ISSN 0040-2508

TELECOMMUNICATIONS AND RADIO ENGINEERING

Volume 76 Number 11 2017

begell
house, inc.
publishers

TELECOMMUNICATIONS AND RADIO ENGINEERING

Volume 76, Issue 11 **2017**

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ON SOME ELECTRIC CHARACTERISTICS OF THE ATMOSPHERE IN THE REGIONS OF THE LARGE-SCALE FIRES AND THE IONOSPHERE/ATMOSPHERE ELECTRIC INTERACTION

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Basic characteristics of the large-scale fires are considered; the formulas for assessment of the excitation of electric characteristics of the surface atmospheric layer are provided on the basis of the volume distribution model for average mass concentration of the smoke aerosol. The possible model of the ionosphere-atmosphere interaction is provided, main mechanisms of transfer of the excitations from the lower atmosphere to the ionosphere and magnetosphere are analyzed briefly and possible environmental effects are considered.

KEY WORDS: *large-scale fires, atmosphere, ionosphere, perturbance of electric characteristics of the atmosphere, ionosphere-atmosphere interaction model, environmental effects*

1. INTRODUCTION

Large-scale fires of a different genesis are frequently occurring in our planet. They cover large areas (hundreds and thousands of square kilometers) and last for long time periods (tens of days). They not only incur a huge environmental damage, but also seriously modify the lower part of atmosphere having varied its electric characteristics substantially and result in a number of wave processes (see, for example, [1,2]). This is related to both the plasma itself (this part of the fires is called the ‘thermic’) and to the smoke plume (the cloud). Wave disturbances, in its turn, result in noticeable and typical variations of the ionospheric electricity at the altitudes of 50…80 km that causes modification of the ionospheric plasma at the above altitudes and, probably, at the altitudes of the ionospheric E-region (see, for example, [3–5]), disruption of radio communication and a number of other problems. As the result of the fires a huge amount of ash and other particles is released into the atmosphere. The ash is influencing upon the electric field of the lower part atmosphere, because these particles acquire electrical charge and a large and dense layer with a high and non-compensated charge is formed near the surface of the Earth. This charge can essentially vary the surface electric field potential gradient that results in forming of the ionized layer near the surface of the Earth on the areas of tens of square meters and with the thickness of tens to hundreds of meters and more. The parameters of a fire depend upon the area size, type of flammable substances, their saturation, type of the terrain, season of the year and the weather conditions. A typical large-scale fire in the woods covers the area of $S \approx 2000-5000$ ha and lasts for $\Delta t \sim 1\ldots10$ days (subsequent speculations and assumptions are also applicable to the fires of any other origin). The specific weight of combustible materials of such fires is $\tilde{m} \approx 20-40\,\text{kg/m}^2$. The average heat flow Π_T and the average power flux $\Pi_p = \Pi_T / \Delta t$ amount to [5]: $\Pi_T = \varepsilon_T \tilde{m}$, $\Pi_p = \Pi_T / \Delta t$. At the average duration of combustion $\Delta t = 10$ days, and the specific combustion value of the combustible materials $\varepsilon_T = 4{\cdot}10^7$ Joule/kg we obtain $\Pi_T \approx 1.6{\cdot}10^9$ Joule /m^2 and the average daily value $\Pi_p = 1.6{\cdot}10^4$ W/m^2. The obtained assessments of the values Π_p allow asserting that similar fires can generate an intensive atmospheric convection of the combustion products and the fire-spouts near the surface of the Earth, which are developed at $\Pi_p > \Pi_{p\min} \approx 10^4$ W/m^2, along with raising of the smoke, soot and dust for substantial altitudes. The energy and power of the fire can be estimated as $E = \varepsilon_T m$, $P = E / \Delta t$ (where m is the mass of the substance that burned). At the fire duration of about 10 days and the estimated mass of the substance that burned $m \approx 15\,000$ t the values of E and P will be equal to about 600 TJoule and 7 GW. The amount of the released heat will be $Q \approx 500$ TJoule.

