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ENVIRONMENTAL PROBLEMS IN GEOPHYSICS

GLOBAL BALANCE OF SW-BAND ELECTROMAGNETIC ENERGY IN CIRCUMTERRESTRIAL SPACE

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Numerical experiments were carried out with a mathematical model describing the planetary distribution of the radio emission stream coming from ground-based radio stations of the SW band. The fractions of energy absorbed by the ionosphere, absorbed by the Earth surface, and emitted into space were determined as functions of the season and universal time.

INTRODUCTION

The energy emitted by ground-based radio stations partially goes into space and partially is absorbed by the Earth surface and the ionosphere. A large portion of the total power of the world's radio broadcasting network is radiated by transmitters located on the European continent. The bulk of the emitted energy is either absorbed in the circumterrestrial space, or reradiated from it at typical distances from the emission source, which are comparable with the length of the first hop from the source [1].

Let us consider the relative fractions of the absorbed and reradiated energy as functions of the universal time (UT) and the year season for average helio-geophysical conditions. For this purpose, we carried out a series of numerical experiments with a model we proposed earlier in [1, 2]. The overall pattern of numerical estimates for the fractions of absorbed and reradiated energy in the 5–25 MHz frequency band is displayed in Fig. 1. Both absolute (P) and relative ($P_{\rm rel} = P/P_\Sigma$, where P_Σ is the total emitted energy) values are given for the energy that goes into space and is absorbed by the ionospheric plasma and by the Earth surface.

ENERGY RERADIATION FROM CIRCUMTERRESTRIAL SPACE

At high and medium frequencies of the SW band the main role in the "leakage" of all emitted energy into space is played by the state of the ionosphere over Central and Eastern Europe, which creates a valve boundary in the ionosphere, separating the regions of electromagnetic energy reflection and transmission. The location of this boundary is determined by the formula

$$f = f_{0F2}/\cos\gamma_0,$$

where γ_0 is the angle of radio wave incidence onto the ionospheric plasma and f_{0F2} is the critical frequency in the $F2$ region of ionospheric plasma:

$$f_{0F2} = 9 \cdot 10^{-6}\sqrt{N_{mF2}},$$

f and f_{0F2} are expressed in megahertzes, the maximum electron concentration N_{mF2} in the $F2$ region is expressed in electrons per cubic meter. If the valve boundary shifts toward lower values of the critical

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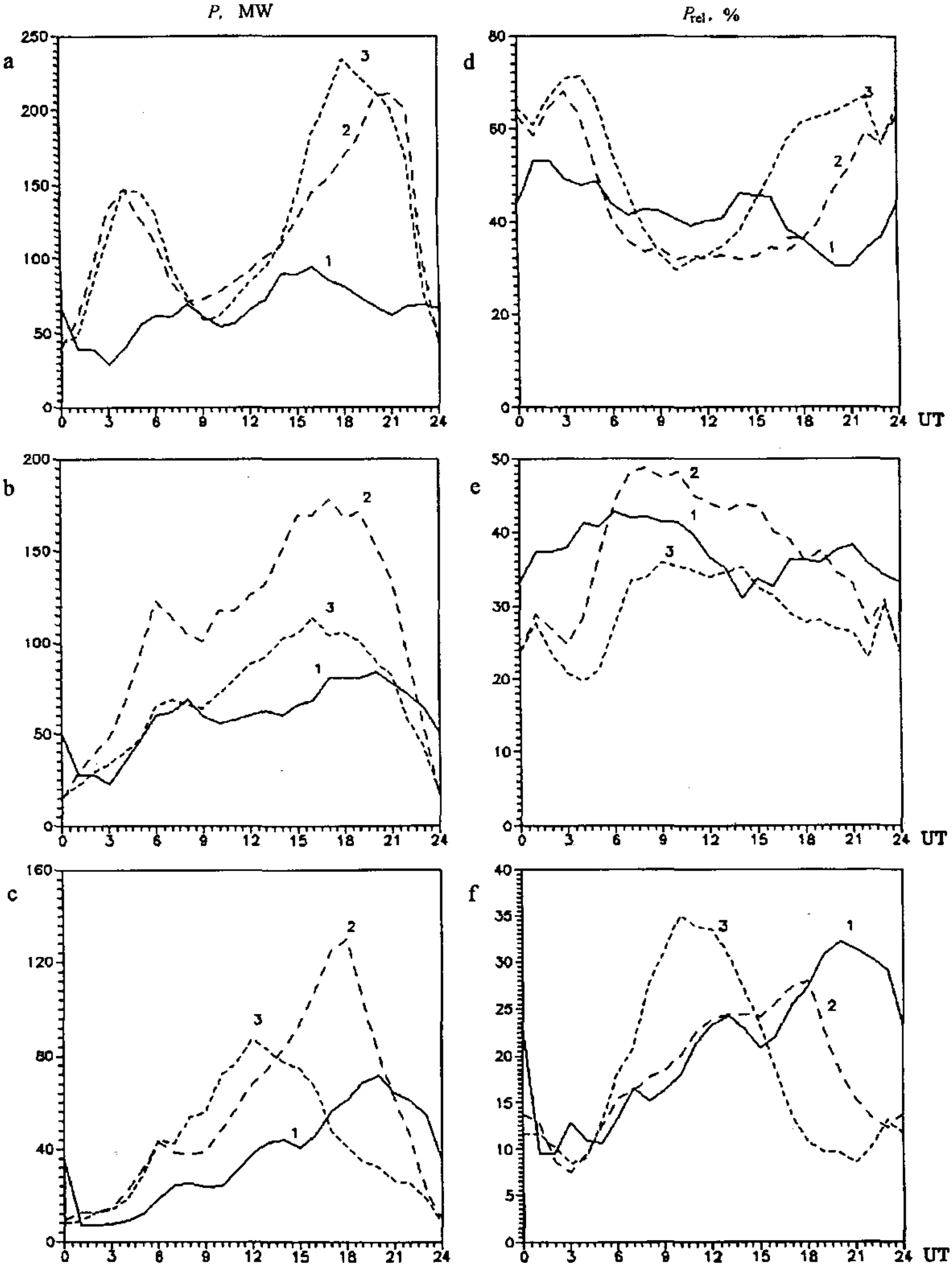

