INTEGRATED MONITORING OF THE PHYSICAL STATE OF THE ATMOSPHERE BY STATIONARY GROUND–BASED MEANS

M.V. Kabanov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received July 1, 1992

A review is presented of the methods and problem–oriented programs of investigation of the Earth's atmosphere which are being accomplished at the Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (IAO SB RAS) in cooperation with the other Siberian institutes.

The Earth's atmosphere is a complex physical object whose state depends on many phenomena as well as on the interacting and acting factors and processes in the atmosphere. Multicomponent composition of the atmosphere and multiparameteric character of the atmospheric–physical processes and phenomena determine both extremely wide range of variations of real states of the Earth's atmosphere and high degree of spatiotemporal variability of these states.

The centuries–old investigations of the Earth's atmosphere have received especially remarkable progress in recent decades. There are significant achievements in the field of developing the set of principally new currently available methods of such investigations.[1] Of principal importance are the methodological foundations and the performance of closed atmospheric experiments like the Complete Radiation Experiment[2] and integrated investigations of aerosol.[3] Now, based precisely on these and other international achievements providing an advanced starting position, the scientists of the Institute of Atmospheric Optics are carrying out the investigations of the Earth's atmosphere in the form of integrated physical and numerical experiments and integrated expedition–field experiments and finally in the form of stationary integrated monitoring of the atmosphere.

The objective of this review is a brief description of integrated monitoring of the atmosphere mainly by the stationary ground–based means which is being performed at the Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences in cooperation with the other scientific research institutes. The base stations of stationary observations are the Tomsk Base Polygon (in Akademgorodok), Southern Polygon (located 25 km south of the town), and Western Polygon (50 km west of the town, on the river Ob').

The integrated monitoring of physical state of the atmosphere by the stationary ground–based means, which is being carried out now, includes the following problem–oriented programs:

1. Monitoring of ozone and of the components of ozone cycle.
2. Monitoring of atmospheric optically active aerosol.
3. Monitoring of the atmospheric radiation fluxes in the UV, visible, and IR wavelength ranges.
4. Monitoring of the atmospheric electromagnetism which covers the electromagnetic fields in the SHF, SW, MW, LW, and SLW ranges as well as the atmospheric electricity and the variations of the geomagnetic field.

All the problem–oriented programs classified in Fig. 1 by the objects of monitoring are formulated on the principle of closed experiment and, as a consequence, suggest the simultaneous monitoring of several components of the atmosphere.

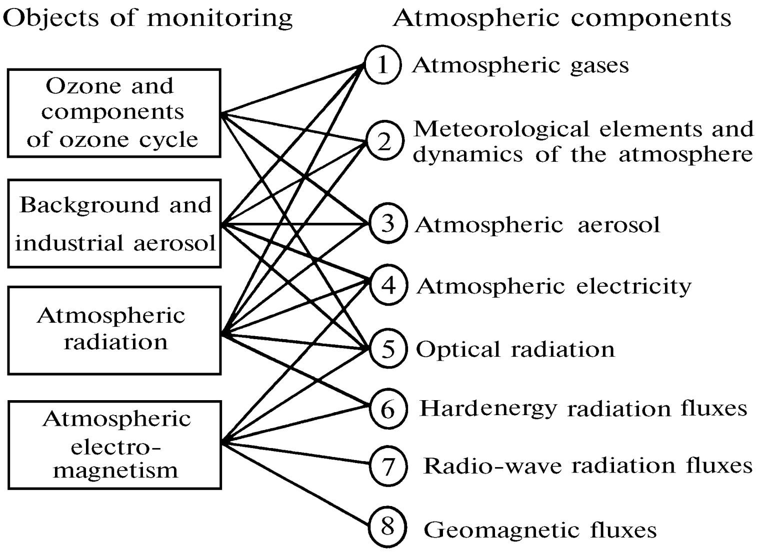
The problem–oriented program on atmospheric electromagnetism being implemented at the Siberian Physicotechnical Institute at the Tomsk State University in cooperation with the Institute of Atmospheric Optics can be regarded in some sense as an extension of the Atmospheric Radiation Program. But it also has its own continuation in the field of simultaneous monitoring of geophysical, biophysical, and medicobiological events. The presentation of the problem–oriented concept, methods, and results obtained as part of the program were the subject of individual publication.[4]

Implementation of the above problem–oriented programs requires to take into account the factors which are external with respect to the atmosphere and can be treated as the environmental components along with the atmospheric components indicated in Fig. 1.

