XVI Всероссийская Открытая конференция
СОВРЕМЕННЫЕ ПРОБЛЕМЫ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ ИЗ КОСМОСА
Институт космофизических исследований и распространения радиоволн ДВО РАН

Резонансное рассеяние на возбужденных ионах и лидарная диагностика состояния ионосферы

Бычков В.В., Пережогин А.С., Середкин И.Н., Шевцов Б.М.
E-mail: vasily.v.bychkov@gmail.com

ABSTRACT

The results of two-frequency lidar sounding of the atmosphere from the altitudes of 100-400 km are presented. Defined light-scattering layers were discovered in the region of 200-400 km. They are caused by presence of excited states atomic oxygen and nitrogen ions. The possibility of reconstruction of excited ions Nh-profile and determination of precipitated electron fluxes by the lidar method are shown.

Keywords: atmosphere, ionosphere, lidar, scattering.

HARDWARE COMPLEX

The lidar main parameters, applied in the experiments, are shown in Table 1.

Table 1. Equipment.

Transmitter 1	Transmitter 2	Receiver
Laser Nd:YAG Brilliant-B Pulse Energy 400 mJ Wavelength 532.08 nm Linewidth 0.4 nm	Dye Laser TDL-90 Pump Laser YG-982E Pulse Energy 100 mJ Wavelength 561.107 nm Linewidth 0.05 nm	Telescope Diameter 60 cm PMT Hamamatsu H8259-01 Photon Counters M8784-01 Spatial resolution 1.5 km Filters Bandwidth 1 nm

In the light guide of the receiver the signal is divided into fluxes with a radiation wavelength of more than 532 nm and a short-wavelength part. The separated fluxes are further directed to the photo-cathodes of two PMTs connected to photon counters.

The scattering by electronic transitions illustrated in Table 2 was investigated.

Table 2. Dipole transitions of excited ions of oxygen and nitrogen atoms falling within the radiation bands of lasers

	Component	Wavelength Air (nm)	A_{ki} (s^{-1})	Lower Level	Term	J	Upper Level	Term	J
1	OII	561.1072	2,14e+06	$2s^22p^2(^1S)3s$	^2S	$^1/_2$	$2s^22p^2(^3P)4p$	$^2P^\circ$	$^1/_2$
2	NII	532.0958	2.52e+07	$2s2p^2(^4P)3p$	$^5P^\circ$	1	$2s2p^2(^4P)3d$	^5P	2

Here OII is an ion O^+, NII an ion N^+.

EXPERIMENTAL DATA

Seven cases of backscattering at the both lidar channels were recorded at the wavelengths of 532 and 561 nm over the period from August to November 2017. The characteristic feature of all the data obtained during this period is the backscattering from the region of 200-400 km and its absence from the region of 100-200 km.

