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OBSERVATIONS BY PARTIAL REFLECTION RADAR DURING NOCTILUCENT CLOUD APPEARANCE

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Abstract. Two cases of observations using the partial reflection 2.7 MHz radar in Tumanny obs. during noctilucent cloud appearance are considered. In both events a decrease of electron concentration near the mesopause was observed, while the character of reflections was different. In one event, there was a reflection from PMSE altitudes 83-86 km, in the other event the reflection covered all altitudes above 70 km and it was also observed at the altitude of 47 km. After the data on horizontal winds in the second event, there were also observed downward movements at the velocity of 2 km/min.

Introduction

In high latitudes in summer, a specific reflection, called PMSE, is observed occasionally by most various radars, varying frequencies from 2 MHz to 1 GHz, at the mesopause altitudes. A great many articles deal with this phenomenon, see e.g. a review by Cho and Rotger [1997]. The similarity of PMSE and noctilucent clouds morphology gave ground to simultaneous observations of both phenomena. Fiedler et al., [1997] established, that PMSE appears as one observes NLC, however the opposite is not true, Both phenomena are somewhat spaced by altitude: NLC is located in the lower part of PMSE.

Simultaneous observations using 53,5 MHz radar and *in situ* rocket measurements of electron concentration during PMSE ([Inhester et al. 1990; Kelley et al. 1990]) showed, that at PMSE altitudes, considerable decreases or "bite-outs' of electron concentration can be observed, reaching one order of the normal size. Characteristic of those "bite-outs' is their sharp edge, measuring some several hundred meters. The maximum amplitude of the reflection, according to these experiments, falls on the electron density depletions.

Roldugin et al. [1999] observed visually and photographed a noctilucent cloud above the EISCAT. The values of the height profile of electron concentration, computed by the standard method, showed the presence of abnormally high values of the mesopause electron concentration, reaching $2{\cdot}10^{11}$ el/cm^3. Authors do not believe these values are consistent with the real ones.

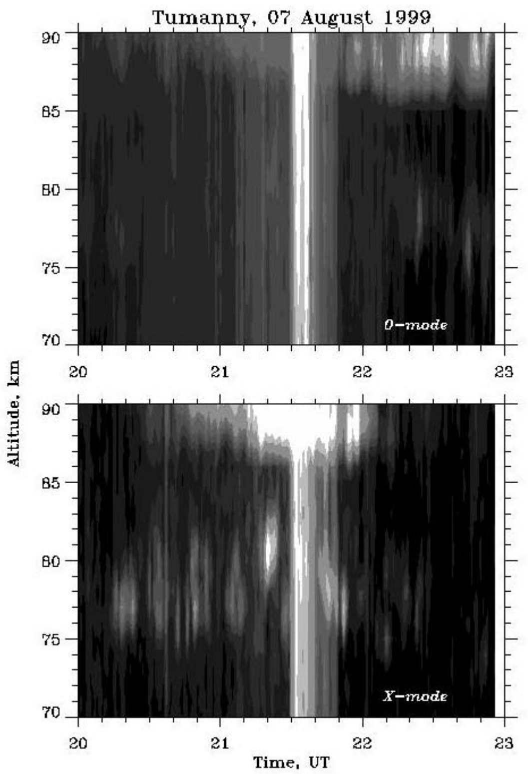

Fig.1. Amplitudes of PRR reflection for usual and unusual waves.

In particular PMSE observations are carried out by the partial reflection radar of the PGI, located in Tumanny village, Kola peninsula, 69.0° N, 35.7° E. It operates at the frequency of 2.7 MHz. The experience of PMSE studies after its data is presented in the paper by Vlaskov and Bogolyubov [1999]. They found, that PMSE had been observed at altitudes of 80-90 km, more often within the interval of 84-87 km; the electron concentration has the maximum at those altitudes; the altitude of the maximum descents at the velocity of 0.3 m/s.

Not all researchers believe the relation of PMSE with NLC to be obvious. Reid [1990] explains the decrease of electrons in the region of PMSE by the presence of small ice particles of the size of 10 nm and he does not believe large ice particles, that form visible noctilucent clouds, to be the cause of "bite-outs'. Fiedler et al. [1997] identify NLCs with corresponding reflections of lidar, which is not altogether correct. The point is not only that lidar observations give no data as to the morphology and dynamics of the phenomenon. The identification of the layer as a noctilucent cloud calls for a certain caution.

We have carried out an experiment using our radar on simultaneous observations of partial reflections and noctilucent clouds. This paper presents the results for the two events.