The first group of these components is referred to as the factors of strong interaction and involves interactions of (1) atmosphere with ocean, (2) atmosphere with ground, and (3) atmosphere with near space.

The second group of the environmental components is referred to as the factors of strong impact and consists of: (1) cosmophysical impacts including solar–terrestrial coupling, (2) macrophysical impacts including meteor showers, volcanic and industrial emissions, explosions, dust storms, and so on, (3) direct and indirect geochemical and geobiophysical impacts, and (4) gravitational effects.

0235-6880/93/02 73-07 $02.00



⑨ Factors of strong interaction:

1. Interaction of the atmosphere with the ocean.
2. Interaction of the atmosphere with the ground.
3. Interaction of the atmosphere with the near space.

⑩ Factors of strong impact:

1. Cosmophysical impacts including solar-terrestrial.
2. Microphysical impacts including meteor showers, volcanic and industrial emissions, explosions, dust storms, and so on.
3. Direct and indirect geochemical and geobiophysical impacts.
4. Gravitational effects.

FIG. 1. Integrated monitoring of the physical state of the atmospheric with stationary means.

Problem–oriented program of investigations of ozone and ozone cycle, as can be seen from the special review on this subject, is being implemented at the IAO on the principle of a closed experiment. This implies that along with remote sensing of ozone, some other gas components of ozone cycle in the atmosphere are simultaneously measured and investigated as well as the other four atmospheric components indicated in the diagram shown in Fig. 1.

In this case the synchronous investigations of a number of associated components are of particular interest. Thus the field measurements of the optical radiation fluxes in the UV spectral range are of particular ecological importance especially in the region of the so–called biologically active ultraviolet radiation (290–330 nm). As is well known,[5] the radiation of shorter wavelengths has the harmful effect on living organisms, while the radiation of longer wavelengths is of great balneological value (for sunburn).

The relative contribution of these three regions of ultraviolet radiation on the whole is determined by the parameter which characterizes the conditions of ultraviolet safety for working people and the most favourable places and seasons for holiday–makers. This parameter is still of limited application in medicine and depends not only on the ozone but also on the aerosol contents in the atmosphere. The results of numerical modeling are plotted in Fig. 2 as a dependence of shortwave threshold of solar UV radiation at the Earth's surface on the aerosol models for weak (curve *1*, S_m = 50 km), moderate (curve *2*, S_m = 10 km), and strong (S_m =2 km, curve *3*) tropospheric turbidities. Roman figures near the curves refer to the different models of ozone content. As can be seen from the figure, the threshold position depends markedly on the aerosol content.

Problem–oriented program of investigations of atmospheric aerosol being implemented at the Institute of Atmospheric Optics is aimed ultimately at determining the optical properties of the atmosphere; therefore, this program deals first of all with the investigation of optically active aerosol. In so doing a large fraction of small particles, whose size is less than 10–100 nm, is excluded from the consideration. The program as a whole consists of three blocks complementing each other.

One of the program blocks consists of accumulating, processing, and generalizing of the complete global information about microphysical and optical characteristics of atmospheric aerosol and elaboration, on this basis, of a global optical model of the aerosol component of the atmosphere.[7] In this direction the third version of the model is currently being completed. At the same time the attempts are made to take into account the best–investigated dynamic processes in aerodisperse systems. As a result, each new modification of the statistical model more correctly takes into account the corresponding dynamic processes compared to its preceding version. This line of investigations is an important part of monitoring of atmospheric aerosol because, on the one hand, it provides the augment of the data bank with the results of direct observations of atmospheric aerosol under the field conditions, and on the other hand, it fills the probable gaps in our knowledge about the atmospheric aerosol as an interfering component in monitoring of the other atmospheric components.

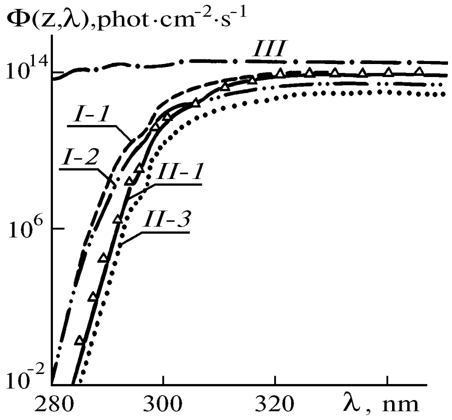


FIG. 2 Dependence of the position of shortwave threshold of solar radiation for ground–based observations. Φ(*z*, λ) *for two models of aerosol vertical profile (I and II) and* Φ (100 km, λ) *at the top of the atmosphere (III).*

The other block of the problem–oriented program on atmospheric aerosol consists of monitoring of stratospheric aerosol and stratified clouds. Monitoring is performed not only with the help of a lidar equipped with 2–m receiving mirror and located at the High–Altitude Sounding Station, but also with the help of a special so–called polarization lidar.

