TECHNOGENIC STIMULATION OF THE GLOW OF THE UPPER ATMOSPHERE

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Technogenic stimulation of the glow of the upper atmosphere produced by various artificial effects including dispersal of substances with prescribed properties and rocket exhausts are considered. Quantitative estimates of the content of such foreign substances producing the observed radiation intensities are given. We demonstrate the importance of such studies from the ecological point of view and the need for monitoring of the evolution of these processes.

The problems of global ecology become of current interest in studies of the upper layers of the terrestrial atmosphere. As a result of various technical activities the atmosphere, the ionosphere, and the magnetosphere are polluted by foreign technogenic components. Such activities are already of a planetary scale and are manifested in the decrease of the total ozone content,[1] the greenhouse effect,[2] and the seven−day pulsation of the geomagnetic field.[3] Dispersal of various substances in to the upper atmosphere affects its natural glow.[4,5] Increase of the number and the scale of these effects in terrestrial space calls for the quantitative estimates of the reactants stimulating this glow. This problem does become very important with launching the super−power carriers of the "Energy" and "Shuttle" series.[6,7] In addition, charting the glow in the upper atmosphere is connected with the problem of identifying the energy zones of high seismic activity.[8,9]

This paper is concerned with certain estimates of the response of the radiation emitted by the upper atmosphere itself in the processes of fluorescence, light scattering, and chemiluminescence, to artificial effects. Brief ecological interpretation of these effects is given.

1. Many of the metals sprayed in the upper atmosphere can easy be detected due to their resonance emissions excited by the solar radiation. Sodium which constantly occur at altitudes of from 90 to 100 km as a result of combustion of micrometeorites is a case in point.[10]

Independent of the means for technical injection of chemical elements which fluoresce while they are irradiated by solar radiation, the quantitative estimate of the amount of substance contained in the glowing parcel of the atmosphere can be obtained from the ratio

$$I = m_X \cdot g_X / M_X \cdot m_H \cdot S, \qquad (1)$$

where I is the number of photons emitted by this substance enclosed in the atmospheric column of the 1 cm^2 cross section in 1 s in the process of fluorescence while it is irradiated by solar radiation, m_X is the total mass of the fluorescent substance (g) g_X is the number of photons of solar radiation scattered in 1 s by a single atom (molecule) of the considered substance, M_X is the atomic (molecular) mass, m_H is the weight of the single atom of hydrogen (g), and S is the cross sectional area of the fluorescent spot (cm^2).

The angular and linear dimensions of this air parcel are estimated visually and transferring from the cross section of the spot in Eq. (1) to its diameter D (cm) we obtain

$$m_X = \pi M_X \cdot m_H \cdot D^2 I / 4 g_X . \qquad (2)$$

Various dispersed substances were detected in the atmosphere: lithium aluminum, sodium, aluminum, oxide, and a number of others.[4,10−13]

Table I gives the wavelengths, the calculated values of g, the absorption coefficients σ on the emission lines at $T = 240$ K typical within the 90−100 km altitude range, and the rates of the extra−atmospheric photoionization j by the solar radiation for various substances. The data incorporated in Table I including the transition probabilities, the photoionization cross sections, and the solar radiation fluxes were borrowed from Refs. 14−16. In addition, the table indicates the amounts of the dispersed substances needed for producing the intensity of the emission $I = 10^{11}$ phot·cm^{-2}·s^{-1} = 100 K Rayleigh at the start of glowing sufficient for stable color separation when this glowing occur in the visible range. The size of the glowing cloud is assumed to be $D = 10$ km. The same table gives average concentrations X obtained on the assumption that the height of the homogeneous atmosphere is $H = 6 \cdot 10^5$ cm. It should be noted that under such prescribed conditions in some cases the vertical optical depth of the atmosphere may exceed unity, as follows from the table.