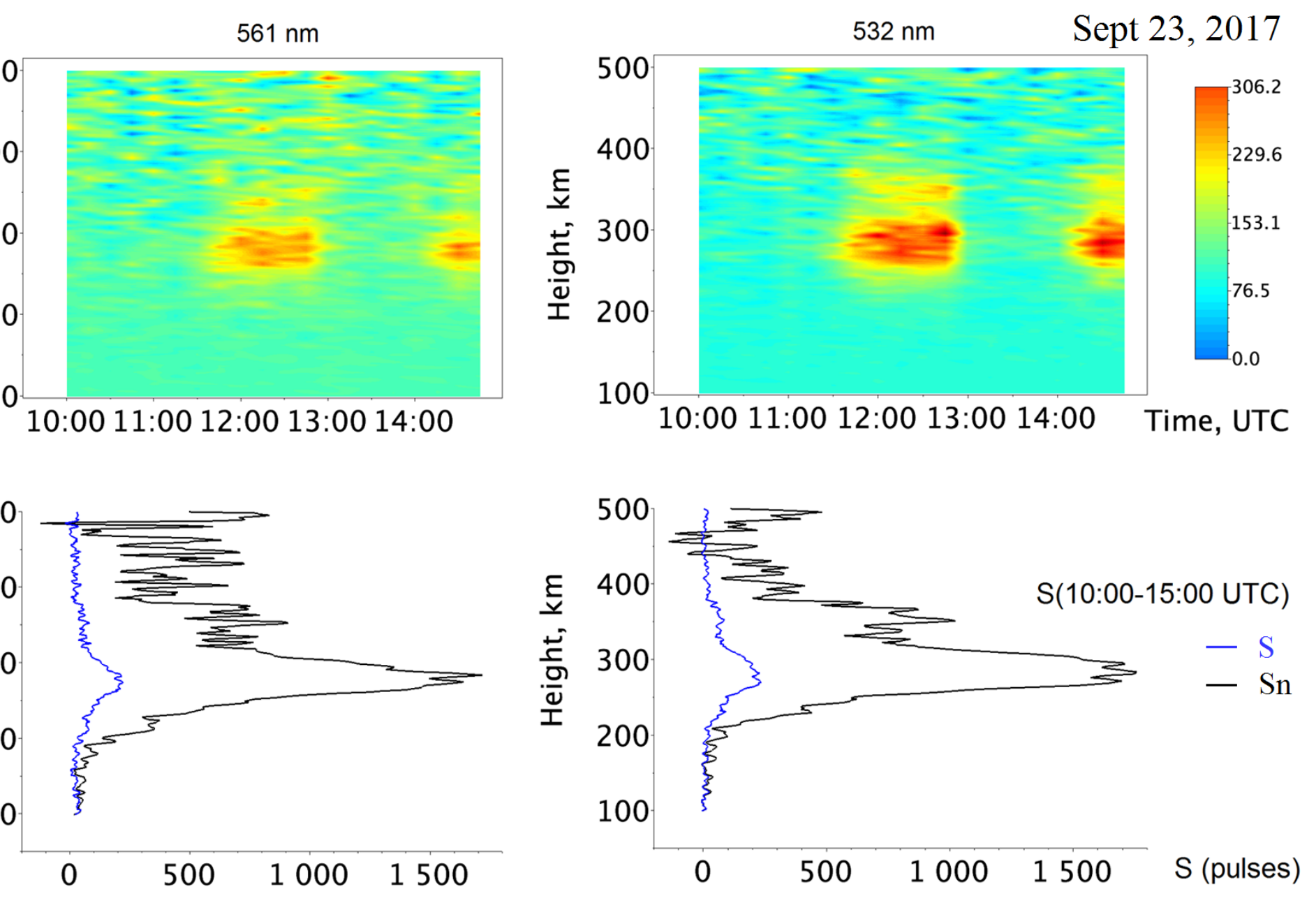

Fig. 1. Lidar «signal-background», total signal S and normalized signal Sn.

Figure 1 uses lidar data with a 15-minute accumulation and a spatial resolution of 1.5 km. Signal values are normalized to the geometric factor $(H/100)^2$, where H is the height.

Figure 2 illustrates the results of lidar and ionospheric measurements carried out on 23.09.2017.

