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OBSERVATIONS OF SHORT-TERM WAVES WITH AN ALL SKY CAMERA IN THE INFRARED OH BRIGHTNESS OVER YAKUTSK

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Abstract

Statistical analysis of internal gravity wave parameters registered by variations of the hydroxyl molecule emission is presented. The wave structures are detected with an all sky infrared camera at the optical station of Maimaga (φ=63˚N; λ=129.50˚E geographic). The data obtained for the period of 1998 to 2002 show that the small-scale internal gravity waves propagate predominantly westward. The observed wavelengths vary from 15.4 to 100 km (the average value is ~40 km), the horizontal phase speeds are between 19 and 166 m s^{-1} (the average value is~63 m s^{-1}) and the estimated periods are 9-90 min (the average value is ~17 min). The wavelengths and horizontal phase speeds are greater than those observed at middle and low latitudes. The rise of wavelengths and phase speeds at high latitudes is probably due to the large intensities of the filtering winds compared to those in the middle atmosphere. The short waves (wavelengths shorter than 17.5 km) propagate in the same direction as the long ones.

Introduction

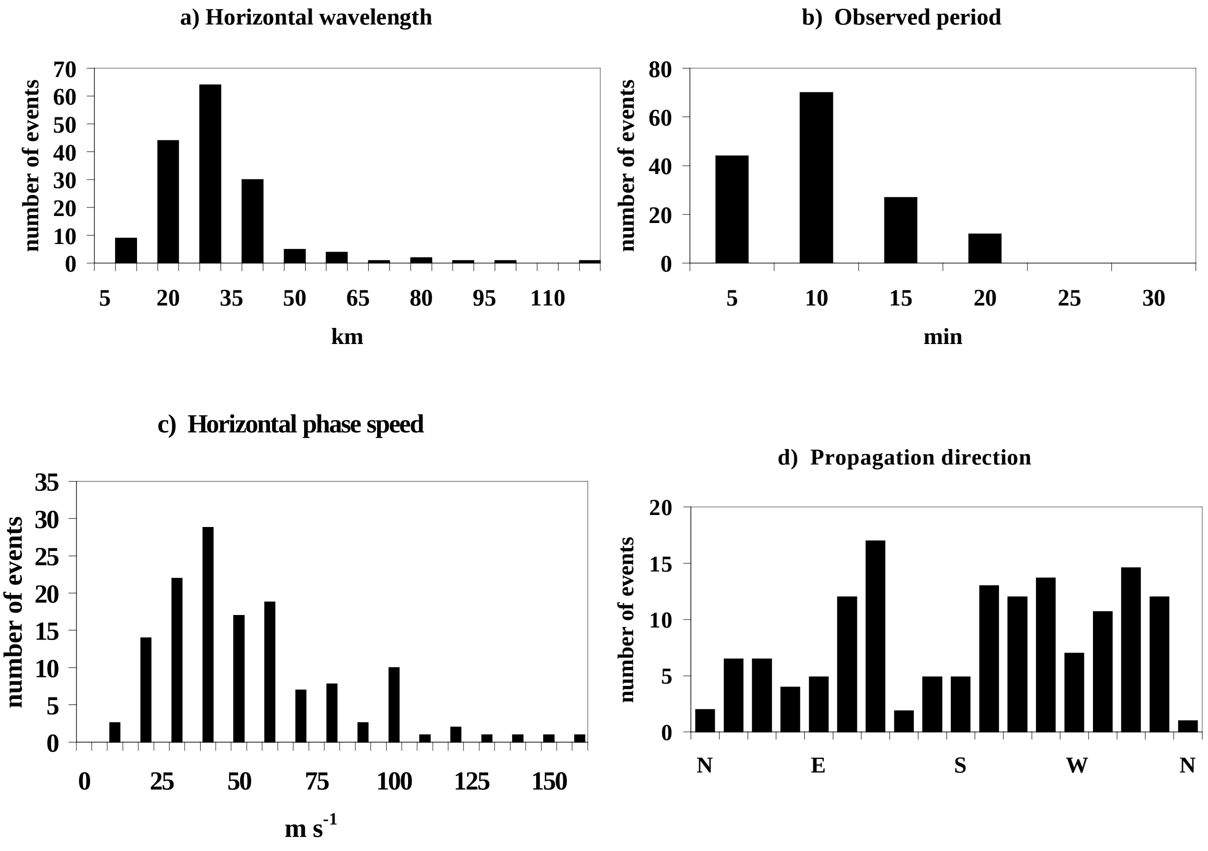
It has been known that the internal gravity waves can play an important role in the transport of energy from the low to high atmosphere. There are different ways to study wave activity in the middle and high atmosphere, such as radar, lidar and satellite observations. The visualization of wave structures in nightglow emissions with the use of all sky cameras is one of the most informative methods of studying the horizontal parameters (Taylor et al., 1995). Early wave observations were mostly performed during observational campaigns (Taylor et al., 1995; Swenson and Mende, 1994). At present, due to developing a system for mesopause state monitoring on a planetary scale PSMOS (Planetary Scale Mesopause Observing System), stationary stations for wave registration by all sky cameras were created (Wu, Killeen, 1996; Nakamura et al., 1999). The Maimaga station (φ=63˚N; λ=129.50˚E) is one of the network points where registration of small-scale waves is performed. In this paper the results of statistical analysis of wave measurements at subauroral latitudes during five observational seasons are presented.

