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# The International Geosphere-Biosphere Programme (IGBP):Key aspects of the requirements of the observational data.

K. Ya. Kondratyev and O.M. Pokrokvsky
*Institute for Lake Research of the USSR Academy of Sciences.*

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**RESUMEN**
En este trabajo se analizan los principales requisitos para los estudios contenidos en el Programa Internacional de la Geosfera-Biosfera (IGBP). Se presenta una sistematización de los requisitos de la información proveniente de satélites para oceanología, hidrología, geología, agricultura y silvicultura. Al comparar los requisitos anteriores con la instrumentación satelitaria actual, se encuentra que las características instrumentales no son óptimas. Utilizando técnicas de información máxima (método de Balash), se pueden determinar los canales básicos multiespectrales satelitarios como una función de la eficiencia económica, cuyos resultados indian la utilización óptima de la información en los campos de investigación anteriormente mencionados.

**PALABRAS CLAVE:** IGBP; satélites; instrumentación; investigación espacial; técnicas de optimización.

**ABSTRACT**
This paper discusses some requirements for studies within the scope of the International Geosphere-Biosphere Programme (IGBP), in particular the requirements of space instrumentation for oceanology, hydrology, geology, forestry and agriculture. When these requirements are compared with the current satellite instrumentation, it is found that the instrumental characteristics are not optimal. Using information techniques (Balash) one can determine multispectral channels as a function of economic efficiency of the space-derived information, wich can be optimally used in these research fields.

**KEY WORDS:** IGBP; satellites; instrumentation; space research; optimization techniques.

## INTRODUCTION

The evolution of geosphere and biosphere is characterized by an intensifying interaction of their components wich is, first of all, determined by an increasing anthropogenic impact on the environment. Due to the interaction between the geospheric and biospheric components, each of them is affected by increasing anthropogenic loads. Uncovering the laws of the geosphere-biosphere interaction requires a systems approach, interdisciplinary studies of unprecedented complexity, placing the respective problems at the front line of the natural sciences today.

## OBJECTS OF INVESTIGATION

The evolutionary processes of the geosphere-biosphere system are characterized by fairly closed global cycles of substances in nature. Therefore, studies of biogeochemical cycles in nature and of the interaction between the components of the geosphere-biosphere system become one of the most important problems of the IGBP (Borisenkov and Kondratyev, 1988; Kondratyev, 1987a and 1987b). Special emphasis must be placed on the problem of climate change.

Climate results from the interaction of the following components of the climatic system: atmosphere, hydrosphere, lithosphere, cryosphere, biosphere. This system is characterized by numerous feedbacks.

The complexity of the evolution of the climatic system increases under the influence of various loads caused by man's activity. The functioning of the climatic system depends on several global cycles. Thus, for instance, the need to study the global carbon cycle is determined by the effect of $CO_2$ concentration in the atmosphere on the global climate (Borisenkov and Kondratyev, 1988). The existence of the vital stratospheric ozone layer depends on releases of chlorofluorocarbon compounds, carbon dioxide, nitrogen and methane oxides, as well as on their evolution in the climatic system's components (Kondratyev, 1988).

These examples illustrate the need for an extensive programme of monitoring the physical, chemical and photochemical processes taking place in the atmosphere on a global scale.

A key factor of the formation of the chemical composition of the atmosphere is its interaction with the ocean wich is a sink for $CO_2$ and nitrogen oxides, but a source (in the regions of coastal lowlands and productive zones) of $CH_4$, $H_2S$ and $(OH_3)_2S$, as well as a source of halogens, nitrous oxide and water vapour for the atmosphere. An urgent problem is to extend the studies of the ocean-atmosphere gas exchange as a result of corresponding chemical. physical and biological processes.

Atmospheric aerosol plays an important role, affecting the formation of climate (Kondratyev, 1987a). The mechanisms of gas-to-particle conversion determine the interrelationship between biogeochemical cycles of sulphur and nitrogen. Cloud cover (Kondratyev, 1987a) and anthropogenic tropospheric aerosol are important objects of investigation.

Bioproductivity (primary productivity) on land and in oceans is another component of the geosphere-biosphere system of high priority. The conditions for biological productivity on land are determined by resources of water, biogenic components and light, and the latter two factors are important only for the oceans. Thus, information must be made available on the global spatial and temporal distributions for rainfall as well as total incoming solar radiation (including UV) at the Earth's surface.

