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GRAVITY WAVES OBSERVED BY THE JICAMARCA VHF RADAR IN THE EQUATORIAL UPPER STRATOSPHERE

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1. INTRODUCTION

Internal gravity waves are known to play an important role in dynamics of the middle atmosphere. They can transport momentum flux from lower atmosphere to upper atmosphere and sometimes break mean flows or large-scale long-period motions due to dissipation process associated with wave flow interaction. However, an entire profile of short period gravity waves has not yet been obtained, since it has been very difficult to detect extremely weak atmospheric echoes from so-called "gap region" of 30-60 km heights.

Recently, the Jicamarca VHF radar system in Peru (*Woodman and A.Guillén*, 1974), which is one of the largest high-power VHF/UHF radars in the world, has been greatly improved in height resolution, and reliable atmospheric echoes have been, for the first time, detected in the gap region by the Jicamarca radar with the high-altitude resolution (500 m). This paper presents new observational results on the upper stratospheric short-period vertical wind oscillations, which have never been resolved by the VHF/UHF radars other than the present revised Jicamarca radar.

2. OBSERVATIONAL RESULTS

2.1. *Vertical Wind Measurements*

The observations were conducted on September 24 - October 2, 1990. The radar antenna consists of two collocated crossed-dipole arrays with a square of 288 m which contains 9216 half-wave (3 m) dipoles. The co-pol array was excited by the peak output power of 1.3 MW, while the echoes were received by both arrays, because the orthogonal array was used to monitor clutter echoes which may enter the antenna sidelobes (*Sato and Woodman*, 1982). The antenna beams were pointed to the vertical direction. Other detailed observational techniques were described elsewhere (*Maekawa et al.*, 1993).

It has been shown that the vertical wind oscillations with periods of less than 1 h have a fairly continuous phase in heights and vertical wave lengths of longer than 20-30 km (*Maekawa et al*, 1994a, b). Also, spectral analysis in time domain has revealed that these oscillation have similar short-period components from the lower stratosphere to the mesosphere, and that the same wave modes exist in all the height ranges.

2.2. *Height Profile of Vertical Wind Oscillation*

Figure 1(a) shows a height profile of the standard deviation of the short-period vertical wind oscillations observed on Sept. 28, 1990. The height profile is, as a whole, inversely proportional to the square root of the atmospheric density: $\rho^{-1/2}$

(*CIRA*, 1986) as indicated by a dashed line in the entire height range of 20-80 km. Thus, the energy of these waves is not very much dissipated in the upper stratosphere. Figure 1(b) illustrates the height profiles of the standard deviation normalized by the inverse square root of the atmospheric density; $\rho^{-1/2}$ that corresponds to the constant wave energy level. Note that the amplitude profile reveals a distinct node around 30 and 60 km heights. Similar features are also found for the observational periods on Sept. 27 and Oct. 2, 1990. This characteristic height profile seems to indicate standing wave structure due to upward and downward propagating waves, since the boundary condition may be satisfied on the ground where the vertical oscillation needs to be diminished.

The vertical wavelength of the waves is inferred to be about 60 km, but it is not easy to resolve such a component by a spectral analysis, as this scale is similar to the entire observational height range from 20 to 80 km. In this case, a predominant vertical scale component is estimated by the least-squares fit of sinusoids for the individual height profiles. The sinusoids with vertical wavelength from 20 to 100 km are successively fitted to each normalized height profile obtained at 5 min intervals, and the average ratio of residual to amplitude is evaluated for the fitted sinusoids. The results are shown in Fig.2. It is found on all the observational days that the ratio is minimized around the vertical wavelength of 60 km, indicating the presence of this vertical scale component.