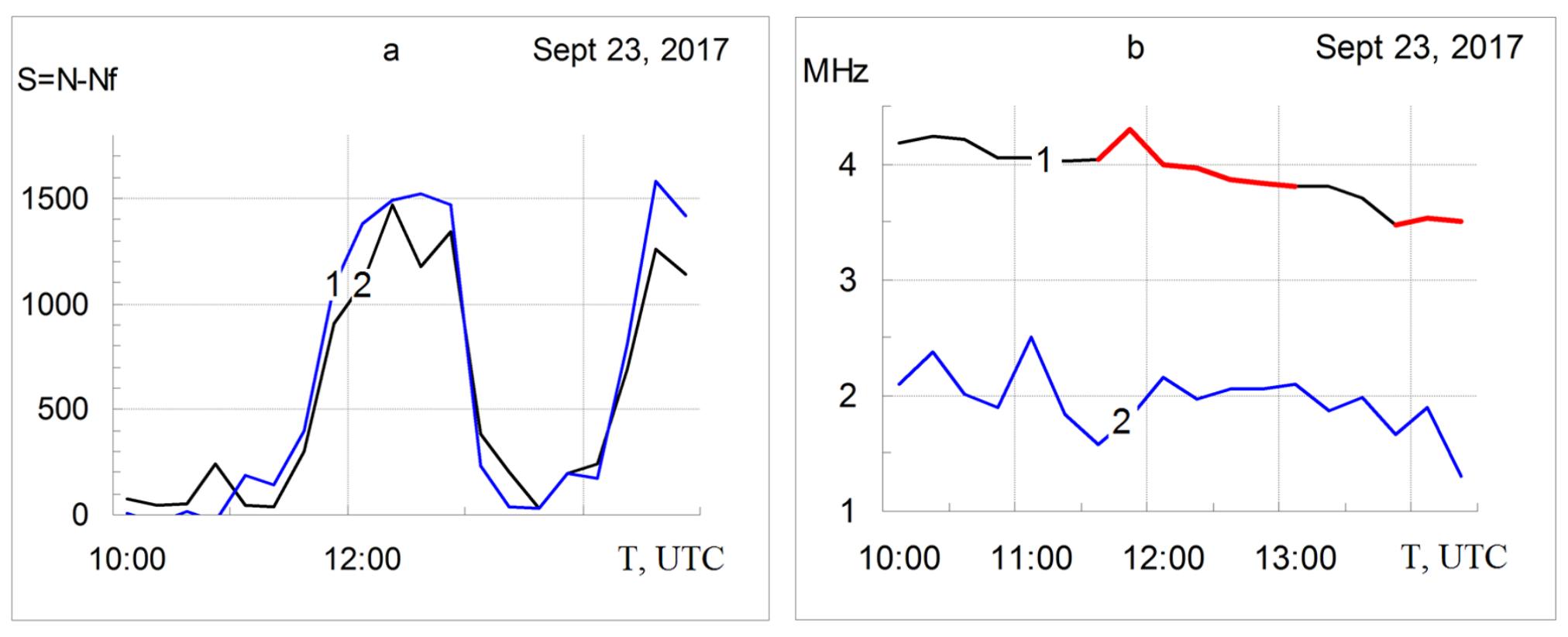

Fig. 2. Lidar «signal-background» summed over the 200-400 km layer (a), and foF2 and foEs (b) during lidar observations.

Figure 2a was compiled on the basis of 15-minute accumulation data. The total signals on the 200-400 km layer at 532(1) and 561(2) nm correlate well and are almost identical.

Figure 2b shows the variations in the critical frequencies of the F and E layers during lidar observations. The appearance of increased backscattering from the ionospheric layer F2 is marked in red. An increase in foF2 is observed with the appearance of resonant backscattering.

Figure 3 illustrates the sounding data on 05.09.2017.

