SATELLITE IMAGES IN ECOLOGICAL MONITORING. DEVELOPMENT OF THE ATLAS *SPACEBORNE METHODS OF GEO–ECOLOGY*

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Received October 20, 1992.

Concept of a scientific–methodical atlas of satellite images Spaceborne Methods of Geo–Ecology *has been proposed.*

In the context of intimate relation of ecology with earth sciences and of the fact that ecological problems become of prime importance in economic policy and international affairs, it is clearly seen the need for satellite data application to ecological studies and development of the methods of satellite image interpretation as applied to ecological monitoring and solution of ecological problems.

In order to work out these methods, to instruct the specialists in different fields of earth sciences and business managers, to promote these methods in practice of ecological studies and geo–ecological expertise, it is necessary to have scientific–methodical guides. We propose to compile a satellite image atlas *Spaceborne Methods of Geo–Ecology* as such a guide. The scientific team of the Laboratory of Aerospace Methods at the Geographical Faculty of the Moscow State University put forward such a proposal. This team is famous for a two–volume atlas of multispectral aerospace images[1,2] compiled in collaboration with the Space Research Institute of the Academy of Sciences of the USSR, a number of Soviet institutions, and in international cooperation under the auspices of the International Council on Space. The atlases were published by Nauka Publishing House in Moscow and Academic Verlag Press in Berlin in Russian, German, and English. The objective of these publications was to provide the scientific–methodical basis for the first wide application of multispectral satellite images and scanner data in their visual and automated processing aimed at the study of natural resources and economic and thematic mapping. The proposed atlas is the third volume of this series and differs in purposeful application of the satellite data to the solution of ecological problems which use various data and methods of their processing and interpretation. The atlas must contribute to the formation of satellite database for the Russian Program on Environmental Protection. This Program comprises the overall Academic Program on Biospheric and Ecological Studies and the International Geosphere–Biosphere Program (IGBP). The objectives of the atlas are:

– generalization of the available little experience and scientific–methodical achievements in application of the satellite data to geo–ecology by the beginning of 1990's,

– development of a technique for image interpretation in the geo–ecological studies and image application to ecological mapping, and

– searching for ways of application of the spaceborne methods to geo–ecological monitoring and solving the ecological problems.

The atlas is structurally planned to comprise scientific–methodical and applied parts.

The scientific–methodical part is assumed to involve characterization of the satellite images used in geo–ecology, methods of satellite image interpretation in the geo–ecological studies, and ecological mapping with the use of the satellite data. Several chapters are proposed to be included in the first part of the atlas. The first chapter is devoted to the basic data such as the satellite images recommended for geo–ecological study and to the geo–ecological system itself being developed under the auspices of such institutions as Scientific–Production Association on Satellite Instrument Manufacture, Space Research Institute of the Russian Academy of Sciences, and Ministry of Nature of the Russian Academy of Sciences.

The second central and largest chapter of the scientific–methodical part of the atlas is planned to demonstrate the advantage of the satellite data application to the study and monitoring of an anthropogenic impact upon the nature and adverse consequences of such an impact. The examples of various anthropogenic impacts on the nature, depicted in the satellite images, and their adverse consequences engendering ecological problems will be given in this part of the atlas with the methodical aim. These examples should be related to different climatic zones and various human activities in the territory. Particular attention must be given to the natural systems being unstable to the impact.

For tundra regions we plan to illustrate technogenic influence on the soil–plant canopy under conditions of permafrost, oil and gas production, laying the oil and gas pipelines, and irrational management of the vehicular traffic in the territory when vehicles move without roads and to demonstrate the state of deer pastures as a result of overgrazing. For taiga regions the influence of intensive forest management on the change in the composition of the forest species which is unavoidable without measures intended to regenerate forests can be presented. Also shown are the feasibilities of monitoring of a violation of felling rules, deforestation of vast territories, and pollution of rivers used for stream logging. Consequences of mass cases of forest diseases, pests, and fires and feasibility of monitoring of forest regeneration in the burnt and felling areas can be illustrated. The results of wrong land reclamation typical of the swampy areas of the forest zone, overdrying the swampy areas, and the processes of peat overwinnowing should also be analyzed.