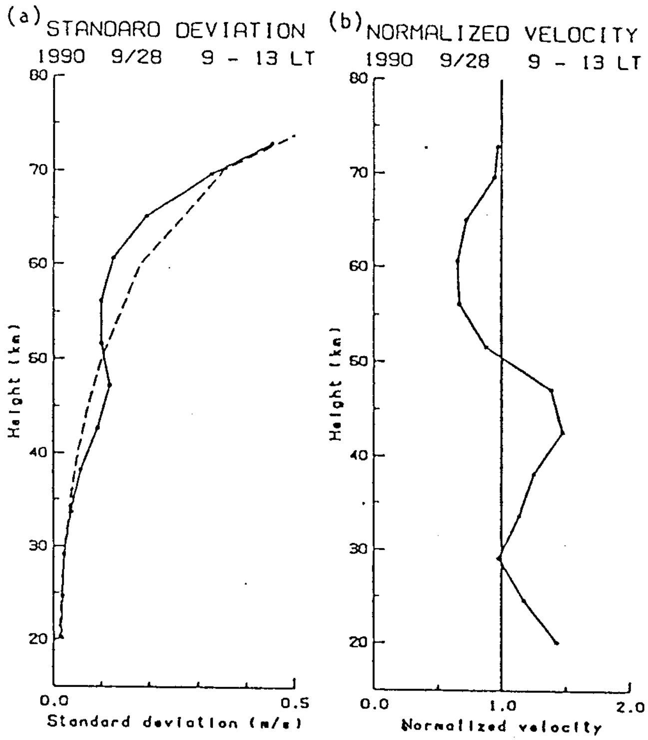

Fig. 1. Height profile of the standard deviation of vertical wind oscillations (a), and that normalized by a constant wave energy (b).

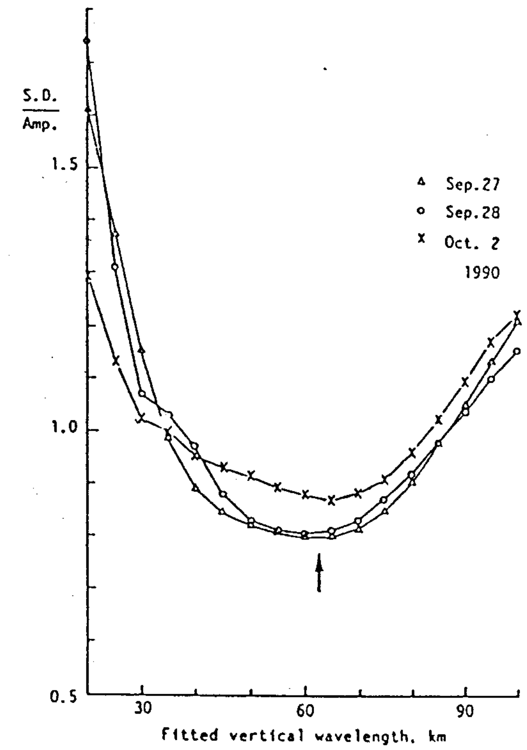

Fig. 2. Average ratio of residual to amplitude of the sinusoids fitted to the normalized height profiles.

2.3. *Complex Spectral Analysis of Wind Velocities*

An example of normalized height profiles obtained at 5 min intervals on Sept. 28, 1990 is shown in Fig.3. These profiles are averaged over 5 km, and thin curves depict fitted sinusoids with vertical wavelength of 60 km. It is found that the profiles oscillate with large amplitude around 40-50 km heights, while they do not vary so much around 30 or 60 km height that corresponds to the node of the standing waves mentioned above.

Next, complex power spectra of these normalized height profiles have been calculated in time domain using time series of cosine and sine coefficients of the fitted sinusoidal function that was shown by the thin curves in Fig.3. Figure 4 indicates the spectra obtained on Sept. 28 and Oct. 2, 1990. Thick and thin lines mean upward and downward propagating components with vertical scale of 60 km, respectively. In both observational cases, the upward propagating component (thick line) is, as a whole, seen to be larger than downward propagating component (thin

