On possible genesis of fractal dimensions in the turbulent pulsations of cosmic plasma – galactic-origin rays – turbulent pulsation in planetary atmosphere system

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1. Introduction

Now it is experimentally determined (Pudovkin and Raspopov 1992) that the cosmic rays, and above all the galactic-origin rays (GOR) containing protons with energies of $10^{11} \div 10^{15}$ eV, extremely efficiently influence processes in the atmosphere at heights 10–20 km. Strong variations of these rays (tens of percents) coincide with solar activity cycles and with atmospheric perturbation variations induced by separate flares on the Sun [1]. Pudovkin and Raspopov (1992) have shown that an evaluation of incoming energy from the GOR spectrum in the magnetosphere and the consequent processes in magnetosphere and ionosphere coincide by order of magnitude with reliably determined values of an actual energy for atmospheric processes ($\sim 10^{19} \div 10^{20}$ J day^{-1}). It allows removing completely traditional "energy-balance" argument of the opponents of efficient and stable influence of the external factors on the Earth's climate variations.

It is known that GOR spectrum is striking stable and has power type in area of $10^{11} \div 10^{15}$ eV [3]:

$\frac{dN}{dE} = CE^{-\nu}, \quad \nu \quad \approx 2.4 \div 2.74.$ (1)

Also it is known that interaction of cosmic particles with gas in the Earth's homosphere, where the density is essential, is resulted intensive turbulent-mode energy and substance exchange in homosphere – upper atmosphere area [4].

The main purpose of present work is definition of a spectrum of turbulent GOR-induced pulsations in the atmosphere and determination of possible manifestation of genesis of fractal dimensions in the system of "spectrum of turbulent pulsations of cosmic plasma – GOR spectrum – spectrum of atmospheric turbulent pulsations".

2. Analysis

It is obviously that according to Eq. (1) the integral GOR spectrum in area of $10^{11} \div 10^{15}$ eV looks like [3]:

$N \sim E^{\mu}$, μ = 1.7. (2)

Assume that the GOR energy is absolutely absorbed in the atmosphere. Then the average energy E_g transferred to atmospheric gas is evaluated as

$E_g \sim NE \sim E^{1-\mu}$. (3)

Let's consider that each cosmic particle induces in moving gaseous medium the initiation of an eddy with a size of λ, which is inversely proportional to an energy of particle E, i.e.

$E \sim \lambda^{-1}$. (4)

The same way as Landau and Livshitz (1986), we shall introduce instead of scales λ appropriate spatial "wave numbers" of pulsations (eddies) as $k \sim 1/\lambda$. Then on the basis of Eqs. (3) and (4) the integral spectrum of eddies E_g will look like

$E_g \sim k^{1-\mu}$. (5)

This corresponds to following spectral density of turbulence:

$E_g(k) \sim k^{-\mu}$, (6)

where $E_g(k)$ is kinetic energy of gaseous eddy with spatial wave number k.

As $\mu \approx 5/3$, it is obvious that the spectrum (6) is nothing else than a known Kolmogorov-Obukhov spectrum (Monin and Yaglom 1981) describing dynamics of high-frequency perturbations or, in other words, structure of small-scale turbulized medium as a skeleton of eddy cluster with fractal dimension D = 5/3 [7].

Here note that corresponding scaling laws, scale ratios and spectral dynamics, in particular within the inertial interval theory, which results energy spectrum of the Kolmogorov-Obukhov eddies, are conventionally applied at atmospheric turbulence modeling but for planetary boundary layer only, i.e. for the air layer, in which the interaction of atmosphere with ground is directly appeared [6,8].

From this it is obvious that detected GOR-induced Kolmogorov-Obukhov spectrum (6) differs not only by the cause, but by the principal location of its appearance: homosphere – upper atmosphere. The experimental data sustaining reality of small-scale turbulence structure in this atmospheric area is not known for authors. On the other hand, if large-scale fractal structure as skeleton of eddy cluster generates in this area, then the possibility of lead-out for part of energy into "infinity", e.g. from the area of turbulent motions into the upper atmosphere, emerges. There is natural question: what consequences should be experimentally observed in this case?

Such time-stable and large-value addition, e.g. as the Joulean heat into upper atmosphere, should essentially vary "center of gravity" in the Earth's energy balance by means of taking into account the turbulent heat flux G generated by variations of the galactic and solar cosmic rays:

$$\frac{\partial U}{\partial t} = S\left[1 - \alpha(T)\right] - I_{?}(T) - Q(T) + G(T), \quad (1)$$

where $\partial U/\partial t$ is the rate of heat generation in the Earth's climate system, T is the temperature, S is the solar irradiance onto top of the atmosphere, α is the albedo of the atmosphere-Earth system, I_a is the intensity of outgoing long-wave atmospheric radiation, Q is the heat quantity leaving considered volume of the climate system owing to the horizontal transport of sensible Q_1 and latent Q_2 heat.

Let's represent I_a, Q, G, and α as function of temperature. First energy term I_a responsible for the long-wave radiation of the Earth with mean temperature T is equal with approximation sufficient for our model:

$I_a = \gamma_a \sigma T^4$, (8)

where σ is the Stephan-Boltzmann constant, γ_a is the coefficient considering area of atmospheric external boundary parallel with the Erth's surface.