Table 1. Characteristics of the Satellite-borne instruments in the visible and near-IR regions.

| Instrument | Spectral channels | Spatial resolution (nadir) | Width of viewing band (km) | Remarks |
|---|---|---|---|---|
| MSS | 0.50-0.60 | | | Multi |
| | 0.60-0.70 | | | spectral |
| | 0.70-0.80 | | | scanner |
| | 0.80-1.10 | 80 m | 185 | |
| TM | 0.45-0.52 | | | |
| | 0.52-0.60 | | | Thematic |
| | 0.63-0.69 | | | mapper |
| | 0.70-0.90 | 30 m | 185 | |
| CZCS | 0.43-0.45 | | | |
| | 0.51-0.53 | | | Coastal |
| | 0.54-0.56 | | | zone |
| | 0.66-0.68 | | | color |
| | 0.70-0.80 | | | scanner |
| | 1.05-1.25 | 825 m | 1636 | |
| WBS | 0.5-0.59 | | | |
| | 0.61-0.68 | | | Water |
| | 0.79-0.89 | | | basin |
| | 0.51-0.73 | 20 m | 60 | survey |

Of primary importance are detailed studies of the global moisture cycle whose origin is determined by an interaction of the thermal regime and atmospheric circulation; the processes of evaporation, transport and phase transformation of water in the atmosphere; and the atmospheric circulation coupled with the radiative regime as affected by anthropogenic variations in the atmospheric composition (Kondratyev *et al.*, 1988). The leading role of the ocean in the formation of the global water cycle and climate determines the key importance of the problem of the atmosphere-ocean interaction (Marchuk *et al.*, 1986).

Snow and ice cover and its variability are fundamental climate-forming factors (Kondratyev, 1987b). On the one hand, a high albedo of snow and ice determines their importance in the formation of the thermal regime. On the other hand, sea ice plays an important role as an insulating layer and as an inertial component that transforms the annual course of temperature by shifting extrema due to the latent-heat release during freezing in autumn and heat expenditure on melting in spring.

The most important data on the land surface needed in an analysis of the interaction of the climatic system's components are as follows (Kondratyev, 1987a): surface albedo (its annual change and interannual variability); surface temperature and roughness; vegetation index as an indicator; soil moisture content; snow cover extent and thickness; parameters describing the land-use variations and the soil erosion; changes in vegetation cover (vegetation dynamics deforestation, forest fires, etc.); parameters of the soil surface-atmosphere energy balance, etc.

## THE USE OF SPACE-BASED OBSERVATIONS

The solution of the above problems requires the development of a global observational system using both conventional and space-based observatories, with the unquestionable priority of the latter, bearing in mind the global scale of the needed information. For this purpose meteorological and Earth's resources satellites as well as manned orbital stations are now widely used.

An analysis of the specifications of some of the operational satellite-borne instruments (Table 1) shows a substantial overlap of various parameters. There is a notable similarity in the choice of spectral channels used in different instruments often carried by the same satellite. The multispectral MSS data are widely used by numerous experts in the field of Earth's resources studies. Therefore, the limits of spectral intervals of the respective sensing channels have been chosen approximately. The characteristics of the thematic mapper (TM) have been chosen, in the interests of a narrower group of problems.

The requirements of only one group of problems in oceanology have been met in spectral characteristics of the coastal zone color scanner (CZCS). Whereas the HRV (WBS) instrument surveys water basins.

The consistency of the needs of individual users of information and of the choice of spectral characteristics of the satellite-borne instruments is illustrated by the data from Kondratyev *et al.*, 1975. This analysis has prompted the present authors (Kondratyev and Pokrovsky, 1977) to analyze the problem of planning space-based multi-purpose remote sensing systems.

Table 2. The Choise of Spectral Intervals (μm) Using Factor Analysis

| Group of Problems | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Oceanology | 0.45 - 0.53<br>0.45 - 0.53 | 0.64 - 0.69<br>0.64 - 0.69 | 0.70 - 0.90<br>0.70 - 0.75 | 0.57 - 0.64<br>0.62 - 0.64 | 0.82 - 1.30<br>0.96 - 1.10 | 0.50 - 0.58<br>0.50 - 0.57 | 0.40 - 0.44<br>0.42 - 0.44 |
| Hydrology | 0.70 - 1.30<br>0.96 - 1.10 | 0.51 - 0.59<br>0.51 - 0.57 | 0.44 - 0.52<br>0.44 - 0.52 | 0.67 - 0.74<br>0.67 - 0.74 | 0.57 - 0.67<br>0.62 - 0.67 | 0.30 - 0.40<br>0.70 - 0.75 | 0.38 - 0.49<br>0.42 - 0.49 |
| Geology | 0.51 - 0.63<br>0.51 - 0.57 | 0.62 - 0.70<br>0.62 - 0.70 | 0.70 - 0.89<br>0.70 - 0.75 | 0.40 - 0.51<br>0.42 - 0.51 | 0.8 - 1.30<br>0.96 - 1.10 | | |
| Forestry and Agriculture | 0.51 - 0.57<br>0.51 - 0.57 | 0.59 - 0.70<br>0.62 - 0.70 | 0.75 - 0.78<br>0.76 - 0.78 | 0.70 - 0.74<br>0.70 - 0.74 | 0.40 - 0.51<br>0.42 - 0.51 | 0.55 - 0.58<br>0.55 - 0.57 | 0.88 - 1.30<br>0.96 - 1.10 |

