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Simultaneous Observations of Mesospheric Gravity Waves with the MU Radar and a Sodium Lidar

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Abstract

Simultaneous observations of mesospheric gravity waves have been carried out using meteor wind measurements with the MU radar at Shigaraki (34.9°N, 136.1°E) and density perturbations of the Sodium lidar at Hachioji, Tokyo (35.6°N, 139.4°E). Using hodograph analysis, the dominant gravity wave was found to exhibit a vertical wavelength of 16 km, an intrinsic period of 9.1 hr and a horizontal wavelength of about 1900 km. Employing the dispersion and polarization relations for linear gravity waves, the wave-induced neutral density perturbations from the MU radar observations were estimated. A comparison with the corresponding density perturbations derived from the sodium density measurements showed good agreement. The amplitude and phase of the neutral density perturbations observed at both locations, which are separated by 310 km, were similar. Time variations of the hourly variance of the density perturbations also agreed quite well between the two independent determinations, which again supports that the radar and the lidar detected the same gravity wave.

1 Introduction

In recent years a significant effort has been made in quantifying the general characteristics of middle atmosphere gravity waves. Theoretical studies as well as a variety of experimental techniques, including in-situ and remote sensing methods, have achieved a great deal of success in helping to clarify the morphology and dynamics of gravity waves. Radar studies, especially, contributed much in explaining the important role played by gravity waves in the large-scale circulation and in the structure of the middle atmosphere [e.g., *Tsuda et al.*, 1990]. Lidars have recently proved to be a very powerful technique to measure the small scale fluctuations in the middle atmosphere [e.g., *Gardner and Voelz*, 1987].

The radar and lidar gravity wave studies have concentrated mainly on individual stations. Since gravity waves of large horizontal structure do exist, simultaneous observations at different locations are very important in order to understand their horizontal propagation characteristics. In this respect, collaborations between the Radio Atmospheric Science Center (RASC) and Tokyo Metropolitan University (TMU) were arranged and simultaneous mesospheric observations made using the MU radar at Shigaraki (34.9°N, 136.1°E) and the sodium density observations using the Sodium lidar at Hachioji, Tokyo (35.6°N, 139.4°E). These two locations, illustrated in Figure 1, are separated by a horizontal distance of 310 km, which is normally shorter than one horizontal wavelength of a large scale gravity wave. In this paper a comparison has been made of gravity wave events at the two locations by taking advantage of the data collected simultaneously with the MU radar and the Sodium lidar.

2 Experimental Setup

(a) MU Radar Observations

In order to observe mesospheric heights simultaneously with the lidar, the MU radar was operated at night in the meteor echo mode, since the turbulence echoes are normally detected only during daylight

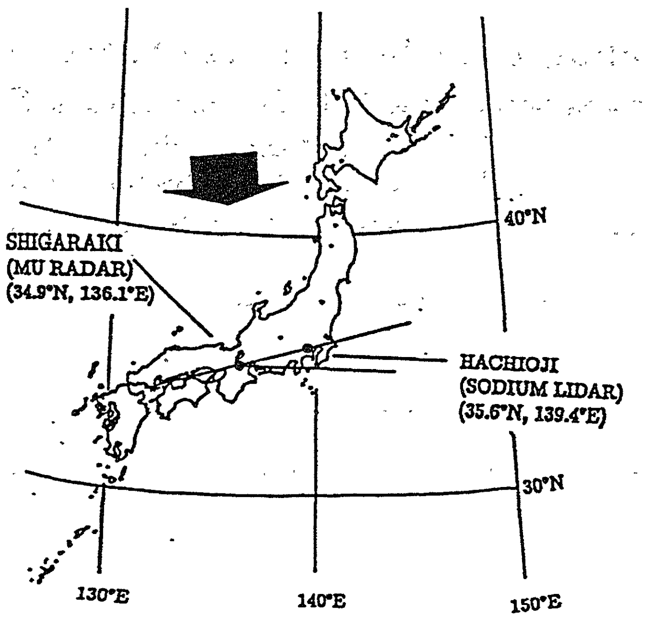

Fig. 1. Locations of the MU radar and Sodium lidar. The base line and the horizontal make an angle of 14.5°. The big arrow schematically indicates the horizontal propagation direction of the gravity wave detected on Dec. 15–16, 1993.

hours. The horizontal wind components are determined from the Doppler velocity shift of the meteor echo, with time and height resolution of 1 hour and 1 km, respectively. The MU radar observations were carried out for 65 hours from 1700 LT on Dec. 13 to 1000 LT on Dec. 16, 1993. The data used for gravity wave analysis, are only from 7 hours of observations on the night of December 15–16, 1993, when simultaneous measurements between the MU radar and the sodium lidar were successfully conducted.

(b) Sodium Lidar Measurements

The sodium lidar was recently installed and operated at the Tokyo Metropolitan University. The details of the system specifications and the method of data analysis are reported in *Nagasawa and Abo* [1994]. The Na density measurements can be used effectively to deduce the atmospheric density perturbations. When the wind perturbations are caused by gravity waves, the relative Na density fluctuations are related to the relative atmospheric density perturbations.

3 Hodograph Analysis of Gravity Waves

We concentrate here on the effects of gravity waves on the structure of a sodium layer. In order to search for large scale gravity waves we have examined 4 nights of the MU radar observations. Unfortunately we only found one night (15–16 December, 1993) data which was dominated by a single wave. Consequently those data have been chosen for our detailed analysis. Similarly for the lidar data we have selected the period from 2200–0500 LT when the superposition of waves was not significant.

