A SODAR "ZVUK–1". NEW APPROACH TO THE DEVELOPMENT

V.A. Gladkikh, V.I. Karpov, N.P. Krasnenko, B.N. Molchanov, and M.G. Fursov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
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The generalized user's requirements to the sodar design are formulated based on the experience of using sodars. A brief description of a commercial version of the sodar developed at the Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences and its software are presented. Possibilities of processing of the obtained data are demonstrated. Sodar "ZVUK–1" is capable of monitoring temperature stratification of the boundary atmospheric layer up to the altitude of 500 m, measuring the structure constant of the temperature field and the mixing layer thickness. It is also capable of estimating the validity of the obtained results according to the signal–to–noise ratio.

Almost all meteorological sodars, which have been produced in our country so far, were used to study the atmospheric processes only by their direct developers or with their participation. The introduction of sodars into the weather service was, among many reasons, restrained by the circumstance that the use of sodar data requires certain skill in their practical application but acquiring such an experience by meteorologists was, in its turn, restrained by the absence of the necessary number of sodars as well as by complexity and poor reliability of sodars available that made them to be of low practical use. The experience of using sodars at the Laboratory of Atmospheric Acoustics, Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences makes it possible to show all disadvantages of such systems from the point of view of their practical use and to develop the concept of designing a commercial version of the sodar. The main ideas of this concept can be formulated as follows:

1. A sodar must have small overall dimensions without any losses in its specifications.
2. A sodar should be interference–free, so that a user must not bother where to install it. In other words, limitations on the place of operation should be minimal.
3. Data obtained with a sodar must be clear and easy applicable to practical meteorology. At the same time all information that the acoustic signal scattered by the atmosphere bears should be stored.
4. A sodar must provide reliable data under any conditions or to have a reliable indicator of the validity of the data acquired.
5. A sodar automation must provide its operation without an operator. Its service should include a minimum number of operations such as: switching on, switching off, and recording the measurement results.

Just these requirements were kept in mind when we started the development of a new sodar "ZVUK–1" intended for monitoring of the temperature stratification of the atmospheric boundary layer. Three most important aspects of this work were concerned with development of a new acoustic antenna, sodar hardware, and software for a computer servicing the sodar.

The antenna is the most important part of a sodar. The efficiency of the sodar and its final energy potential are entirely determined by the design, dimensions, and materials used to make up an antenna.

The following limitations were imposed on the antenna construction: the width of the main lobe of the directional pattern at half–maximum of the power must be within the 15... 20°, the side–lobes level must be less than – 40 dB in the direction perpendicular to the acoustic axis and less than – 35 dB at an angle of 70° from the acoustic axis. A specular type antenna with a parabolic reflector supplied with a shielding blend in the form of a frustum of a cone was selected as the basic version of the antenna construction. The directional pattern of such an antenna (in the far field) is described by a modified Kirchhoff diffraction integral[1,2]

$$P(\theta) = \pi(1 + \cos\theta) \int\limits_0^{R_{s\max}} A(R_s)\, e^{j\varphi(R_s)}\, J_0(kR_s\sin\theta)\, R_s\, dR_s .$$

Here θ is the angle counted from the acoustic axis, $A(R_s)e^{j\varphi(R_s)}$ is the amplitude–phase distribution of the acoustic pressure over the upper aperture of the shielding blend, R_s is the current radius of the upper aperture, k is the wave number, J_0 is the Bessel function of zeroth order. The distribution of the pressure over the upper aperture is described as follows:

$$A(R_s)\, e^{j\varphi}(R_s) = \int\limits_0^{2\pi} \int\limits_0^{R_{\max}} A(R)\, e^{j\varphi(R)}\, e^{jk(D-H)} \gamma(D)\, R dR d\Phi ,$$

where R is the current radius of the aperture of the paraboloid, H is the height of the shielding blend, Φ is the angle in the plane of the paraboloid aperture $D = \sqrt{R^2(\sin\Phi)^2 + (R_s - R\cos\Phi)^2 + H^2}$, and $\gamma(D) = (1 - H/D)/2D$.

