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## *THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME: THE ROLE AND PLACE OF SUN-ATMOSPHERE RELATIONSHIPS*

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### RESUMEN

La consolidación de los estudios ecológicos propuestos en el Programa Internacional de la Geosfera-Biosfera (IGBP) permite formular los aspectos conceptuales de este programa y en particular, definir el papel y el lugar que deben tener los problemas derivados de las relaciones solares atmosféricas. A este respecto, primero caracterizaremos brevemente el IGBP (Kondratyev, 1987).

### ABSTRACT

The consolidation of the ecological studies proposed in the International Geosphere-Biosphere Programme (IGBP) leads one to formulate the conceptual aspects of this programme and, in particular, to define the role and place of the problems of the sun-atmosphere relationships. In this connection we shall, first, briefly characterize the IGBP.

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## 1. A BRIEF CHARACTERISTIC OF THE IGBP

The evolution of the geosphere and the biosphere is characterized by an intensifying interaction of their components which is, first of all, determined by an increasing anthropogenic impact on the environment. This impact is largely manifested through the transformation of nature by man and the growing anthropogenic loads on the environment which affect practically all the components of the geosphere and the biosphere (in some cases at global scale) and require a systematic approach to study the coupled processes within the geosphere and the biosphere. The discovery of the laws which govern the interaction between the geosphere and the biosphere requires interdisciplinary studies of unprecedented complexity, pushing the respective problems to the front line of the current natural sciences.

Complex studies of the geosphere and the biosphere have been since long needed, as it has been revealed in the recent decades with the establishment of numerous large-scale programmes: the International Geophysical Year (IGY), the subsequent International Quiet Sun Year (IQSY), the World Weather Watch (WWW) and the Global Atmospheric Research Programme (GARP).

Recently a realization has been started of the large-scale Middle-Atmosphere Programme (MAP), International Lithosphere Programme, World Climate Programme (with the World Climate Research Programme as a component), a specialized International Satellite Cloud Climatology Project (ISCCP), as well as a large-scale Soviet programme "Sections" aimed at studies of the role of oceans in the short-term climate changes. There are also two new international programmes with the same objective: the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere (TOGA).

The following international projects on studies of biogeochemical cycles of various components are being realized under the aegis of SCOPE and UNEP: the American Programme of the Global Tropospheric Chemistry, the International Hydrobiological Programme, and the Man and Biosphere Programme (within the framework of UNESCO).

Each of the enumerated (and some other) programmes is characterized by a complex approach to solve their respective problems. An analysis of the global ecological problem, on the whole, shows, however, an urgent need of coordinated efforts to

achieve the goals of various programmes and substantiating a "super-programme" covering the key aspects of the geosphere-biosphere studies.

These circumstances have stimulated the development of the long-term International Geosphere-Biosphere Programme (IGBP) (the full launching of the observational system is planned for the 90's) aimed at studies of global changes, especially with a view to the anthropogenic impact on the biochemical cycles of carbon, nitrogen, sulphur, phosphorous, water, and the dynamics of some factors of life support such as solar radiation, the quality of air and natural waters, soil fertility, as well as the interrelationships between biospheric and geospheric events. Under the auspices of NASA (USA) an independent (but closely related to the IGBP) programme "Global Change: Impact on Habitability" is being developed.

This situation requires an analysis of key problems of the geosphere-biosphere studies. The following three relevant circumstances are of primary importance: first, in the time scales of decades and longer it is most clearly seen that the geospheric components constitute a coupled system, the interaction of individual components being characterized by synergetic manifestations (by the feedbacks that sometimes lead to a mutual intensification of various processes). This circumstance determines an exceptional importance of a systematic approach, as well as interdisciplinary studies of the physical, chemical and biological processes based on the implementation of a joint programme.