The duration of the fluorescence needed for providing the sufficiently bright glow is ensured not only by the processes of cloud spreading due to diffusion and wind motions but also by the ionization of the radiating components, which leads to the decrease of their concentrations. The ionization takes place during the recharging reactions with the atmospheric ions: $X + M^+ \rightarrow X^+ + M$. Typical rate constants are of the order of $2 \cdot 10^{-9}$ cm^3 s^{-1} (Ref. 10). In the dusk when such experiments are usually performed the content of such ions M^+ at an altitude of ~ 250 km is about $5 \cdot 10^5$ cm^{-3}, and at an altitude of ~ 100 km it is about $5 \cdot 10^4$ cm^{-3}. This indicates that the time constants of these reactions are of the order of 10^3 and 10^4s, respectively.

TABLE I. Characteristics of the fluorescent elements.

Emitting substance	Atomic mass, M	Wave length, λ, μm	g, s^{-1}	σ, cm^2	j, s^{-1}	m, g	$[X]$, cm^{-3}
Li	7	0.6708	15.5	6.7(−12)	2.6(−5)	0.06	1.1(4)
Na	23	0.589	0.80	1.5(−11)	1.8(−5)	3.7	2.1(5)
Mg	24	0.2852	0.056	1.8(−11)	3.7(−7)	56	3.0(6)
Mg$^+$	24	0.280	0.057	6.0(−12)	3.8(−9)	55	3.0(6)
Al	27	0.3962	0.24	1.2(−12)	4 (−4)	15	7.0(5)
		0.3944	0.21	1.2(−12)		17	8.0(5)
K	39	0.7699	0.67	1.3(−11)	2.7(−6)	7.6	2.5(5)
		0.4045	0.04	1.1(−13)		130	4.2(6)
Ca	40	0.4227	6.7	3.6(−11)	6.5(−5)	0.78	2.5(4)
Ca$^+$	40	0.3968	0.15	6.5(−12)	1 (−8)	35	1.1(6)
		0.3964	0.30	1.3(−11)		17	5.6(5)
Fe	56	0.3860	0.034	3.9(−13)	5 (−7)	210	4.9(6)
		0.3720	0.077	1.3(−12)		95	2.2(6)
Sr	88	0.4607	2.4	8.7(−12)	2.2(−4)	4.8	7.0(4)
Sr$^+$	88	0.4216	0.32	1.5(−12)	4.0(−8)	36	5.2(5)
		0.4078	0.44	2.3(−12)		26	3.8(5)
Cs	133	0.8944	9.7	2.6(−11)	4.0(−4)	1.8	1.7(4)
		0.8521	27	7.3(−11)		0.6	6.2(3)
		0.4593	0.25	1.1(−12)		69	6.7(5)
		0.4555	0.11	5.1(−13)		160	1.5(6)
Ba	138	0.5535	20	6.8(−11)	6.1(−4)	0.9	8.4(3)
Ba+	138	0.4934	3.6	1.5(−11)	1.1(−7)	5	4.6(4)
		0.4554	6	3.0(−11)		3	2.8(4)
Eu	152	0.4661	1.8	8.1(−12)	5.0(−4)	11	9.3(4)
		0.4627	2.0	9.6(−12)		10	8.4(4)
		0.4594	2.3	1.1(−11)		8.6	7.3(4)
Eu$^+$	152	0.4205	0.56	3.6(−12)	1 (−7)	35	3.0(5)
		0.4130	0.31	2.0(−12)		64	5.4(5)
H$_2$O	18				1 (−5)	2900	1.9(8)
H$_2$O$^+$	18	0.6158	0.06	8.7(−14)	1 (−5)	39	2.5(6)
AlO	43	0.4650	0.04	1.2(−13)	1.4(−7)	140	4.2(6)

Simultaneously with these processes the timelife of the atoms in a given atmospheric parcel is determined by photoionization, diffusion, and radiative transfer

$$\tau = 1/\alpha\{M^+\} + j + D .$$

Therefore, the observed rate of attenuation of glowing will give information about the actual processes taking place in the cloud. Naturally, the cloud altitude and changes of its size should be taken into account.