The function $A(R)e^{j\varphi(R)}$ describes the amplitude–phase distribution of the acoustic pressure over the paraboloid aperture. It can be shown that if an exponential horn with the diameter of the aperture exceeding the critical one for the given wavelength (the reactive component of the radiated wave can be neglected) is used as an exciter of the paraboloid then the distribution of the acoustic pressure over the aperture of the paraboloid can be described by the expression:

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$$A(R)\ e^{j\varphi(R)} = \frac{3F^2(4F^2 - R^2)}{(4F^2 + R^2)^2 - 0.25(4F^2 - R^2)^2},$$

where F is the focal length of the paraboloid. Geometrical dimensions of the parabolic mirror were calculated using a graphic method of determining the concentration coefficient with an account of necessary width of the main lobe of the directional pattern[3] and using the formulas relating the paraboloid gain to its geometrical dimensions.[4] The horn exciter of the paraboloid was calculated according to the technique presented in Ref. 5. The geometrical dimensions of the shielding blend were calculated using the obtained geometrical dimensions as the initial ones and the above–mentioned modified Kirchhoff integral. The influence of deviations in dimensions from the optimum ones on the shape of the directional pattern of the antenna was estimated. It was shown that the error in the choice of the geometrical dimensions of some centimeters leads to an increase of the perpendicular side–lobe level of the pattern by a factor of 10 and more, and the change in the blend angular aperture by 3 ... 5° leads to the angular shift of the side lobes and to broadening of the main lobe. The directional patterns of the developed antenna which were measured at different stages of antenna manufacturing are shown in Fig. 1. For the finished antenna the perpendicular side–lobe level was – 52 dB and at the angle 70° with respect to the horizontal direction it was – 47 dB that was essentially greater than the initial parameters used in calculations. The produced antenna is rather compact, its height only slightly exceeds 1.5 m and its weight is about 70 kg. The paraboloid of the antenna is equipped with a thermostat that makes the locator be capable of operating under winter conditions. No cleaning of the paraboloid from precipitations is required.

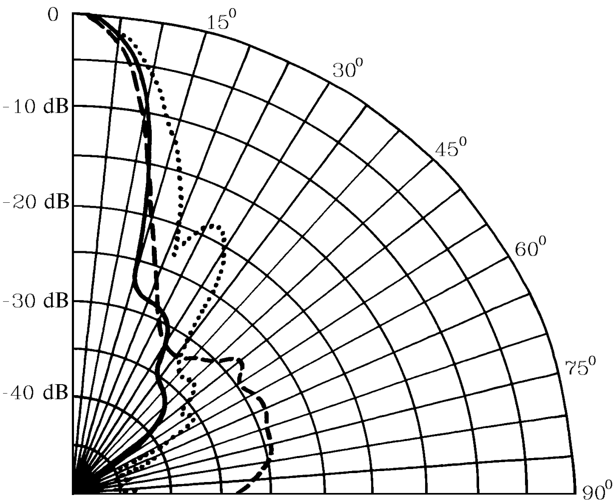

FIG. 1. The directional patterns of the ZVUK–1 sodar antenna at different stages of its manufacturing: the directional pattern of the paraboloid (dashed line), the directional pattern of the antenna with the shielding blend without a layer absorbing sound (dotted line), and the directional pattern of the finished antenna (solid line).

Hardware of the sodar electronics is designed in the form of a desk device. Block diagram of the receiving–transmitting channel is rather conventional. The peculiarity of this sodar is in a careful design of all parts of the instrument aimed at providing easy servicing of the sodar, its reliability, low cost at improved performance chararcteristics. The receiving–transmitting channel of the sodar can operate with IBM PC/AT as well as without it. In the latter case the reflected signal is recorded by a compact electro–spark echograph developed especially for sodars and the echogramms are recorded on the TB–2 thermopaper.

The transmitter of this sodar emits into the atmosphere a trapezoidal–shaped pulse with a sinusoidal filling in. Such a shape of the pulse, compared to a rectangular one, provides narrower radiation spectrum and considerably increases the lifetime of the electro–acoustic converter of the antenna. If necessary the receiving–transmitting channel can operate in the adaptive mode, and in this case the transmission coefficient of the receiving channel is adapted to the level of the ambient noise and the average level of signal at the receiver output is maintained at a constant level. Most frequently this mode of operation is employed in a combination with the electro–spark recorder of the echograms.

