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# Analysis of the influence of barometric pressure on the passage of photosynthetically active radiation of the sun through the atmosphere

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Abstract: The influence of atmospheric optical thickness on the transmission of photosynthetically active solar radiation to the Earth's surface is analyzed. Specifically, it is considered that Rayleigh scattering, a component of atmospheric optical density, depends on the atmospheric pressure at the given location. Taking into account the influence of pressure, the problem of studying the possibility of an extreme value of atmospheric optical thickness in areas with high atmospheric pressure is formulated. Model calculations using the Buchholz model and a variational optimization problem demonstrate that such a maximum can occur at negative wavelengths, which, in principle, do not exist in nature. Therefore, the answer to the formulated question is that extreme values of atmospheric optical density should not be expected in the PAR component wavelength range due to the influence of atmospheric pressure.
Keywords: atmosphere, solar radiation, barometric pressure, photosynthetically active optical radiation, optimization

## 1. Introduction

The role of solar optical radiation in sustaining life on the planet is well known [ 1-3 ]. It is important to emphasize the consistency between the properties and functions of the atmosphere and solar optical radiation in terms of sustaining life on the planet. For example, harmful ultraviolet radiation from the Sun with a wavelength below 0.35 μm is not transmitted by the atmosphere to the Earth's surface, and conversely, photosynthetically active solar radiation in the range of 0.5–0.7 μm is transmitted by the atmosphere with minimal attenuation [ 4-6 ].

At the same time, as emphasized in the work [7-8], insolation on the earth’s surface is the most important factor for studying the relationship between the Earth and the atmosphere as a single dynamic system.

Thus, insolation, i.e., solar optical radiation at the Earth's surface, is a measure of the coordination of the aforementioned components of the unified dynamic system supporting life on the planet, taking into account the aforementioned diversity of possible influences of solar optical radiation existing outside the atmosphere. In this regard, one possible area for further research is to examine the influence of various atmospheric components and factors on the passage of the photosynthetically active part (hereinafter PAR ) of solar optical radiation to the Earth's surface.

PAR radiation maintains the phenological rhythm or phase of development of the plant world.

In this regard, it is important to note the unit of measurement of PAR radiation. While solar radiation density is measured in watts/m2 ‚ PAR radiation is measured in different units that take into account the interaction of this radiation with living molecules. This unit of measurement is $\frac{мкмол}{м^2/сек}$, denoting the number of photons in a certain wavelength range (400–700) nm involved in the process of photosynthesis occurring in the molecules of living organisms. Thus, PAR is estimated as a certain number of moles of photons per unit area per unit time, in the visible range for which there are 6.023 x [1023] photons per mole (Avogadro's number).

The most important atmospheric component affecting the attenuation of PAR radiation reaching the Earth's surface. Aerosols consist of liquid or solid particles, the sizes of which vary from several tens of nanometers to several micrometers [8]. A distinction is made accordingly between fine, medium, and coarse aerosols. The classic formula for determining the optical density of atmospheric aerosols is the Ångström formula [9]:

$$\tau_\alpha = \beta \cdot \lambda^{-\gamma} \qquad (1)$$

where $\tau_\alpha$ is the optical density of atmospheric aerosol;

β – aerosol turbidity of the atmosphere;

γ – Angstrom exponent;

λ – wavelength, μm.

From (1) we obtain

$$\beta = \tau_\alpha, \quad \text{при } \lambda = 1 \text{ мкм}$$

Other atmospheric components that influence the attenuation of PAR radiation reaching the Earth's surface are atmospheric ozone and Rayleigh scattering of atmospheric gases.

In general, the optical thickness of the atmosphere in the range of 0.4÷0.7 μm is defined as

$$\tau = \tau_{ozone} + \tau_R + \tau_{aer} \,,$$

where $\tau_{ozon}$ is the optical thickness of ozone;

$\tau_R$ – optical thickness of Rayleigh scattering;

$\tau_{aer}$ – optical thickness of atmospheric aerosol.

However, it is well known that the optical density of Rayleigh scattering depends on atmospheric pressure [10].

In general, there is a Buchholz model for calculating the optical density of the atmosphere in the visible range in the following form [7]

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$$\tau_\alpha = \left(\frac{P}{P_0}\right) \cdot A \cdot \lambda \cdot \left(-B - C \cdot \lambda - \frac{D}{\lambda}\right) \qquad (2)$$

where $P / P_0$ is the ratio of the actual barometric pressure in a particular area to the standard pressure at sea level (1013.25 mbar);

λ – wavelength in micrometers;

A , B , C , D are constant coefficients, the values of which will be given below.

As can be seen from expression (2), $\tau_\alpha$ is directly dependent on P, i.e., the pressure at a given location. The research problem is formulated as follows: determine the wavelength at which, due to abnormally high pressure, the optical density of the atmosphere could reach its maximum , which would presumably lead to a strong attenuation of the photosynthetically active PAR component of solar optical radiation. Let us consider the proposed solution to this problem.

