AN EXPERIMENT IN THERMAL SOUNDING OF THE ATMOSPHERE FROM SATELLITES

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Abstract

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In recent years, indirect methods for studying the Earth' s atmosphere from satellites have been developing intensively [1,2]. Particularly great progress has been achieved in solving the problem of thermal sounding of the atmosphere [3]. In this case, information on the vertical profile of atmospheric temperature is extracted from measurements of the outgoing thermal radiation of the Earth-atmosphere system.

The solution of the problem of thermal sounding is associated with a number of difficulties. First of all, in order to make it possible to reconstruct the temperature profile with the required accuracy (1–2°), measurements of the outgoing radiation must be carried out with high accuracy (0.5–1%). Strict requirements are imposed on the spectral and angular resolution (the latter is especially true when interpreting measurement data under conditions of partial cloudiness [3]). Despite the difficulties mentioned, specialized instruments for solving the problem under consideration have by now been created and tested [4].

In March 1969, the meteorological satellite "Nimbus III" was successfully launched; on board it were spectrometers for solving the problem of thermal sounding of the atmosphere, which for the first time made it possible to obtain a solution of this problem under real conditions of a satellite experiment. Preliminary results of processing the measurement data were published earlier [5,6]. Interpretation of data from this kind of measurement, i.e., the transition from values of outgoing radiation in various spectral intervals to temperature values corresponding to definite levels in the atmosphere, is a complex problem. This is due above all to the fact that, from the mathematical point of view, the problem of thermal sounding of the atmosphere reduces to the solution of a Fredholm integral equation of the first kind, which is ill-posed from the classical point of view:

$$I(\nu) = \int K(\nu, p)\varphi(p)\, dp. \tag{1}$$

With different approaches to solving the problem, the meaning of the functions $I(\nu)$, $K(\nu, p)$, and $\varphi(p)$ may be different. It is important, however, that in every case the initial information is the spectral dependence of the intensity of the outgoing thermal radiation ($I(\nu)$), known from experiment, while the desired quantity is the temperature profile (the deviation of the temperature profile from the mean) or the profile of the Planck-function $\varphi(p)$ uniquely related to it. The kernel of the integral equation $K(\nu, p)$ is determined by the absorption characteristics of atmospheric gases in the spectral ranges under consideration.

In any approaches to solving the problem, a fundamental role in determining the kernel of equation (1) is played by the transmission functions of the real atmosphere [3]. The methods for obtaining transmission functions, as well as the complex physical nature of the transfer of thermal radiation in the real atmosphere, do not allow these functions, and consequently the kernel of equation (1), to be specified exactly. This feature further complicates the obtaining of exact

information on the vertical temperature profile. In the concrete solution of equation (1), one or another regularization technique is used, with the incorporation of varying amounts of a priori information about the sought function.

In the present work, two methods were used to solve the integral equation (1): the regularization method (^7), with selection of a quasi-optimal approximation according to the procedure proposed by one of the authors, and M. Shakhin' s method (^8), based on minimizing the mean-square difference between the measured and theoretically calculated values of the radiation. The initial information—the values of the outgoing radiation and the kernels of the equations—was completely identical in both methods. The values of the outgoing radiation were taken from measurements made with an interference spectrometer relating to Brownsville, Texas (USA) (22 April 1969). This makes it possible to carry out not only an interpretation of the radiation data, but also the first correct comparison of different interpretation techniques.

Figure 1 presents the results of interpretation by two methods: M. Shakhin' s method (dashed line) and regularization (points). The solid curve corresponds to radiosonde data. As can be seen, there is good overall agreement between the direct and indirect determinations of temperature. However, the errors in determining temperature from satellite data in a number of atmospheric cases are significant, reaching near the 100 mb level approximately 10° when interpreted by Shakhin's method and 8° by the regularization method. The root-mean-square deviations for both methods of interpretation are approximately the same and close to 3°.

Fig. 1. Vertical temperature profiles obtained from radiosonde data and from the spectrum of outgoing radiation recorded by an interference spectrometer on the Nimbus III satellite. *1* —radiosonde, *2* —by M. Shakhin' s method (^5), *3* —by the regularization method.

The relatively large errors in the indirect determination of temperature may be

Figure 1. Vertical temperature profiles obtained from radiosonde data and from the spectrum of outgoing radiation recorded by an interference spectrometer on the Nimbus III satellite. 1 —radiosonde, 2 —by M. Shakhin' s method (5), 3 —by the regularization method.

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explained by a number of causes: errors in the radiation measurements; errors in specifying the kernel of equation (1); errors arising in the numerical solution of the integral equation (approximation errors, rounding errors, etc.).

In our view, the principal sources of error are the first two. As numerical experiments (ˆ3) have shown, errors in specifying the kernel of equation (1) can have an especially large influence. With high measurement accuracy, they can substantially degrade the accuracy of restoring the temperature profile. This indicates that, despite the great progress made in investigating the transmission functions of the 15 μ CO_2 band, further efforts in this direction are needed, which may make it possible to improve the accuracy of the indirect determination of atmospheric temperature.

A single example comparing two interpretation techniques does not, of course, permit serious conclusions to be drawn about the advantages of one or another approach to solving the problem. It may only be noted that the regularization method made it possible to restore the profile more accurately

temperatures in the region above 100 mb and proved to be somewhat worse than Shakhin' s method in the pressure range from 100 to 500 mb. Finally, let us note that both interpretation methods use no statistical information about the temperature profile being sought.

In solving the problem by the regularization method, different numbers of spectral intervals in the short-wave branch of the CO_2 band were taken: 20, 15, 10, 7, and 6. As the results of the calculations show, with a reasonable choice of spectral intervals no significant difference is observed in reconstructing the temperature profile using different numbers of intervals, which indicates the limited volume of independent measurement data.

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