Especially for the sodar "ZVUK–1" we have created a software package that provides operation of the whole device under the control of IBM PC/AT. The software includes the programs intended for solving the following problems:

1. The FAX_WRIT.EXE program is capable of displaying a facsimile recording of the signal reflected by the atmosphere and the profile of the received signal amplitude. Displayed data are stored on a hard disk in the form of a file, in addition, the image of the facsimile recording is also stored in the same file as graphic information, the amplitude of the signal received from every pulse in the form of integer numbers, and the time of a pulse sending into the atmosphere accurately to a second are simultaneously stored in the file. The use of the program is convenient due to the window structure of the presented graphic information.

2. The PRF_WRIT.EXE program includes all the possibilities of the previous program. The difference is that this program creates an additional file in which the altitude profiles of the received signal amplitude having a fourfold greater altitude resolution are stored (compared to the resolution of the graphic data). The size of the recorded files depend on the number of reserved profiles of signals and are equal to 132 bytes per profile for the graphic–numerical files and 264 bytes per profile for the files with high resolution.

3. The FAX_READ.EXE program is capable of displaying the facsimile recordings of signals and the profiles of the received signal from preliminary stored files. A possibility of scanning all the images of the facsimile recordings from the file, selecting a necessary fragment of the recording, scanning over a selected fragment in detail, printing the facsimile recording (completely or its fragment alone) with the printer in the graphic mode is provided for with this program.

4. The FAXTOOLS.EXE program is capable of displaying the facsimile recordings at the rate exceeding the rate of displaying by the FAX_READ.EXE program by a factor of 5. This program removes the noise background from the facsimile recordings, calculates the dependence of the mixing layer thickness on time, shows this dependence on the facsimile recording, and stores it in a special file.