Equipment and Observations

A digital all-sky imager capable of recording spatial inhomogeneities in nightglow emission has been designed by us and placed at Maimaga. A wide-angular objective "fish-eye" (by "Nikkor", Japan), (8 mm f/2,8) with an angle of lens view equal to 180˚ is used as a basic objective-lens. The registrations are performed with CCD ST-6 camera (Santa Barbara Instrument Group). The camera is assembled in the form of a head including the CCD, semiconducting cooling system, which reduces the temperature of the head by 50º below the ambient level. The camera can operate in three regimes: 250x374, 241x250, 120x250 pixels. The size of one pixel is 23x27 μm, corresponding to a horizontal resolution of ~1.5 km at a zenith, at the height of 87 km. Images of the night sky are recorded with average spatial resolution, an exposure time of 150 s and at an interval of 3 min in the near-infrared (660-1000 nm) range, where the hydroxyl molecular bands mostly emit. The waves with zenith angles smaller than 45º were used to prevent distortion of the wave structures. In order to separate spatial from temporal variations in the emission intensity we used the time difference (TD) method. Description of the instrumentation, observations and processing technique is given by Ammosov and Gavrilyeva (1999), Gavrilyeva and Ammosov (2002).

To investigate wave processes, the data obtained at clear moonless nights without aurora in the period from December to March of 1998-2002 were used. The total time of all-sky survey was 512 hours. We defined "a gravity wave event" to be a wave-like pattern seen in OH TD images, which lasts at least for four successive images, the wave parameters not changing significantly. From 83 observational nights, 167 wave disturbances defined as the internal gravity waves have been detected, 86.8% of which are waves of a "band" type (horizontal wave length is >17.5 km), and only 13.2% are the waves of a "ripple" type (horizontal wave length is <17.5 km).

The registered wavelengths vary from 12 to 122 km. Fig. 1 presents the distribution of "band" type internal gravity wave parameters. Fig. 1a is a histogram of the wavelength distribution. It is seen that most of registered waves (65) have lengths from 25 to 35 km (39%). About 140 wave structures (84%) have wavelengths from 20 to 40 km. The estimated periods change from 3 to 90 min (the average value is 10.7 min) (Fig. 1b). It is seen that ~70 waves (42%) have those of ~ 10 min. The observed horizontal phase speeds are from 15 to 166 m s^{-1} (the average value is 59.7 m s^{-1}) (Fig. 1c). It is evident from the speed histogram (Fig. 1c) that more than 27 waves are of ~ 40 m s^{-1}. The average speed of all waves registered is ~ 60 m s^{-1}. A major part of the waves are of the speed from 20 to 70 m s^{-1}. From Fig. 1d it follows that the waves registered mainly propagate in the azimuth range of 220-350°, i. e. in the west direction. During the whole observational period the "ripple" waves were registered 22 times.



a) Horizontal wavelength

b) Observed period

c) Horizontal phase speed

d) Propagation direction

Fig. 1 Distribution of gravity wave parameters as registered over Yakutsk

Short lifetime is a distinctive peculiarity of the "ripple" waves. In most cases those waves are observed at TD frames during 5-20 min. From 22 waves only 3 are observed for more than 1 hour. Their periods change from 5 to 21 min (the average value is 10.7 min). The observed horizontal phase speed varies from 14 to 77 m s^{-1} (the average value is 38.3 m s^{-1}). The "ripple" waves mostly propagate westward.

Discussion

At the nights when the OH emission intensity is high, the waves are observed nearly every time, whereas at the nights characterized by low emission intensity, their occurrence rate decreases in spite of atmospheric transparency being high.

The distribution of the wave parameters that we registered is close to that at middle and low latitudes. Thus the wave period distribution nearly reproduces the distribution at middle latitudes (Nakamure et al., 1999) with the same average period of the waves. Under similar distributions of the wavelengths and propagation speeds, their average values at sub-auroral latitudes turn out to be greater than at middle latitudes. It is known that the wavelengths measured within the all sky camera framework are correct. Unlike the periods or phase speeds, they are not distorted by the background wind. Therefore, the large values of the wavelengths at sub-auroral latitudes can be considered as an undoubted experimental fact. It can be interpreted under a suggestion that the filtering background wind in the stratosphere at high latitudes is stronger than at middle latitudes. The wave propagation both at middle and sub-auroral latitudes is westward, which indicates the same filtration mechanism. Earlier measurements of the large-scale waves with a spectrometer at Maimaga station (Ammosov, Gavrilyeva, 1998) showed that they propagate in the same direction as the "band" waves. Apparently, those waves are generated in lower atmospheric layers and filtered at heights of 50-70 km in accordance with the Lindzen theory (1981). In contrast to the results related to middle latitudes, the occurrence rate of the "ripple" waves is the lowest. These waves move westward as well as the "band" waves. It should be noted that at middle latitudes in winter the short waves also have a tendency to propagate to the west (Nakamura et al., 1999), although it is not evident in our case. Because of a small number of the "ripple" waves registered, it is hardly possible to examine their parameters.

Conclusion

For the first time a spatial picture of wave structures in the nightglow luminosity, which reflects passing of internal gravity waves at the height of hydroxyl molecular emission excitation, has been reproduced based on a great number of observations obtained at sub-auroral latitudes. It is shown that the wave parameters, including the wavelength, period and propagation direction, registered in winter during the period from 1998 to 2002 do not differ much from those at middle and low latitudes. The azimuth distribution of the wave propagation directions is consistent with the theory of wave filtration by the background flow in the middle atmosphere, the predominant propagation being westward. Slightly greater wavelengths and propagation speeds are probably related to stronger filtering wind in the stratosphere at sub-auroral latitudes. The “ripple” waves are observed most rarely and propagate westward as well as the “band” waves.

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