Evolution of erosions is planned to be demonstrated for steppe–forest and steppe regions which are mainly used in agriculture. In particular, imaging of the evolution of linear erosion of soils, their surface erosion from running water and humus content will be presented. For the above–indicated zone monitoring of the pollution of soils and through them food products caused by excessive use of chemical fertilization and pesticides is of

extraordinary importance. However, the space research cannot provide for such a monitoring. Another important problem is to monitor the degree of filling of small water reservoirs, ponds, and basins and to monitor the quality of their waters, because they characterize the landscape of a steppe zone where precipitation are scarce. Satellite images can also be used to monitor such parameters as water turbidity, degree of filling of water basins, and their eutrophication therefore they are planned to be identified in the atlas.

In dry steppe and semi–desert regions a feasibility of monitoring of soil deflation and dust storms should be characterized. For regions of pastoral farming application (semi–desert and desert pastures) we plan to image the pasture digression as a result of overgrazing, formation of abrading spots near wells and devastated tracks of driving cattle, evolution of deflation and then formation of eolian relief in the areas left without vegetation and in poor soils due to overgrazing, vehicular traffic, and mining and exploitation of mineral deposits. Such processes as secondary salinization of soils as a result of irrigation water discharge and swamping and salinization of soils due to water leakage from irrigation canals are planned to be analyzed from the images. Other consequences of irrigation activity having an effect on the adjacent areas are typical of these regions, namely, intake of water storages of the main water arteries for irrigation needs, transformation of rivers into drying water streams, inland water basins suffering from complete or partial deprivation of river discharges feeding these basins and hence their drying, desertification of the bare surfaces of bottoms with their subsequent transformation into solonchak deserts, evolution of deflation and transfer of salts, etc. In the mountain regions the images should be applied to identify the spontaneous natural disasters both endogenous (such as seismic activities, earthquakes, and volcanism) and exogenous (first of all, avalanchers and mud flows, landslips, and stone and rock falls), as well as to determine the dependence of their activity on an anthropogenic impact.

In addition to this totality of adverse processes caused by an anthropogenic impact in different climatic zones with typical human activities it is also required to image the intensive anthropogenic (mainly industrial) activity being as though azonic but manifested variously under conditions of different climatic zones. Some of these processes are associated with exploitation of the territory itself as a resource. That is most typical of mining industry. These are stripping works including the formation of quarries, spoil heaps, and tailing dumps of ore–dressing plants that destroy completely the landscapes existed there before and call for recultivation of these territories in the course of or after open–cast mining, filling up the tailing dumps, and spoil heap formation. These are also underground mining activities whose intensive development engenders the problems associated with ground subsidence, occurrence of underground stream, groundwater pollution or change in groundwater level. These are the system of oil wells and pipeline–collectors inevitably affecting the state of a soil–plant canopy. The problems associated with the creation of the water reservoirs for needs of hydraulic power engineering should also be referred to the above–discussed problems. In particular, they are the change in banks and water quality of water storage reservoirs, the formation of a special microclimate, and the effect of a groundwater table rise on the temperature regime of rivers, on vegetation of adjacent territories, and on evolution of abrasion and erosion processes.

Since the ecological problems are most acute in large industrial cities, we plan to image, on the one hand, the main types of ecological situations in heavily populated areas and city agglomerations, on the other, the new recreation zones and territories.

Analysis of the ecological problems of different climatic zones and azonic landscapes as well as the above–given considerations motivate the incorporation of about 40 ecologically important scenarios into the discussed chapter of the scientific–methodical part of the atlas. Within the framework of these scenarios we would characterize the main ecologically hazardous types of an anthropogenic impact on the nature, formulate the interpreting criteria for the impact of such types, and recommend a technique for their visual and automated interpretation.

The third chapter of the scientific–methodical part of the atlas should be devoted to the problems of ecological mapping from satellite images. It is planned to include different types of ecological maps from the reference maps of both crisis ecological state and maps of general ecological situation of the entire country to the mid– and large–scale maps of individual ecologically hazardous regions with an analysis of the situation and recommendations for its normalization. Since for regions with different climatic and economic conditions the content of such maps is different, there is a good reason to give the examples of such maps for the territories of different types.