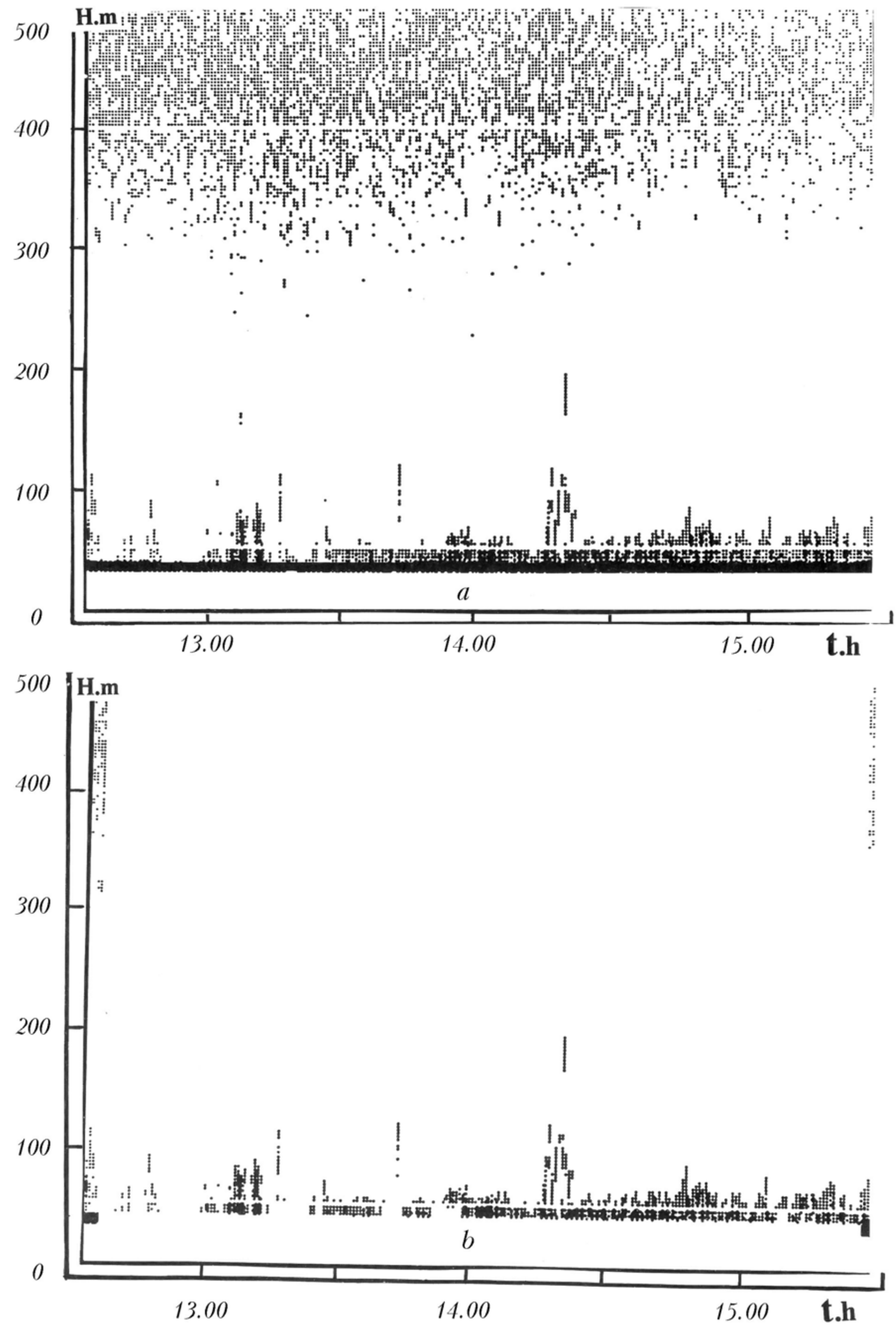

FIG. 2. The removal of noise from the facsimile recordings of the echo–signal: initial record (a), refined record (b).