Figure 2 shows a typical hodograph and height profile of the gravity wave of interest for 0200 LT on December 16, 1993. As is evident in Figure 2, the wind vector rotates in the clockwise direction with an increase in altitude, indicating a positive vertical group velocity. The ability to fit the winds to an ellipse indicates that a monochromatic gravity wave is dominant and such a wave is observed in all the hodographs except at 0500 LT. The horizontal propagation direction, found to be in the north-south direction, is consistent in all the other hodographs. The exact propagation direction is, however, unable to be determined by using a hodograph, but it can be inferred from the phase relations between the horizontal wind components and the temperature perturbations. It is found that the wave propagated from north to south. The figure is indicated with the azimuth of propagation. The arrow in the figure represents the direction of propagation of the wave.

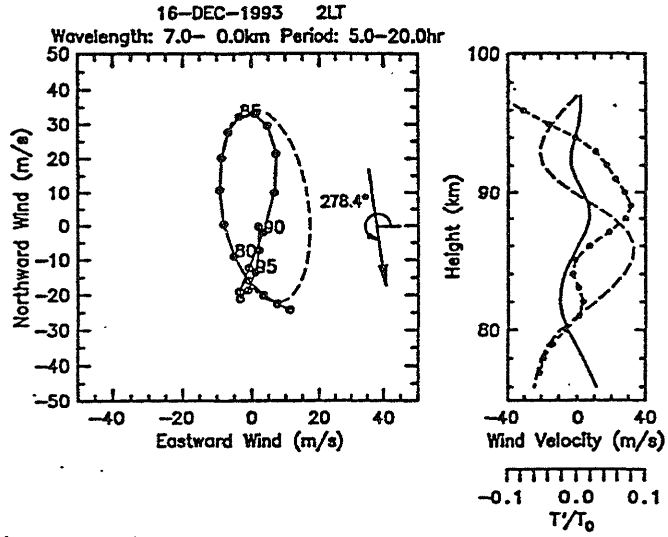

Fig. 2. The hodograph and height profile obtained at 0200 LT on December 16, 1993. Only wave components with periods of 5–20 hr and vertical wavelength longer than 7 km are retained. The numbers and the dashed ellipse in the left panel indicate the height in km and the least squares fit to the hodograph, respectively. The azimuthal angle is also given in the left panel. The arrow indicates the horizontal propagation direction of the gravity wave. In the right panel the fluctuations of eastward (solid line) and northward (dashed) winds, and temperature (dashed line with solid circle) are given.

4 Comparison Between the MU Radar and the Lidar

Our major interest here is to compare the wave induced neutral density perturbations calculated from the radar data to the atmospheric density perturbations obtained with the sodium lidar observations. The derivation of the density perturbation is based upon the gravity wave dispersion and polarization relations.

Figure 3 is a composite picture of the density perturbations estimated from the MU radar and the observed values from the lidar. The continuous curve indicates the MU radar observations and the dashed curve represents the lidar measurements.

Comparison of the profiles reveals qualitative agreement between the two observations with all but the 0500 LT profile showing good resemblance. The phase descent of both profiles also is quite similar. It should be remembered that there is a difference in the height resolution of the two databases and also that a time-series filtering for the lidar data has not been performed due to the limited number of hours of nighttime observations. Bearing this in mind, a smoothed pattern of the lidar profiles will give even better agreements with the MU radar profiles. It is also important to note that the density perturbations observed at both locations are very similar with a maximum value of ~7%.

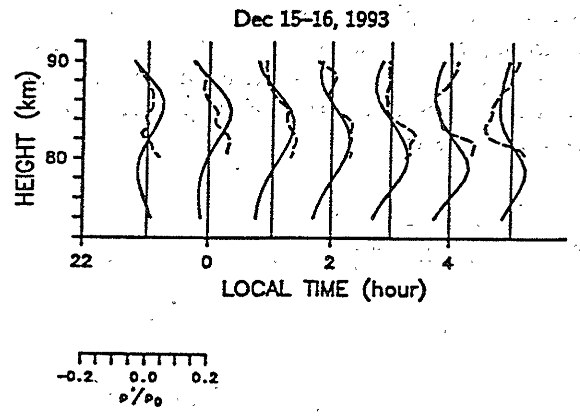

Fig. 3. Time-height variations of the atmospheric density perturbations obtained from the MU radar and sodium lidar, for December 15-16, 1993. The solid and dashed curves represent the MU radar and lidar observations, respectively.

We have analyzed the variance of the neutral density fluctuations caused by gravity waves. It is observed that a good agreement between the two observations, the time variations show a nearly identical response at both locations and so reaffirms the hypothesis that the same gravity wave is being observed over Shigaraki and Hachioji.

5 Concluding Remarks

The present study focussed on the comparison of observations of mesospheric gravity waves by means of the MU radar and the Sodium lidar. We used 7 hours of data collected simultaneously on the night of December 15–16, 1993. The study aimed at analyzing a dominant monochromatic gravity wave event at both the radar and lidar sites which are separated by a horizontal distance of 310 km.

The dominant gravity wave and its characteristics were delineated by using a hodograph analysis, which revealed that the wave propagated with an average vertical wavelength of 16 km, an intrinsic period of 9.1 hr and a horizontal wavelength of 1900 km. We furthermore detected that the gravity wave showed upward energy propagation, and that it propagated southward.

The comparison of the density perturbations obtained by the MU radar and the sodium lidar observations indicated very similar responses at both locations. The density perturbations showed a maximum of 7% at the two sites and the observed similarities were an indication that the same gravity wave was being detected. The variance analysis conducted for the density perturbations also showed very good agreement in temporal variations, which is additional support for the view that the radar and lidar observed the same gravity wave.

References

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