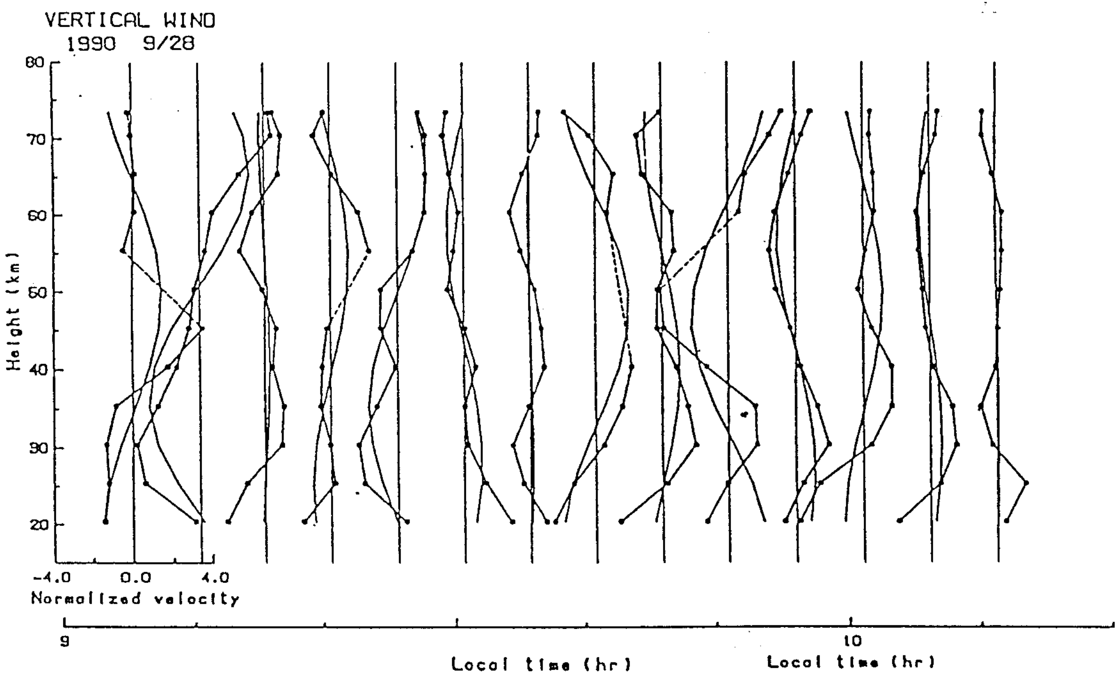

Fig. 3. Example of normalized height profiles of vertical wind velocity and fitted sinusoids with vertical wavelength of 60 km.

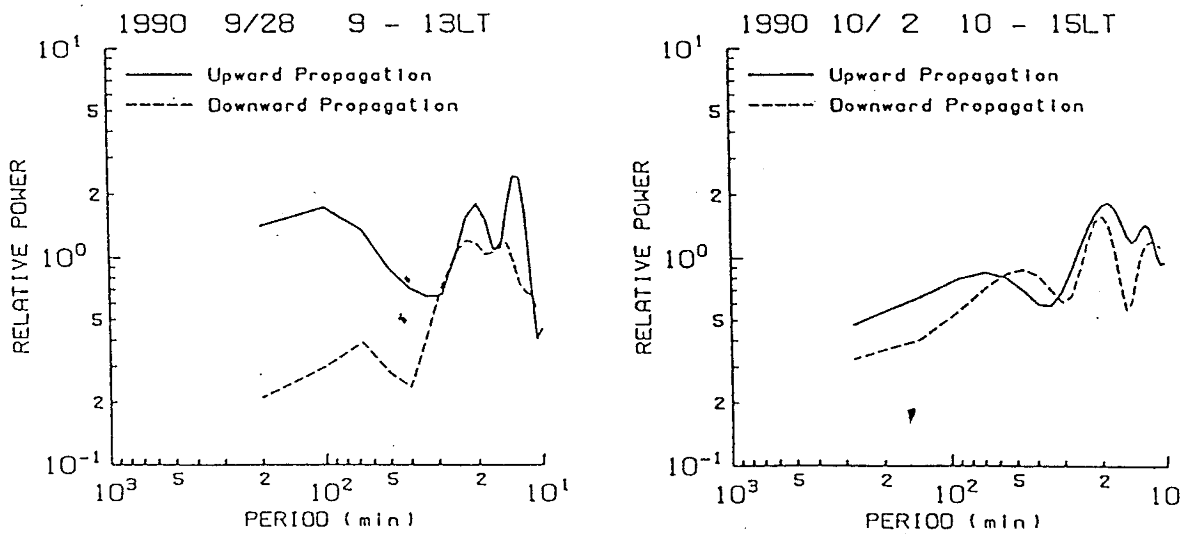

Fig. 4. Complex power spectra of the normalized wind velocity indicating upward (thick line) and downward (thin line) propagating component with vertical wavelength of 60 km.

line). Thus, the observed standing wave-like structure of vertical profiles seems to be formed by the internal gravity waves which may be generated near the ground and subject to reflection at the upper mesosphere (Hines, 1960). These waves possibly correspond to "ducted mores" composed of upward and downward propagating waves between the ground and the upper mesosphere.

3. Conclusion

The present observations have, for the first time, revealed vertical wind oscillations in the 30-60 km heights, using Jicamarca VHF radar equipped with high altitude and time resolution. These oscillations indicates that the specific mode of internal gravity wave exists in both stratosphere and mesosphere similarly, suggesting that a particular mode can reach the mesosphere as a result of selective process. The height profiles of the wave amplitude reveal that the short-period (<1 h) gravity waves are not so dissipative as the long-period (>1 h) gravity waves. Also, the standing wave-like structure is suggested by a distinct node at 30 and 60 km heights which is found in the amplitude profiles normalized by the inverse square root of the atmospheric density. These profiles are found to be best fitted by a sinusoid with vertical wavelength of 60 km. The complex spectral analysis of the fitted 60 km sinusoids indicates that the profiles are formed by ducted modes of upward and downward propagating internal gravity waves between the ground and the upper mesosphere. In future, the dissipation and reflection process of the internal gravity waves in the upper mesosphere should be investigated in more detail.

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