Probable influence of the large-scale fires upon the lower ionosphere is studied insufficiently (see, for example, [1–5]). It is known that the large-scale fires are accompanied by generation of the acoustic radiation within a broad frequency range [2–5]. The power of such radiation is determined by a share of the power η_a, which is converted into the acoustic radiation power P_a. Normally, based on the observations it is considered that $\eta_a \approx 0.3\%$. The pulsing fire torches in the region of the fire generate the noise electromagnetic radiation within the frequency bandwidth of ~1 Hz…100 MHz with the inhomogeneous spectrum, in which the spectral components are separated. They include eigen frequencies of the atmosphere: the estimations provide for: $\omega_a \approx 1.9{\cdot}10^{-2}$s, $\omega_b = 1.2{\cdot}10^{-2}$s. During the fires it becomes possible to generate the oscillations caused by the wind streamlining of the flame torch surface or of the thermic with the frequencies of $f_r = v \cdot \text{St}^{-1} / d \approx 0.21 v / d$ [2,5], where St is the Strouhal number; v is the wind velocity; d is the conditional diameter of a torch or a thermic. For example, for a separately taken torch at $d = 100$ m, $v = 1\ldots10$ mps we have $f_r \approx 0.002\ldots0.02$ Hz. Strong gas turbulence occurs within the limits of the torch that also facilitates radiation of the acoustic waves with the typical frequencies of $f_t \approx v_t / d \approx 0.1\ldots1$ Hz, where $v_t \approx 1\ldots100$ mps is the average velocity of the turbulent flow depending upon the scale and intensity of the fire. As the result of transformation of the atmospheric electric field power into the energy of the low-frequency electromagnetic radiation it is possible to obtain generation or increasing of the radiation in the low-frequency domain of the radio wave band.

During recently it is observed a significant increase in the interest to studying the problem of the "troposphere-stratosphere-ionosphere" interaction. It is introduced the term of the "space weather" (see, for example, [6]) due to experimental evidence of the interrelation of the meteorological processes in the troposphere and stratosphere with the processes in the ionosphere. It is known that the atmospheric electric field is an important component of the global and regional (local) atmospheric electricity, which is represented in the physical terms by the quasi-static electric field, created by volume charges in different layers of the atmosphere and eigen charge of the Earth. It is also determined that often at strong winds (at propagation of the atmospheric fronts etc.), thunderstorms, dust storms and the large-scale and long lasting fires the electric field intensity in the regions may attain 1 000 W/m and more.

2. THE IONOSPHERE-ATMOSPHERE INTERACTION MODEL

The model of volume distribution of average mass concentration of the smoke aerosol $<M>(x,y,z)$ with the unipolar charge can be developed on the basis of the assumption that distribution of the substance in three directions within the zone of the fire occurs independently and under the normal law. The origin of the rectangular Cartesian system of coordinates is positioned in a conditional middle of the line of the fire (the axis OY); the direction of the average wind matches with the positive direction of the axis OX, the axis OZ is vertical to the surface of the Earth. As a rule the zone of plasma (combustion) occupies a smaller area than the aerosol volume zone, and, therefore, modification of the atmospheric electricity by the conditionally uniformly spatially distributed smoke aerosol is considered as the basic source. Vertical scattering of the aerosol is considered as if in the infinite space. The smoke plume evolution in the model is stipulated primarily by the turbulence characteristics of the atmosphere, because, as it is shown by the estimations, other processes (settling of the ions of the air upon the charged particles, the Coulomb interactions etc.) exert no essential influence. Distribution of the aerosol volume charge can be obtained from the formula for the distribution $<M>(x,y,z)$. On the basis of the known distribution of the volume charge density $\rho(x,y,z)$ it is possible to calculate the electric field intensity $E(x,y,z)$ in an arbitrary point of the space enveloping the smoke plume of the fire. To describe variations of $<M>(x,y,z)$ we use the Gifford fluctuating flow model with application of the hypothesis of the Lagrangian turbulence characteristics [7]. We admit that in the lower troposphere (z < 4 km) there exist up to 80…90% of the aerosol particles from their total content within up to 30 km [8]. Approximately 10% of them fall on the man-made sources, up to 30…40% – on the saline particles generated by the sea and 30…40% – on the aerosols generated by the surface of the Earth. In the region of the fire total number of the aerosol particles is increased substantially, and the percentage of the aerosols originated in the process of combustion may attain 80…90% of their total quantity [9]. The equation for $<M>(x, y, z)$ in the considered case is similar to [7] and described by the following expression (it is obtained for the continuous point source raised to the effective altitude of z *):

