FREE ROSTRUM

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Biophysics of the Indian Summer: Reflections on the Relationship of Photosynthesis with Seasonal Temperature Variations

A. K. PETROV, N. E. POLYAKOV

Voevodsky Institute of Chemical Kinetics and Combustion,
Siberian Branch of the Russian Academy of Sciences,
Novosibirsk, Russia

E-mail: polyakov@kinetics.nsc.ru

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Abstract

For a long time, the inhabitants of the middle latitudes of the Earth mark annually recurring natural anomalies: at the end of May and beginning of June – a two-week return of cold weather, while at the end of September and beginning of October heat returns for the same couple of weeks. In time, these phenomena coincide with the beginning and end of photosynthesis in the respective regions. Although on the average the plants on the planet spend only about 1 % of solar energy for biosynthesis, we tried to prove that from the point of view of biophysics, these are strictly interrelated natural phenomena, and the beginning and end of plant biosynthesis can lead to a jump in air temperature in the surface layer by 5–10 degrees.

Keywords: photosynthesis, greenhouse effect, carbon dioxide, seasonal temperature variations

Maples coloured out town
With a tint of magic beauty,
This is women's summer coming
As a yearly autumn duty.

Igor Kokhanovskiy

The majority of the Earth's population lives in the tropical and subtropical zones, *i.e.* between the 30° n. l. and 30° s. l. This is the climatic zone with a positive average annual temperature [1], with evergreen vegetation and continuous photosynthesis in the green plants. However, now we will speak of those who live in Europe (35–70° n. l., the 2nd place in population), the USA (30–50° n. l., the 3rd place), Russia and Canada (50–70° n. l.) – embracing about 30 % of the land. In the southern hemisphere, parts of Argentine and Chile are situated within the corresponding latitudes (Tierra del Fuego – 55° s. l.). For the listed territories, which are situated to the north or south from the 35th parallel, except for the coastal zones under the global effect of the oceanic thermostat, a sharp interruption of photosynthesis for the period of negative temperatures is characteristic, as well as a sharp renewal with the beginning of warm days.

For many hundred years, the population of these territories experiences a two-week return of cold weather at the end of May – beginning of June, though the Sun shines for 16 h per day (in Russia, this period coincides with the blossoming

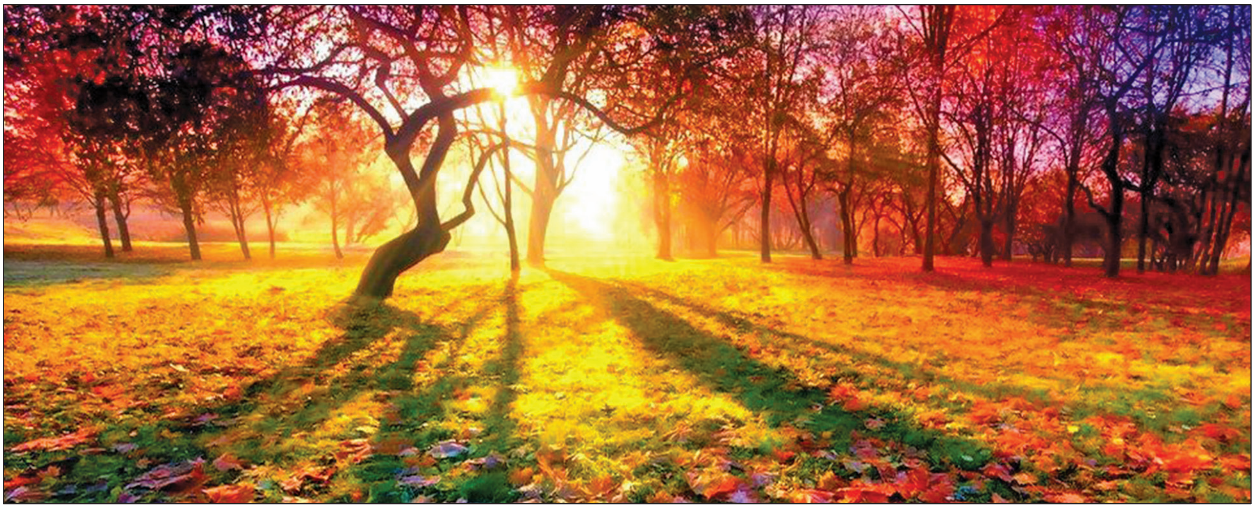

Fig. 1. Women's summer.

of bird cherry trees), and the return of warm weather for a period of approximately the same length at the end of September – beginning of October, with the daytime duration of 12 h. In Russia, this period is called women's summer, in Germany – old womanish, in Bulgaria, Macedonia and Roumania it is called Gypsy summer, in Spain and Italy it is Santa Marina, while in the USA it is Indian summer. This gift from Nature is highly appreciated in Russia, where frosts are possible in October, and winter comes in November. In Siberia, peasants often are in time with harvesting during these days. The physical reasons of temperature rise are somewhat discussed in the popular science publications, but the biophysics of annual cold snap at the beginning of the summer season has escaped the attention of the scientific community.