The recombination of such metal ions X^+ takes place mainly in the process of triple collisions accompanied by the formation of the molecular ions. Their subsequent reactions again result in the formation of the ions, because the recombination reaction $X^+ + e \rightarrow X + h\nu$ is slow (rate of its reaction is $\beta = 1\cdot10^{-12}$cm^{3}s^{-1}, Ref. 10). Thus the ratio

$$[X^+]/[X] = ([M^+] + j + D)/\beta\cdot n_e$$

is mostly of the order of $10^2 + 10^4$. It can be measured experimentally, since many metals have fluorescing ions.

2. In the region of temperature minimum near the mesopause (at an altitude of about 90 km) unusually glowing clouds are sometimes observed under certain conditions (the occurence of water vapor and condensation nuclei). These clouds have a fine structure consisting of the ice crystals and noctilucent−bluish color. These are the highest clouds in the terristrial atmosphere called noctilucent clouds because of their color.[17,18] The natural concentration of water vapor at these altitudes is about $10^8 - 10^9$ cm^{-3}. Small ice crystals are not formed for such water vapor concentrations and at the temperatures above 150 K. In order the water vapor could condense into ice crystals at temperatures typical of the mesopause (which are, as a rule, above 150 K), much higher water vapor concentration is needed.

Table II presents the vertical temperature profiles in the region of the mesopause for various seasons based on the CIRA−72 atmospheric model.[19] The same table also gives the corresponding saturated water vapor pressures above ice (mm Hg) calculated for the concentrations of the water vapor molecules required for crystallization.

TABLE II. *Water vapor concentrations needed for condensation in the region of mesopause.*

Altitude, km	Winter			Equinox			Summer		
	T, K	P_{H_2O}, mm Hg	H_2O, cm^{-3}	T, K	P_{H_2O}, mm Hg	H_2O, cm^{-3}	T, K	P_{H_2O}, mm Hg	H_2O, cm^{-3}
70	227	4.46(−2)	3.4 (15)	222	2.5 (−2)	1.9 (15)	217	1.4 (−2)	1.06(15)
80	212	7.08(−3)	5.4 (14)	198	1.0 (−3)	7.6 (13)	164	1.26(−6)	9.6 (10)
90	205	2.6 (−3)	1.97(14)	187	1.5 (−4)	1.14(13)	150	3.16(−8)	2.4 (9)
100	213	7.9 (−3)	6.0 (14)	212	7.08(−3)	5.4 (14)	214	8.9 (−3)	6.7 (14)

As can be seen from Table II, the noctilucent clouds can be formed under normal conditions only in summer when the temperature in the mesosphere falls to 150 K and even lower. At other temperatures the water content would require which is substantially greater than the natural content. In addition, it is well known that even under conditions of supersaturation not all the water vapor condenses into ice (one of the possible reasons for this is the lack of the condensation nuclei).[17,18]

The mass of water contained in a saturated vapor which occupy the atmospheric parcel with the cross sectional area S and height equal to the height H of the homogeneous atmosphere can be estimated from the relation

$$m_{H_2O} = S \cdot H \cdot [H_2O] \cdot M_{H_2O} \cdot m_H = \pi D^2/4 \cdot H \cdot [H_2O] \cdot M \cdot m_H ,$$

where D is the diameter of glowing spot, $H = 6 \cdot 10^5$ cm (for the mesosphere), $[H_2O]$ is the water vapor concentration (cm^{-3}), M_{H_2O} is the molecular mass of water, and $M_{H_2O} \cdot m_H$ is the mass of a water molecule equal to $3.0 \cdot 10^{-23}$ g. For $D = 10^7$ cm and natural water vapor concentration of about 10^8 cm^{-3} we have $m_{H_2O} = 140$ kg. Similar to fluorescence, light scattering by ice crystals can also be observed only in the irradiated atmospheric parcels.