$$< M > (x, y, z) \simeq \frac{K_u Q e^{-y^2/2\sigma_y^2}}{2\pi \frac{dx}{dt} \sigma_y(x) \sigma_z(x)} \left[e^{-\frac{(z-z^*)^2}{2\sigma_z^2}} + e^{-\frac{(z+z^*)^2}{2\sigma_z^2}} \right], \qquad (1)$$

where $dx/dt = u$ is the average wind velocity (normally, $u \approx 1 - 20$ mps); $\sigma_y(x)$ and $\sigma_z(x)$ are the absolute dispersions of the coordinates along the respective axes; Q is the operation efficiency of the continuous point source denominated in grams per second; K_u is the coefficient of use in the generator. On the basis of visual observations we also consider that the average wind velocity is substantially higher than the velocity of propagation of the fire zone along the coordinate y. Considering that the smoke plume evolution in the model is stipulated primarily by the turbulence characteristics, then in order to estimate electric characteristics of the surface atmospheric layer similar to (1) we can put down the equation for distribution of the aerosol volume charge:

$$\rho(x, y, z) \simeq \frac{I_o e^{-y^2/2\sigma_y^2}}{2\pi \frac{dx}{dt} \sigma_y(x) \sigma_z(x)} \left[e^{-\frac{(z-z^*)^2}{2\sigma_z^2}} + e^{-\frac{(z+z^*)^2}{2\sigma_z^2}} \right], \qquad (2)$$

Knowing the distribution of $\rho(x, y, z)$ we can calculate the field intensity in any point of the space near the epicenter of the fire. The electric field potential in the point (x_1, y_1, z_1) within the considered system of coordinates could be put down in the following form:

$$\varphi(x_1, y_1, z_1) = 4\int_0^\infty \int_0^\infty \int_0^\infty \frac{\rho(x, y, z)}{\sqrt{(x-x_1)^2 + y^2 + (z-z_1)^2}} dxdydz. \qquad (3)$$

In this case it is considered the symmetrical manner of ρ along the axis oy. Near the surface of the Earth the lines of force of the electrostatic field E possess predominantly the normal component E_z and then $E_z(x_1) = (-d\varphi / dz_1)\big|_{z_1 \to 0}$. To obtain an analytical solution to $E_z(x_1)$ we assume that all the smoke particles are concentrated within the elliptical cone, the dimensions of which along the axes y and z are equal to $\simeq \sigma_y(x)$ and $, \simeq \sigma_z(x)$, and inside of the above cone at the fixed $x_1 > z^*$ the value of

ρ depends on the coordinate *x*; for the purpose of simplification of the solution the integration limits can be selected as $x_1/2$ and $3x_1/2$ similar to [10]. Then the equation for $E_z(x_1)$ suitable for performance of the assessments can be represented in the following form:

$$E_z(x_1) = 4\rho_0(x_1)^2 \int_{x_1/2}^{3x_1/2} \frac{1}{x} \ln\left[\left(\frac{1+\sqrt{4A/\sigma_y^2(x)}}{1+\sqrt{4B/\sigma_y^2(x)}}\right)\sqrt{B/A}\right] dx, \qquad (4)$$

where $A = (x - x_1)^2 + (z^* + \sigma_z/2)^2$ and $B = (x - x_1)^2 + (z^* - \sigma_z/2)^2$.