To begin with, let us consider the existing versions of temperature rise in the lower atmospheric layers during the beginning of autumn. Meteorologists explain the phenomenon of women's summer by the formation of the Azor cyclone above the Atlantic Ocean, which moves to the east and reaches Russia [2]. But what is to be done with the Indian summer in America (that is, in the west) and with the return of frosts related to bird cherry trees? In our conviction, both the bird-cherry-tree frosts and the women's summer are clearly connected with the start and finish of photosynthesis in the middle latitudes. The women's summer starts immediately after the first autumn cold nights and only in the regions with the continental climate. During frost episodes, the amount of water entering the plants from soil decreases, so, to decrease the loss of moisture evaporating from the leaf surface, the trees drop their leaves. At the same time, in connection with a decrease in daylight time, the decomposition of chlorophyll occurs, and other leaf pigments become visible: carotenoids colour the leaves in yellow and orange, while flavonoids – in red and violet (Fig. 1).

Academician V. I. Vernadsky, who was studying the Earth's noosphere, put forward the hypothesis that warming after leaf fall is a natural process for the zone of deciduous forests. He linked this phenomenon with the rotting of a large amount of leaves, which is accompanied by a large amount of heat. Taking into account the enormous amounts of leaves changing their colour all over the vast territory of the planet (Fig. 2), in the opinion of Vernadsky, the scattered and evolved heat is sufficient to raise atmospheric pressure and to generate the ascending air flow [3]. The air cools in the upper layers of the atmosphere, and the vertical air flow changes for the horizontal one driving the clouds away above the region. The absence of precipitation and the rays of yet high sun make their business – dry and warm weather comes for a couple of weeks.

Well, if temperature rise after leaf fall may be explained by heat evolution during rotting a large amount of leaves, what may be the physical reasons of frosts at the beginning of summer? We suppose this is connected with the start of photosynthesis. About 42 % of the energy of Sun within the wavelength region 400–700 nm reaches the Earth's surface; only 1–3 % of this amount as an average is consumed for photosynthesis [4]. At first glance, this is very small, but the main con-

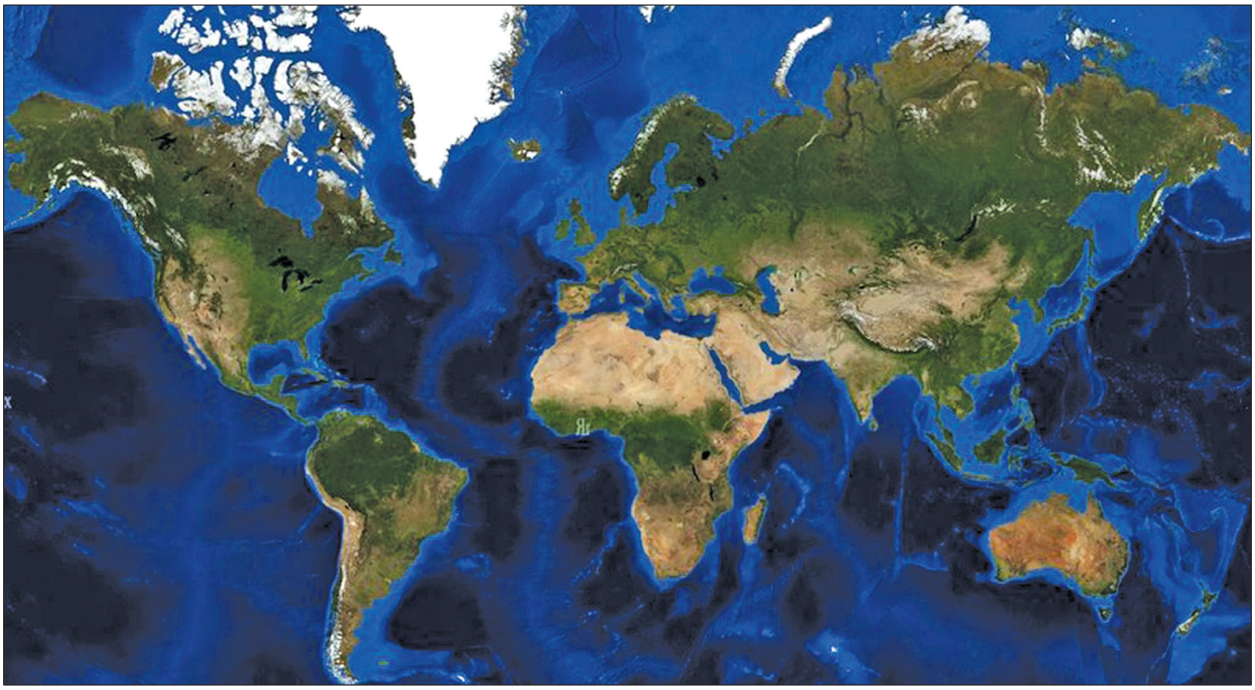

Fig. 2. Satellite photograph of the Earth.

