A1.6 Observational Studies on the Coupling of Dynamical and Chemical Processes In theMiddle Atmosphere

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Abstract

Temperature profiles collected with the NIES ozone lidar system are used for the study of gravity waves in the middle atmosphere. The study implies that the vertical variation of the amplitudes of temperature/density perturbation profiles is an important tracer of gravity waves in the middle atmosphere. It is observed that the vertical growth of the potential energy spectral density ceases near the broadband convection instability saturated limit. The study also focuses the role of structure of the stratopause in upward propagation of gravity waves. It suggests that large time variations in the gravity wave activity in the mesosphere can be correlated with variations in the stratopause structure.

Keywords: Rayleigh lidar, Temperature, Gravity waves

1. Introduction

Gravity wave studies are well placed among the middle atmospheric researche community due to the important role that the internal gravity waves can play in influencing the state of the middle atmosphere by their ability to generate turbulence and to contribute to the energy and momentum budget of the middle atmosphere. A number of theoretical as well as experimental investigations have taken place in this direction (e.g. Holton, 1982; Matsuno, 1982; Tsuda et al., 1990; Namboothiri et al., 1996). In the experimental side, until recently radar studies were the major sources of information. Lidar observations have now proven their capability in determining the gravity wave characteristics. Density and temperature profiles obtained by lidar have been used for the study of gravity waves in the middle atmosphere (e.g., Mitchell et al., 1990; Whiteway and Carswell, 1995). High temporal and spatial profiles produced by lidars have particular advantage in determining the gravity wave characteristics. Mesoscale fluctuations observed in the density and temperature profiles are being interpreted as induced by the atmospheric gravity waves. The gravity wave field is characterized by the temporal and vertical variation in the amplitude of fractional temperature perturbation, associated available potential energy density, and vertical wavenumber spectra.

The ozone lidar observation at the National Institute for Environmental Studies (NIES), Tsukuba is continuing on routine basis. The system was intended primarily for stratospheric ozone Differential Absorption Lidar (DIAL) measurements but is also used simultaneously as a Rayleigh lidar. This lidar observations now contribute significantly to the global ozone monitoring program, the international Network for the Detection of Stratospheric Change (NDSC) (Kurylo and Solomon, 1990). The instrumentation, measurements, and analysis technique are described elsewhere (Sugimoto et al., 1989; Nakane et al., 1992; Namboothiri et al., 1999). In the present study 33 temperature profiles collected during the winter seasons of 1995 and 1996 have been used. Majority of the profiles were suitable for gravity wave studies. The observations carried out here, being only of temperature/density fluctuations, will be interpreted mainly with regard to the linear instability theory.

2. Results and Discussion

The observation on 20 December 1995 is chosen to illustrate the vertical structure and temporal variability of temperature fluctuations in the 30- to 60-km height region. Figure 1 shows sequences of half-hour (~33 min) average temperature profiles for that night. Vertical smoothing was applied here using a running mean over 12 points (1.8 km). The inner and outer lines represent the measurement uncertainty. The short average temperature profiles can be used to identify regions of convective instability by comparison with the adiabatic lapse rate.

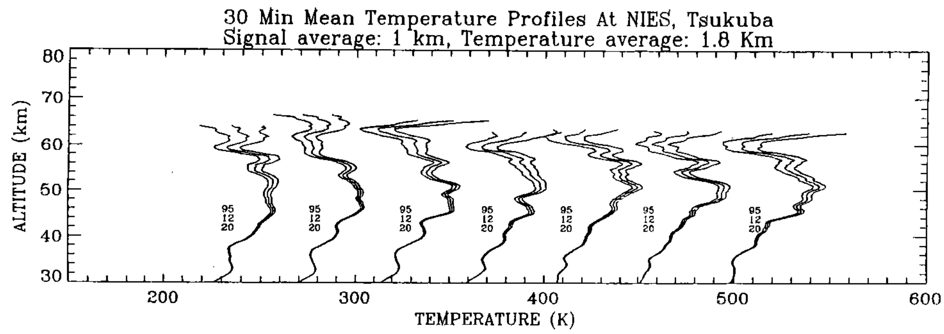

Fig. 1. Sequence of half-hour average temperature profiles for the night of 20 December 1995. Labels on the temperature scale refer only to the first profile, while subsequent profiles are shifted by 45 K. Inner and outer lines represent the measurement uncertainty.

Atmospheric internal gravity waves were observed in profiles of fractional temperature perturbations, T'(z)/T0(z). Perturbations T'(z)=T(z)-T0(z), were extracted from half-hour average temperature profiles by approximating an unperturbed background state, T0(z). This was accomplished by fitting a third order polynomial fit to the unperturbed background state. Figure 2(a) shows the nightly mean temperature profile derived for 20 December 1995, together with the estimated unperturbed background temperatureprofile (dashed line) for that night. Also given in Figure 2 are the half-hourly fractional temperature perturbations, which correspond to the profiles shown in Figure 1. There is a wavelike disturbance growing in amplitude with height. A distinct dominant vertical wavelength was often observed in a given profile, but there was significant variability within an observational period of several hours. Generally a random superposition of vertical wavelength less than 10 km is observed. Vertical phase propagation apperars to be downward, implying upward group velocity. An accurate measurement of vertical phase velocity was generally not possible.