## OPTIMAL PLANNING OF AN OBSERVATIONAL SYSTEM

The importance of the problem of optimal planning of a system of remote sensing from space is determined by a number of circumstances, including the cost of the experiments, limitations for the weight of instruments, power supply, and the volume of the on-board stored information. Besides, a number of scientific aspects of the problem of the satellite data interpretation must be borne in mind: mathematicaly flaws of the inverse problem (using the characteristics of either reflected or absorbed radiation to retrieve the parameters of the medium); the uncontrolled fluctuations of the atmospheric optical medium, etc.

In solving the problem of planning remote sensing experiments, two extreme cases must be excluded: excessive or insufficient information obtained because of poor choice of the observational conditions. In both cases the solution of the inverse problem may greatly deteriorate in view of its incorrectness.

Two approaches have been developed to the solution of the problem of planning multi-purpose remote sensing systems: Informative and economic. In both cases it is assumed that the information users in various fields of economics can accurately formulate the requirements to major characteristics of the information (spectral channels, observational geometry, spatial and temporal resolution, etc.). In the studies discussed below the authors used a summary of these requirements described in Kondratyev *et al.*, 1975, and related to four groups of problems: I-oceanology (102 requirements), II-hydrology (33), III-geology (36), IV-forestry and agriculture (32).

### Information approach

The idea of this approach (Kondratyev and Pokrovsky, 1977) is to select the most important factors and to determine the respective vectors of the factor loads in the formalized space of requirements. The way of constructing the space of requirements and a modification of the applied scheme of factor analysis are given in Kondratyev and Pokrovsky, 1977. The results of the determination of the optimal sets of spectral intervals are given in Table 2 for I-IV groups of problems. The same reference contains the results of calculations for various complexes of problems. Note, that the data of Table 2 (line 1) have been obtained exclusively from the requirements of user's who do not take into account the atmospheric correction in various regions of the electromagnetic spectrum, as well as the economic characteristics of the space-based experiments. Table 2 (line 2) shows the limits of spectral channels of sounding, specified with the $H_2O$, $O_3$ and $NO_2$ absorption bands excluded in the following intervals: 0.38-0.42; 0.57-0.62; 0.755-0.760; 0.785-0.790; 0.810-0.845; 0.910-0.960; 1.10-1.16 μm. The large contribution of molecular scattering by the atmosphere determines the small information content of the channel 0.30-0.40 μm. Therefore, this channel is not used in the instruments of remote sensing systems (see Table 1).

### Analysis of the potential of instruments with due regard to the user's requirements

With the chosen spectral channels of sounding organized in the order of increasing wavelengths, it is obtained a relationship between similar channels for various groups of problems (Table 3). As it is seen, the shortwave channel 0.42-0.44 μm is used only in the oceanology problems. From the data of Table 1 the respective channel 0.43-0.45 μm is also used only in a specialized oceanographic instrument CZCS. A set of channels given in Table 3 for oceanology problems has much in common with a set of spectral intervals for CZCS (Table 1). The limits of the spectral intervals are determined by the fact that the scheme of the oceanographic scanner does not take into proper account

Tabla 3. Optimal spectral channels of sounding corresponding to basic groups of problems.

| Group of problems | Spectral channels of sounding (μm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Oceanology | 0.42 -0.44 | 0.45 - 0.53 | 0.50 - 0.57 | | 0.62 - 0.64 | 0.64 - 0.69 | 0.70 - 0.75 | | 0.96 - 1.10 |
| Hydrology | | 0.44 - 0.52 | 0.51 - 0.57 | | 0.62 - 0.67 | 0.67 - 0.74 | 0.70 - 0.75 | | 0.96 - 1.10 |
| Geology | | 0.42 - 0.51 | 0.51 - 0.57 | | 0.62 - 0.70 | | 0.70 - 0.75 | | 0.96 - 1.10 |
| Forestry and Agriculture | | 0.42 - 0.51 | 0.51 - 0.57 | 0.55 - 0.57 | 0.62 - 0.70 | | 0.70 - 0.74 | 0.76 - 0.78 | 0.96 - 1.10 |

the user's requirements (Kondratyev *et al.*, 1975) or the spectral optical characteristics of the atmosphere. Thus, for instance, the spectral channel 0.62-0.64 μm, required by each of the problems of the group "oceanology" is absent in the scheme of CZCS (Kondratyev *et al.*, 1975).