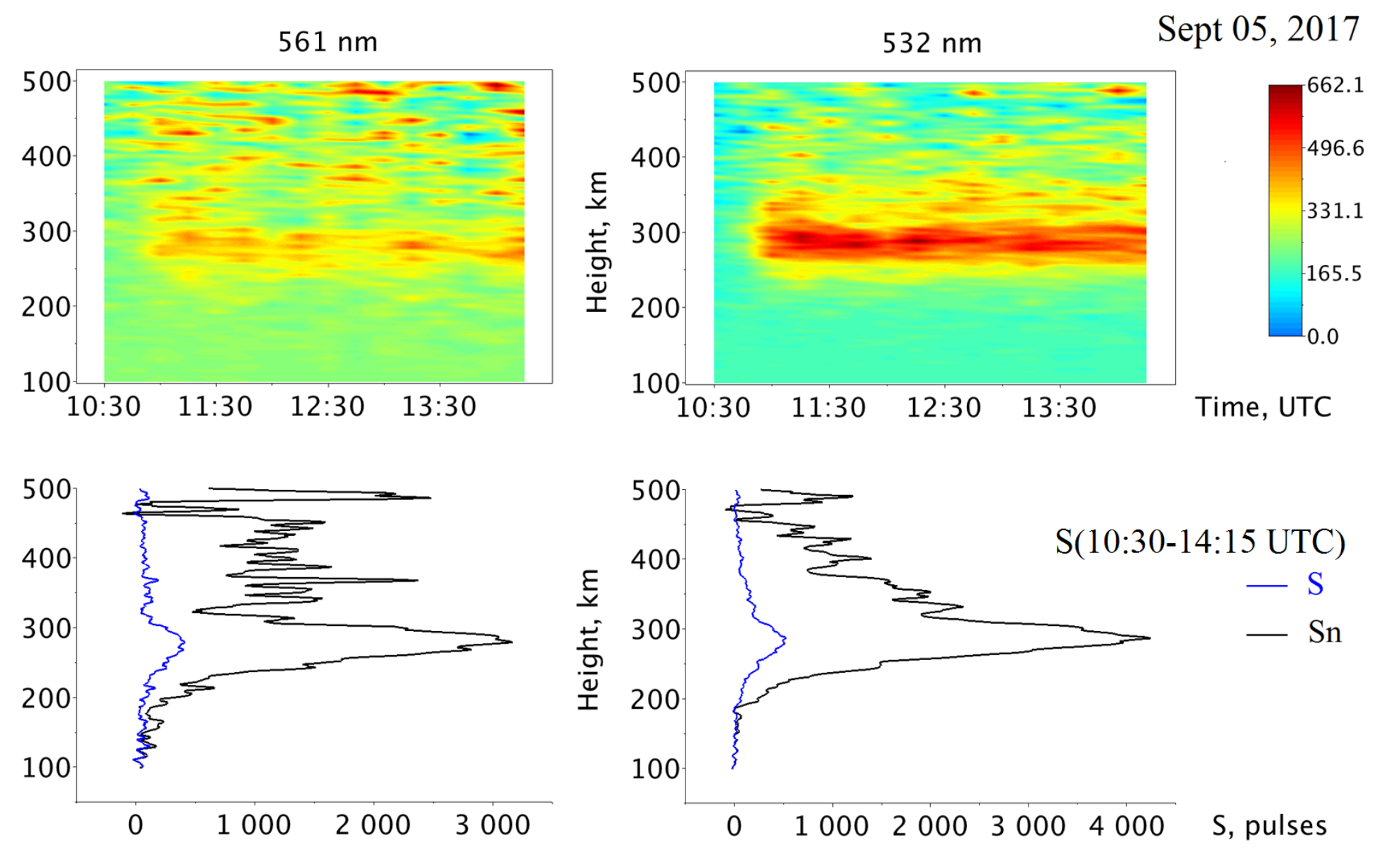

Fig. 3. Lidar «signal-background» in the region of 100-500 km, total signal S and normalized signal Sn.

1. Signal profiles shown in Fig. 3 have a maximum at the height of 280-290 km. At 11:30 UTC the F2 layer moved to a height of 300 km and remained in the 300-350 km area, which does not correspond to the lidar signal maximum.
2. The normalized signal at a wavelength of 561 nm differs from the signal at a wavelength of 532 nm by higher values in the 300-450 km region, forming there a second local maximum.
3. It was expected that the lidar signal at a wavelength of 561 nm would be several times greater than the signal at 532 nm since in the F2 region the N^+ ion content is 2 orders of magnitude smaller than the O^+ content. The total signal at a wavelength of 532 nm is usually 20-30% higher (Fig. 1,3).

Possible reasons for the formation of these signal features are discussed in the next section.

RESULT AND DISCUSSION

Figure 4 illustrates lidar signal profiles (a), and profiles of the ionization rate by precipitated electrons (b) were calculated based on the results of the paper [1].