The nightly mean vertical wavenumber potential energy spectra and density perturbations, computed over the altitude intervals 30-45 and 45-60 km, are shown in Figure 3. An interval of 15 km was required to observe the longest vertical wavelength components. Also given along the spectrum is the linear instability spectral model (Dewan and Good, 1986; Smith et al., 1987). The potential energy spectral density for saturated vertical wavenumber m is of the form N2/10m3, which is the convective instability limit. Vertical growth of spectral density at a given wavenumber, within a broad spectrum, will cease at this convective instability limit.

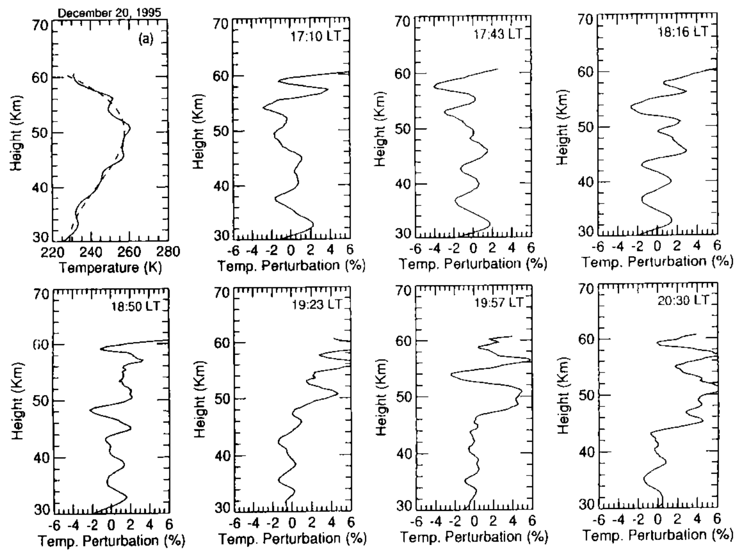

Fig. 2. Nightly mean temperature profile with estimated background state for 20 December 1995. Also shown are the fractional temperature perturbation profiles corresponding to the temperature profiles of Figure 1.

Density perturbations shown in the left panel show clear wave motion with their amplitude increasing with altitude, especially at the upper altitudes. The spectra reflect the general characteristics of Figure 1 and 2. Vertical growth in spectral magnitude is observed mainly at the smaller wavenumbers. At the lower altitudes the spectral magnitudes seen below the convective limit and at the hight altitude interval it has attained values equivalent or slightly above the convective instability limit. For example, the spectral amplitude for m=2x10-4 c/m (or 5 km in vertical wavelength) showed an increase with the altitude, i.e., they were 3 x 104 m3s2 in the lower height interval, increased to nearly 2 x 105 m3s2 in the upper height layer. Analysis of the short averaged profiles (Figure 1) indicates that there was considerable variability in the distribution of spectral energy over the period of observations. One or more dominant wave components are usually seen and it points out that the nightly mean spectra cannot be considered generally as a representation of the wave field at any particular instant. Also we have observed significant day-to-day variations. Observations at other sites also reported similar variations as well as seasonal variations (Mitchell et al., 1990; Wilson et al., 1991). Since we have the data only for the winter season, we couldn't conduct a study on the seasonal variation of gravity wave activity.