Using the data given in Table II for various seasons together with the data on the size of the observed glowing clouds it is easy to estimate the amount of water needed for the formation of ice crystals and to relate it to launching of rockets of different powers. It is natural to expect that the parcels of enhanced water vapor content have limited dimensions of the order of several hundreds of kilometers.

According to the available data on noctilucent clouds the average size of their scattering particles is 10^{-5} cm (Ref. 18). If we assume that all the water vapor forms the crystals (which is, of course, an exaggeration), the ratio of the number of ice crystals n to the water vapor concentration will be

$$n/[H_2O] = 6 \cdot 10^{-8}.$$

However, since the actual values of n are about 1 cm^{-3}, this ratio would most probably be $n/[H_2O] \sim 10^{-8}$. It also follows from the data given in Refs. 17 and 18 that the scattering coefficient of such a particle is about $5 \cdot 10^{-11}$ cm^2.

Hence the intensity of scattered radiation is

$$I_{H_2O} = 10^{-8} \sigma H [H_2O] F,$$

where $F = 1.3 \cdot 10^{17}$ phot·cm^{-2}s^{-1} is the solar radiation intensity in the visible. If we now disperse m_{H_2O} (g) of water in the form of a spot with diameter D (cm), the scattered radiation intensity in the dusk can be estimated in Rayleigh, provided the condition for condensation is satisfied, from the relation

$$I = 3 \cdot 10^{15} m_{H_2O}/D^2.$$

The brightness of the glow under these conditions is 4 MRayleigh, which is 40 times as high as the sky brightness at a zenith angle of 40° in the solar azimuth when sun is located at an angle of 10° below the horizon.

3. Chemiluminescence is primarily produced during the launch and flight of rockets and space vehicles. It is less intense than fluorescence and may be detected from the ground only at night. Conditions for night observations of the chemiluminescence can be determined following Ref. 20.

Now dwell on the glow of nitrogen oxide, oxygen, and hydrogen molecules. The continuous green–tint glow of the upper atmosphere is produced during the reaction described for the atmospheric conditions in Ref. 21

$$NO = O — NO_2 + h\nu.$$

Then the NO_2 molecule dissociates with simultaneous reduction of the O_2 molecule according to the reaction

$$NO_2 + O \rightarrow NO + O_2.$$

Spectral distribution of the continual emission of the night sky was obtained in Ref. 22 for both the atmospheric and the extra–atmospheric components. The continuum of pure NO was studied in Ref. 23, where its intensity was estimated to be 5–10 Rayleigh/nm in the visible. The results of laboratory studies of the continuous glow of NO and its spectral distribution were given in Refs. 24 and 25.

In order to the radiation continuum produced during the combustion of the nitrogen–containing rocket fuel exceeds the natural background, the following inequality should be satisfied:

$$[NO]_{art} \gg [NO]_{nat} .$$

The brackets denote concentration. The maximum intensity of the natural continuum takes place in the range of the maximum atomic oxygen concentration, i.e., at altitudes of from 90 to 100 km.

The intensity I of the continuous glow of NO can be represented in the form

$$I = [NO][O] \cdot \alpha_{16} \cdot H,$$

where $[NO] \simeq 10^8$ cm^{-3} $[O] \simeq 4.1 \cdot 10^{11}$ cm^{-3}; α_{16} is the rate constant and is equal to $6.4 \cdot 10^{-17}$ cm^3 s^{-1} (Refs. 24 and 26); and H is the height of the homogeneous atmosphere and is equal to $6 \cdot 10^5$ cm. Substituting all the above–considered values into our formula we obtain $I = 1.6 \cdot 10^9$ phot·cm^{-2}·s^{-1} = 1.6 K Rayleigh. The amount of natural nitrogen oxide m_{NO} needed to produce the background intensity of the glow can be calculated from the relation

$$m_{NO} = M_{NO} m_H [NO] H S,$$

where $M_{NO} \cdot m_H$ is the mass of the NO molecule and is equal to $5 \cdot 10^{-23}$ g, M_{NO} is the molecular mass of NO, and S is the cross sectional area of the glowing spot with the diameter D. If D is equal to 10^7 cm then m_{NO} amounts to 240 kg.