The performed assessments showed that for the smoke plumes of the fires covering the efficient volume of $V \sim 5\times10^{10}\,\mathrm{m}^3$ maximum deviation of the atmospheric electric field potential gradient from the background values amounts to ± 10 kV/m that is comparable to its variations during the dust storms [11]. The equation (4) allows performing assessments of E_z : for $x_1 = 1$ m $E_z \approx \cdot 10^3$ W/m, for x_1 = 100 m – $E_z \approx 10^2$ W/m. The obtained estimation of the excitations E_z is comparable in its value with the experimentally obtained variations of E_z before the earthquakes (see, for example, [12]).

The issue of transfer of the excitations from the lower atmosphere to the ionosphere and magnetosphere is studied insufficiently. Let us briefly consider the basic mechanisms.

Perturbations of the vertical electrostatic field. In [12,13] it is performed calculation of the process of penetration into the ionosphere of the electric field generated by a local region in the surface atmospheric layer (the case of the seismic source field), and it is also shown that the field penetration efficiency is higher at night than during the day being strongly dependent upon the dimensions of the vertical field localization region. The electric field intensity possesses a substantial value (0.3…0.7 W/m) at the ionospheric altitudes solely for the sources with the typical dimension of approximately 100 km under the condition that its value in the epicenter is $|E_z| \approx 10^3$ W/m. As it is evident from the provided above estimates performed according to the formula (4) such fields can be real in the zone of a very large-scale fire. Therefore, one can assert that the considered source may result in variations of the field intensity at the ionospheric altitudes (and the possibility of recording the electron concentration perturbation) by means of penetration of the electric field, which is generated by a local region of a very large-scale fire in the surface atmospheric layer.

Variations of the atmospheric gas density. It is known that the large-scale fires are accompanied by generation of the acoustic radiation within a broad frequency bandwidth, the total power of which radiation is increased by hundreds of times as compared to the non-disturbed conditions (see, for example, [1–4]). Variations of the atmospheric gas density near the surface of the Earth in the region of the fire are quite efficiently penetrating to the ionospheric altitudes, that is, there occurs a transfer of the excitations from the lower part of the atmosphere to the upper one up to the ionospheric altitudes where there occurs their transformation (amplification or generation) into the waves of different types (see, for example, [1–4]) due to interaction with the magnetically active plasma. The acoustic effects resulting from the fires may have not only the local effects, because propagating upwards the waves are dissipated at the altitudes of 100…250 km and change the dynamic regime of the middle latitude and upper atmosphere. We admit that performance of specific estimations for this mechanism represents a rather complicated problem, and it is not the subject of this investigation.

Perturbations of the global electric circuit parameters. The fires are substantially varying the electric parameters of the surface atmosphere. The conductivity of the flame torch and the hot air over it is essentially higher than the conductivity of the air outside of the fire epicenter. An extended spatial length of the fire epicenter result in a significant increase of the conductivity current in the regions of excitation of the atmosphere, because, as it is known, the surface atmospheric layer possesses the highest value of impedance in the global electric circuit. Therefore, transfer of excitations into the ionosphere can be also executed as the result of excitation of the global electric circuit parameters (see, for example, [14,15]) that results from the release of huge masses of the electrified combustion products. The typical duration would, apparently, amount to ~ $10^3 \ldots 10^4$ s.