The data of Table 3 show also that for the problems of the group "forestry and agriculture" alone, measurements in two narrow channels are needed: 0.55-0.57; 0.76-0.78 μm. Yet, specialists interested in this group of problems, cannot now obtain information in these spectral intervals using any available instrument. Narrow channel No. 6 is needed for oceanology and hydrology. Specialists in geology and forestry and agriculture use information obtained in the broad spectral interval 0.62-0.70 μm wich combines channels Nos. 5 and 6 for problems I and II. This spectral region is represented in the existing instruments as a single spectral interval. This means that the available instruments do not meet the requirements of the groups I and II, as far as the data of channels 5 and 6 are concerned.

A comparison of the data of Tables 1 and 3 shows that the information obtained with the TM agrees best with the requirements of the group III, but less well with the group II. The MSS meets less the requirements of the users. The reason is that it gives no information for channel 2 (Table 3). In its scheme channels 5 and 6 of the optimal set are combined into one channel. Information for channels 0.70-0.80 and 0.80-1.10 μm is much distorted due to the absorption of reflected radiation by the atmosphere. These data suggest that the available satellite-borne instruments are inadequate for the needs of the space information user's in various fields of application.

## Economic approach

Bearing in mind that in the future the development and realization of the space-based remote sensing systems will be fully financed by economic applications interested in space-derived information, a problem arises of economic profitability of the planned instrumental systems with long-term functioning on board space-based platforms. The multispectral character of the space-derived information and its multipurpose applicability make it possible to analyze the problem of optimal planning of the respective observational systems from the viewpoint of maximization of the integral economic efficiency factor. For a multipurpose observational system V under condition that the efficiencies for individual problems $v_i$ (i=1,...,N) are regulated by special limitations of the type of unequalities from above and from below.

We shall dwell on the posing of the problem. Let $C_{ij}$ be the economic efficiency of the use of the j-th measuring channel (j=1,...,M) for the purpose of the i-th individual problem; $d_j$ total cost of the functioning and processing of the information of the j-th measuring channel of the multipurpose measuring system; $b_i^+$, $b_i^-$ are maximum and minimum values of the economic efficiency of the use of observational data for the i-th problem. In this case, for the economic efficiency $k_j$ of the use of the j-th measuring channel we obtain the expression:

$$k_j = \sum_i C_{ij} - d_j \qquad (j=1,\ldots,M)$$

Introducing the variable $y_j$ to indicate the inclusion in the observational system of the j - th channel :

$$y_j = \begin{cases} 0 \\ 1 \end{cases}$$

we formulate the basic problem of planning an optimization as an standard problem of the Bulev whole-number programming (Korbut and Finkelstein, 1969):

$$y = \min{}'_{y_1,\ldots,y_M} \left\{ - \sum_{j=1}^{M} k_j y_j \right\} \tag{1}$$

$$y_j = \begin{cases} 0 \\ 1 \end{cases} , \quad (j=1,\ldots M) \} \tag{2}$$

$$b_i^- \leq \sum_{j=1}^{M} C_{ij} y_j \; b_1^+ (i=1,\ldots N) \tag{3}$$

One of the most efficient numerical algorithms for the solution of equations (1)-(3) is the method of Balash.

This method, realized in a standard set of computer programmes (Korbut and Finkelstein, 1969), was used in calculations for planning the multipurpose systems of remote sensing of environmental objects from space. All the problems (Kondratyev *et al.*, 1975; Kondratyev and Pokrovsky, 1977) are divided into four large groups: oceanology, hydrology, geology, and forestry and agriculture. Each of these groups is subdivided into sub-groups. The number of indidivual problems in each of the basic groups, varies from 9 to 14. As an illustration, we shall consider the results of the choice of an optimal set of spectral channels for a multipurpose survey in the interests of oceanology (Table 4) (Pokrovsky, 1981, 1984).