As has already been noted above, the molecules of NO_2 are rapidly reduced to NO. Therefore, at night the NO concentration remains practically at its starting level. The reduction rate constant τ is determined from the relation $\tau = 1/\alpha_{14}[O]$, (s), where α_{14} is the rate constant for the reaction of NO_2 dissociation and is equal to $3.2 \cdot 10^{-11} \cdot \exp(-300/T)$ cm^3 s^{-1} (Ref. 10).

At T = 200 K (which is typical of the mesopause) and for $\alpha_{14} = 7 \cdot 10^{-12}$ cm^{3}s^{-1} we found $\tau = 0.34$ s. Thus, in order for the artificial chemiluminescence was above the natural, the injection of nitrogen oxide not less than 240 kg is needed which is quite feasible.

In the upper atmosphere (in the range 250–300 km) where positive ions of atomic oxygen predominate these ions emit in the red range at a wavelength of 630.0 nm in the transition from the metastable state ^1D. Oxygen is excited and emits following the reaction chains[10,24]

$O^+ + O_2^+ \to O_2^+ + O$, $\alpha_{19} = 2 \cdot 10^{-11}$ cm^{3}s^{-1},

$O^+ + e \to O(^1D) + O$,

$\alpha_{20} = 2 \cdot 10^{-7}$ cm^{3}s^{-1}, $O(^1D) \to O + h\nu$ (630.0 nm).
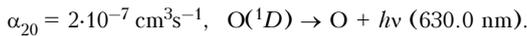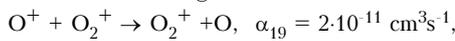
The natural intensity of this emission $I_{630.0}$ amounts to 100 Rayleigh (10^8 phot·cm^{-2}·s^{-1}) in the absence of aurora. However, it can be increased because of the injection of carbon dioxide produced by rocket engines into the upper atmosphere as well as because of exhausts of surplus oxygen and hydrogen. In these cases the additional intensity of red emission is produced during the following reactions[27,28]:

$O^+ + CO_2^+ \to CO^+ + O_2^+$, $\alpha_{21} = 9.4 \cdot 10^{-10}$ cm^{3}s^{-1},

$O^+ + O \to O + O_2^+$, $\alpha_{22} = 2 \cdot 10^{-11}$ cm^{3}s^{-1},

$O^+ + H_2 \to OH^+ + H$, $\alpha_{23} = 2 \cdot 10^{-9}$ cm^{3}s^{-1},

$OH^+ + e \to H + O(^1D)$, $\alpha_{24} = 2.2 \cdot 10^{-8}$ cm^{3}s^{-1},

$O(^1D) \to O + h\nu$ (630.0 nm).
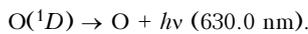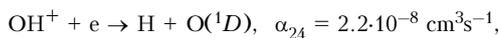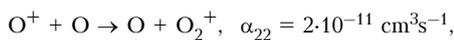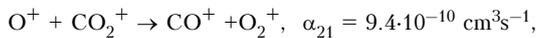
Let us denote the natural concentration of molecular oxygen by $[O_2]$ and the concentrations of the components (CO_2, O_2, and H_2) favouring the production of surplus oxygen at these altitudes by $[X]$. In this case a noticeable amplification of red emission will take place when $[X] \cdot \alpha_X \gg [O_2] \cdot \alpha$.