tribution into this figure is made by evergreen tropical forests for which the nature has invented additional protective mechanisms of the utilization of excess solar energy [5, 6]. Quite the contrary, in the middle latitudes of Russia, the beginning of summer is characterized by the intense growth of plant biomass, and the efficiency of the consumption of the solar energy increases substantially. Its fraction consumed for heating the soil surface becomes minimal. It is sufficient to look at the satellite photograph of the planet to evaluate the scale of the green biomass in the middle latitudes of the Earth and its potential for absorbing the solar energy (see Fig. 2). Academician V. I. Vernadsky carried out analyses and calculations and then concluded that the surface area of green leaves of trees, stalks of grass and green algae exceeds the surface area of the Earth by a factor of more than 10 000 [3]. During recent years, Academician I. I. Gitelzon carried out a similar evaluation, and his results coincided with the data obtained by Vernadsky half a century ago [7].

A total solar eclipse was observed in Novosibirsk on August 1, 2008; the width of the eclipse band reached 200 km. We took part in the monitoring of this phenomenon; all the results are published in [8]. The phase of the total eclipse lasted for 30 min. During this time, the radiation balance (the difference between the absorbed and emitted energy per unit surface area) in the ground layer of the atmosphere became negative and reached -115 W/m^2; the air temperature near the surface decreased by 2.2 °C. The consumption of solar energy in the middle latitudes, which form a band up to 4000 km wide, for 12–16 h per day for photosynthesis, which starts sharply, during two weeks and finishes sharply may cause a much more noticeable jump of temperature. Some simple estimations may be made. As we have already mentioned, a part of solar energy that may be used by plants for photosynthesis, so-called photosynthetic active radiation (PAR), accounts for 42 % of the total energy f solar radiation. The coefficient of PAR assimilation, which is the amount of energy accumulated in the biomass per unit surface area, in percent of PAR reaching this area during vegetation, is 1–3 %. Vegetation time in the middle latitudes varies from 3 to 5 months, however, an intense increase in the biomass of forests mainly fits within the first two weeks. This means that the coefficient of PAR assimilation at the peak of plant growth may reach 30 %, or 15 % of the total amount of incoming solar energy. Taking into account the middle air temperatures in January (-10... -30 °C) and in June (+20... +30 °C), a decrease in temperature due to the sharp start of photosynthesis may be 5–10 °C.

The utilization of solar energy during the time of intense growth of plant biomass is not the only consequence of photosynthesis. Indeed, the major part of solar energy before the start of photosynthesis is consumed for heating the Earth's surface. By the beginning of summer, an equilibrium is established, when the amount of the falling solar energy is equal to the amount of energy emitted from the Earth's surface in the form of infrared radiation [9]. Fortunately for humans, this radiation is absorbed in the ground air layer by greenhouse gases (absorption wavelengths are indicated in parentheses): water (6.0 and 2.7 μm), methane (7.7 and 3.3 μm) and the most efficient greenhouse gas – carbon dioxide (15.0, 4.5 and 2.7 μm). However, the latter gas together with water and the red (0.68 μm) light forms the basis for photosynthesis [10, 11]. The concentration of carbon dioxide in the air decreases due to a sharp acceleration of photosynthesis in spring and then increases to the former equilibrium value, with a sharp deceleration in autumn [12]. This may also affect cooling and warming. Indeed, the seasonal variations of CO_2 concentration in the ground layer of the atmosphere in higher latitudes 63–82° n. l. are 22 to 27 ppm [12], which is about 10 % of the total CO_2 content in the atmosphere. It is assumed that the determining role in the seasonal variations of CO_2 content is played by the ground plant cover [13]. It should be noted that the very existence of life on the Earth is closely connected with the presence of carbon dioxide in the atmosphere; essential are both biosynthesis and the greenhouse effect – the conservation of the heat emitted by the Earth's surface heated with sun rays. Due to the greenhouse effect alone, the annual average temperature near the Earth's surface is equal to approximately 15 °C, while without it the temperature would drop by 39 °C – to −24 °C, which would make the existence of life on the Earth impossible [14]. So, a 10 % decrease in the concentration of carbon dioxide in the atmosphere as a result of intense photosynthesis may lead to a decrease in temperature by 3–5 °C only due to the greenhouse effect. A comparative contribution into temperature drop (5–10 °C) will be also made by a decrease in the fraction of incident energy consumed for heating of the atmosphere.

Correspondingly, in autumn, during women's summer, in connection with the finish of photosynthesis and the start of leaf fall, CO_2 concentration in the atmosphere increases, and the greenhouse effect becomes more pronounced. In addition, the absorption of solar energy by plants is ceased, that is, the whole energy coming from the Sun is consumed for heating the soil and atmosphere. Peasants in Siberia have reasons to hope for the women's summer and to be careful with the bird-cherry frost.

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