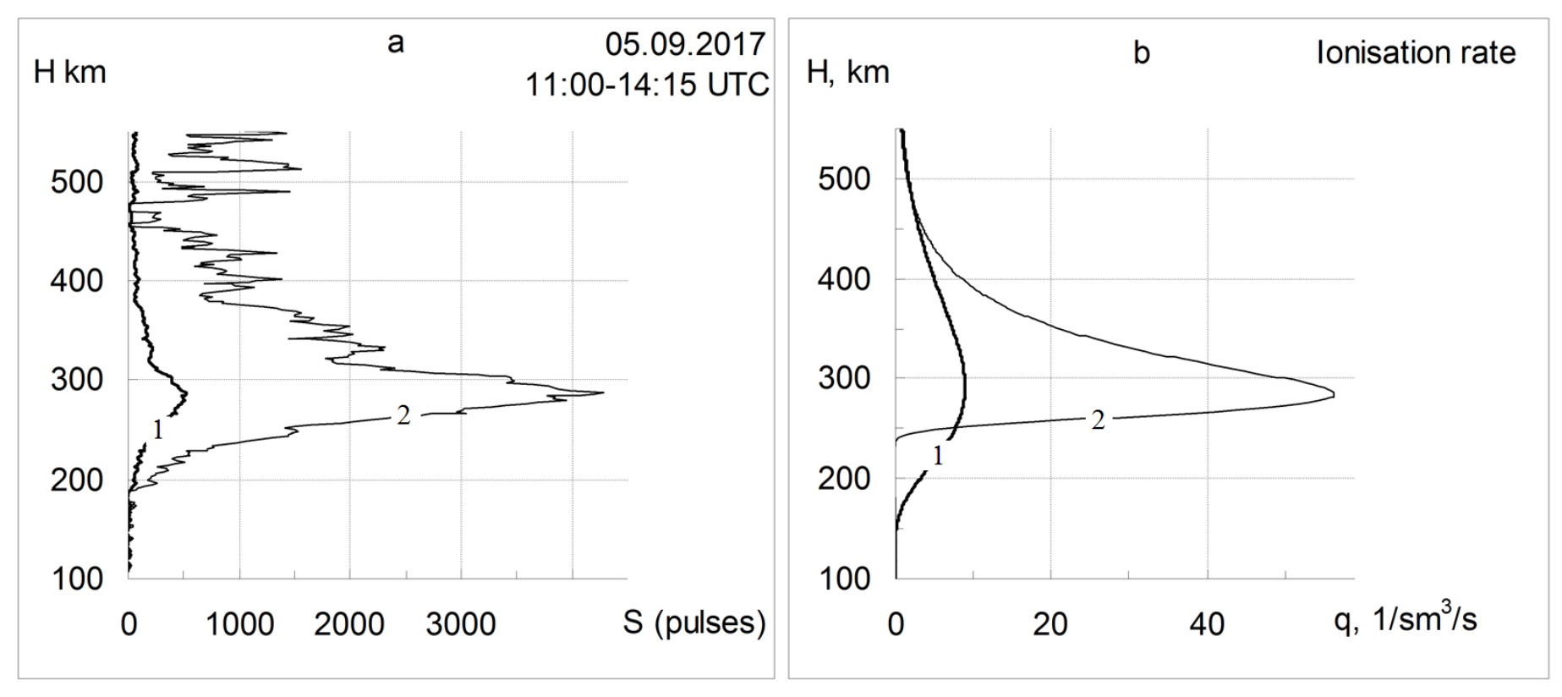

Fig. 4.Lidar signal profiles observed on September 05, 2017 (a) and ionization rates for Maxwell and monoenergetic spectra of the precipitated electrons (b).

Figure 4a shows total lidar signal S (1) obtained at the wavelength of 532 nm and the same signal Sn (2) normalized to the geometric factor $(H/100)^2$.

Figure 4b illustrates the ionization rate calculated for the Maxwell spectra of electrons with the characteristic energy of 120 eV (1) and for the monoenergetic beam of electrons with the energy of 330 eV (2). Electron energy was chosen so that the ionization rate maximum corresponded in height to the signal maximum (285 km). The electron unknown flux was defined by the value $J_0=10^8$ $cm^{-2}s^{-1}$ which is characteristic for the auroral zone. From the comparison of Fgures 4a, 4b, we can conclude that electron precipitations with the energies close to 330 eV were observed.

The conclusion from the obtained data is that the backscattering signal value is determined not only by the corresponding ion content but by the rate of their appearance. More than half of all ions formed in photochemical reactions are ions in excited states. The rates of atomic nitrogen and oxygen ion formation have the same magnitude order [2].

The contribution from the direct excitation of oxygen and nitrogen atomic ions begins to manifest in the height region of 300-450 km. In this region, the signal from excited ions, formed in the result of photochemical reactions decreases. This circumstance explains the second signal maximum in the region of height 300-450 km along the signal profile from oxygen ions, which is weakly expressed on the signal profile of nitrogen ions.

The states of the “Lower level” in Table 2 are also excited. The radiation lifetime τ of each exited ion is determined as $\tau=1/\Sigma A_{ki}$ of all the states the transition into which is possible. We found the values τ equal to 1.06 and 12.82 ns for OII and NII respectively. The pulse duration T_{pulse} at wavelengths 532 and 561 nm is 5 and 10 ns, respectively.

The interaction of laser pulse radiation with excited ions occurs during the time T_{pulse}. Excited ions, not only those which appeared during the time T_{pulse}, but also those which appeared there during the time τ, immediately preceding the probe pulse arrival, are involved in the interaction. The interaction time should be estimated by the sum $T_{pulse}+\tau$. For the wavelengths of 532 and 561 nm, it will be 17.8 and 11 ns, respectively.

The recorded relations of the lidar signal at the wavelength of 532 and 561.1 nm correspond to the obtained estimates.

MIDDLE ATMOSPHERE

When ionization sources appear, the conditions for the appearance of resonant scattering in the middle atmosphere are preserved. The Doppler broadening of the lines of ions of atomic nitrogen and oxygen for a temperature of 800 ° K is 0.04 nm, for a temperature of 200 ° K it is 0.02 nm.

The electron-neutral collision frequency for an altitude of 10 km is 3.8 GHz [3]. The ion-neutral collision frequency is two to three orders of magnitude lower than that of electrons. For excited ions with a radiation lifetime of 10^{-8} s, an increase in the number of collisions at altitudes of 10 km and above does not play any noticeable role.

Figure 5 shows the scattering ratio profiles obtained on September 5 and 9, 2017 at a wavelength of 532 nm.

