AIRCRAFT-LABORATORY OF THE IAO SB RAS IN THE STUDY OF THE LAKE BAYKAL ENVIRONMENT

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A review of investigations performed by researchers of the Institute of Atmospheric Optics of the SB RAS in the region of Lake Baykal is given, Starting from the formulated problem, the emphasis is on an analysis of the aircraft-laboratory application to salvaging of the Baykal environment. It is demonstrated that the aircraft-laboratory, capable of investigating the atmosphere on a regional scale, is the most important means for pursuance of integrated experiments, because its potentialities are adequate to scales of the examined phenomena that should be well understood to study correctly the ecological problems.

INTRODUCTION

Injurious effects of man's economic activity on the environment can be minimized only based on a careful comprehensive study of the entire set of variable natural factors and anthropogenic effects as well as on justified prediction of their possible consequences. It is clear that to solve this problem, we should have a developed network for monitoring of the main climatic and ecological parameters. It is also clear that implementation of this program is still a good distance in the future because of the economic situation in our country. Hence, it follows that at present we should concentrate our efforts and available material and intellectual resources on the most important and interesting object (on a regional scale for geophysics) to develop a scientific approach to a solution of these problems and to provide practical recommendations for the pursuance of measurements and analysis of the obtained data.

CHOICE OF THE REGION OF INVESTIGATION

Among the most valuable natural complexes of Siberia, Baykal occupies its right special place and the problem of salvaging its environment goes far beyond pure regional problems and is important on a global scale.

The international science community was correct in assuming that Lake Baykal is a natural laboratory for comprehensive investigations on the GLOBAL CHANGE program.[1] Actually, the Baykal region has different relief unique lake, and vast territories unchanged by human activity and covered with rich vegetation. Large industrial plants that emit practically all pollutants into the atmosphere are also concentrated here. The regional climate is also unique here because, of the interaction between the global atmospheric circulation above Western Siberia and the air circulation of the Baykal basin.[2] Moreover, Lake Baykal is vulnerable to anthropogenic effect, because it has a large catchment area (about 570 000 km, see Ref.2) and hence all the pollutants emitted in the region or transferred by transboundary air flows and precipitated on the underground surface or accumulated by vegetation may then penetrate the lake water through precipitation, show melting, or forest fires. This means that a large part of pollutants penetrates the lake water through the atmospheric channel.

These circumstances provided a basis for design of our geophysical experiments with the aircraft-laboratory.[3]

We were guided by the reasoning that investigations of the phenomena on regional scale call for either multipoint measurements or mobile means capable of surveying vast territories in a limited time.

APPLICATION OF THE AIRCRAFT-LABORATORY

Considering that transfer and transformation of gases and aerosol particles cannot be understood without knowledge of their spatiotemporal variability (their vertical variability becomes highly important for stationary air masses), we chose the aircraft as a main means of placement of our measurement instrumentation.

It should be noted that researches of the Institute of Limnology of the SB RAS carry out multipurpose investigations of practically all significant ecological parameters perform regular measurements in the atmospheric layer adjacent to the water surface in the entire area of Lake Baykal, and develop regular ground- based aerosol monitoring network.[4] Researchers of the Institute of Solar-

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Terrestrial Physics receive and process satellite data. These circumstances increase many times our possibilities for successful interpretation of the results of integrated experiments and for making practical recommendations.

EXPERIMENTAL INVESTIGATIONS

We carried out a number of flight missions over Lake Baykal and adjacent territories in 1991, 1995 and 1996 to evaluate the quality of the atmospheric air and pollutant transport in the Baykal region (in some of flight missions we charted the water turbidity in addition to measurements of the atmospheric parameters).

The experiments were performed using the Optic-E AN-30 aircraft-laboratory. Its instrumentation and a set of measurable parameters were described in detail in Ref.5.

The integrated study of the state of the air basin above Lake Baykal and adjacent territories was performed by the researchers of the Institute of Atmospheric Optics in cooperation with the researches from the Industrial Geophysical Amalgamation (IGA) Buryat Geology in September 1991. This study was initiated by the IGA Buryat Geology and was aimed at investigation of the pollutant distribution above the Baykal region and evaluation of possible ways of water pollution through the atmospheric channel. Here, we dwell only on the main points, because the data of this experiment have already been discussed in Ref. 6 in detail.