The second part of the atlas is applied and devoted to a solution of specific global, regional, and local ecological problems. It must comprise the results of analysis of an ecological situation from the images, mapping of the situation, and the examples of satellite data application to both the state description and solution of the arising problems. Consideration of these problems illustrating the natural system degradation at different hierarchical levels calls for the images of different scales and resolutions.

Today, when humanity concentrates its serious attention on our home –– the Earth, it is of particular importance to demonstrate the examples and feasibilities of satellite data application to the study of the global ecological problems.

Consideration of the problems concerning an anthropogenic impact on the Earth as on the system as a whole leads to a conclusion that it is necessary to include in the atlas the data on the following subjects: reduction of living matter on the Earth (including the problems of deforestation and desertification), monitoring of the living matter level and its distribution over the ocean, pollution of the atmosphere and water, destruction of the protective ozone layer, and dynamics of the land fund of the planet.

For global problems only the problem of assessment of their state by individual examples can be posed in the atlas but for regional ecological problems this is insufficient. With the help of satellite images and results of their interpretation, the feature peculiar to the acute problems arising in individual regions should be determined and the possible ways out of the examined situation, variants of the problem solution, ecologic prediction for various types of human activity in a territory, as well as some examples of geo–ecological expertise of individual projects should be illustrated. Thus an active and constructive geographical approach rather than the descriptive one should be realized in this chapter. Such "hot" points of the country as the Aral sea, Kalmyk, Baikal lake, the region of Baikal–Amur Main

Line (BAML), Western Siberia, northern regions of petroleum production and industrial project, Moscow agglomeration, etc. should be considered as examples.

The examples of the problems arising in the regions of operation of the individual industrial complexes of mining enterprises, metallurgical plants, heat–and–power stations, etc. can be given as the local problems. There is no need to cover all the ecologically stressed regions in the atlas, it is sufficient to consider several typical examples; however, by way of these examples the real benefit of satellite data application to the ecological state assessment and recommendations for improving this situation should be illustrated.

In conclusion of the applied part of the atlas it is expedient to consider not only a negative human impact on nature but also positive examples of human life and activity being in harmony with nature, its truly rational exploitation, "ecologization" of the human economic activity by means of its blending into a landscape and formation of optimal agricultural–landscape systems. Here it is pertinent to demonstrate the feasibility of application to environmental protection, in particular, for organization and control over reservations, national parks, and other territories under protection.

At present the work on several series of pages of the atlas related mainly to the second applied part has been completed.

The ecological problems associated with desertification are considered by the examples of the Near–Aral sea region and Kalmyk.

A series of pages devoted to the Near–Aral sea region encompasses an assessment of the ecological state of the vast area influenced by the Aral sea. A series consisting of four maps on a 1:8 M scale was compiled from satellite images of the Kyzylkum desert obtained by E.V. Glushko. It comprises the maps of the landscapes and desertifications (the latter identifies the types of desertification and relief changes, surface runoff of groundwater, and plant canopy) as well as the maps indicating the degree of desertification with recommendations for its prevention.

The map of the geo–ecological assessment of the landscape state completes this series.

Further, analogous maps were compiled to a 1:2.5 M scale for the coastal regions of the Aral sea. The map of the sourth Near–Aral sea region with the Amu–Darya delta is compiled to a scale of 1:1.5 M. It comprises geo–ecological assessment of landscape changes and characterizes classes and degrees of changes and their prevailing type and evolution. A series of satellite images (obtained from onboard the "Kosmos" satellites at different times) is presented for the lower part of the Amu–Darya delta to a scale of 1:1 M while for the entire delta and its individual sections clearly depicting the changes occurred there –– to a scale of 1:0.2 M. For 1978 and 1988 P.R. Reimov has compiled the maps of the state of hydrogenous ecosystems which are most strongly influenced by the sea level changes and flooding of a territory as well as the map depicting the dynamics of such systems within the span of ten years to a scale of 1:1 M. For one of the delta sections in the region of Dautkil' lake the evolution of ecological systems were analyzed in detail from the images obtained in 1982, 1984, and 1986 to a scale of 1:0.2 M and the corresponding maps indicating the dynamics of these ecosystems and feasibilities of routine monitoring of their state from satellite images were constructed.