The latter is of special interest in investigation of aerosol since it is capable to obtain all the components of scattering matrix at altitudes up to 15–20 km. The lidar measurements were performed in the photon counting regime that implies 10–min averaging of the obtained results. In the last four years about 250 observations were made with the help of this lidar including about 100 complete cycles of measurements of all components of the backscattering matrix (for four polarization states of radiation of a transmitter).

The illustrative results of measurements with polarization lidar are shown in Fig. 3. In this figure one can see the experimental profiles of the Stokes parameters and of the lidar ratio $R = (\beta_{\text{paer}} + \beta_{\text{pmol}})/\beta_{\text{pmol}}$ borrowed from Ref. 8. Here β_{paer} and β_{pmol} are the backscattering coefficients (aerosol and molecular). Four parts of the figure correspond to four polarization states of radiation of the transmitter indicated by arrows (linear horizontal, linear vertical, linear at an angle of 45°, and circular polarizations). As can be seen from the figure, all the Stokes parameters characterize differently the scattering properties of an aerosol layer at an altitude of 7.5 km, but become insensitive to thinner layers at higher altitudes.

The complete cycle of measurements of the Stokes parameters shown in Fig. 3 allows the calculation of all components of the backscattering matrix. For the above–presented example of the layer at an altitude of 7.5 km the normalized backscattering matrix (the absolute values of its elements can be obtained by multiplying by β_{paer}) has the form

$$a_{ij} = \begin{pmatrix} 1 & -0.12 & -0.01 & 0.06 \\ -0.12 & 0.40 & -0.02 & 0.10 \\ 0.01 & 0.02 & -0.21 & -0.20 \\ 0.06 & 0.10 & -0.20 & -0.20 \end{pmatrix}.$$

Qualitative analysis of individual components and their relations, as well as their comparison with the results of calculations for various aerosol models show that the investigated aerosol layer at an altitude of 7.5 km consists of preferably oriented needle ice crystals.

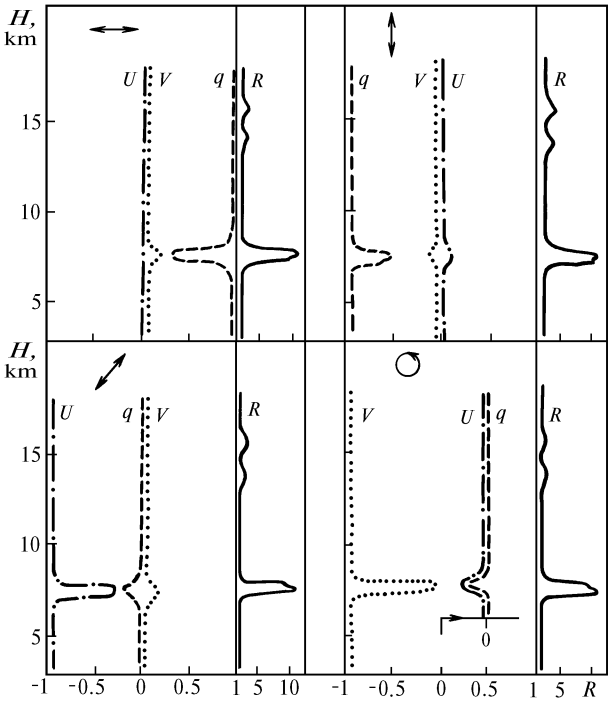


FIG. 3. Experimental vertical profiles of the lidar ratio R and the Stokes parameters borrowed from Ref. 8.

The third block of the problem–oriented program on atmospheric aerosol centers round the monitoring of tropospheric aerosol. In this context the objects of investigations are the natural and industrial aerosols, while the methods of investigation are expeditionary and stationary.