In 1991, we investigated about 250, 000 km^2 of the territory. Flight routes were chosen so that to intersect the prevailing direction (west-eastern) of air transfer and to pass over Lake Baykal and large rivers (Selenga, Dzhida, Uda, and Barguzin). The flight routes were spaced at 90–180 km. They were subdivided into sections 120–150 km in lengths determined by the time of aerosol and gas sampling. We flew at altitudes 400 and 900 m above the local relief including the lake and river basins. We took off and landed in Irkutsk and Ulan-Ude airports.

Based on these measurements, 50 charts were compiled in the IGA Buryat Geology for each altitude comprising the data on one gas or element of aerosol composition.

Figure 1 illustrates the integrated index of gaseous pollution[6] in the Baykal region measured for altitudes 400–600 m above the water surface. To calculate this parameter, we considered the following gases: NH_3, NO, NO_2, SO_2, O_3, CO, CO_2, Cl_2, acetone, acetylene, benzine, benzene, xylene, and toluene.

It is seen from the figure that gaseous pollutants enter the lake basin from the Irkutsk industrial zone through the southern part of the lake without ridges and then spread over the entire territory moving along the eastern shore of Lake Baykal.

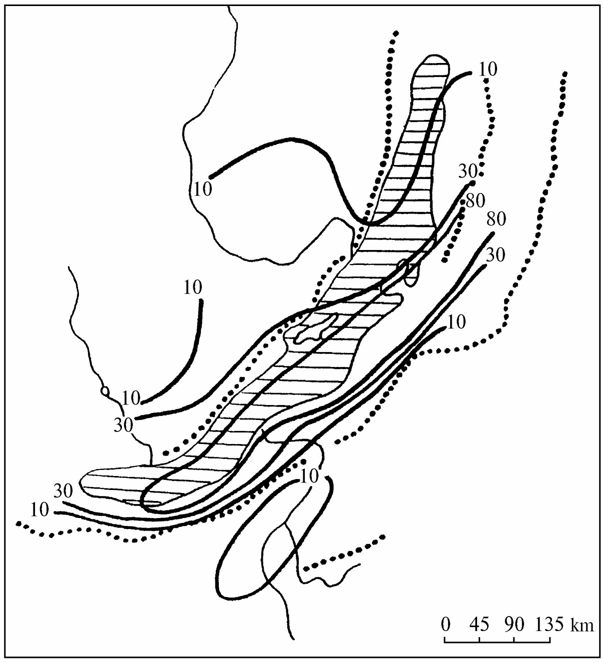

FIG. 1. Integrated index of gaseous atmospheric pollution at altitudes 400–600 m.

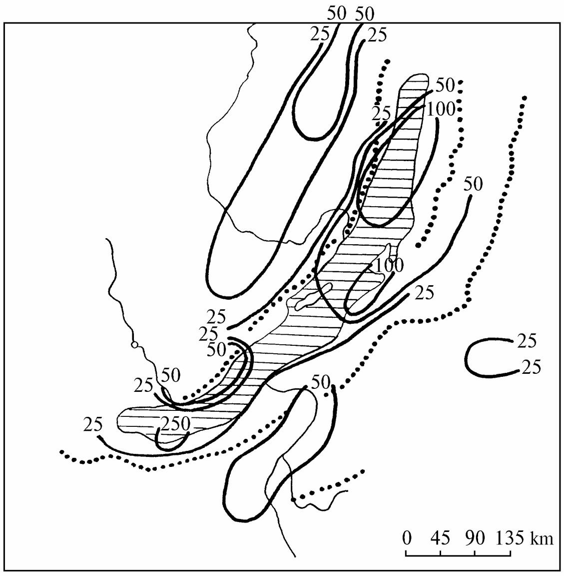

FIG. 2. Integrated index of air pollution by toxic elements at altitudes 400–600 m.

