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OBSERVATIONS BY PARTIAL REFLECTION RADAR IN TUMANNY DURING NOCTILUCENT CLOUDS

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Abstract. During appearance of noctilucent clouds on 12 August 2016 variations of the reflected ordinary wave amplitude at the frequency of 2.66 MHz of the partial reflection radar located at the Tumanny observatory (69.0ºN, 35.7ºE) were considered. The noctilucent clouds have been registered by the all sky camera in the Lovozero observatory (67.98ºN, 35.08ºE) with the time resolution of 30 s. They stretched from the northern to the southern horizon, moved in the southern direction, had wavy structures with the periods from 15 till 100 km. During the presence of the noctilucent clouds over the radar the Polar Mesospheric Summer Echoes at the heights of 83-86 km were recorded. Detailed analysis has revealed that for the Polar Mesospheric Summer Echoes appearance was not enough only existence of noctilucent clouds over the antenna, also heterogeneity of the noctilucent clouds was required. Polar Mesospheric Summer Echoes heights decreased with speeds of 0.5 and 1.3 m/s.

Introduction

One of the interesting geophysical phenomena in high latitudes is the Polar Mesospheric Summer Echoes (PMSE). It is defined as abnormally intensive reflections of sounding signals in summertime, May-August, at the heights of 80-90 km. Data of the partial reflection radar (PRR) of PGI at the Tumanny observatory at the frequency of 2.7 MHz have shown existence of the phenomenon in the short wave range [*Vlaskov and Bogolyubov*, 1998]. Authors have noted features of PMSE during the observations: the reflecting layers were thin and were most often at the heights of 84-87 km, they moved down with the speed of 0.3 m/s, and wave processes were observed in the reflecting layers. Almost all researchers of PMSE marked their connection with noctilucent clouds (NLCs): both phenomena were observed during the summer period, were at heights 80-90 km in the mesopause, were correlated with the decrease of temperature in the mesosphere. Long parallel observations of PMSE and NLCs are difficult since observations of the NLCs demand the clear sky and the Sun position must be lower than the horizon at about -5° - -10°. However before *Stebel et al.* [2000] have reported that sometimes PMSE were observed without NLCs, sometimes on the contrary. In the question of connection between NLCs and PMSE there is a lot of uncertainty. Therefore the researches of the received data by the partial reflection radar (PRR) of the Tumanny observatory (69.0ºN, 35.7ºE) of the Polar Geophysical Institute (PGI) during the 12 August 2016 and the NLCs event are of interest.

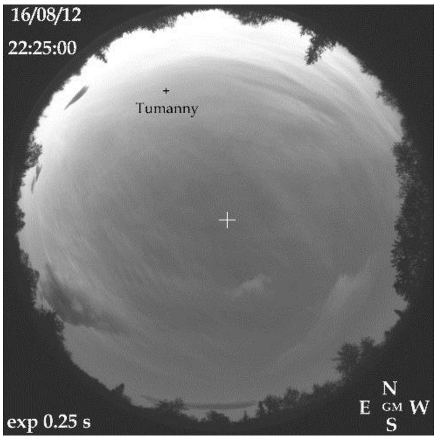

Figure 1. The picture of the Lovozero camera with NLCs. Date, time and orientation of the camera are specified. The layered structure in the north and gravity waves in the southeast is visible.

Equipment

In the summer of 2016 the patrol all sky camera of PGI for regular observations of aurora in the Lovozero observatory (67.98N, 35.08ºE) on the Kola Peninsula was upgraded. The camera has, in comparison with earlier operated one, increased angular and temporary resolutions and expanded dynamic range, provides formation of a color image. The device is created on the basis of the semi-professional A7S camera and fish-eye Nikon 8mm F2.8 Nikkor lens. The matrix consists of 4-pixel clusters in which two pixels work via the green filter (color channel G), one pixel works through blue filter (color channel B) and one pixel works through red filter (color channel R).