The expeditionary investigations of tropospheric aerosol as part of the problem–oriented program are aimed at required improvement of the available aerosol–optical models and are carried out in some typical geographical regions. Thus, long–standing expeditionary investigations were conducted with the help of spectrometric (in the wavelength range 0.4–13 μm) and nephelometric apparatus at the Karadag Station of the Main Geophysical Observatory (the Crimea). These measurements were accompanied by simultaneous meteorological observations and measurements of aerosol chemical composition.[9] As a result, a number of regional features in time variability of coastal aerosol and its optical properties were revealed including the influence of wind direction and humidity on transformation of the aerosol composition and on the relative contribution of continental and marine aerosols. Although some specific features were revealed, the same applicability limits were verified for a single–parameter model of reconstructing the spectral behavior of the extinction coefficients as those for the model elaborated at the Institute of Atmospheric Physics of the Russian Academy of Sciences based on the results of investigations at the Zvenigorod Station as well as a two–parameteric model for the region under investigation was elaborated.

Tropospheric aerosol was also investigated in the expeditionary regime in the Kazakhstan arid zone.

The measurements of the atmospheric thicknesses in the wide wavelength range (0.4–12 μm) have been carried out or planned to be carried out over the Atlantic ocean with a multichannel spectrophotometer,[10] although limited in number and with somewhat different purposes. These measurements provide the solution of an inverse problem and acquisition of the microphysical characteristics averaged over the altitude but mainly within the troposphere. Only in a few cases such measurements reveal the stratospheric aerosol. It was precisely so in the mission No. 43 in 1991, when enhanced turbidity (varying from the standard value of $\tau_{0.55}$ being equal to 0.06 to 0.10) was observed in the region of the Canary. We discussed this result with our american colleagues, compared it to satellite photographies, and finally arrived at a conclusion that it would be natural to explain such an enhanced turbidity by the Pinatubo eruption (Joint Seminar of the Working Group on Earth Sciences held in Baltimore, USA, in 1991).

The observations are currently being conducted in the stationary regime with the help of ground–based means, which are elaborated and commonly used in the expeditionary regime, at the Base Polygon in Tomsk.

To summarize the discussion of the problem–oriented program on atmospheric aerosol, it is necessary to underline on the whole the importance of simultaneous observations of the other atmospheric components provided in the program. In particular, as laboratory and some field experiments show,[11,12] in the investigation of both aerosol and atmospheric gas composition, for unambiguous interpretation of results it is necessary to record simultaneously the quasistatic electromagnetic fields. Their effect on the optical properties of certain gases and aerosol fractions appears to be so pronounced that the methods of their remote diagnostics have been developed based on the corresponding dependences.

The problem–oriented program on atmospheric radiation being implemented at the IAO SB RAS is aimed at the solution of three problems. The first classic problem is associated with the radiation regime of the atmosphere. The matter is that up till now one of the principal disadvantages of the available climate models is the wide scatter of data when taking account of radiation regime with the use of various parametrization schemes even for the cloudless atmosphere. The scatter becomes still wider under conditions of cloudy atmosphere. In both cases further improvement of radiation blocks of climate models would be impossible without complex field measurements on the principle of a closed experiment. It was this principle that we have used in monitoring of the atmospheric radiation when solving the problems of allowance for the radiation regime in the modern climate models.

The problem of adequate account of extremely high degree of spatiotemporal variability of radiation fields still remains important and is far from being solved completely. All available parametrization schemes of radiation regime disregard almost completely the stochastic structure of radiation fields modulated by the cloud fields with random geometry (i.e., by broken clouds), wavy water surface covered with foam, mountains (being random in their altitudes, orientation of normals to the surface, and surface albedo), and so forth. As an illustration of the essence of the problem, we consider the radiation fields under conditions of broken cloudiness.

We describe the net budget of outgoing and incoming radiation fluxes in broken cloudiness in terms of the so–called climate sensitivity parameter

$$\delta = -\frac{S_0}{4}\frac{\partial A}{\partial N} - \frac{\partial F}{\partial N},$$

where S_0 is the solar constant, A is the albedo at the top of the atmosphere, F is the flux of outgoing IR radiation, and N is the cloud cover index. In calculations it is commonly assumed that the quantities A and F depend linearly on N and, in particular, that $A = A_s(1 - N) + A_c N$, where A_s and A_c are the albedos of cloudless and cloudy atmosphere, respectively. However, the investigations show[13] that in reality this dependence appears to be strongly nonlinear. As an example, the dependences of the climate sensitivity parameter δ on the cloud cover index are shown in Fig. 4 for two cloud types (dashed lines are for *St* and solid lines are for *Cu*). It is evident from the figure that only for stratus clouds this dependence is close to linear. This result is of principal significance for estimates of the regional climate changes especially from the viewpoint of increasing possibilities of parametrization in the modeling schemes developed to date.