Figure 2 shows the integrated index of atmospheric pollution with toxic elements and ions F^-, Cl^-, Br^-, Hg^{2+}, As^{5+}, Zn^{2+}, Cd^{2+}, Fe, Mn, Mg, Pb, Cr, Sn, Ni, Al, Ti, Cu, V, Mo, Co, Ca, Si, Ba, Be, B and Sb. It is seen from the figure that the aerosol distribution above the lake and nearby is less uniform than the gaseous distribution.

High values of the integrated index of atmospheric pollution above northern regions of the lake (Fig. 2) without sources of anthropogenic aerosol can be explained only by local air circulation around the lake basin.[7]

Hence it follows that the pollutants that enter the Baykal basin due to west–eastern transfer from the Irkutsk industrial zone take part in the local air circulation and spread over the entire basin. In addition, the air circulation along the eastern shore of the lake contributes to the pollution of valleys of rivers flowing into the lake in its eastern part, as demonstrated by enhanced indices of pollution in Barguzin and Selenga valleys. This was visually observed in flights.

It should be noted that during our experiment the air was predominantly transferred from the Irkutsk industrial zone. However, pollutants may enter from Buryat and Chita regions for other types of atmospheric circulation.

In 1995, investigations of the Baykal region were continued. In the two flights, the aircraft flew on the perimeter of the lake above the water near the shore. The first flight was at an altitude of 400 m. The second flight was at a variable altitude that roughly followed the local relief. The third flight was almost completely devoted to investigations of the Baykal Pulp and Paper Integrated Plant (BPPIP). In this experiment, we succeeded in charting of the aerosol distribution profiles from the flight altitude to the water surface on the perimeter of the lake from the data of simultaneous measurements with a nephelometer and an airborne lidar.[8] A fragment of spatial distribution of the scattering coefficient (in case of submicron particles, it is proportional to their specific volume[9]) is displayed in Fig. 3 for the eastern shore of the lake.