When NLCs were in the antenna directional pattern zone of PRR observations of the reflected signal amplitude of the ordinary wave have been executed. Radar transmitter power at the working frequency of 2.66 MHz was equal to about 60 kW, impulse duration was about 15 mcs. The antenna directional pattern was about 19×22º, its section at the height of 90 km had the linear size about 30 km. More detailed technical specification of the partial reflection facility is given in work [*Tereshchenko et al*., 2003].

Expanded dynamic range of the used camera had allowed beginning observations at the zenith angle of immersion of the Sun lower -12º and more when the shadow was at the height over 100 km, and at the angle -5º when the height of a shadow of only 50 km. NLCs are observed in high latitudes in the summer to the middle of August, but their detection in June or July is difficult because of the polar day. Auroral observations from the moment of immersion of the Sun below -12º near the zone of auroral observations begin at the end of August when NLCs are already extremely rare. Therefore modernization of the patrol all sky camera and expansion of its dynamic range have allowed increasing the period of optical observations in the Lovozero observatory. Regular observations can be made since the beginning of August now that gives more opportunities to register NLCs appearance in high latitudes.

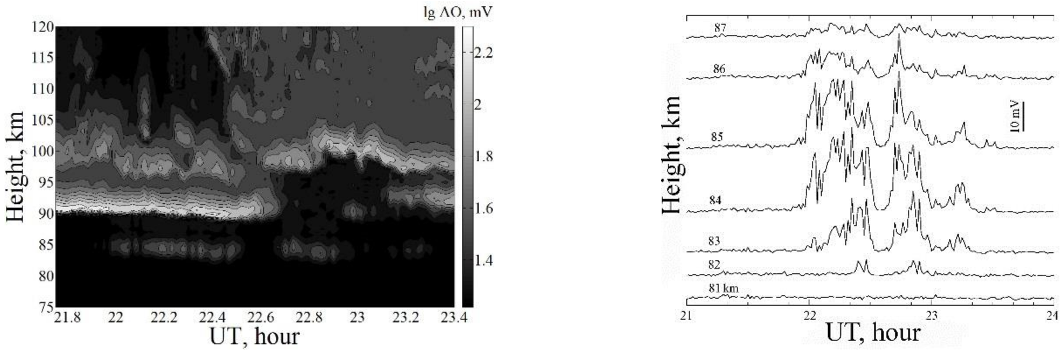

Figure 2. The ordinary wave amplitude of the radar (*left*) and its variations at different heights (*right*).

Data

In 2016 observations have been begun since August 1, time of observations was 2-3 hours in the first days. It was succeeded to record NLCs by the upgraded all sky camera at 8, 9 and 12 August 2016. Because of bad weather these observations there were not acceptable for detailed researches except only data for 12 August.

In Fig. 1 the shot of the all sky camera at 22:25:00 UT 12 August 2016 constructed using blue pixels is presented. The white cross is the zenith above the all sky camera, and black one is the zenith over the Tumanny observatory at the height of 84 km. It is visible that NLC were observed also in the neighborhood of the Tumanny observatory over PRR. Tropospheric clouds can be seen at the picture also. NLCs in this area have wavy structure, they are extended along the horizon. Other pictures show that NLCs move to the south - southwest direction. The characteristic distance between maxima of brightness is 50–100 km, and the speed is about 3-4 km/min at the height of 84 km. In the left bottom corner of the figure the wavy structure with the period about 20 km is visible.

During NLCs appearance records of ordinary wave amplitude of PRR have been received. The two-dimensional picture of the amplitude is presented on the left panel of Fig. 2. According to the all sky camera between 22:00 and 23:00 UT the area over the radar became covered by NLCs, and, during the same time interval, additional reflections at the heights about 82-87 km appeared. We connect the appearance of these sporadic reflections with NLCs. On the right panel the ordinary wave amplitudes for heights of 81-87 km are given; it is clearly visible that reflections happen, mainly, from the heights of 83-86 km and have sometimes quasiperiodic structures. The maximum amplitude is observed at the height of 84 km. For this reason when determining wavelength and speed of NLCs this height was accepted.

