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Modeling and natural researches of physical processes in the upper layers of the atmosphere

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The circumterraneous space, being a zone of dwelling of the man, is under influence of natural and artificial origin processes, which developing on the Earth and in the lower atmosphere (hurricanes, earthquakes, volcanos, underground, ground and high-altitude nuclear explosions...). Such indignations, more often, arising on a surface of the Earth and causing numerous catastrophic and ecological consequences directed upwards to an ionosphere, forming on the way many plasmic and other formations with strong optical radiation.

Natural cataclysms (e.g., hurricanes, tornados, etc.) are accompanied by vortical movements and generate powerful acoustic waves. These acoustic waves exert strong influences on many processes in the atmosphere.

The annual economic damage from such extreme natural disasters reaches to hundred billions dollars with numerous victims (up to tens of thousands human lives).

Research of all these processes connected with ecological accidents is an urgent task of a science. Development of such works can be done by the way of natural researches and modeling - in laboratory conditions. The aim of this project is to design a novel devise, which will register signals in optical and microwave regions, which can be the results of perturbations of upper layers of atmosphere. This devise may give us the opportunity to make predictions of ecological accidents and their strength.

In the past decade, bright shining flashes extending over large distances (i.e., sprites) have been found in the upper layers of the atmosphere. This phenomenon is of significant scientific interest as evidenced by more than a hundred published articles [*cf.*, 2–10]. Sprites with pronounced radiation in the red region of the spectrum have been observed to occur in the upper atmosphere at altitudes of 90–100 km. In the literature, it is accepted that sprites are generated by pulsed electric fields extending from storm clouds upwards to the ionosphere. Sprites are observed most often above the northern end of the Caribbean Sea during the stormy summer and autumn months, which is when hurricanes and tornados occur. The acoustic waves arising from these events are directed into the ionosphere [11, 12]. As it propagates upwards, the high-frequency component of these acoustic waves is absorbed by the atmosphere, resulting in only the infrasound component arriving at the upper layers. These powerful infrasound waves cause vortical movement of the atmosphere [13, 14].

References [11,12] establish a new observation based upon modeling calculations: the speed of hydrodynamical particles in an acoustic wave achieves a maximum in the field at altitudes on the order of 100 km., irrespective of initial power of an acoustic beam. It is possible to confirm that, at $\sim$100 km altitudes, the curvature of phase plane of oscillating speeds of an acoustic wave distorts. Due to the inhomogeneity of the acoustic field, an acoustic vortex arises in the acoustic wave. The scale of vortex is comparable to the wavelength of acoustic wave.

Monograph [15] lists significant sources of infrasonic waves such as nuclear and large chemical explosions, and also infrasound generated by rockets and planes. Natural sources of infrasounds include volcanic eruptions, earthquakes, polar lights, strong thunder storms, the sea surface during storms, and probably movement of air above the terrestrial surface cut up by mountains. Waves with such low frequencies possess very long wavelengths and the wave systems cover rather extensive layers of atmosphere. Indeed, they reach from the terrestrial surface up to the ionosphere.

The results of spectral measurements of red sprites are given in [8], in which one can clearly see a distinct spectral line with wavelength of $\sim$6700 Å in the spectral diagram. In [8], the red color of sprites is explained as being due to the excitation of the main bands of molecular nitrogen $N_2$1PG. In addition, it is established that sprites also generate microwave radiation.

In [16] it is shown that the pulsed nature of sprites and the sufficiently high spectral density of flash radiance show that these flashes are induced and caused by high excited (Rydberg levels) oxygen atoms. Note that similar flashes were recorded also in the argon discharge [17, 18], apparently induced by acoustic waves. The radiation of these flashes has a superluminescence origin.

In [19], results of experimental investigations on discharges in air are given. Red flashes similar to what turn out in the upper layers of an atmosphere (sprites) are received. Besides in work there are the results of influence by acoustic waves on an atmosphere, which resulted the response in the form of optical radiation and impulse electromagnetic waves is received.

Let us consider the results of the aforementioned experimental investigations [19]. At the instant when the gas is let in, some vortices occur in the discharge that lead to a redistribution of gas density in the discharge section and to a change of electron distribution in the positive column section [13, 14]. The letting in of air leads also to a reduction of gas temperature and to an increase in its density, which causes the dissociating attachment rate to increase, i.e.,

e+$O_2 \rightarrow O^-$+O*.