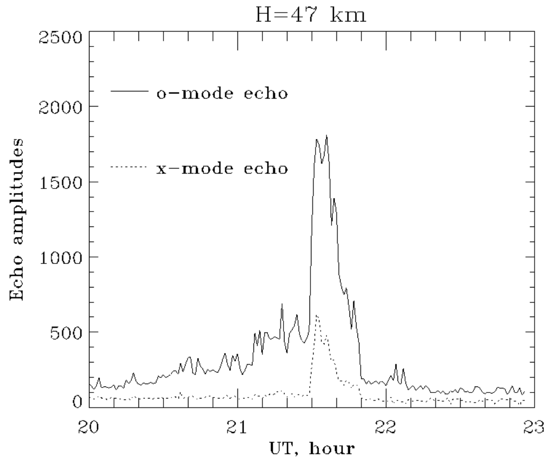

Fig.2. Time variations of usual and unusual waves reflected from 47 km on 7 August 1999.

Observation results for the event of August 7, 1999

On the night of 7 to 8 August, 1999 a noctilucent cloud was observed from Umba (66.7° N, 34.3° E) and it was situated in the northern part of the sky, above the partial reflection radar (PRR). Morphologically it can be defined as ridges of low intensity. The cloud appeared between 2125 and 2138 UT on August, 7 and disappeared at 2150 UT.

At the time of the cloud appearance the radar was observing reflections of high amplitude, in both usual and unusual waves. Those anomalous reflections were well observable at all altitudes, at which registering was carried out: from 70 to 90 km as well as at 47 km. Fig.1 displays reflection amplitudes for both waves, usual and unusual ones. The signal value remains almost constant for both modes as the altitude grows during NLC period 2130 2150 UT. At the altitude of 70 km, which is considerably lower than the altitude of PMSE and NLCs, the signal amplitude is the same as at the altitude of 85 km. Fig. 2 shows the time variation of the amplitude of both waves at the altitude of 47 km. The amplitude of the usual wave, reflected from 47 km is only 20 % less than the one, reflected from 85 km.

During the period of an anomalous radio reflection the density of electron concentration dropped, while the concentration decrease was becoming more obvious as the altitude grew from 70 to 85 km. The ratio of mean values for the total interval outside the clouds 2110-2130 and 2150-2210 to the mean value during the noctilucent cloud 2130-2140 makes 3.7 for 80 km and 7.7 for 85 km.

The height profiles of the electron concentration, averaged according to time intervals prior to, during and after a noctilucent cloud appearance are given in Fig.3. One can see, that at altitudes of 76-84 km, when the noctilucent cloud appeared, a considerable drop of electron concentration took place as follows: from $5{\cdot}10^2$ before the cloud to $1\text{-}2{\cdot}10^2$ during the cloud appearance.

Besides the amplitude and electron profiles, PRR also provide information on horizontal winds. Fig. 4 shows directions and velocity of winds from 2000 to 2300 UT at altitudes from 70 to 100 km. As one can see from the figure, a 20-minute appearance of the noctilucent cloud at 2130-2150 UT had no anything particular about it. The movement eastward was the prevailing direction, at small velocities, about 200 m/s, however it was changing chaotically, which is the evidence of turbulence.

Our attention is drawn by the appearance of certain uniform movements downward. The characteristic velocity vector is occasionally kept with a delay all along the height interval, as if a certain volume is moving downward, while keeping its horizontal velocity. Such movements are clearly visible between 2000-2020, 2040-2055, 2230-2240 UT. The descent by 30 km, from the altitude of 100 to 70 km, takes about 15 min., e.g. at the rate of 2 km/min or 30 m/s. This is much less than the speed of sound, the movement proceeds only downward, so it can not be identified with acoustic waves. This value also exceeds the vertical wind velocities.