The heat quantity Q is calculated as follows. It is known that poleward heat flux is defined the equator-pole temperature gradient. In the other words, the more gradient causes the intensive poleward heat flux. Following assumption was made within our model: for horizontal transport the meridional gradient is proportional to the mean temperature of the Earth's climate system. In this case the heat flux Q is formulated as follows:

$Q = Q_1 + Q_1 = \gamma_{adv} \mu_{adv} T + \gamma_{adv} m_{wv} c(T_{wv} - T)$, (9)

where μ_{adv} is the advection coefficient, γ_{adv} is the coefficient considering total area for lateral sides of the Earth's climate system, m_{wv} is the weight velocity for the condensation of water vapour molecules, c is the specific heat.

Dependence of the effective value of albedo for Earth-atmosphere system from temperature determines essentially quantity of assimilated direct solar radiation for Earth's climate system. This dependence is taken as the continuous Fegr's parameterization [9]:

α(T) = 0.486 - $\eta_\alpha (T - 273)$, (10)

where η_α = 0.0092 K^{-1}.

At last, about heat transport G in the turbulent mode. Universal behaviors obtained within the inertial interval theory or, in other words, the Kolmogorov-Obukhov scaling laws [6] were developed for description of statistical structure for temperature turbulent pulsations when they not essentially affect flow structure [10]. At that, has been shown that the structure of temperature field for turbulent mode is defined not only by the dissipation rate of turbulent kinetic energy per mass unit ε, but also by the dissipation rate for intensity of temperature fluctuations N_T that equal in value order to

$N_T \quad \cong (\Delta T)^2 \Delta u L^{-1}$, (11)

where Δu and L are the typical size for velocity and length of main energy-carrier eddies, ΔT is the typical temperature variation in the flow at its external scale L. At that, it is easily to show that the integral spectrum of eddies E_g looks like:

$E_T = C_{1t}(\Delta T)^2$. (12)

Analysis of Eq. (12) allows to lossless write the common form of dependence for the heat flux in the turbulent mode from typical temperature variation ΔT in the flow at its external scale L. Assuming $\Delta T \quad \sim \beta T$, where $\beta \quad < 1$, this dependence looks as follows:

$G \quad \sim \quad g(\Delta T)^2 \quad \sim (g\beta)T^2$, (13)

where g is the dimensional coefficient, W K^{-2}.

At last, summing all contributions of the flux (8)-(10) and (13) into resulting energy-balance equations (1), we obtain:

$$S - \frac{\partial U}{\partial t} = \gamma_a \sigma T^4 - (g\beta)\, T^2 + (\gamma_{adv}\mu_{adv} + \eta_a S - \gamma_{adv} m_{wv} c)\, T + \text{free term}. \quad (2)$$

Rewriting Eq. (2) in suitable form for further presentation, we obtain:

$$\frac{1}{4\gamma_a \sigma}\left(S - \frac{\partial U}{\partial t}\right) = F\,(T, a, b) = \frac{1}{4}T^4 + \frac{1}{2}aT^2 + bT + \text{free term}, \quad (3)$$

where

$$a = -\frac{g\beta}{2\gamma_a \sigma}, \quad (4)$$

$$b = \frac{\gamma_{adv}\mu_{adv} + \eta_a S - \gamma_{adv} m_{wv} c}{4\gamma_a \sigma}. \quad (5)$$

Here, we assume that power $F(T, a, b)$ not practically depends on time and this seems as physically lawful. It is obviously, then Eq. (3) describes family of functions $F(T,$

a, b) depending on two control parameters a and b. So-called potential of assembly catastrophe is easy recognized in this equation [11].

Solution corresponding asymmetric (with regard to coordinate axis a) cyclic path in plane ($a - -b$) is modeled under following conditions: a = –0.5, $b(t)$ = [–$b$cos$\omega t + \Delta$], where Δ = ($b - - 2|b_c|$)/4, and b_c is determined by equation of semi cubical parabola describing bifurcation set of assembly catastrophe. Fig. 1 shows time evolution of mean value $\langle T \rangle$ and dispersion var(T) for temperature. This evolution starts at time t = 0 in corresponding critical point on bifurcation set.

Analysis well-known experimental data obtained at Antarctic station Vostok and concerning temperature variations during last 260 thousand years [12] confirm existence of period $\sim$120 thousand years and the latter agree with data of earlier works [13]. Also this analysis demonstrates fact that the reason organizing just so periodical behavior of control parameter b is periodical variations of Earth's orbit geometry (eccentricity) initiating variations of solar radiation or, in other wards, physical mechanism for "controlling" of global climate that long time ago concerned in the Milankovitch's theory of ice age rhytms [14].

3. Conclusions

Considered possibility of existence in the atmosphere of spectrum for Kolmogorov-Obukhov turbulent kinetic energy dissipation induced by the GOR establish attractive problem associated with genesis of scaling invariance and scaling representation of turbulent spectrums. It becomes evidently apparent under simple analysis of Eqs. (1)-(6), which shows that procedure of derivation for connection of fractal dimensions in the GOR spectrum with Kolmogorov-Obukhov spectrum could be carried out in inverse manner. The latter means that wonderful behavior of the GOR spectrum allows not only suppose certain mechanism of initiation for these particles [3], but predetermine conclusion about this mechanism should also describe initiation of large-scale fractal structures in the cosmic plasma that stipulated by turbulence with Kolmogorov-Obukhov spectrum.

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