Fig. 1

Diurnal behaviors of the absolute (P) and relative (P_{rel}) energy fraction values in the 5–25 MHz frequency range, which go into space (a, d), are absorbed by the ionospheric plasma (b, e) and by the Earth surface (c, f), at the periods of the June (*1*) and December (*3*) solstices and the autumn equinox (*2*).

frequency f_{0F2}, radio waves of ground origin have the opportunity of leaving the circumterrestrial space (the transmission region grows wider, and the reflection region becomes narrower); if the boundary shifts toward higher f_{0F2}, the picture is the opposite. Therefore the diurnal variations of the energy lost into the space are in opposite phase with the daily behavior of the critical frequencies in the ionosphere's $F2$ region at middle latitudes.

A clearly manifested periodicity of energy "leakage" was found in all seasons of the year (see Fig. 1*a* and *d*). The lowest energy drain (35%) was observed in December from 9:00 to 13:00 *UT* (60 MW) and in the equinox period from 6:00 to 18:00 *UT* (70 MW) and in June from 17:00 to 23:00 *UT* (50 MW). The dependence of this minimum on the universal time is due to the fact that the highest critical frequencies f_{0F2}, which cause the greatest shifts of the valve boundary over the European continent, are observed from 12:00 to 14:00 local time (*LT*) in winter and in evening hours (from 18:00 to 20:00 *LT*) in summer. The highest amplitude of the half-day wave in these variations (35–70%) was recorded in winter (60–230 MW) and during the equinox (70–210 MW), the lowest amplitude (30–50%) was observed at the summer solstice (30–80 MW). The effects of "superposition" between the diurnal variations of the electron concentration in the $F2$ ionospheric region, the nonuniform distribution of radio emitters over the Earth surface, and the diurnal variations and frequency distribution of the emitted power occur in winter.

The primary "channels" of radio wave energy "leakage" from the circumterrestrial space are located at high latitudes of both hemispheres and near the morning terminator. They are also the primary channels for the cosmic SW radiation arriving into the Earth–ionosphere system.