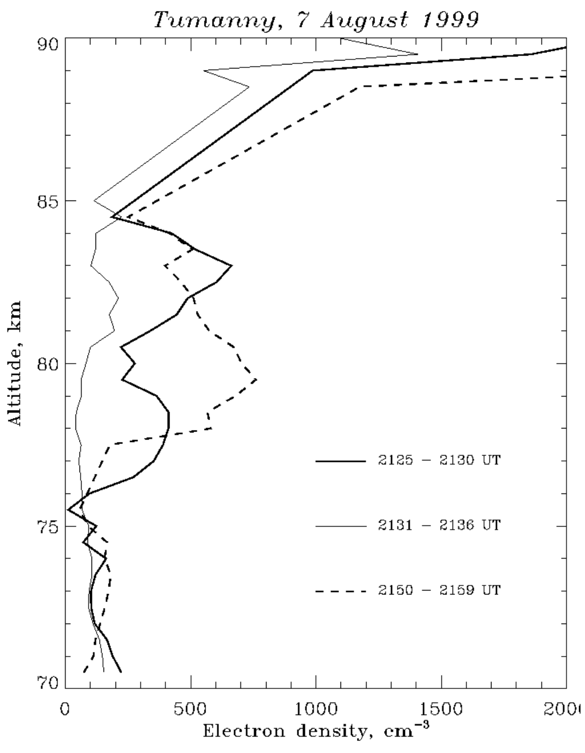

Fig.3. The electron density profiles before, during and after the noctilucenr cloud appearance.

Observation results for the event of August 6, 1999

On August 6, 1999, noctilucent clouds were observed above PRR at 2130-2340 UT from Lycksele, Sweden. During that time there was continuous cloudiness above Umba. The amplitude of the reflected signal of the usual wave as a function of time and height is shown in the upper panel of Fig. 5. One can see that during this noctilucent cloud observation the PRR was registering reflections that can be defined as typical PMSE. They were situated at altitudes of 83-86 km. The bottom panel displays the electrons concentration. As in the event of August 7, one can see a considerable decrease of electrons concentration, "bite-outs" at altitudes of the cloud and PMSE. Prior to PMSE appearance at 2100, the density of electrons at the altitude of 87 km made about $5{\cdot}10^3$ el/cm^{-3}, whereas after

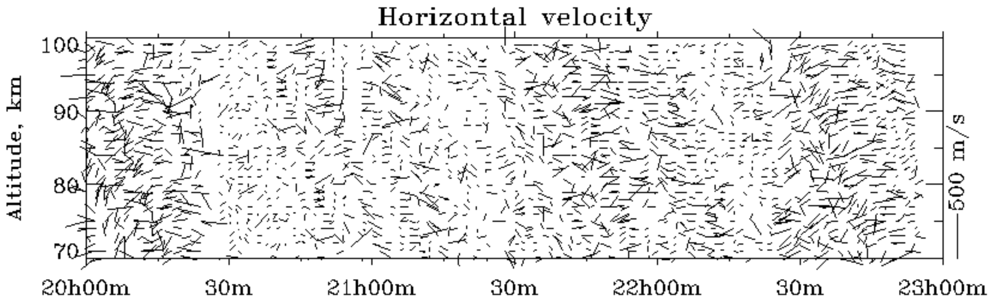

Fig.4. Wind velocity pattern on 7 August 1999.

the appearance, the density dropped one order of the above value. In the figure one can clearly see a gap in the electron density at 2130-2300 at altitudes of 85-89 km, close to altitudes of PMSE. The largest electron diminution had a place in the upper part of PMSE.

The wind pattern did not demonstrate any movements downward, such as in the event of August 7. Chaotic movement at the rate of several hundred meters per second was observed. The appearance of PMSE at 2100 was accompanied by the change of the westward wind direction to the eastward one.

Analysis of observation results

The two considered events of noctilucent clouds manifestation above radar have, in both cases, shown the appearance of a strong reflected signal, however the character of reflection differed. On August, 6 a typical situation for PMSE was observed: reflection at altitudes of 83-86 km, usual for noctilucent clouds. On August 7 an intense reflection from all registration altitudes was observed, i.e. 47 km and 70-90 km. We can say nothing concerning altitudes between 47 and 70 km.

We suppose that in this case we should speak of the PMSE of anomalous type, when we began to observe reflection from altitudes, much lower than the noctilucent cloud altitude. Noctilucent clouds differed in these events: on August, 6 these were intense and long-term formations, whereas short-term and weak ones were observed on August, 7. An event of continuous reflection from 80 to 90 km above PRR, similar to our Fig. 1, is presented in Fig. 1 in the paper by Vlaskov and Bogolyubov [1998].

In both events the decrease of electron concentration took place at 85 km altitude. An inconceivable increase of the electron concentration in the mesopause, observed by Roldugin et al. [1999], when a noctilucent cloud appeared above EISCAT, is, of course, a fictitious one. Apparently, in the computation methods applied for incoherent scattering, the electron density at a certain altitude is proportional to the amplitude of the signal reflected at the same altitude. The computation of electron concentration in the method of partial reflection is based on some other principle, e.g. on the comparison of usual and unusual constituents of the signal. The ratio of these waves' amplitudes during the appearance of a noctilucent cloud on August, 7 did not change essentially. That is why, we believe that the obtained decrease of electron concentration at the altitude of 85 km on August, 7, 1999 by 7.7 times and one order on August, 6, 1999 are real and similar to the ones, observed by rockets [Inhester et al., 1990; Kelley et al., 1990].