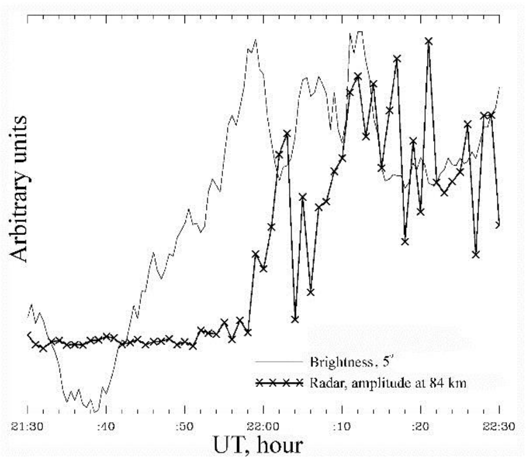

Figure 3. Sky luminescence variations in the circle with the radius of 5° above the radar (the simple line) and ordinary wave amplitude of the radar at the height of 84 km (the bold line with crosses).

The variations of sky intensity in the circle with the radius of 5° above the radar were calculated and the course of sky luminescence intensity in this area was drawn. In Fig. 3 sky luminescence intensity and ordinary wave amplitude during 21:30–22:30 UT are shown. At that time according to ascafilms NLCs were above the radar. As we can see from the figure, there is no good compliance between curves of luminescence and the reflected signal: the signal of the radar is late for 15–20 minutes after the photographic data show covering the chart of the antenna by NLCs.

According to ascafilms, before growth of amplitude of the radar there was a change of the NLCs form in the field of the chart of the antenna. In Fig. 4 parts of ascafilms for the moments 21:45, 21:53 and 22:00 UT are shown. Circular sections of the chart of the antenna at the height of 84 km are shown by lines. At 21:45 the area over the radar is covered with a uniform cloud, a veil on the standard classification, and the signal at this time reflected in the radar was at the quiet level. At 21:53 UT on northern border of the directional pattern appears wavy structure with wavelength about 15 km, and signal amplitude slightly increases. At 22:00 UT in the field of the directional pattern of the radar the NLCs are non-uniform, the dimensions of irregularities of NLCs are less than the diameter of directional pattern and the radar signal considerably increases; the wavy structure was displaced to the right, to the west.

The amplitude of reflection, Fig. 2 (left), shows also little change of height of the maximum of "sporadic reflection". These layers are given in Fig. 5 in more detail. The shaped line has shown positions of the maximum of layers before and after the gap at 22:30–22:40 UT. The movement down of these layers in both cases and also quasiperiodic changes of amplitude of a signal are visible. Speeds on these two intervals aren't equal: before the gap it is equal to 0.5 m/s, and after the gap it is 1.3 m/s.

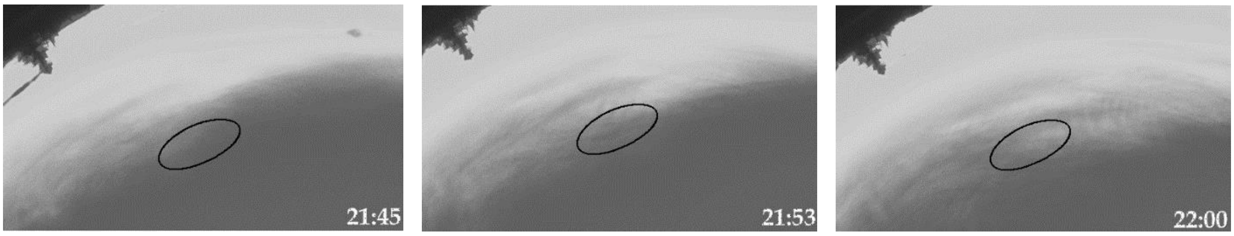

Figure 4. The northeast parts of ascafilms are given for three moments (UT). The lines have shown a circle with radius 10º at the height of 84 km over the radar.

