which are used to explain observed seasonal variations of gravity wave amplitudes. However, these same arguments cannot explain the geographical variability evident in measurements. The theoretical investigation is therefore extended through the use of a more complex numerical model, which simulates gravity wave propagation through the zonally–averaged middle atmosphere. The model is used to help explain various observed features of middle–atmospheric gravity waves, and deliberately avoids including any initial amplitude or wave–propagation anisotropy, so that any such anisotropy which subsequently arises must be due to propagation effects. Results from model simulations support more rigorously the simple earlier arguments as to the origin of the seasonal variations in wave activity. However, the model also produces information on many other gravity–wave parameters, and these findings are compared with available measurements, with apparent agreement in some cases. The model also highlights, and enables investigation of, an important physical process by which horizontal wavelengths and ground–based phase speeds can change due to horizontal refraction of the wave.

In its entirety, this work provides not only observational information on the nature of gravity waves in a number of different regions of the atmosphere, but in all cases theoretical analysis of these data casts light on some of the processes which act to produce this observed structure.