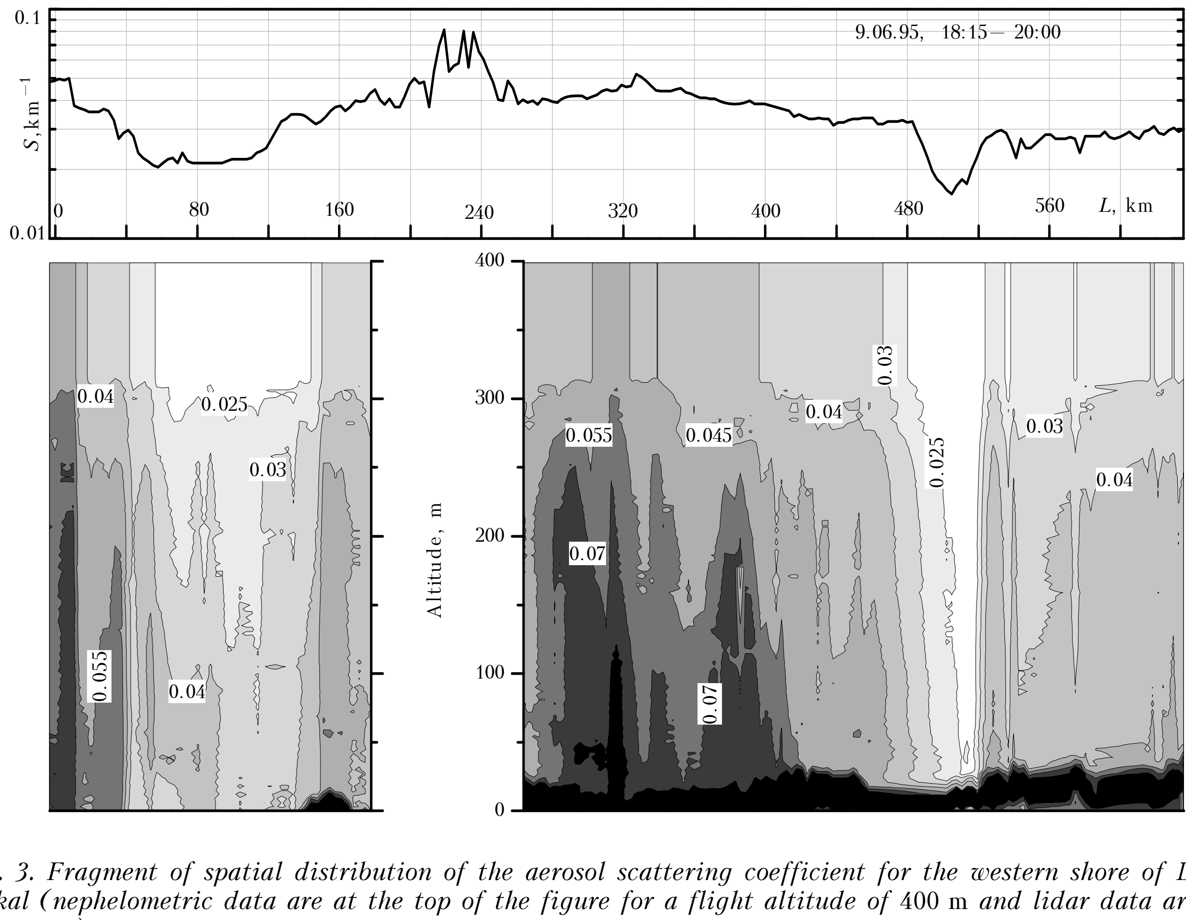

FIG. 3. Fragment of spatial distribution of the aerosol scattering coefficient for the western shore of Lake Baykal (nephelometric data are at the top of the figure for a flight altitude of 400 m *and lidar data are at the bottom).*

It is seen from the data presented here that, on the whole, the atmosphere above Lake Baykal was weakly turbid by aerosol particles (at all altitudes the aerosol scattering coefficient was only several times greater than the clear–air molecular scattering coefficient). However, the complex character of the spatial distribution of aerosol content testifies once again to the necessity of application of highly mobile means to carry out investigations aimed at the estimation of the environmental quality.

From this it follows that large variations of the content of various elements also should be expected in samples collected in the flight route subdivided into 12 sections each about 100 km long. In the course of the experiment, more than 300 samples were collected for subsequent chemical analysis. It is a bit premature to speak about a complete pattern of distribution of the chemical elements, because we have addressed ourselves to our colleagues from different scientific centers of Tomsk, Irkutsk, Novosibirsk, U.S.A., and Belgium to compare their data obtained by various methods. By now only researchers of the Tomsk Polytechnic University[10] have already completed their analysis, while other groups are still processing their filters. Therefore, here we dwell only on some points that are noteworthy.

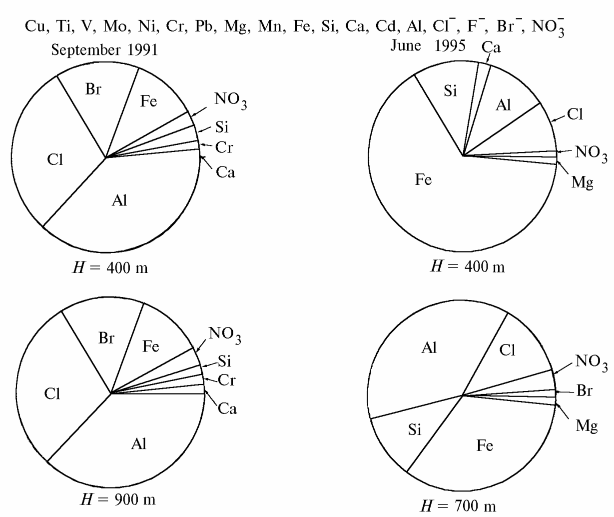

FIG. 4. Relative content of indicated elements and ions in aerosol samples collected on the Baykal perimeter.