20 December, 1995

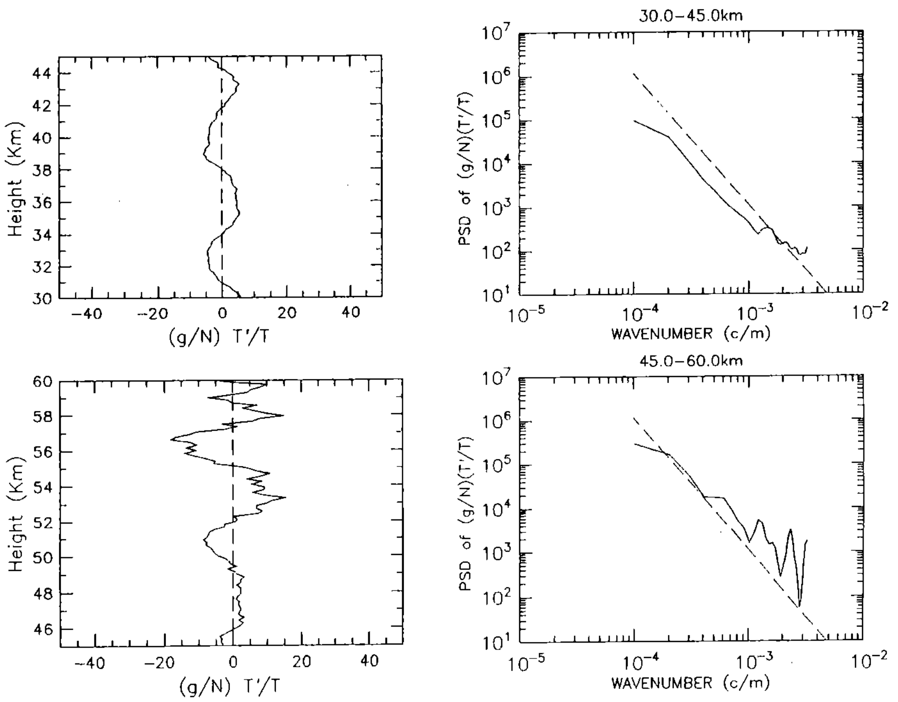

Fig. 3. Density perturbation profile and nightly mean vertical wavenumber potential energy spectra computed foe the 30-45 and 45-60 km altitude region for 20 December 1995. The broadband convective instability (dashed line) limit is also given.

Next we would like to focus on the significance of the stratopause on the upward propagation of gravity waves. The available data have been classified into to groups: the normal stratopause days and peaky (warmer) stratopause days. Here the average temperature for normal stratopause days is 260 K and that for peaky stratopause days is nearly 275 K. We study here vertical structure of the density variance focussing the effect of the decrease of yhe static stability near the stratopause on the upward propagation characteristics of gravity waves.

Figure 4 and 5 represent the temperature (T), Brunt-Vaisala frequency squared (N2), and density variance (r'/r)2 profiles for the normal stratopause days and peaky stratopause days, respectively. In the plots dashed curves show the hourly mean values and the solid line is their median values. Brunt-Vaisala frequency is derived from the vertical temperature gradient. Comparing the Figure 4 and 5, it can be seen that there is a big difference in the patterns of N2 and the density variance profiles. In the case of peaky stratopause days the stratopause with a temperature of 275 K is detected at 45-46 km, coinciding with a sharp decrease in N2 values.

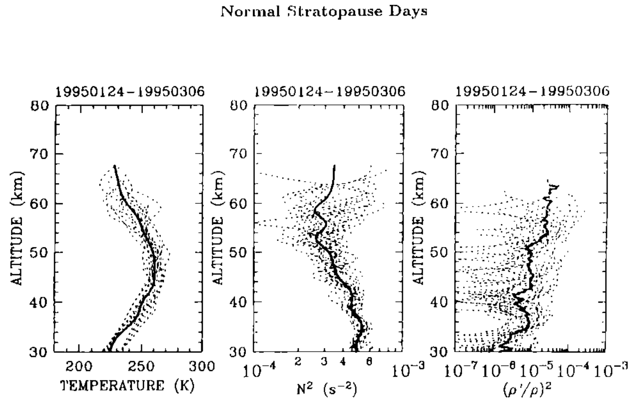

Fig. 4. Profiles of T, N2, and (r'/r)2 for normal stratopause days. Dashed curves are the hourly mean values and the solid curves is their median values.

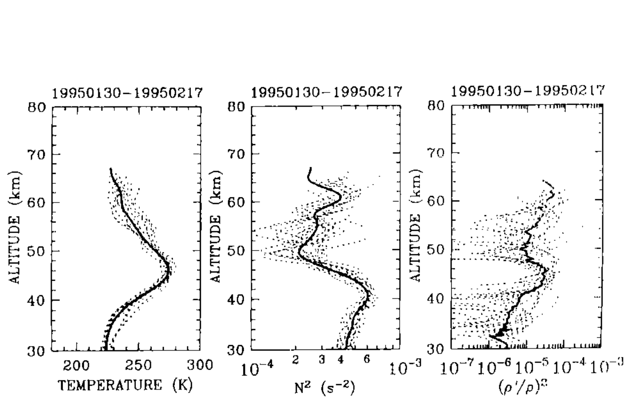

Fig. 5. Same as Figure 4, but for the peaky stratopause days.

In Figure 4 the density variance is found to increase in the sampled height region. However, when the stratopause is peaky (Figure 5) it is noted that it increases almost linearly in the 30-45 km, and then abruptly decreased above the stratopause and again grows above 50 km. To summarize these features, it seems obvious that the propagation characteristics of the gravity waves are largely affected by the temperature structure near the stratopause, or more explicitly by the height variation of the static stability there. This study leads to the important point that the gravity wave energy, passing through the stratopause into the mesosphere, can be controlled by the stratopause structure. Large time variations in the gravity wave activity in the mesosphere might be correlated with variations in the stratopause structure.

3. Concluding Remarks

In this report, we focus the study of temperature/density fluctuations in the upper stratosphere and lower mesosphere with vertical and temporal scales that are characteristics of internal gravity waves. We have used two successive winter seasons (1995 and 1996) observation data which compile 33 nights temperature records. The study draws features of gravity wave propagation. Temperature perturbations observed show the wave activities, increasing the wave amplitude from the lower altitude to the upper altitudes. Spectral studies identified the dominant wave activities in the upper stratosphere and lower mesosphere. It is found that waves with small vertical wavelength get saturated in the lower altitudes. Density variance studies point out that the structure of the stratopause can control the gravity wave propagation from the stratosphere to the mesosphere.

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