Second, an increasing anthropogenic impact on geosphere-biosphere necessitates studies of the global-scale processes and their changes. From the viewpoint of planning an observational system, this testifies to an important role of the observations from space with the preserved importance of conventional observational systems both now and in the future. For these problems, on the whole, paleo and comparatively planetary analogs become particularly urgent. The latter means that geospheric studies must be closely connected with investigations of the origin and evolution of the solar system. This conclusion is important because the geosphere-biosphere system is not closed in a sense that it is affected by various extraterrestrial factors (solar activity, galactic cosmic rays, etc.). Thus, there is no doubt that the atmosphere, ocean, cryosphere, lithosphere and extra-terrestrial factors are key objects in studies of the geosphere and the biosphere.

Naturally, in studying an exceptionally complicated interdisciplinary problem it is

of primary importance to determine its key aspects, among them the problem of climate and its changes. The climate is a result of interaction between the components of the climate system (atmosphere-hydrosphere-lithosphere-cryosphere-biosphere), with numerous feedbacks. At present there is no problem in natural sciences of great global-scale complexity, in requiring an account of complicated anthropogenic impacts.

In connection with the climate problem the role of the geosphere-biosphere interaction requires serious attention. This role is clearly seen, in particular, when the climatic effect of the anthropogenic CO<sub>2</sub> concentration increases is considered. During the recent years this problem has brought forth controversial conclusions about possible climate changes. This has been caused by two circumstances: (i) the lack of reliable enough models of the global carbon cycle (so far, the contribution from marine and continental biota is not clear); (ii) an inadequacy of the climate theory from the viewpoint of interactive account of the processes in the geosphere and the biosphere. Though the climate theory can serve as an illustration of the importance of considering the effect of extra-terrestrial factors, the physical mechanisms determining this effect are still unknown.

The climate problem is also very important from the practical point of view. It is well known that man's activities depend (sometimes critically) on climatic conditions, particularly concerning agriculture. Recently a new aspect of the problem has been outlined: a possible impact of a nuclear war on the climate and biosphere (Kondratyev, 1980, 1986). The respective estimates show an unavoidable global ecological catastrophe due to a strong climate cooling ("nuclear winter"), which must result from a decreased solar radiation at the Earth's surface because of strong attenuation by urban and forest post-nuclear fires. Of still more importance is a climatic instability under conditions of strong disturbances of the climate system.

Bearing in mind the importance of the climate problem, a respective interdisciplinary section within the IGBP must be formulated, taking into account the WCRP and other programmes (WOCE, TOGA, ISCCP, etc.) which are now being accomplished. Considering specific features of these programmes, it is clear that studies of interrelated problems of the physics and chemistry of the atmosphere as well as biochemical cycles of such components as carbon, nitrogen, phosphorous, sulphur, and sun-atmosphere interrelationships within the IGBP claim for most serious attention since they are not properly foreseen in the on-going programmes.

The problems of atmospheric physics and chemistry are very important from the point of view of assessing the prospects for the evolution of the biosphere (its productivity) in conditions of growing anthropogenic impacts. Among other problems the emphasis must be placed on the problem of affecting the stratospheric ozone layer which protects the biosphere from harmful effects of the UV solar radiation.

## 2. THE SUN-ATMOSPHERE INTERRELATIONSHIPS

Although the causes of climatic change are still poorly understood, they are, nevertheless, numerous, and most of these changes are determined by internal processes of interaction between the components of the atmosphere-ocean-land-snow and ice cover system. There is doubt, however, that certain contributions to climatic variability are made by such external factors as volcanic eruptions, variations of the Earth orbital parameters, anthropogenic pollution of the atmosphere, and solar activity, which can cause long-term variations in climate on the scales of years, decades, centuries and millennia (Borisenkov *et al.*, 1986; Wolf and Hickey, 1987).

Statistical correlations between several indices of solar activity and climate changes necessitate the precise monitoring of spectral and total extra-atmospheric solar radiation. The Nimbus-6 and subsequent Nimbus-7 measurements have not revealed significant changes in the total solar constant. Satellite measurements revealed, however, a considerable variability of the shortwave UV solar radiation. Strong variations of X-ray and radio-emission were established as well as corpuscular solar emission (various manifestations of solar activity are, apparently, connected with convective motions and circulation in the solar atmosphere).

