Rayleigh-Lidar Observations of Mesospheric Instabilities

Gabriel C. Taylor
Durga N. Kafle
Vincent B. Wickwar
Utah State University

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Gabriel C. Taylor, Durga N. Kafle and Vincent B. Wickwar
Physics Department and Center for Atmospheric and Space Sciences (CASS)
Utah State University, Logan, UT

INTRODUCTION

We usually think of the atmosphere as being horizontally stratified with a balance between gravitational and pressure forces. This balance can be perturbed by wind blowing over mountains, by storm systems, and by the jet stream. When this happens, the perturbation can lead to the generation of buoyancy or "gravity" waves. Examples are shown for 2 nights in Figure 2. On the left the waves have a vertical wavelength of ~10 km, on the right ~15-20 km. The maximum frequency of these waves is given by the Brunt-Väisälä frequency, \( N \), which is calculated from

\[
N^2 = \left( \frac{g}{c_p} \right) \left( \frac{\partial T}{\partial z} \right) - \frac{g}{\rho_0} \frac{\partial \rho}{\partial z}
\]

where \( T(z) \) is the temperature profile, \( g \) is the gravitational acceleration, and \( c_p \) is the specific heat at constant pressure. \( N \) is typically the order of 3.0 \( \times \) \( 10^2 \) Hz or 1.9 \( \times \) \( 10^2 \) radians/s. The corresponding minimum period for these waves is 5.6 minutes. The figure shows \( N^2 \) taking on larger values when the temperature is increasing with altitude and smaller values when the temperature is decreasing particularly rapidly with altitude. These swings between large and small values increase with the wave amplitude and, hence, with increasing altitude.

ABSTRACT

Abstract: From 1993 to 2004 the Utah State University Rayleigh lidar, known as the USU green laser, collected 900 nights of data from the mesosphere (45-90 km). From these observations profiles of relative neutral densities and absolute temperatures were derived. Usually, the atmosphere is horizontally stratified with a balance between gravitational and pressure forces. When this balance is perturbed, it leads to the generation of buoyancy or "gravity" waves. An example of these is clear air turbulence, which can have dramatic effects on airplanes. As these waves propagate upward, the decrease in atmospheric density and conservation of energy combine to give rise to a large increase in amplitude. These growing waves can become large enough that they "break," giving up their energy to the surrounding atmosphere. The common analogy used here is that of ocean waves in which the waves break near shore. One manifestation of this in the atmosphere is the occurrence of an instability, the convective instability. With this instability detected in the lidar data on several nights, it has become the focus of this work. It is characterized by the buoyancy frequency, the Brunt-Väisälä frequency, becoming zero or imaginary.

PROCEDURES & OBSERVATIONS

Approximately 600 all-night integrations were examined to look for cases of zero or negative \( N^2 \). Using very conservative criteria, such \( N^2 \) values were found on 1% of the nights. They appear to be associated with relatively isolated temperature increases, which are often referred to as mesospheric inversion layers (MILs). Two spring examples are shown in Figure 3 and two fall examples are shown in Figure 4. While none of these examples show strong wave activity at all altitudes as in Figure 2, three of the four show a strong wave at higher altitudes and three of the four show some indication of small amplitude wave activity at lower altitudes. Whatever the conditions, what these nights have in common is a very strong negative temperature gradient just above the peak temperature in the MIL. The gradient is negative enough that near 76 km \( N^2 \) is zero or negative for the whole night.

CONCLUSIONS

Previously, Kafle and Wickwar have found in long, climatological averages that the mesosphere is stable. However, in examining shorter, all-night averages, we have found that on about 1% of the nights, the temperature gradient is so negative that \( N^2 \) is zero or negative for the whole night. Under these conditions, a convective instability is set up and the gravity waves break, giving up much of their energy to the surrounding atmosphere. In these examples, this occurs at ~76 km. In future analyses, we will use shorter integration times to see if more unstable regions can be detected.