The number of spectral channels for the solution of 12 problems (N=12) in the group "oceanology" (table 3) totals 37 (M=37), the number of particular channels $m_I$ for the i-th specific problem ranges between 18 and 33 ($18 \le m_i \ge 33$). This means that the volume of information for each of the specific problems is sufficiently large.

Table 4. Specific Problems Within the Group "Oceanology".

| Problem |
| --- |
| 1.- Sea surface state. |
| 2.- Water turbidity. |
| 3.- Sea ice. |
| 4.- General near-shore marine survey. |
| 5.- Mapping the coastal currents and tides. |
| 6.- Global-scale mapping of currents, sea surface survey. |
| 7.- Mapping the coastline and shallow waters. |
| 8.- Bathymetry and topography ice. |
| 9.- Distribution and migration of aquatic organisms. |
| 10.- Pollution of coastal waters. |
| 11.- Impact of pollution on marine medium. |
| 12.- Studies of bars, reefs, etc. |

It constitutes at least half the total volume of information for the group of problems "oceanology".

In constructing multispectral instruments one can proceed from the fact that the cost will be inversely proportional to the width of the spectral interval and directly proportional to the spectral resolution. Let ß be the cost of a measuring channel with a resolution of 1 nm. Then the cost $d_{\Delta\lambda}$ of a channel with resolution $\Delta\lambda$ (nm) will be $d_{\Delta\lambda} = \beta/\Delta\lambda$. Let "$b_i$" be total efficiency of the use of space-derived information in the i-th problem of oceanology. Then $\Sigma_i b_i = b$. Assume all $bi_i$ equal. Then $b_i = b/N$ is the average efficiency, related to one individual problem. Introducing a threshold value $\alpha(0<\alpha<1)$ of permissible deviations from average efficiencies, we define for equation (3) the constrains:

$$b_i^+ = (1+\alpha)\, b_i\, ;\;\; b_i^- = (1-\alpha) b_i \quad (i=1,...,M) \qquad \text{in (3)}$$

Let $I_i$ be the set of the numbers of channels included into the requirements of the observational system for the i-th individual problem.

We introduce the indicator function of the j-th channel, according to the equality:

$$X_j(I_i) = \left\{ \begin{array}{l} 1,\ \text{if } jEI_i \\ 0,\ \text{otherwise} \end{array} \right\}$$

Then a set of coefficients $C_{ij}$ in the optimization problem (1)-(3) is determined from the equality:

$$C_{ij} = \frac{b_i}{m_i} X_j (I_i)$$

$$(\, i=1,...M\, ;\, j=1,...,N\, ) \qquad (4)$$

Using the following numerical values: ß=5, a=31 (Pokrovsky, 1981), all the parameters in (1)-(3) were calculated.

Calculations for the economic efficiency factors of the measurement channels $k_j(j=1,...,N)$ show that some channels are potentially unprofitable (negative values of $k_j$) from the viewpoint of multipurpose application of the observational system. These are the channels 0.40-0.45 µm and 0.69-0.73 µm. The measurements in the following spectral channels are the best economically justified: 0.53-0.55; 0.66-0.68; 0.59-0.61; 0.61-0.64; 0.55-0.57. Here maximum values of $\{k_j\}$ are reached. Thus, even simple calculations make it possible to select from a large initial list of spectral channels those most advantageous from the viewpoint of economic criteria.

Channels 1,7 in the optimal scheme of the problems "oceanology" on the other hand, are less useful compared to others given in Table 3. However, this information should be taken into account only when designing specialized oceanographic instruments. Other group of problems also have their own "unprofitable" spectral regions.

Thus, for instance, from the economic point of view, for the group of problems "forestry and agriculture" it is more useful to obtain information for the channel 1.5-1.8 µm than for channel No. 9 (0.96-1.10 µm), however, for the group of problems "hydrology" all spectral channels are profitable.

## CONCLUSIONS

1. The main requirements for studies within the IGBP have been analyzed.

2. Requirements of the space- derived information users for basic groups of economic problems have been systematized.

3. A comparison of these requirements and characteristics of the available instrumentation of meteorological and Earth resources satellites has shown that their features are not optimal.

4. An optimization by information maximum enabled one to determine a set of spectral channels of sensing in the interests of the four groups of fields: Oceanology, hydrology, geology, forestry and agriculture.

5.The maximization of the total index of economic efficiency that takes into account the multispectral and multipurpose character of the space-derived information makes it possible to differentiate spectral channels of sensign for each group of problems according to their economic benefits.

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K. Ya. Kondratyev and O.M. Pokrokvsky
*Institute for Lake Research of the USSR Academy of Sciences. Sevastyanov str.9, 196199 Leningrad, USSR.*