In [20,21], it was noted that, at the electron impact dissociation of molecules, there appear highly excited atoms. As the highly excited states of atoms of the Rydberg levels with n =5,6 are fairly long lived, i.e., 10^{-4} – 10^{-3}s [1, 22], let us consider the destruction of atomic states of this kind as a result of impacts with atoms and molecules. According to the theory of atomic collisions [23], the probability of transition between two levels depends on the Messi parameter $\xi \sim \delta_e/nV_a$ (with probability ∼exp(-ξ)), where n is the principal quantum number, V_a is the velocity of nucleus motion, and δ_e is the quantum defect, which depends on the orbital moment. When the orbital moment increases, the value of quantum defect sharply falls. On account of the smallness of the quantum defect for $n, l >> 1$, the Messi parameter is small and appropriate transitions are made freely. The situation is different when highly excited states with orbital momentum l = 0–1 are involved. In these cases, for values of n that are not large, the Messi parameter $\xi \geq 1$. In this case, the quenching of such states is of low probability.

Thus, owing to the quenching of highly excited states of atoms, these are quickly emptied via collisions with atoms and molecules, i.e., those with $n, l >> 1$, and an accumulation of oxygen atoms at levels 6s, 5s, 4s, 4d, and 3d occurs. This process leads to an abrupt increase in the population of the mentioned levels, and possibly even to overpopulation, simultaneously increasing the intensity of radiation of the spectral lines from the mentioned levels. When the overpopulation threshold is crossed, an emission of radiation in the form of flashes will be induced.

In [1, 22], the formation processes were considered of highly excited Rydberg atoms and molecules with $n >> 1$ in ionosphere and upper layers of atmosphere, which may play an important role in formation of bright flashes of sprites. In [1, 22] there are multiple analyses of the problems of electron-impact excitation of Rydberg states of the upper atmosphere components and their role in the emission of radiation with wide energy spectrum.

The Rydberg state emissions are permanently detected via observations of the visible radiation in the upper atmosphere [19] as well as in experiments when the upper atmosphere was irradiated with high power radio wave pulses at frequencies of 4.7–6.8 MHz. In response to that high power radio waves, microwave radiation (in the decimeter range) as well as luminescence emission of red lines from oxygen atoms is generated in the ionosphere.

The range of induced generation of microwaves [20] coincides by altitude ($\sim$200 km) with positions [24] of the maximum of altitude profiles of Rydberg state excitation rates in ionosphere under natural conditions.

Very important and interesting aspects in aeronomy is the elucidation of the effect of acoustic and shock waves on processes in the upper atmosphere, ionosphere and formation of sprites.

In [26], an experiment on the effect of shock wave from a surface shot (in one experiment 300 ton of trinitrotoluene was used) that reached a definite altitude, where conditions prevail for electric discharge in the "wave front–ionosphere" gap, as a result of which electromagnetic oscillations were detected on the satellite. For explanation of electromagnetic perturbations in ionosphere, a hypothesis was advanced in [26, 27] about electric discharge between the front of shock wave and ionosphere. The shock wave from surface shot rises to altitudes where conditions for electric discharge are formed. The crucial point in the proposed hypothesis is the assumption that electrical conductivity at the shock front exceeds that of the surrounding environment. According to this model, the ascending electric discharges may be initiated not only by the storm lightnings, but also by intense acoustic waves in atmosphere.

In [26] a novel method for giving rise to acoustic perturbations in atmosphere was offered and experimentally verified. Acoustic perturbations in atmosphere were produced by a running rotor, the ends of which revolved at the speed exceeding the sound velocity. The maximum rotor speed of 18×10^3 rev/min. provided the velocity of rotor ends of 480 m/sec. For 55 kW power of rotor revolution drive, the sound intensity level at the end face of acoustic horn was 160 dB.

The experiments on observation of airglow after acoustic perturbations were carried out using an acoustic radiator of this kind [28]. Concurrently, measurements in the radio region at 151 MHz were taken. For increasing the penetration height of sound, two acoustic radiators with slight frequency unbalance was used. At nonlinear interactions of acoustic waves in atmosphere a resonance frequency of $\sim$24 Hz was formed.

For registration of airglow a camera with film sensitivity of 1000 units was used with exposure time of 100 sec.

Concurrent with photographing, the registration of electromagnetic responses at a frequency of 151 MHz was made. With this aim, an interferometer with two vertically directed antennas was used. Of 10 experimental efforts made, 5 proved to be successful and in these an increase in airglow was observed after acoustic action. The estimation of airglow level was made by photometry of frames.

The change of summary airglow as calculated by the middle lines of frames. The augmentation of airglow occurs with the change of signal from the interferometer. Simultaneously, the augmentation of airglow occurred.

These experiments are of a qualitative nature. However, those acoustic perturbations in the atmosphere have an influence on the glow of the upper atmosphere and are, possibly, important for formation of sprite.

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