Concerning the region of generation of natural radiation of the outer ionosphere at frequencies lower than 300 Hz

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The satellite-observed peculiarities in the space-time distribution of the natural radiation of the outer ionosphere are explained under the assumption that the radiation is excited at altitudes 300–400 km.

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The measurements were performed with the satellite "Interkosmos-5" from December 1971 through April 1972, at heights $200 \lesssim h \lesssim 1200$ km at 12 selective frequencies 70 Hz $\leq f \leq$ 20 kHz. The parameter L had a range $1.1 \lesssim L \lesssim 5$ ($L = R_{eq}/R_3$ is the ratio of the geocentric distance to the top of the force line in the equatorial plane to the earth's radius). The receiver sensitivity threshold was $b_0 = 4.5 \times 10^{-1}$ G-Hz$^{-1/2}$ relative to the amplitude of the magnetic field or 1.6×10^{-22} erg-cm^{-3}-Hz relative to the radiation power.[1]

The following experimental facts were established:

1. The radiation intensity is maximal during the daytime hours of local time (7^h–17^h *LT*) and is minimal at nighttime. All the characteristics that follow will be referred to local daylight time.

2. On different L shells, the emission spectra are similar in the entire frequency band. The radiation maximum lies in the interval $0.3 \leq f(\text{kHz}) \lesssim 1.6$.

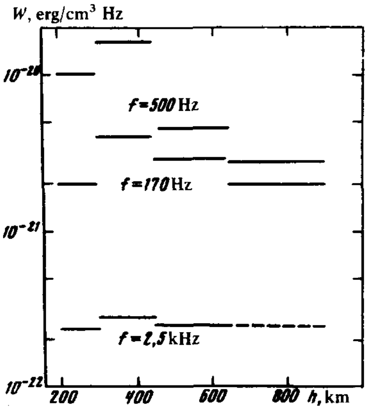
3. With increasing L shell, the radiation intensity increases. At the frequency 0.5 kHz, the field of the wave increases starting with $L \simeq 1.1$ to $L \simeq 3$–3.2, after which it is approximately constant. The intensity at the frequency $f = 2.5$ kHz increases noticeably from $L \approx 2$ and reaches a maximum at $L \approx 3$. The radiation level at 0.5 kHz is higher by one order of magnitude than the level at $f = 2.5$ kHz.

4. On a given L shell, there is a maximum of the radiation intensity at a height 300–400 km for $f = 0.5$ kHz. When the height is increased to ~1000 km, the radiation intensity decreases by one order of magnitude. This regularity is not observed at $f = 2.5$ kHz (see the figure).

5. At a fixed L shell and height, within the limits of ionospheric heights, the geomagnetic induction in various regions of the earth varies in the range $0.25 \lesssim B \leq 0.55$ G. The radiation intensity at $f = 0.5$ kHz decreases with increasing B by an approximate factor of 10, and at 2.5 kHz an increase of the intensity by approximately two times is observed ($L \approx 2$; $h \in 200$–300 km).

The foregoing regularities, which are obviously due to peculiarities of the excitation and propagation of low-frequency waves, give grounds for stating, despite the widely held view (see, e.g.,[2]), that at least part of the radiation is produced at ionospheric heights and is genetically connected with the high-energy protons and electrons of the radiation belts. The justification for this statement is the following:

It is known that on the considered L shells at large heights, under quiescent conditions, there is no day-night asymmetry in distribution of the high-energy particles. In addition, at $h \gtrsim 1000$ km the concentration of the ionospheric plasma remains practically unchanged during the day and night. Therefore, if the radiation were to be generated at large altitudes near the equator, then it would be difficult to understand the dependence of the radiation intensity on the local time. The increased radiation level during the day is due obviously to the fact that at ionospheric heights, in the region illuminated by the sun, the electron concentration is much higher than at night. This causes the phase velocity of the low-frequency waves on the daytime side to be relatively lower (by approximately one order of magnitude). In this case, as follows from the necessary conditions for Cerenkov and synchrotron radiation, the number of emitted particles increases greatly, and consequently the level of the excited radiation rises. This effect should not be present if the generation occurs high outside the ionosphere. Moreover, one should expect here the level at low altitudes to be higher at night, for at that time the concentration of the charged particles in the ionosphere and the effective number of collisions is much smaller, i.e., the absorption of the waves arriving from above is smaller.



Averaged height variation of the radiation intensity at the frequencies 170, 500, and 2500 Hz.

The height dependence of the radiation intensity indicates that the radiation moves upward and downward from the 300–400 km level. Let us consider the change of the amplitude of these waves in the ionosphere. In the geometrical-optics approximation, the field b of the wave varies with distance like

$$b \propto n^{1/4} \exp\left(-\frac{\omega}{c}\int_{h_1}^{h_2} \kappa \, dz\right) ,$$

where n is the refractive index and κ is the extinction coefficient. The ionosphere parameters are such[3] that the quantity $n^{1/2}$ changes by approximately a factor of two and the exponential changes by approximately a factor of two in the altitude interval 300–800 km. That is to say, over the path considered, the level of the radiation at the frequency 0.5 kHz decreases by a factor of about 10 as the wave propagates from the earth upwards, in good agreement with experiment.

The absence of an altitude dependence at $f = 2.5$ kHz can be explained by assuming that this radiation comes from above. The amplitude of the wave b, owing to the increase of n, is doubled but the absorption decreases the amplitude by approximately a factor of two. The net result is an approximately constant wave field.

Thus, within the framework of the assumption that the continuous extremely low frequency radiation in the 0.5 kHz band is generated at small heights and that at $f = 2.5$ kHz it is generated in the vicinity of the magnetic equator at low latitudes, we are able to explain the observed height dependence of the wave energy density.

Near $f = 500$ Hz, according to land-based data, there is frequently no correlation between the emissions in the magnetically-conjugate regions. This also indicates that there is a low probability of radiation in the vicinity of the vertex of the force line, for otherwise it would be impossible to explain the absence of a signal at one of the conjugate points. We note also that when waves are generated in the vicinity of the equator there should be no dependence of the radiation on the local values of the geomagnetic field at the satellite level.

As to the growth of the radiation intensity with increasing geomagnetic latitude (the L shell), this can be the result of the increase of the high-energy particle concentration (protrons and electrons), which are responsible for the wave excitation, with increasing latitude.

We emphasize in conclusion that if we assume coherent cyclotron or Cerenkov radiation of electrons (or protons) we obtain an upper bound for the radiation energy flux, namely 10^{-13} W/m^{2}Hz, which is close to the measured values. We note that although at ionospheric altitudes the number of high-energy particles is much smaller than at the equator, nonetheless their distribution function is the most anisotropic, since the particles present mainly are those with pitch angles close to $\pi/2$. This must lead to emission with maximum possible increments.

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