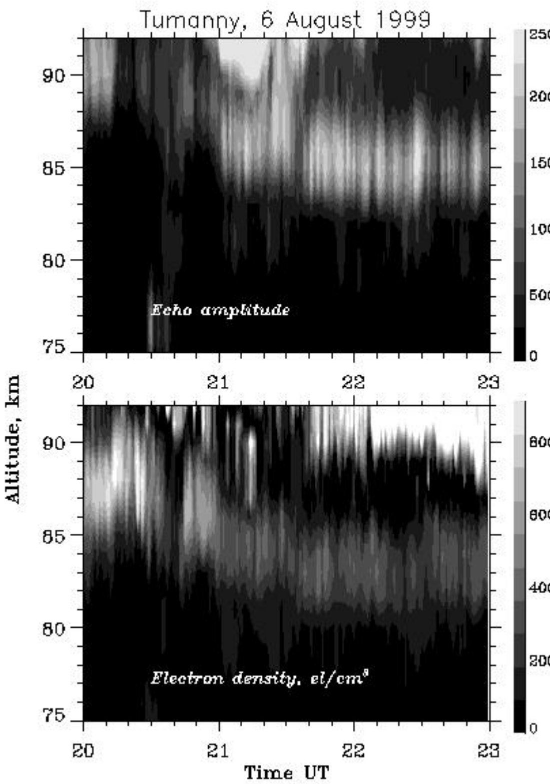

Fig.5. Amplitudes of usual wave (top panel) and electron density profile (bottom panel) during NLC event.

The recombination of charges on the particles, that form the cloud, is a physical reason of the decrease. Let us roughly estimate the recombination coefficient α alteration. If we ignore electrons adhesion, let us formulate ionization N balance equation as $dN/dt = q - \alpha N^2$, where q - is the ion production rate. For a stationary event $dN/dt=0$ we have $q=\alpha_1 N_1^2=\alpha_2 N_2^2$, where symbols 1 and 2 refer to normal and abnormal conditions. Hence, the recombination α coefficient alteration during the cloud appearance is $\alpha_2=\alpha_1 N_1^2/N_2^2$. For the altitude of 85 km $\alpha_2= 50\alpha_1$.

Many researchers note, that PMSE patterns by different radars display a slow decrease of abnormal reflection altitude at the rate of the order of 1 km/hour. In the paper by Roldugin et al. [1999] a hypothesis was suggested, saying that particles, forming a noctilucent cloud are metal dust particles, micrometeorites, surrounded by a light shell of large size. The paper suggests a formula (3) for the descent velocity of such particles.

In our event of 7 August, we did not manage to observe any slow descent like this during a short 20-minute cloud appearance. However, prior to and after the cloud appearance, we registered the descent of some unknown reflecting objects at the velocity of 30 m/s, see Fig. 5. One can suggest, that such descent is related to micrometeorites, that could not get any "wings". The formula (3) for the descent rate from the above paper can, in such case, be rewritten as follows:

$$v = \sqrt{g \frac{\rho_{nucl}}{\rho_{air}} a_{nucl}} \; .$$

Assuming the acceleration of gravity g=980 cm/s, the relative density of a particle ρ_{nucl}=10 g/cm^3, the air density in the mesopause ρ_{air}=10^{-8} g/cm^3, and the particle radius a_{nucl}=10^{-5} cm, we obtain V=30 m/s, which agrees well with the observed value.

The given hypothesis contradicts with the concept about tiny pieces of ice of about 10 nm size as the principal agent, that gives rise to the electron concentration decrease, see Reid [1990], Klostermeyer [1996]. The hypothesis of tiny ice pieces is based on the fact of high positive ion concentration in the region of electron decrease. However, we may cite an argument against it too. Visual observations of noctilucent clouds reveal the absence of iridescence, e.g. their iridescent coloring, which is the evidence of large size particles, exceeding 5000 nm. If the electron decrease is due to the large number of micro ice particles about of 10 nm size, and at the same time a great number of large particles is observed, there should possibly be present large quantities of the middle-size particles of about 500 nm as well, which should have been iridescent as a consequence of Mie scattering.

The problem of the difference of two types of PMSE is still to be discussed. Its solution is, apparently, related to the question, what produces reflections: either small ice crystals or conductive micrometeorites or non-uniformity of the electron concentration, that appears when noctilucent clouds are formed, or is it something else?

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