The simplest and most natural mechanism of the effect of solar activity is connected with taking into account the solar constant variations. According to C. Fröhlich (1987), analysis of available balloon and satellite data on the total solar constant (SC) revealed variations with periods from minutes to several hours with an amplitude within the millionths - hundredths of per cent, as well as variations with characteristic time from several days to months with an amplitude reaching several tenths of per cent. The latter is a manifestation of solar activity connected with variations of solar spots and flares.

The entire spectral range of variability covering frequencies (periods) from 70 nHz (150 days) to 5  $\mu$ Hz (3.3 min.) can be divided into three major intervals. The SC

variations in the interval (70 nHz - 2  $\mu$ Hz (5.8 - 150 days) are mainly determined by solar activity whose intensity varies by an order of magnitude during a cycle of solar activity. The spectrum of variations is characterized by prominent peaks at periods 51.4, 23.4, and 7.0 days, which, probably, exist independently of solar activity. In the periods of high solar activity the integrated power of variations reaches  $7.5 \times 10^{-7}$  (46 ppm mean amplitude), decreasing to  $1.5 \times 10^{-7}$  (21 ppm) during weak solar activity.

The second spectral interval of SC variations, covering 2-20  $\mu$ Hz (14 hours - 5.8 days), follows the law  $\nu^{-2}$  ( $\nu$  is the frequency), which may be due to g-modes. The integrated power in this range is  $3.1 \times 10^{-9}$  (3.7 ppm mean amplitude). Within the third interval 20  $\mu$ Hz - 5 mHz (14 hours - 3.3 min.) the spectrum follows a  $\nu^{-1}$  law, with a broad peak around a 5-min period which is due to p-modes yielding amplitudes of several ppm. The integrated power is  $1.5 \times 10^{-8}$  (0.5 ppm).

The linear structure of the variability spectrum within the third interval, revealed by balloon photometric observations, shows a spatial coherence of granulations and supergranulations, at least, during several hours. As for the long-term trends, the observational data reliably reveal the decreasing trend for the SC 0.018% per year after the year 1980, whereas during the late 60's - 70's an increasing trend of about 0.029 per year was observed for the SC. The long-term trends and their causes can reliably be determined only on the basis of continuous satellite observations of the solar constant.

Solar UV radiation forms in very thin external parts of the solar atmosphere. Though the UV radiation at wavelengths shorter than 300 nm constitutes only about 1% of total solar constant, its variability affecting the processes in the upper atmosphere of the Earth is of great interest. As from data of J. Lean (1987), maximum increase of UV radiation recorded during cycle 21 for characteristic scales of the Sun's rotation (days, months) constitutes (wavelengths are in brackets): 1% (300 nm); 2.5% (250 nm); 6% (200 nm); 16% (150 nm); 40% (in the Lyman-alpha line); 60% (30.4 and 120.6 nm); and 200% (28.4 nm). The amplitude of a longer-term variability (for instance, 11-year) of UV radiation is still unknown, despite long observation series. Available data show that the extra-atmospheric UV radiation has been increasing during cycle 21 with growing solar activity by <1% (300 nm); 1.5 - 4% (250 nm); 2.5 - 9.3% (200 nm); 16 - 100% (150 nm); 80 - 155% (the Lyman-

alpha line, 121.6 nm), about 100% in chromospheric emission lines in the extreme UV range (102.6, 58.4, 20.4, etc.), from 100% to an order of magnitude in coronal emission lines of the extreme UV range. Though 11-year variations of the frequency of occurrence of floccules with intensified UV radiation reflect a possible 11-year modulation of the extra-atmospheric UV radiation, the amplitude of such variations has not reliably been estimated. Probably, therefore, in fact, this modulation is of a longer period.

The data of satellite daily observations of the UV solar constant enabled one to perform a detailed analysis of its short-period variability. The time series of data are characterized by a high autocorrelation and instability with non-deterministic cycles 27 and 13 days. Observations confirmed a consistency between short-period variations of UV radiation and the evolution and rotation of active regions (floccules) on the sun's disc. The emissions of the upper photosphere and chromosphere have, apparently, similar temporal structures which differ, however, from the variability of coronal emissions or 10.7 cm thermal emission. As for the indicators of short-period variations of UV radiation formed beneath the corona and determined from ground-based observations, the best are the emission CA II K and an equivalent width of the 1083 nm line.