We shall consider the ionosphere/atmosphere electric interaction in the region of the large-scale fires according to the methodology provided in [15,16]. It is based on representing of the mesosphere as an active element of the global atmospheric electric circuit. To analyze the electrodynamic ionosphere-troposphere couplings we shall use the mesosphere-troposphere electric circuit model with the following parameters: the source of the mesospheric current with the current density of $j_m \approx 10^{-9-10} \ldots 10^{-8}\,\text{A/m}^2$, which is the reason for the temperature changing and the efficient rate of electron collisions up to the order of the value; local surface impedance R_t; local impedance R_m of the mesospheric source; and external impedance of the global atmospheric layer between the surface of the Earth and the lower boundary of the ionosphere $R_a \approx 200$ Ohm. Under the undisturbed atmospheric conditions the discharge current density of the global capacitor is $j_a \approx 10^{-12}\,\text{A/m}^2$ and $j_m >> j_a$, therefore, under availability of j_m the value of j_a can be neglected. Under the undisturbed conditions $R_t >> R_m >> R_a$, and thus, total impedance of the load of the mesospheric current source is $R_i = R_m R_t / (R_m + R_t) \approx R_m$, i.e., the electric mesosphere/troposphere couplings are not revealed [15,16]. Under the perturbed conditions in the region over the large-scale fires the impedance R_t may decrease by an order and more, the correlation between R_t and R_m is varied and, thus, R_i is varied too. For example, at decreasing of R_i to two orders $R_t << R_m$, and $R_i \approx R_t$. Then the difference between the potentials U in the mesosphere determining the intensity E of the mesospheric electric field becomes dependent upon R_i. Whereas decreasing of R and R_t results in the correspondent decreasing of E and, as a consequence, in reducing of the temperature of electrons T_e in the mesosphere due to increasing of the tropospheric conductivity (up to the non-disturbed values). Therefore, realization of the above mechanism [15] is possible under availability of the powerful mesospheric electric fields over the region of the large-scale fires. The increase by one or two orders of the tropospheric conductivity over the region by means of the mesosphere-troposphere electric couplings results in decreasing of the mesospheric electric field intensity that causes rapid relaxation decreasing of the temperature T_e and the effective rate of the electron collisions ν, and the correspondent variation of the mesospheric conductivity. The latter effect may result in a rapid change in the radio wave propagation conditions in the lower ionosphere over the region. A significant variation of the electric potential in the mesosphere over the region of the fire may result in variation of the difference of the mesospheric potentials between the region of the fire and the remote region of observation that is equivalent to variation of the mesospheric electric field intensity over the region of the observations. Therefore, development of the mesospheric plasma excitations is also possible over the region of observations. The perturbation may be recorded with the help of the radio physical methods [16].

Increasing of the atmospheric convention and turbulence. A substantial increase of the atmospheric convection and development of the turbulence that takes place at rather high altitudes occur in the region of the fire. Due to the foregoing there occurs an increase of the convectional current value as the result of what the transfer of excitations into the ionosphere becomes possible (see, for example, [17]). Typical duration of the transfer is apparently ~ 1…10 days. We admit that the experimental data obtained, for example, in [3] during the warfare in the Persian Gulf and in Kosovo are the most evident confirmation of the above mechanism. This mechanism of transfer of the excitations requires further investigation.

3. ENVIRONMENTAL EFFECTS

We understand under the ecological effects noticeable deviations of the environmental parameters from the natural undisturbed conditions, which deviations are influencing upon the plants and wild life of the planet. We admit that the conditions of the large-scale fires are characterized by a significant duration of the factors influencing upon the habitat. Environmental consequences of the large-scale fires are related to: 1) mass releasing of the combustion products into the surface atmosphere; 2) variations of the surface atmosphere electric field; 3) generation and amplification of the electromagnetic and acoustic wave processes. Let us perform a brief consideration of the influence exerted by the above factors.

Release of the combustion products into the atmosphere. The most substantial environmental impacts are related to releasing of the fine dust, smoke and soot, which are screening the solar radiation. Providing for a powerful vertical thrust (the velocities of the air flows attain the values of ~ 10 mps), the large-scale fires facilitate penetration of the aerosols composed of the smoke and soot up to the stratospheric altitudes over a large area in the region. Smoke and soot result in a strong scattering and the solar radiation absorption correspondingly. At that, it is formed a powerful absorption (screening) layer. The weight of the aerosols may amount to ~ 10…100 ktons. The duration of the aerosols staying in the stratosphere amounts to tens of days that result in essential environmental effects. The fact of the possibility of stimulation of the secondary – far more powerful – processes is important. They are related to scattering of the solar radiation by the aerosols and its absorption by the soot, and, therefore, to a partial screening of the surface of the Earth. The energy of the secondary processes is exceeding the energy of the primary source by 3 to 5 orders. As it is shown in [5] the generated disturbances are propagated to the distances of ~ 1000 km and cover, apparently, the ionosphere and magnetosphere in addition to the lower atmosphere. As the result of screening of the solar radiation the surface of the Earth would not receive, for example, about 10^{23} Joule of energy for 10 days of fire. Approximately the same amount of energy will be released in the atmosphere. These violations of the energy balance have a significant value for both the surface of the Earth and for the atmosphere. It is important that occurrence of the environmental effects will be noticeable (and often substantial and inadvertent) far beyond the limits of the fire zone and during a long period of time after the fire.