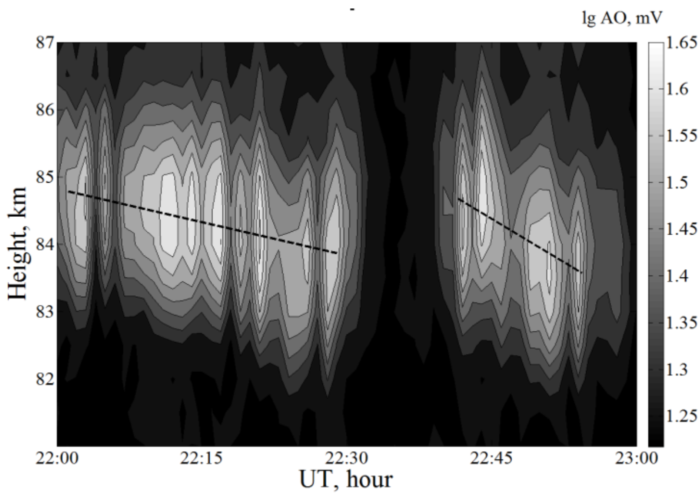

Figure 5. The ordinary wave amplitude at the heights of 81-87 km. The shaped line has shown the change of the amplitude maximum height.

In the Fig. 6a (left) the acoustic and Brunt-Väisälä periods for various heights in the atmosphere from [*Knížová and Mošna*, 2011] are shown. In the acoustic domain waves spread, which have only poor acoustic nature. In the gravity domain acoustic waves show presence of the gravity effect in their features. In the intermediate area these acoustic and acoustic-gravity waves are considerably weakened. On Fig. 6b (right) of spectral power density of ordinary wave amplitude for the considered period is given. It is visible that the amplitudes with the periods from 5 to 6.5 min are weakened. Thus in the range of the reflected ordinary wave amplitude it is possible to select areas with the periods less than 5 min (acoustic waves) and more than 6.5 min (acoustic-gravity waves or internal gravity waves).

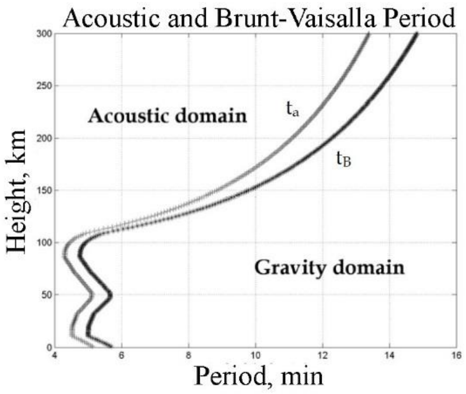

Figure 6a. Acoustic and gravity domains [*Knížová and Mošna*, 2011].

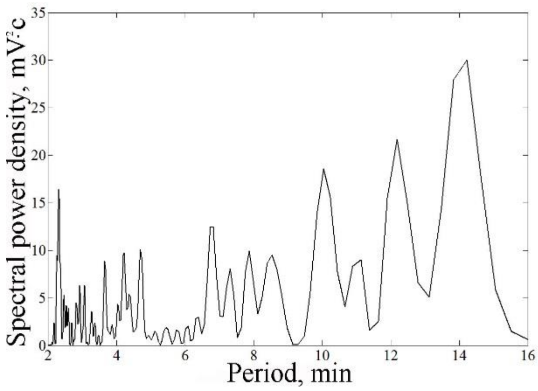

Figure 6b. Spectral power density of ordinary waves during sounding of NLCs.

In the Fig. 7 (above) the reflected ordinary wave amplitude at the height of 84 km is shown. Increasing of amplitude coincides with appearance of NLCs over the partial reflection radar. Comparison of the reflected ordinary wave amplitude with the wavelet-spectrum (Fig. 7 (down)) shows that increasing of the amplitude is connected with appearance in the spectrum of the reflected signal of the acoustic wave periods (less 5 minutes).