Therefore, in order to detect the significant increase in the intensity emission at $\lambda = 630.0$ nm the intensity of excess glow I_X should be by a factor of n above the background intensity $I_{630.0}$ (which is about 100 Rayleigh), i. e.,

$$I_X/I_{630.0} [X] \cdot \alpha_X/[O_2] \cdot \alpha = n. \qquad (3)$$

We now estimate the net mass of natural molecular oxygen m_{O_2} contained in a given glowing atmospheric

parcel with the diameter D, and the masses of gases (CO_2, O_2, and H_2) artificially injected into this glowing parcel and favouring the production of surplus oxygen.

The average height of the homogeneous atmosphere for these components and in the given region of altitudes (~250–300 km) is $5 \cdot 10^6$ cm. Thus, we obtain on account of Eq. (2) for the masses of the corresponding molecules (CO_2, O_2, and H_2): $M_{O_2} \cdot m_H = 5.3 \cdot 10^{-23}$ g, $M_{CO_2} \cdot m_H = 7.3 \cdot 10^{-23}$ g, and $M_{H_2} \cdot m_H = 3.3 \cdot 10^{-24}$ g.

The ratios of their net masses must satisfy the condition

$$m_X/m_{O_2} = [X] \cdot M_X/[O_2] M_{O_2}.$$

Using relation (3) we obtain

$$m_X/m_{O_2} = n \cdot M_X/M_{O_2} - \alpha/\alpha_X.$$

Substituting the molecular masses and rate constants we find

$$m_{C_2O}/m_{O_2} = 1.02; \quad m_{O_2}/m_{O_2} = n; \quad m_H/m_{O_2} = 6.2 \cdot 10^{-4}. \quad (4)$$

To evaluate the obtained results the following example must be considered. The night sky glow at $\lambda = 630.0$ nm has the form of a spot ~$5 \cdot 10^7$ cm in diameter. A typical concentration of molecular oxygen within the 250–300 km altitude range is about $2 \cdot 10^7$ cm^{-3}. According to the above estimate m_{O_2} is equal to 10 t. To increase the red emission by a factor of 10 it is necessary to inject additionally about 100 t of CO_2, 100 t of O_2, and 0.063 t of H_2 in accordance with relations (4).

The most significant effect on the indicated variations of red emission at 630.0 nm, apparently, has the exhaust of hydrogen. More accurate conclusions can be made from realistic data on the size of glowing spots accompanying rocket launches.

4. The three types of glow of the upper atmosphere observed in the natural regimes of their origin and cessation bear an information about the physico–chemical character of processes at the indicated altitudes. These emissions may be stimulated by either the cosmogenic factors (geomagnetic perturbations, influx of meteoric substance) or by the planetary ones (volcanic activity, seismo–ionospheric perturbations, etc.). However, as the technogenic effects intensify in the terrestrial space, the frequency and intensity of glows increase. This fact testifies to the global changes in the physico–chemical conditions in the regions of concentrated technogenic effects on the terrestrial space.

There are two principal types of such effects: special–purpose injection of various chemical elements and exhausts of the products of combustion of the rocket fuel and operation of the orbiting rocket engines (shuttle systems).

The chemically active reactants enjected by rocket engines include sodium trimethyl aluminum, aluminum oxide, nitrogen oxide, carbon dioxide, water vapor, strontium, caesium, barium, etc. The appearance of such substances stimulates the glow and results in generation of electric field when ions drift from the point of injection across the magnetic field. Night experiments were directly related to the injection of chemiluminescent clouds (trimethyl aluminum). For example, $1.5 \cdot 10^{27}$ molecules of H_2O, $1.5 \cdot 10^{26}$ molecules of CO_2, and $6.6 \cdot 10^{26}$ molecules of H_2 were injected into the ionosphere at low latitudes in the

"LAGOPEDO" experiment.[4] The changes in ionic composition were observed in the form of a glowing spot up to 80 km in diameter at an altitude of 261 km.