The determination of the long-period variability of extra-atmospheric solar UV radiation is hindered by a limited volume of reliable observational data. The accuracy of measurements varies usually within 10 - 30%, *i.e.* within the same order of magnitude like the variability of UV radiation within its long-wavelength region during an 11-year cycle. There are, however, grounds to suppose much larger systematic errors. These circumstances determine the hypothetic character of mechanisms for the long-term variability of the extra-atmospheric solar radiation.

The variations in solar magnetic activity are usually supposed to be a reason for the 11-year cycles, but these correlations have not been estimated quantitatively. The factors of other cycles (apart from the 11-year one) are still less determined. An accuracy of several per cent for the extra-atmospheric UV radiation measurements is very difficult to achieve. In developing the satellite instrumentation which will operate during cycle 22, the emphasis has been placed on the reliability of the pre-flight absolute and in-flight calibrations of these instruments. Absolute errors within 5 - 10% with relative errors not more than 1% are supposed to be reached in the wavelength interval 100 - 300 nm. The simultaneous use of several instruments after the

thorough absolute calibration, will make it possible to assess the reliability of measurements.

Numerous publications of the last decades contain a diverse argumentation favouring the variability of the weather and climate caused, for instance, by 11- and 22-year cycles of solar activity, which suggests correlations between the weather and radiation variations, depending on various phenomena on the sun (German and Goldberg, 1981; Loginov *et al.*, 1980; Newkirk, 1983; Proc. ICSC, 1981). For instance, an 11-year cyclicity of precipitation and a 22-year periodicity of various indicators of weather (the winter- and summer-time temperature, draughts) are clearly seen. There are numerous manifestations of correlations between the short-period weather variability and the magnetic field, most substantial in the auroral zone. Though the evidence for the effect of the auroral zone on the lower atmosphere raises doubts, some of the sun-weather relationships are supposed to be determined by high-energy particles intruding into the polar-latitude atmosphere.

The conclusions based on analysis of the sun-atmosphere correlations and the estimates of the statistical significance of these correlations are rather controversial. Therefore, a search for physical mechanisms for the sun-weather-climate interrelationships gains importance. Studies of correlations between solar activity, weather and climate are, first of all, directed to revealing correlations for three spatial and temporal scales: (i) climate changes from centuries to millennia due to long-period variations of solar activity; (ii) climate changes connected with a 22-year cycle; (iii) weather changes on a scale of several days due to short-period phenomena on the sun. Though in these cases we have no convincing evidence for the respective correlations, there are enough data for further studies on the sun-atmosphere interrelationships.

As for the long-term climatic variability, it may partially be caused by variations of solar radiance followed by marked changes in the solar constant. The nature of the sun-weather correlations ought to be different. In this case sensitive correlations must be sought for in the system "sun - solar wind - magnetosphere - stratosphere - troposphere" which manifest that slight variations of the incoming energy can stimulate relatively large-scale consequences based on the "trigger" mechanisms (Borisov, 1986; Zadvorniuk and Mikhnevich, 1985; Rakipova and Efimova, 1975; Nicolet, 1985).



Estimates of the energy connected with manifestations of solar activity (*i.e.* corpuscular radiation) show small quantities of such energy compared to the extra-atmospheric solar insolation and the energy needed to affect typical tropospheric weather-forming systems.

The difference between the quantities of corpuscular radiation and total insolation decreases, however, in high latitudes where the annual mean insolation is minimum (in winter it is absent, at all), and corpuscular radiation is maximum due to the effect of the Earth's magnetic field.

Available estimates show that in high latitudes a strong local increase takes place in the ratio of corpuscular emission to insolation. It follows that the effect of solar activity on the weather and climate must be maximum in the high-latitude winter. The types of radiation which can manifest at various latitudes in polar regions are as follows: (i) galactic cosmic rays "modulated" by solar activity - usually a basic factor of electric properties of the atmosphere at altitudes 5 - 30 km; (ii) solar protons events (SPE) which are relatively rare but can intensify the ionization near 300 km by several orders of magnitude; (iii) precipitating relativistic electrons (PRE), which is energetically less substantial but more frequent and can increasingly affect the ozone layer; (iv) very frequent local precipitation of electrons in the zone of northern lights, which leads to the production of X-ray emission.