## 2. Research methodology

We rewrite expressions (2) in the following form

$$\tau_\alpha = -(AB \cdot \lambda \cdot \gamma) + A\gamma\lambda^2 C + AD\gamma \qquad (3)$$

Where

$$\gamma = \frac{P}{P_0} \qquad (4)$$

Let us introduce for consideration the average integral indicator of the optical density of the atmosphere in the form

$$\tau_{\alpha cp} = \frac{1}{\Delta\gamma} \int_{\gamma_{min}}^{\gamma_{max}} -(AB \cdot \lambda \cdot \gamma + AC\lambda^2\gamma + AD\gamma) d\gamma \qquad (5)$$

Where

$\Delta\gamma = \gamma_{max} - \gamma_{min}$

We also introduce for consideration the relationship function between λ and γ in the form

$$\lambda = f(\gamma) \qquad (6)$$

Further, to calculate the specific form of function (6), we will assume that the function f (γ) can be selected from a certain set of twice differentiable and continuous functions satisfying the following restrictive condition:

$$\int_{\gamma_{min}}^{\gamma_{max}} f(\gamma)\, d\gamma = C_1 \,; \quad C_1 = const \qquad (7)$$

Taking into account expressions (5) ÷ (7), we form the following target functional F of variational optimization

$$F = \frac{1}{\gamma_{max}} \int_0^{\gamma_{max}} -[ABf(\gamma)\gamma d\gamma + ACf(\gamma)^2 \cdot \gamma + AD\gamma]\, d\gamma + L\left[\int_0^{\gamma_{max}} f(\gamma) d\gamma - C_1\right] \qquad (8)$$

where L is the Lagrange multiplier.

The solution according to Euler's method satisfies the following condition

$$d\frac{\{-[ABf(\gamma) + ACf(\gamma)^2 \cdot \gamma + AD\gamma] + Lf(\gamma)\}}{df(\gamma)} = 0 \qquad (9)$$

From condition (9) we obtain

$$-[AB\gamma + 2AC \cdot \gamma \cdot f(\gamma) + AD] + L = 0 \qquad (10)$$

From expression (10) we find

$$f(\gamma) = \frac{L}{2AC\gamma} - \frac{AB}{2AC} - \frac{D}{2C\gamma} \qquad (11)$$

When solving (11), the functional F reaches a maximum, which is easily verified using the Lagrange criterion, according to which an extremum is a maximum if the derivative of expression (10) with respect to the function f ( γ ) is negative. It is easy to verify that this condition is satisfied.

To determine the value of L, we use expressions (7) and (11). We have

$$\int_{\gamma_{min}}^{\gamma_{max}} \left(\frac{L}{2AC} + \frac{D}{2C}\right)\frac{d\gamma}{\gamma} + \int_{\gamma_{min}}^{\gamma_{max}} \frac{B}{2C} d\gamma = C_1 \qquad (12)$$

From ( 12 ) we obtain

$$\left(\frac{L}{2AC} + \frac{D}{2C}\right) \cdot \int_{\gamma_{min}}^{\gamma_{max}} \frac{d\gamma}{\gamma} + \frac{B}{2C}(\Delta\gamma) = C_1 \qquad (13)$$

From (1 3 ) we find

$$\left(\frac{L}{2AC} + \frac{D}{2C}\right) = \frac{C_{1-} - \frac{\Delta\gamma \cdot B}{2C}}{ln\left(\frac{\gamma_{max}}{\gamma_{min}}\right)} \qquad (14)$$

From expression (1 4 ) we obtain

$$L = \frac{2AC \cdot C_1 - \frac{AB \cdot \Delta\gamma}{C}}{ln\left(\frac{\gamma_{max}}{\gamma_{min}}\right)} - AD \qquad (15)$$

Let us carry out model calculations using the obtained expressions (11) and (15).

**Modeling studies**

To carry out model calculations, we will use the tabular data of the values A , B , C , D given in the table [ Alexandru Dan Toma , 2023 ].

**Table 1**

**Tabular data of the values**

| coefficient | at λ <0.5 μm | at λ> 0.5 μm |
|---|---|---|
| A | $6.5 \cdot 10^{-3}$ | 8.65 |
| B | 3.4 | 4 |
| C | 1.36 | 1.1 |
| D | 0.12 | 2.7 |

Next we take $\gamma_{max} = 2.71$; $\gamma_{min} = 1$; therefore, we have

$$\frac{\gamma_{max}}{\gamma_{min}} = 2{,}71$$

$$\Delta\gamma = \gamma_{max} - \gamma_{min} = 1{,}71$$

the value of $C_1$ as

$$C_1 = \left(\frac{\lambda_{max} - \lambda_{min}}{2}\right)\Delta\gamma;$$

at $\lambda_{max} = 1$ μm ; $\lambda_{min} = 0.1$ μm we have

$$C_1 = 0{,}3 \cdot \Delta\gamma = 0{,}45 \cdot 1{,}71 \approx 0{,}8 \text{ мкм}$$

Let us calculate L using formula (15) taking into account the obtained values of Δγ and $ln\left(\frac{\gamma_{max}}{\gamma_{min}}\right)$, as well as $C_1 = 0.5$ μm at λ>0.5 μm.

We get L ≈ 92.38.

According to formula (11), we obtain

$$f(\gamma) = \frac{L_0}{2 \cdot 8{,}65 \cdot 1{,}1 \cdot 2{,}71} - \frac{4}{2 \cdot 1{,}1} - \frac{2{,}7}{2 \cdot 1{,}1 \cdot 2{,}71} = \frac{92{,}38}{51{,}58} - 1{,}82 - 0{,}46 = -0{,}48 \text{ мкм}$$

Therefore, theoretically, the optical thickness of the atmosphere can reach its maximum due to high pressure at negative wavelengths, which in principle do not exist in nature.

## 3. Conclusion

Using the Buchholz model of the optical density of the atmosphere, as well as the results of solving a newly formulated variational optimization problem, it is shown that in the region of real wavelengths of the PAR component of solar optical radiation, high atmospheric pressure cannot lead to the formation of any extremum of the optical density of the atmosphere.

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