Variations of the atmosphere electric field near the surface of the Earth. Variations of the surface atmosphere electric field in the region of the large-scale fire, as it is mentioned above, would result in variations of the surface atmospheric layer conductivity over a substantial area near the surface of the Earth. Considering that this atmopheric layer possesses the highest value of the impedance in the global electric circuit then there would occur excitations of the electric parameters in that circuit, which would result in a number of secondary processes in the atmosphere, ionosphere and magnetosphere [5,12,14]. The latter, in their turn, are influencing upon the surface environment in the global scale. It is very difficult to predict their impact upon the habitat, but it cannot be excluded that the said influence might be essential.

Generation and increasing of electromagnetic and acoustic wave processes. As the result of generation and increasing of electromagnetic and acoustic wave processes in the region of the fire the flow of the wave radiation power is increasing by hundreds of times as compared to the undisturbed conditions [1–4]. For example, according to [18] the flow of the acoustic radiation power amounts to $\Pi_{a0} \approx 0.3\ldots1$ MW/m^2 under the natural conditions. The estimates made on the basis of the methodology [5] provide for the following: over the area of 50 km^2 we shall have the acoustic radiation power of $P_{a0} = \Pi_{a0} S \approx 15\ldots50$ kW; during the fire the acoustic radiation power increases up to $P_a \approx 10$ MW over the same area. We admit that $P_a >> P_{a0}$. Most part of the acoustic radiation energy falls onto the share of the low-frequency acoustic-gravity waves, which are efficiently penetrating into the ionosphere up to 200…300 km, get dissipated there and play an important role in variation of the dynamic mode of the middle latitude and upper atmosphere.

4. CONCLUSIONS

1. The large-scale fires covering the areas of more than 2 000…5 000 ha result in the noticeable, substantial and inadvertent variations within the Earth-atmosphere-ionosphere system. Their revealing in the system is complex – they exert a serious influence upon the environmental situation, upon distribution of the atmospheric electricity, upon the global electric circuit parameters, and upon the thermal balance of the atmosphere and its dynamics. Average power and released amount of energy of the fire attain $1\ldots10^2$ GW and $10^2 - 10^3$ TJoule correspondingly.
2. The atmospheric electric field exceeds the background value by tens and hundreds of times and can amount to $|E_z| \approx 10^3$ W/m in the vicinity of the large-scale fire zone. The excitation of the vertical electrostatic field in the surface atmospheric layer might result in variations of the field intensity at the ionospheric altitudes and the recorded excitation of the electron concentrations.
3. The increase by 1…2 orders of the tropospheric conductivity over the region of the fire at availability over the said domain of the powerful mesospheric electric fields with the help of the mesosphere-troposphere electric couplings might result in variation of the difference of the mesospheric potentials between the region of the fire and the remote region of observation that would cause development of the mesospheric plasma excitations over the remote region of observation as well, which excitations are recorded with the help of the radio physical methods.
4. As the result of generation and increasing of electromagnetic and acoustic wave processes in the atmosphere over the region of the fire the flow of the wave radiation power is increasing by hundreds of times. Most part of the acoustic radiation energy falls onto the share of the low-frequency AGW, which are efficiently penetrating up to the ionospheric altitudes, get dissipated there and play an important role in variation of the dynamic mode of middle latitude and upper atmosphere of the Earth.
5. The large-scale fires may result in stimulation of the secondary far more powerful processes in the global scale. They are related to scattering of the solar radiation by the combustion products released into the stratosphere. The energy of the secondary processes is exceeding by 3 to 5 orders the energy of the primary source. These violations of the energy balance have a significant value for both the surface of the Earth and for the atmosphere. Occurrence of the environmental effects will be noticeable and often substantial and inadvertent far beyond the limits of the fire zone and over a long period of time after the fire.

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