ENERGY ABSORPTION BY IONOSPHERIC PLASMA

Let us consider the variations in that portion of energy which is absorbed by the ionosphere. It is well known that the absorption of radio waves is mainly determined by the altitude distribution of the electron concentration in the lower layer of the ionospheric plasma. In winter and at equinox in the middle latitudes, the ionospheric D-region is formed only in day hours; in summer it practically exists at any time of day [3]. Therefore the variations in the diurnal history of ionosphere-absorbed energy are most clearly manifested in winter and at equinox, being virtually constant in summer. The highest share in the diurnal variation is associated with radio waves from the lower part of the SW band (5–10 MHz). Our calculations (see Fig. 1*b*,*e*) revealed two maxima (i.e., a half-day harmonic) in the diurnal variation of the absolute absorbed energy:

(1) winter—6:00 *UT* (60 MW), equinox—7:00 *UT* (130 MW), summer—8:00 *UT* (60 MW);

(2) winter—16:00 *UT* (180 MW), equinox—17:00 *UT* (180 MW), summer—21:00 UT (80 MW).

The existence of the first maximum is due to two processes: the emerging D region in the illuminated ionosphere, bringing the main contribution into radio wave absorption, and the simultaneous daytime diminishing of the electromagnetic energy fraction that arrives into the low-frequency part of the SW band. The second maximum is associated with the main maximum in the diurnal cycle of the total power emitted by radio broadcast stations.

ENERGY ABSORPTION BY THE EARTH

The diurnal variation of the energy absorbed by the Earth surface has a clearly manifested minimum, observed at night by the universal time (see Fig. 1*c*, *f*). The maximum of absorbed energy occurs at 20:00 *UT* in summer, at 10:00 *UT* in winter, and at 18:00 *UT* at equinox. This distribution of the absorbed energy is caused by two main factors.

The first factor consists in the following. The amount of absorbed energy is determined by the quantity of the radio emission flux incident on the Earth surface. However, only a fraction of the emitted electromagnetic energy is reflected by the ionosphere (and falls onto the Earth surface). In the daylight sector, the following processes occur: absorption of radio waves on the ascending part of their path in the E- and D-layers, reflection by the ionosphere (with a fraction of the energy reradiated into the space), absorption of radio waves on the descending part of their path in the E- and D-layers, and, finally, partial energy absorption by the Earth surface as it reflects the incident radio wave beam. This process is repeated at the next hop. At night, the absorption in the E- and D-ionospheric layers disappears, and the primary factors which decrease the signal level reflected by the ionosphere are now the partial "leakage" of electromagnetic energy into the space and the partial energy absorption by the Earth surface when it reflects the incident radio wave beam. The process is repeated at the next hop. Owing to these facts, the amount of energy absorbed from the flux incident onto the Earth surface depends both on the emitted energy and on the energies absorbed by the ionospheric plasma and radiated into the space.

The second factor (less significant than the first) is associated with the physical properties of the Earth surface. The coefficient of absorption χ is determined by the dispersion properies of the surface (ε, σ) and the radio wave incidence angle γ [4]:

$$\chi_0(\theta,\varphi) = \ln R(\theta,\varphi), \tag{1}$$

$$R(\theta,\varphi) = \left|\frac{\cos\gamma - \sqrt{n_0^2(\theta,\varphi) - \sin^2\gamma}}{\cos\gamma + \sqrt{n_0^2(\theta,\varphi) - \sin^2\gamma}}\right|, \tag{2}$$

$$n^2(\theta,\varphi) = \frac{\varepsilon(\theta,\varphi)}{2} + \sqrt{\left(\frac{\varepsilon(\theta,\varphi)}{2}\right)^2 + \left(\frac{\sigma(\theta,\varphi)}{f}\right)^2}. \tag{3}$$

Here $R(\theta,\varphi)$ is the coefficient of radio wave reflection by the Earth surface, $n(\theta,\varphi)$ is the refraction index, θ and φ are the latitude and longitude. Since the permittivity ε and conductivity σ suffer significant changes over the year (depending on the refraction index n, the soil humidity, the presence of a snow cover, etc.), they also give a contribution into the variations of the amount of energy absorbed by the Earth surface.

CONCLUSION

1. Numerical estimates of the total electromagnetic energy losses in the circumterrestrial space showed that, averaged over a day's period, about 20% of the total energy emitted by the world's network of radio broadcasting stations was absorbed by the Earth surface, about 30% was absorbed by the ionosphere, and about 50% left the circumterrestrial space.

2. It was found that the most important channels of electromagnetic energy exchange, created by sources of terrestrial and space origin, were the channels located at high latitudes and at the eastern terminator.

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