Circular diagrams of the relative content of some elements and ions are drawn in Fig. 4 for all samples collected on the perimeter of the lake in flights at two altitudes performed in 1991 and 1995. In these diagrams, we considered only the elements and ions whose relative content exceeded 1%. As seen from this figure, the elements of possible soil origin (Fe, Si, Al, Ca) that also can be emitted into the atmosphere by heat–and–power stations, have contributed noticeably to the examined aerosol. It should be noted that the observed relation of the relative content of Fe to that of Si is indicative of predominating contribution from emissions of the heat–and–power stations. The noticeable number of the NO_3 ions is indicative of anthropogenic sources that emit into the atmosphere vapors of aerosol–forming compounds. At present, when the data from scientific centers have yet to be obtained, we cannot explain the high content of Al. However, it should be noted that in 1991 and 1995 we recorded the maximum content of this element at all altitudes in the northern part of the eastern shore of Lake Baykal that hardly could be attributed to errors in chemical analysis or careless sampling. Experts were doubtful of the noticeable content of chlorine in all samples collected by us in 1991. These results were then confirmed in 1995, when the chlorine content was determined independently by researchers of the Tomsk Polytechnic University and of the Institute of Limnology of the SB RAS.

As noted above, the aircraft-laboratory is capable of measuring not only the atmospheric parameters, but also characteristics of the underlying surface. In particular, charts of water transparency were compiled using the airborne lidar data obtained in 1991 and 1996. An example of spatial distribution of the water transparency defined as a depth of visibility of a standard Secchi disc is displayed in Fig. 5. This chart was compiled from the data of airborne lidar sensing on 21–22 September 1991. The flight was at an altitude of 300 m on the lake perimeter at distances 1–5 km from the shore line. Laser pulses were emitted with a frequency of 1 Hz, which ensured the spatial resolution along the flight route approximately 80–100 m given that the flight velocity was about 300 km/hr. The depth resolution of backscattered laser radiation coming from underwater was 1.1 m.

The water extinction coefficient ε was calculated from lidar return signals coming from subsurface water layers (from depths 3–25 m) by the logarithmic derivative method

$$\varepsilon = \frac{n}{2(z_2 - z_1)} \ln \left(\frac{F_1(z_1)\,(H + z_1/n)^2}{F_2(z_2)\,(H + z_2/n)^2} \right), \qquad (1)$$

where z_1 and z_2 are the depths of counting, n is the refractive index of water, $F_1(z_1)$ and $F_2(z_2)$ are the signal amplitudes from these depths, and H is the flight altitude above the water surface.

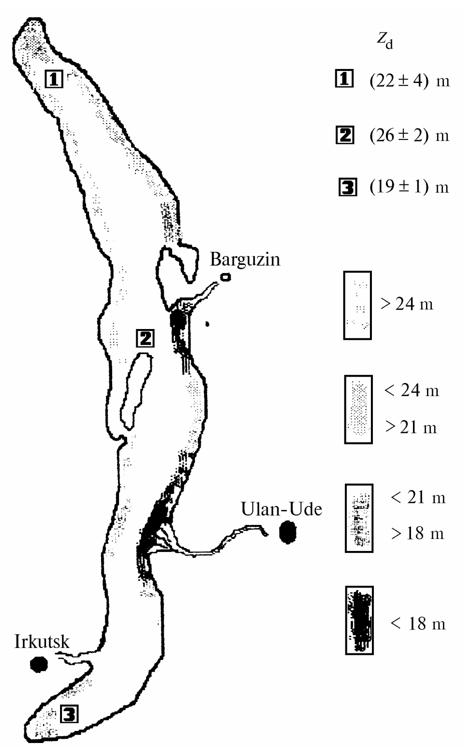

FIG. 5. Chart of water transparency (in units of visibility depth of the Secchi disc).

Then the water transparency was determined from the empirical relation[11] $z_d = 3.35/\varepsilon$, defined as a depth of visibility z_d of the Secchi disc. This parameter is measured regularly since 1990. Then the values of the water transparency so obtained were averaged over sections of the flight route 12 km long and plotted on the chart as gradients. Squares in Fig. 5 indicate the square reference sites 20x20 km, around which the aircraft flew many times.