The H_2O^+ ions can fluoresce at the altitudes near 250 km, their glowing time is $5 \cdot 10^2 - 5 \cdot 10^3$ s. The glow of these ions at high altitudes is fluorescence (see Table I). The H_2O^+ ions are produced during the ion–exchange reaction

$$H_2O + O^+ \to H_2O^+ + O .$$
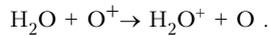
The rate constant of this reaction is $\alpha_{32} = 2.3 \cdot 10^{-9}$ cm^3 s^{-1} (Refs. 10 and 24). The H_2O content given in Table I was estimated from the data of Ref. 11 provided that $[H_2O] \simeq 74[H_2O^+]$.

The scale of a single injection of water vapor molecules into the upper atmosphere is illustrated in the example of the HEAO–C satellite which was launched with the help of an Atlas–Centaur rocket carrier on September 20, 1979 accompanying by the injection of $7 \cdot 10^{29}$ molecules of water vapor and hydrogen into the upper atmosphere. The intensity of emission at 630.0 nm in the "hole" 3000 km in length from west to east and 800 km in length from south to north was 8300 Rayleigh (against the background of 100 Rayleigh) while the emission at 557.7 nm increased from 300 to 900 Rayleigh.[4]

The principal mechanism of technogenic effect on terrestrial space is the transportation of substances into the highly sensitive upper atmosphere by rockets. At low, middle, and high altitudes the local pollution by such surplus substances results from the use of powerful hoisting lcarriers of the "Energy" and "Shuttle" series. Large scale perturbations in the ionosphere occur due to burning out the flight track by the jet of a rocket engine and thermal compression in the process of interaction between inflowing air and flame of a jet engine.

With the advent of the systems of shuttle series a new period in technogenic transformation of the terrestrial space has started which is accompanied by intensification of artificial processes in the upper atmosphere. The partial cycles of operation of rocket engines for orbit corrections, docks, indocks, and fuel drainage should also be taken into account. It should be noted that the total number of launches exceeds tens of thousands. In order to analyze the exhaust of a single launch of either the "Energy" or the "Shuttle" carriers let us draw our attention to Table III borrowed from Ref. 6. We must recall here that a noticeable increase in the chemiluminescence of the local air parcels of the upper atmosphere takes place when 240 kg of nitrogen oxides, 100 t of CO_2, 100 t of O_2, and 63 kg of H_2 are injected into these parcels. It can readily be seen that a single "vollay" of heavy carriers exceeds the quantitative estimates of stimulators of these chemiluminescence by several orders of magnitude .

The components fluorescing around 100 km are mainly Li, Na, and AlO, their typical glowing time is of the order of $10^4 - 10^5$ s. Along with the technogenic transportation of these ingredients at the given altitude their influx from the outer space, particularly in the case of Na and Li, should also be taken into account. The increase in both Li and Na content often is directly correlated with volcanic activity and high–altitude nuclear explosions.[5,9] The effect of the El–Chichon eruption on March 3, 1982 on the hydrogen content in the upper atmosphere was also noted.[29]

TABLE III. Exhausts of rocket engines. [6]

| Carrier | Chemical compounds | | | | | |
	Chlorine and hydrogen chloride, t	Nitrogen oxides, t	Carbon oxides, t	Water vapor and hydrogen, t	Alumi–num oxides, t	Net weight, t
"Energy" series	0	0	740	750	0	1490
"Shuttle" series	187	7	378	346 + 166	177	1261
The sum of the re–actants	187	7	1118	1262	177	2751

Thus, with increasing the technogenic effect on the terrestrial space the probability of large–scale newly originating processes representing the response on the transformation of the highly sensitive nature of the upper atmosphere also increases as can be clearly traced from the data of Ref. 30. Such processes may be manifested in the more frequent glowing air parcels.[8] Studying their functional role is quite important due to unpredictability of both their origin and results.

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