The transformation of electrons energy to the energy of X-ray photons ensures the penetration of radiation deeper into the atmosphere, determining, thereby, the effects of solar activity in the layers below the levels reached by electrons responsible for X-ray emission. Simultaneous observations of stratospheric ozone and particles intrusion reveal a correlation between them. So, for instance, during the SPE a decrease of ozone takes place at altitudes below 60 km. After the SPE in August 1972 the daily mean zonal mean ozone content in high latitudes decreased by about 20%. There was an increase of ozone concentration near 50 km caused by X-ray emission. The resulting changes in the absorption of solar radiation by stratospheric ozone and the stratospheric heating can affect the weather in the troposphere. All this suggests that the stratosphere acts as a buffer zone in the transfer of the sun-induced perturbations from the upper atmosphere to the troposphere. The magnetically caused variations in the weather necessitate an analysis of the geophysical phenomena which vary during a solar cycle and are affected by the Earth magnetic field (cosmic rays, for instance). It was found out that the X-ray induced ionization at the level 500

hPa decreases by a factor of 4 in the period from minimum to maximum solar activity.

With the supposed correlation between ionization and thunderstorm activity there is a possibility of the sun-induced modulation of climate: changes of the lower atmosphere conductivity connected with the solar cycle can affect the electric field, cloud formation temperature, thunderstorm activity, and precipitation. Ozone is an important atmospheric component, varying during the solar cycle as well as at very short-term variations (SPE), which has stimulated special interest in the ozone mechanism of the solar-atmospheric interrelationships (Gille *et al.*, 1984; Heath and Schlesinger, 1986; Hood, 1987; McPeters and Jackman, 1985; Solomon and Crutzen, 1981; Solomon *et al.*, 1982).

Besides, various other mechanisms have been suggested: (i) the effect of the energetically weak phenomena in the upper atmosphere upon the lower atmosphere in close-to-resonance conditions; (ii) the manifestation of an 11-year cycle in the troposphere as a total effect of the short-period variability connected with either solar flares or geomagnetic storms, most frequent during a maximum of sun spots; (iii) the effect of water vapor formed under the influence of solar wind; (iv) the possible effect of the solar constant variations during a solar cycle; (v) a cyclic variability of the solar wind - magnetosphere interaction when the direction of the interplanetary magnetic field changes; (vi) the variability of the reflection of the upward gravity waves by the upper atmosphere.

During the last years the emphasis has been placed on the mechanisms of sun-atmosphere interrelationships manifesting through the effect of solar and galactic cosmic rays on the chemical composition of the atmosphere (Kondratyev and Nikolsky, 1978).

One of the most likely mechanisms of the effect of solar activity on the weather and climate is connected with the consideration of an additional formation in the stratosphere of nitrogen oxides (NO and NO<sub>2</sub>) due to galactic cosmic rays (GCR) and solar protons events (SPE). The ozone-destructing effect of the GCR and SPE reduces the ozone content, which decreases the absorption of solar radiation by the stratosphere, but in the case of intense corpuscular fluxes large amounts of NO<sub>2</sub> are produced, which leads to net stratospheric warming at altitudes 32 - 42 km due to absorption of solar radiation by NO<sub>2</sub>. The precipitation of high-energy particles of

radiation belts during magnetic perturbations may also be a factor in the formation of nitrogen oxides.

The estimates of the effect of modulation of the stratospheric chemical composition due to GCR and SPE on the vertical temperature profile have shown that the content of nitrogen oxides  $\text{NO}_x$  formed due to GCR is not large (compared to background concentrations) at all the altitudes. Above 20 km the time for the doubling of  $\text{NO}_x$  concentration due to GCR exceeds 11 years and even at 15 km it amounts to 2 - 4 years. Therefore, it is difficult to suppose that the  $\text{NO}_x$  production due to GCR can cause great variations of the concentrations of ozone and temperature.