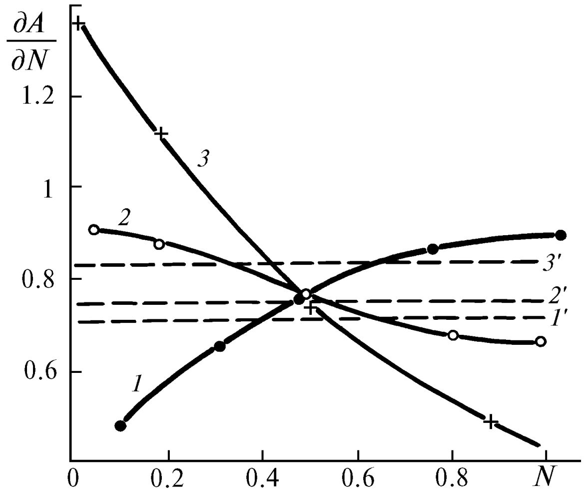


FIG. 4. Dependence of ∂A/∂N on the cloud cover index N (with cloud size of 0.25 km, *thickness of* 0.5 km, *and extinction coefficient of* 60 km^{-1}*) for different solar zenith angles:* $\xi = 0°$ (*curves 1 and 1'*); 30° (*2 and 2'*), *and* 60° (*3 and 3'*).

The next problem being the part of the problem–oriented program on atmospheric radiation is associated with local bursts of increased intensity. This is the common problem for the entire spectrum of electromagnetic waves. In the optical wavelength range it is generally referred to as optical phenomena in the atmosphere. In recent decades monitoring of such phenomena is no longer a purely pragmatic problem but takes again one global meaning. In this context it will be sufficient to recall about the increasing number of eye–witnesses of the UFO's. From this viewpoint the investigations of other optical phenomena percepted not so emotionally remain an urgent problem today.

Finally, it should be specially noted a great ecological and technological significance of investigations in individual spectral regions of optical radiation such as ultraviolet, whose significance has already been mentioned above, photosynthetically active radiation, whose investigations are referred to as photoactinometry, photographic, thermal, and other radiations whose names themselves reflect the direction of their technological applications. The practical significance of such applications is comparable to that of individual radio wavelength ranges. Together with investigations of quasistatic electromagnetic fields they make up the problem–oriented basis for monitoring of atmospheric electromagnetism.

All the three above–discussed problem–oriented investigation programs implemented in the monitoring regime make up the content of the integrated monitoring of physical state of the atmosphere.