The second region illustrating the application of satellite data to the study of desertification processes is Kalmyk. On the first pages of this series compiled from the data obtained by I.A. Trofimov the map of Kalmyk land used for farming (to a scale of 1:2 M) and indication of desertification processes associated with each type of human activity are presented. A series of the fragments of satellite images (to a scale of 1:0.2 M) displays the main factors and types of desertification as a consequence of the human activity being a source of deflation, pastoral digression, dust storms engendered by ploughing of sandy areas, sand winnowing, strewing of roads and buildings with sand, land desertification caused by irrational reclamation, and salinization of water meadows in the course of water–engineering works.

The feasibilities of application of the images obtained at different times to monitoring of the desertification processes are illustrated by the examples of sand winnowing dynamics studied from these images including their automated processing. In connection with photogenic reclamation of coastal solonchak regions, their dynamics is also illustrated. Based on the mapping of the lands used for farming and the current status of desertification (such maps characterize the degree, processes, and factors of desertification), its hazard is assessed, i.e., 20–30 year prediction is given in two variants: for the present regime of farming and for rational use and improvement of lands. Such series of prognostic maps were compiled for the section of the Central Chernozem Plain to a scale of 1:0.15 M and for the entire Kalmyk to a scale of 1:14 M. The special series of pages is devoted to the assessment of the state and monitoring of the dynamics of the meadow lands which hold the major value for the animal husbandry in this arid area.

Another ecological problem that develops into the global one along with desertification is deforestation. In this connection a series of pages devoted to the study of forest dynamics derived on the basis of comparison of the present satellite images with old maps is included into the atlas. The satellite images obtained in winter, when forest margins stand out clearly against a background of snowed–up areas without forests, are used for this purpose. The data on a number of reference regions of the European territory of our country are presented.

The forest dynamics within the span of 40 years are studied in the Kostroma region (by way of comparing the satellite images with general topographic maps) while for Novgorod, Vologda, Verkhne–Kamsk, Moscow–Oksk, Bryansk, Udmurt, Chuvash, and Mordovian regions such investigations were performed using a 10–verst (35000 feet) map which was constructed by the Corps of Military Topographers in the last century and spans one hundred years.

The special technique of comparison of the data obtained at different times with the use of a computer was developed for these investigations and included in the atlas. The results of investigations in the form of a series of maps of forest dynamics indicate a complicated opposite changes. For example, the appearance of new forest areas (true, they are usually occupied by secondary forests with low productivity) along with substantial deforestation of large areas is typical of several regions, especially in connection with the consequences of the war and abandonment of agricultural lands. A forest distruction by fires, timber felling, entoparasites, and agricultural and industrial production is characterized by the examples of Siberian forests in Krasnoyarskii Krai.

The work has begun on a series of pages related to a technogenic impact on the nature of northern regions which can be characterized by the examples of Kolsk peninsular and Noril'sk region. A special series of pages is devoted to a snow–cover pollution in urban territories

revealed by the investigation technique developed by Prokacheva et al. by the examples of St. Petersburg and Vorkuta suburbs. The aureoles of pollution were analyzed for the regions of Industrial Center, Ural, and Kuzbass. The series of pages of the atlas that have already been done and discussed at the Conferences on Ecological Mapping in 1990–91 are of unremitting interest for specialists and, undoubtedly, they will serve to further application of satellite images to ecological problem solution. In so doing, the current content of the atlas, clearly, is being refined and somewhat transformed comparing to the projected one.

The atlas must provide the basis for ecological education of people dealing with the national economy and, more generally, population of the country. For experts in the field of earth sciences it can serve as the scientific–methodical guide on satellite data application to ecological monitoring and mapping, ecological situation assessment, and ecological problem solution.

REFERENCES

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