ECOLOGICAL MONITORING OF THE LOW-LEVEL ATMOSPHERE BY REMOTE SENSING FOR NATURAL RESOURCE EXPLORATION AS A SINGLE METROLOGICAL TASK

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Low-level atmospheric monitoring and remote sensing for natural resource exploration are discussed from a general metrological point of view. It has been found that the spectrophotometric and spectroradiometric measuring procedures and instruments in the two cases can be unified.

Monitoring, which in the given case is construed as automatic checking of the state and behavior of an object or medium, is based on quantitative information about the main parameters and characteristics that is obtained from them by means of modern devices. The process of obtaining such information constitutes measurement and its reliability is guaranteed by an appropriate metrological assurance system, which covers the methods and devices for reproducing, storing, and transferring the dimensions of the units of the physical quantities that participate in the process, as well as the required standards and specifications.

Monitoring, therefore, is a problem of measurement. The quality of the solution depends on how reliable is the mathematical model chosen for the object or medium and how good are the procedures and instruments that check the adequacy of the measured substance of the model adopted and generate a positive or negative feedback signal and also verify the reliability of the algorithm for taking a solution from the results of the measurement. Fairly often monitoring is carried out by using a telemetric channel, in which case the information in the measuring process is borne by the parameters of the optical signal that are inherent to the object or medium (passive mode) or are excited in them by an external source (active mode).

In the past two decades natural resource and ecological monitoring has become increasingly widespread. Natural resource monitoring refers to on-board photography from a satellite, airplane, or helicopter when the image, showing a view of part of the ground or water surface, is a source of useful information. The image is taken in the optical range of wavelengths, most often in the visible and infrared (IR) regions of the spectrum. The image is processed on board or are transmitted by a telemetric channel to Earth for mathematical processing. The layer of atmosphere serves as an information-transferring channel and at the same time, as the main source of noise.

Ecological monitoring is taken to mean photography from the ground or from a flying craft (most often a satellite, a small airplane, or a helicopter), when the scene photographed is the contaminated low-level layer of the troposphere of a certain thickness. The image is taken in the optical range (most frequently in the ultraviolet (UV) and visible regions of the spectrum, and more rarely in the IR region) and optical windows in the atmosphere are chosen. The results are processed on board or can be sent to the Earth by a telemetric channel. Often the information is simply recorded on a carrier and are processed later in a chamber. In the second case, therefore, the layer of atmosphere acts as a source of useful information and the noise comes from the background radiation from the ground or water surface. In both modes the image can be taken either in the passive mode (with natural light, without additional illumination of the scene) or in the active mode (with illumination or irradiation of the scene, e.g., by a lamp or laser).

Since the photographic tasks and even the conditions are seen to be the same (the only difference is in the object under study), the structure of the apparatus should be identical. In both modes the apparatus incorporates an optical system, a recep-
tion-amplification unit, an information-recording and processing system, and, if necessary, a unit for controlling and transmitting the data back to Earth. In the active mode the apparatus is supplemented with a radiation source.

In order to classify both forms of monitoring as measuring tasks, the simple photographing apparatus must be transformed into a measuring instrument that delivers reliable quantitative information about the object. For that purpose the same apparatus, which is made with extra measures to stabilize its transfer functions, should be calibrated or graduated in units of the measurable quantities and, furthermore, should be capable of executing those operations periodically during use.

Hence the need to clearly define the quantities measured, to choose acceptable methods of measurement and procedures for reliable evaluation and minimization of the systematic error, to analyze the ways of building the measuring apparatus and minimizing the instrumental errors, to choose promising directions for building a metrological base for both pre-flight and in situ calibration of the entire measuring setup, and, if necessary, metrological assurance of its main units, component by component.

The situation is complicated because it proves inadequate to calibrate only the input devices of the apparatus (e.g., the optical system and the reception-amplification unit); metrological assurance of the entire measuring and computing setup is required to make the results more reliable.

The interrelated concepts of measurable quantities and informative parameters must be clearly formulated beforehand. In the cases under discussion measurable should be taken to mean the physical quantities that are the end goal of the measuring experiment and characterize the objects of interest to the user. In agricultural resource monitoring those quantities may be, for example, the chlorophyll content in the green material, the amount of plankton in the surface layers of the ocean, the germination and growth data, and so forth. In ecological monitoring the measurables are primarily the volume or mass concentrations of gaseous contaminants — methane, carbon dioxide, NO$_2$, SO$_2$, etc.

Those very quantities, however, cannot be measured directly but informative parameters that are related to the measurables deterministically or statistically are determined during the photographing. The measuring procedure, therefore, comes down to solving the direct problem of directly determining the informative parameters that act on the sensing elements of the measuring equipment and then solving the inverse problem of getting agreement between the experimental data and the desired measurables, the relation between which is predetermined by the available mathematical models.

The complexity of the problem consists in, first, obtaining the most reliable direct-acting transducer about the informative parameters and, second, guaranteeing that those data are adequate for the mathematical model adopted to describe the measurables.

Overcoming the first complication requires a complete metrological assurance system and overcoming the second requires a large data bank containing representative statistical material about the relations between the informative parameters and the measurables.

In the given conception we considered only part of the problem, namely, the solution of the direct problem. Questions pertaining to identification of the objects or media measured from the results of measurements of the informative parameters requires special consideration.

What values of the informative parameters are involved in those measurements? When a spectrophotometer and the radiance of the scene is measured, the range of measured values lie within the limits of a few mW/cm$^2$·sr. The spectroradiometer used should have a range of roughly 300 K (should distinguish temperature contrasts of 0.1 to 1 K, depending on the measurement accuracy requirements).

For natural resource monitoring on-board equipment makes measurements in various subranges of the optical spectrum. Almost all satellite and aircraft instruments at present, however, operate primarily in the visible, near IR, and far IR sub-regions. In all three subregions spectrometers are used to measure the reflective characteristics of the Earth's surface, i.e., the on-board equipment makes a spectral analysis of the radiant flux from the Earth to the on-board entry optical system.

From the metrological standpoint the spectral composition of the solar radiation reflected from the Earth's surface is of greatest interest in the visible and near IR subregions and the spectral composition of the intrinsic thermal radiation of the surveyed scene, in the intermediate IR subregion. Therefore spectrophotometry is involved in the first case and spectroradiometry, in the second. In the overwhelming majority of cases a parallel spectral analysis is made of the radiation from the scene, which is scanned three-dimensionally by mechanical or electronic means. Parallel analyses are made by using multichannel (spectral) equipment.