The effect of SPE can be more substantial. Available estimates show that one strong solar proton event can lead to the formation of a larger amount of nitrogen oxides than the GCR during the whole year.

G. Brasseur *et al.* (1987) have suggested a theory of the effect of solar activity on the ozone layer and the stratospheric temperature field manifesting as periodic variations of the extra-atmospheric solar UV radiation, bearing in mind the subsequent comparison of theoretical estimates with the data of new satellite observations.. Calculations of the effect of short-term UV radiation variations on the stratospheric chemical composition (ozone included) and temperature were based on the use of a 1-D chemical-radiative time-dependent model (0 - 100 km), in which 40 components were taken into account (oxygen, carbon, hydrogen, nitrogen and chlorine compounds). The external forcing was taken as a sinusoidal variation of solar UV radiation with periods of 27 and 13.5 days (the second case simulates the existence of two active areas on the opposite sides of the sun). The amplitude of solar radiation changes varies depending on wavelength, according to the data of Nimbus-7 spectrometer measuring the backscattered solar UV radiation.

According to numerical modeling data, the sensitivity of temperature to UV radiation variations grows with altitude. The calculated amplitudes turned out to be much below those determined by the effect of the atmospheric dynamics. So, for instance, in the case of the periodicity of perturbations equal to 27 days the temperature at the level 1 hPa grows by 0.13 K with a 1% increase of solar radiation flux at 205 nm wavelength. The calculated phase shift (at 1 hPa level the temperature increase lags behind the UV radiation increase) constitutes 1.5 days. Apparently, the effect of solar activity on the thermal regime shows itself not directly (through ra-

diative heating) but indirectly (through the dynamical processes, including planetary waves).

Calculations have shown that maximum sensitivity of ozone to solar activity is observed near the level 3 hPa, the amplitude and phase of ozone variability strongly depending on the ozone-temperature feedback taken into account. The temperature field - ozone content interaction is realized so that it causes a strong phase shift in the variability of ozone in the upper stratosphere and mesosphere due to the effect of negative temperature feedback. Maximum ozone in the layer 0.2 - 0.5 hPa is reached several days earlier than maximum solar UV radiation.

As a rule, theoretical conclusions agree with observational data. However, the calculated phase shift in the ozone response is 2 - 4 times less than the observed one, which points to the existence of processes not considered by the model. According to the theory, a strong negative sensitivity of ozone and positive sensitivity of temperature must be observed in the mesosphere to UV radiation variations caused by the absorption of solar radiation by molecular oxygen in Lyman-alpha line.

It follows from calculations that variations of the nitric acid mixing ratio in the stratosphere must be twice as large compared to the respective (opposite in sign) variations of ozone concentration and, hence, more easily detectable from observational data. With solar radiation flux at 205 nm wavelength supposed to vary within 2 - 15% during an 11-year cycle, the calculations give the limits of variability of ozone and temperature shown in Table 1.

Table 1

Possible variations of ozone and temperature during an 11-year cycle

Pressure hPa	Approximate altitude km	Ozone %	Temperature K
0.5	54	0.16 - 0.9	0.32 - 2.4
1.0	48	0.20 - 1.7	0.32 - 2.1
2.0	43	0.40 - 3.2	0.32 - 2.1
5.0	36	0.7 - 5.1	0.20 - 1.3
10.0	31	0.6 - 4.2	0.16 - 1.0

As it is seen, maximum variation in ozone content is 5%, temperature 2K, but most probable are the limits 2.8 - 3.5% and 1.3 - 1.6 K, respectively (with assumed variability of 205 nm radiation 8 - 10%). Note that the estimates of the limits of the long-term variability of total ozone (0.3 - 2.6%) agree with the data of Nimbus-4 spectrometer measuring the backscattered UV radiation.

The controversy of results of analysis of the sun-weather-climate interrelationships and the hypothetic character of physical mechanisms supposedly responsible for them, necessitate a well balanced approach to the assessment of the present state of the problem of sun-atmosphere interrelationships, even more so that a great number of unjustified optimistic considerations and assessments have appeared in this field.

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