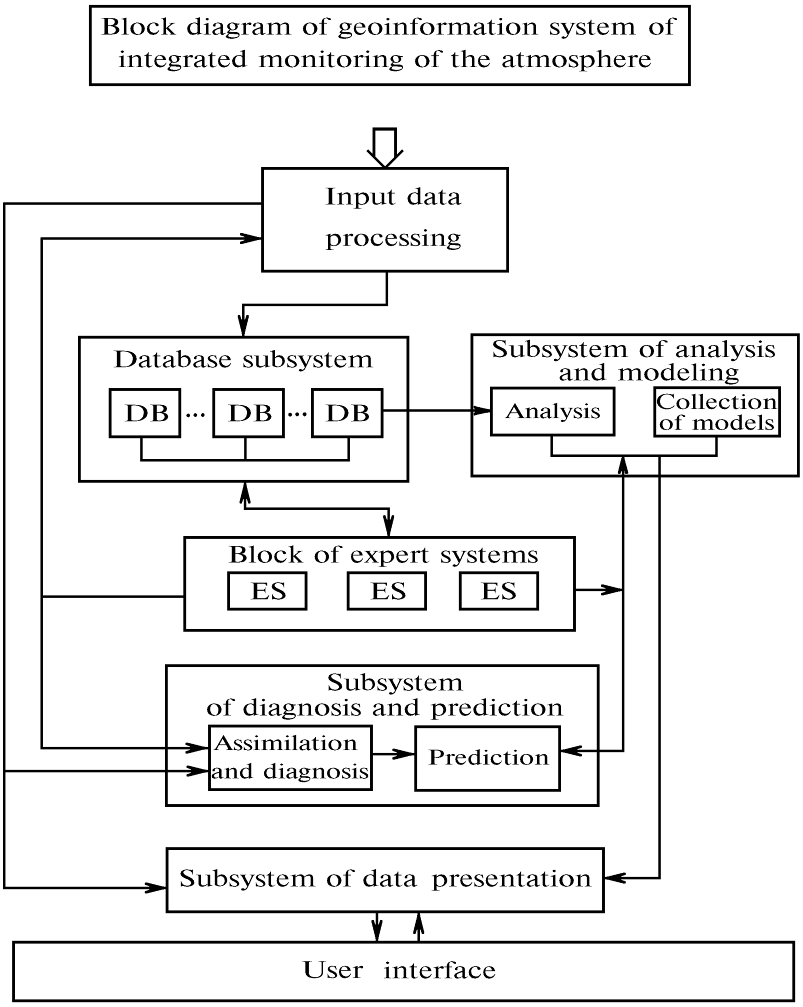


FIG. 5.

This integrated monitoring needs to be supplied by effective information technology. In this connection the so–called geoinformation system seems to be attractive for use. As to the problems of atmospheric physics, on the basis of the data bank created at the IAO SB RAS for the parameters of various atmospheric components, now we are simultaneously forming the corresponding geoinformation system[14] shown in Fig. 5. Development of this versatile system applicable to various sciences of the Department of Oceanology, Atmospheric Physics, and Geography plays uniting role both from ecological and climatological viewpoints, while the system itself fits naturally in one form or another into the scientific–technical program on Global Changes of Environment and Climate.

REFERENCES

1. V.E. Zuev and V.V. Zuev, *Current Problems of Atmospheric Optics: Remote Optical Sounding of the Atmosphere* (Gidrometeoizdat, Leningrad, 1991), Vol. 8, 232 pp.
2. K.Ya. Kondratiev, *Radiation Factors of Present Day Global Climate Changes* (Gidrometeoizdat, Leningrad, 1980), 279 pp.
3. G.V. Rozenberg, G.I. Gorchakov, Yu.S. Georgievskii, and Yu.S. Lyubovtseva, in: *Atmospheric Physics and Problems of Climate* (Nauka, Moscow, 1980), pp. 216–257.
4. V.A. Donchenko, M.V. Kabanov, and A.G. Kolesnik, Izv. Vyssh. Uchebn. Zaved., Fiz., No. 12, 69–79 (1991).

5. V.A. Belinskii, M.P. Garadzha, L.M. Mezhennaya, and V.I. Nezval', *Solar and Sky Ultraviolet Radiation* (Moscow State University Publishing House, Moscow, 1968), 228 pp.

6. G.F. Banakh, I.I. Ippolitov, and T.A. Lopasova, Kosm. Issled. **24**, No. 6, 890–895 (1986).

7. V.E. Zuev and G.M. Krekov, *Current Problems of Atmospheric Optics: Optical Models of the Atmosphere* (Gidrometeoizdat, Leningrad, 1986), Vol. 2, 256 pp.

8. B.V. Kaul, A.L. Kuznetsov, and E.R. Polovtseva, in: *Abstracts of Reports at the Sixteenth* International Laser Radar Conference, Cambridge, USA, 1992.

9. M.V. Kabanov, M.V. Panchenko, Yu.A. Pkhalagov, et al., *Optical Properties of Coastal Atmospheric Hazes* (Nauka, Novosibirsk, 1988), 201 pp.

10. S.M. Sakerin, S.V. Afonin, T.A. Eremina, A.M. Ignatov, and D.M. Kabanov, Atm. Opt. **4**, No. 7, 695–705 (1991).

11. V.E. Zuev, Yu.S. Makushkin, and Yu.N. Ponomarev, *Current Problems of Atmospheric Optics: Spectroscopy of the Atmosphere* (Gidrometeoizdat, Leningrad, 1987), Vol. 3, 247 pp.

12. V.E. Zuev and M.V. Kabanov, *Current Problems of Atmospheric Optics: Optics of Atmospheric Aerosol* (Gidrometeoizdat, Leningrad, 1987), Vol. 4, 254 pp.

13. G.A. Titov, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **23**, No. 8, 851–858 (1987).

14. A.V. Koshkarev and V.P. Karakin, *Regional Geoinformation Systems* (Nauka, Moscow, 1988), 126 pp.