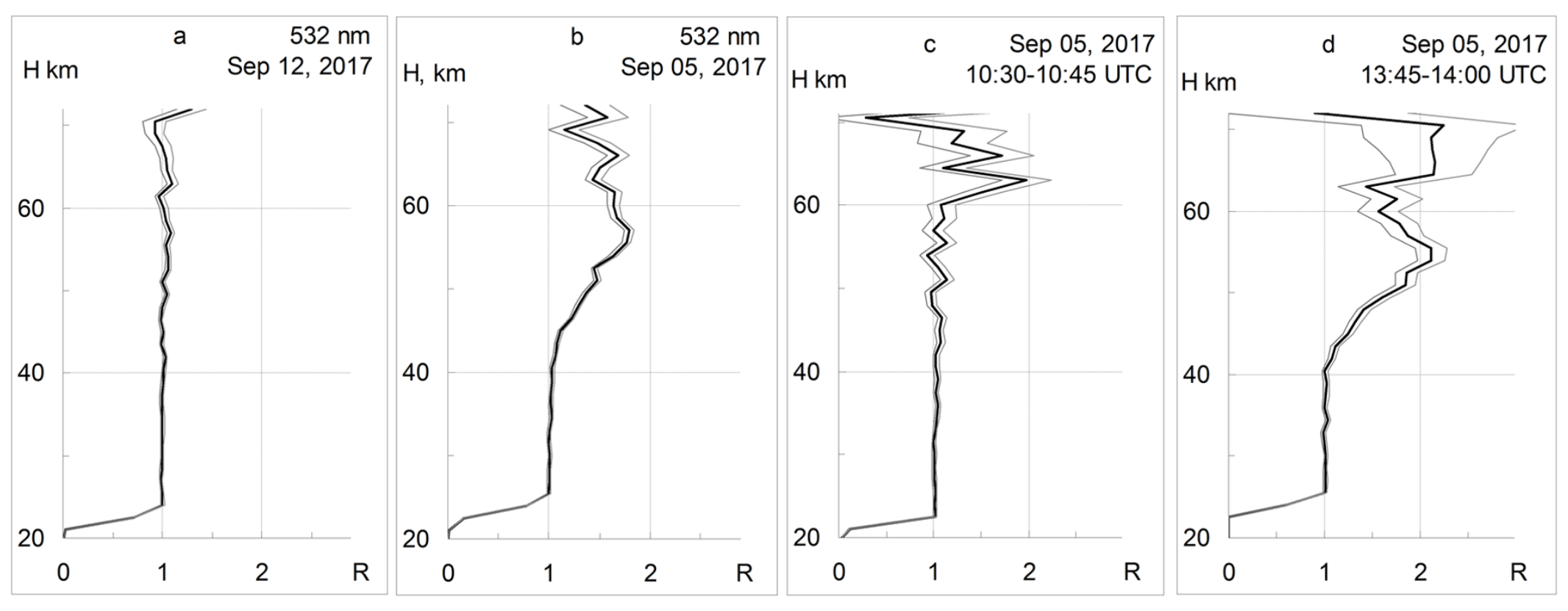

Fig. 5. The scattering ratio profiles obtained on September 5 and 9, 2017.

The overall profile for the night 09.09.2017 (Fig. 5a) is typical for the autumn season. There are no aerosol formations. Resonance scattering in the upper atmosphere was also not observed. On the total profile of the night 05.09.2017 (Fig. 5b), a scattering layer is observed in the region of 50-70 km. Profiles with an accumulation of 15 minutes in Figure 5c were obtained before the appearance of the layer in the thermosphere, in Figure 5d in its presence.

The appearance of these layers is caused by the precipitation of electrons with energies greater than 100 keV. Aerosol formations are imaginary

CONCLUSIONS

It was shown the possibility to determine the energies of precipitated electrons by the lidar method when sounding at the wavelength of 532 and 561.1 nm.

The resultant lidar signal can be considered as a sum of resonance scattering on excited ions formed in the result of photochemical reactions and scattering on atomic oxygen and nitrogen ions excited by precipitated electrons.

The sum of these signals determines the form of the obtained profile and depends on the precipitated electron spectrum.

Acknowledgement Financial support RSCF 14-11-00194

References.

- 1. Deminov, in: Plasma heliogeophysics, M:Fizmatlit, Moscow, (2008)
- 2. Richards, JGR, 116, A08307, (2011) doi:10.1029/2011JA016613
- 3. Shefov et. al, “Radiation of the upper...”, M.: GEOS, (2006)