Discussion

Advantage of photographic data is simplicity of detection of wavy structures and irregularities in NLCs. In our case on 12 August 2016 waves and thin structures of NLCs took place practically all the time, as examples see Fig. 1 and 4. The absence of PMSE and increase in the signal amplitude of the radar during NLCs can be explained with uniformity of NLCs within the directional pattern: for appearance of radio reflection heterogeneity of electron concentration or density of the charged aerosols are necessary. Increasing of the reflected ordinary wave amplitude could be caused by appearance over the radar irregularities of reflected structures. The reflections could have not partial reflection nature but poor radar reflections caused by structures of NLCs. The structures could be created by acoustic waves with periods less 5 minutes during acoustic compression and rarefaction effects. Gravity waves have the feature of buoyancy and only move the atmosphere layers without sufficient changing of their properties. In this case received reflection is at low level.

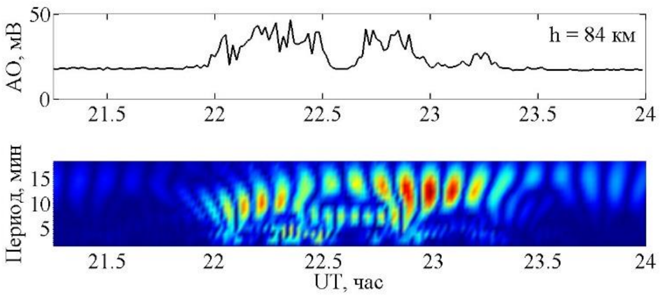

Figure 7. Amplitude of the reflected ordinary wave (*above*) and its wavelet-spectrum (*below*).

Vertical movements of PMSE also can be connected with irregularities. About the movements it is often mentioned in literature but values of speeds are given seldom. *Vlaskov and Bogolyubov* [1998] tell about 0.3 m/s, [*Roldugin et. al.*, 2000] according to EISCAT data specify 0.14 – 0.83 m/s, *Roldugin et al.* [2001] give the value in 1000 times more – 30 m/s. In the work the vertical speed of 0.5 m/s and 1.3 m/s are given. Vertical movements can have two reasons: passing of gravitational waves through a layer, or falling of aerosols or meteor dust. Big speeds in work [*Roldugin et al*., 2001] are obviously connected not with aerosols, but with the areas of turbulence. In the considered case the night peak of activity of the meteor shower Perseid was observed at 12-13 August 2016. The formula for the speed of falling of the meteoric dust surrounded by the ice cover was offered in [*Roldugin et. al*., 2000], and assessment by it gives the size of 0.2 m/s. The dispersion from 0.14 to 1.3 m/s can be caused by different parameters of meteor dust and/or the size of aerosols.

We think that the reason of uncertainty of interpretations of connection of NLCs and PMSE is obscurity of the nature and dynamics of the particles responsible for both phenomena.

Summary

On 12 August 2016 over the Tumanny observatory the all sky camera of the Lovozero observatory observed NLCs. Presence of NLCs over the partial reflection facility has caused increase in amplitudes of ordinary and unusual waves at the heights of 82-87 km. In photos of NLCs of the all sky camera the wave structure of clouds was clearly seen. The similar wave structure was visible also in behavior of amplitudes of the reflected ordinary wave. We connect change of amplitude of the reflected signal with passing of NLCs over the partial reflection facility. Heterogeneity of NLCs within the antenna directional pattern which was caused by both acoustic and acoustic-gravity waves, and thin structures of NLCs were necessary for appearance of radio reflection. The reason of the observed vertical movements down with speeds of 0.5 m/s and 1.3 m/s is falling of the ice aerosols formed around particles of meteoric dust. Joint observation of the all sky camera and the partial reflection facility give possibility to estimate heights and thickness of NLCs and also periodic structure of NLCs.

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