It is quite natural that we flew around plumes of emissions from the Baykal Pulp and Paper Integrated Plant and took air samples directly at the centers of plumes and on their periphery when we performed investigations in the Baykal region. We succeeded in monitoring the spread of pollutants from mouths of stacks to distances at which the air pollution took its background value as long as several tens of kilometers in the horizontal direction and several hundreds of meters in the vertical direction with the help of the lidar. Undoubtedly, the obtained results will be useful for approbation and testing of models that describe transport of pollutants from the BPPIP and for evaluation of its negative environmental effects; however, in this paper we restrict ourselves to Fig. 6 that illustrates the panorama of plumes of pollutants restored from images taken by a TV camera from on board the aircraft (computer restoration of the panorama was performed by V.P. Galileiskii and A.M. Morosov, researchers of the IAO SB RAS).

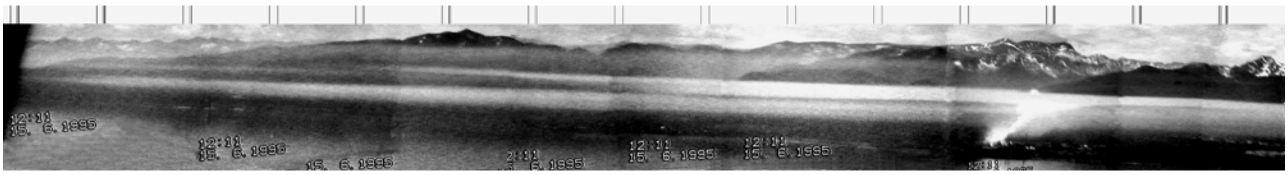

FIG. 6. Panorama of emissions from the BPPIP.

Showing this panorama, we do not pretend to debate the expediency of location of this plant on the Lake Baykal shore. However, we cannot disagree with the very convincing statement of M.A. Grachev, Corresponding Member of the RAS, Director of the Institute of Limnology made at the session of the Commission on Baykal Problems at the Presidium of the SB RAS: "Even starting from conventional humanistic (aesthetic) considerations, Baykal and enterprises on its shore are incompatible."

In this case, we show this panorama to confirm visually the occurrence of complex air circulation resulting in the pollutant transport along the shore line. It can be also seen from this TV image that the temperature inversion blocks the penetration of pollutants into higher atmospheric layers and in combination with breeze circulation contributes to sedimentation of pollutants on nearby surface areas and hence increases the probability of their penetration into waters of Lake Baykal.

Showing this fragment of the TV image, we would like to call attention to a methodological aspect. Most problems centered on charting of distribution of various pollutants in the atmospheric air call for detailed spatial resolution when taking air samples or for application of remote means of sensing of the sought–after characteristic. In both cases, a huge volume of data should be collected and processed to reconstruct the 3–D distribution of the pollutant.

In the design of field experiments of different kind the problem of optimal integration of available methods and hardware is most important. It is especially important to form a complex in a right way and to adjust the spatial and temporal sampling rates when using such expensive means as the aircraft-laboratory. Our experience in investigation of large–scale processes that can be observed visually (for example, plumes of industrial enterprises and so on) suggests that TV imaging can be recommended not only as an auxiliary method, but also as an important means of the mobile complex. In particular, TV images in combination with lidar and nephelometric data have allowed us to estimate the total aerosol content in the emissions from the BPPIP for some specific sensing periods.[12]

CONCLUSION

We believe that the examples given above provide strong evidence that the aircraft-laboratory capable of atmospheric investigations on a regional scale is the most important means in the design of integrated experiments, because its capabilities are adequate for scales of the phenomena that should be understood to study correctly the ecological problem.

On behalf of the staff of the aircraft-laboratory, we would like to acknowledge authoritative science foundations (ISF and RFFR) and the Presidium of the SB RAS for financial support of these investigations (Grant NY 2000 (1995) of the International Science Foundation, Grant NY 2300 "Airborne Investigations of Effects of Anthropogenic Sources and Forest Fires on Climatic and Ecological State of the Region of Lake Baykal" of the International Science Foundation and Government of Russian Federation, Grant 95-05-16562 (1995) of the Russian Foundation for Fundamental Research, and Expedition Grant "Airborne Sensing of the Atmosphere" of the SB RAS).

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