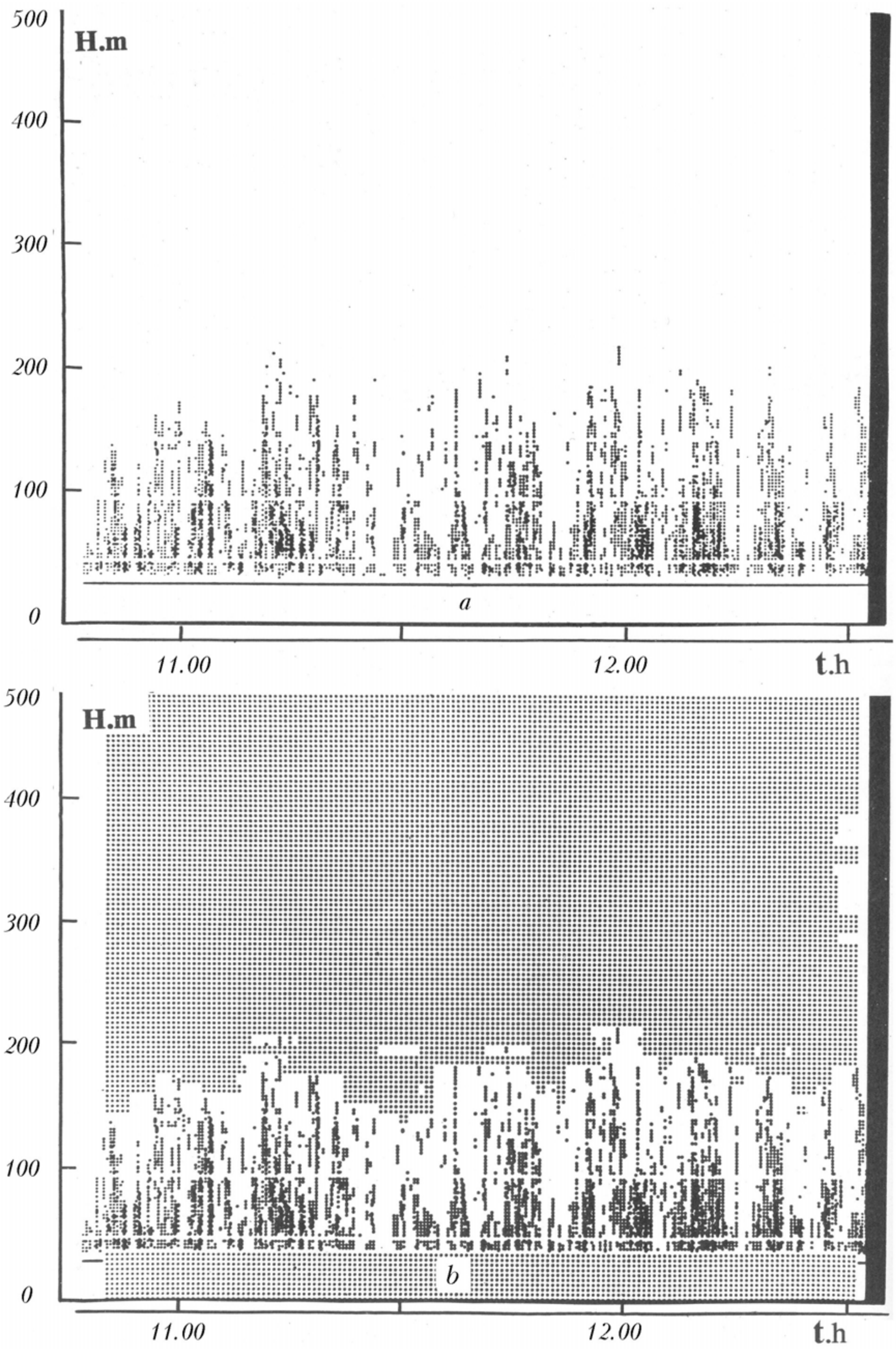

FIG. 3. Separation out of the echo–signal from the mixing layer on the facsimile recording: echo–signal recorded by the sodar (a) and mixing layer of the atmosphere detected by the sodar (nonshaded region) (b).

5. The CT2.EXE program calculates the profiles of the structure constant C_T^2 of the temperature field based on the sodar data preliminary stored in the files by the FAX_READ.EXE and PRF_READ.EXE programs. The program checks the validity of the result according to the signal–to–noise ratio and automatically rejects the doubtful values of C_T^2. The calculated values are stored in a separate file whose name is identical to the name of the initial file except for the extension *ct*2.

6. The CT2READ.EXE program displays the altitude profiles of C_T^2 from the files with the extension *ct*2 in the graphic form.

In addition to the above–listed programs some other programs have been written for servicing the operation of this sodar. These programs allow one to compile large arrays of data, to calculate the statistical characteristics of such arrays, to display cross–correlation functions of signal profiles on the monitor screen, as well as a three–dimensional image of a signal in coordinates amplitude–altitude–current time, and so on. All of the developed programs possess high service capabilities and they widely use the possibilities of the color graphics of the computer. The software of the sodar is constantly being improved and its possibilities are being extended more and more.

The capability of the FAXTOOLS.EXE program to remove the ambient noise from the received signal is demonstrated in Fig. 2. The facsimile recording of the signal is shown in Fig. 2*a*. At the upper part of this recording starting with the altitude 250 m and higher we can observe the noise background caused by the effect of the corrector of the sound beam divergence. In the bottom of this same figure one can see a distinct black strip at the altitudes of from 35 to 40 m, which is due to interference occurring during the transient processes in electronics. Such facsimile recordings were rather rare and were obtained when sounding the boundary layer of the atmosphere under the stratification condition close to the neutral one when the average level of the reflected signal was small compared to the ambient noise. Interpretation of such records requires certain skill and in some cases can be incorrect.

The FAXTOOLS.EXE program analyzes the signal at the sodar receiver output, identifies its validity, and removes from the facsimile records all spurious signals irrespective of their origin and position on the record. A refined facsimile recording of the signal shown in Fig. 2*a*, is depicted in Fig. 2*b*. Both the background noise and the black strip caused by the transition processes are removed from this record. The program also successfully removes the reflections from the local topographic objects.

The FAXTOOLS.EXE program is capable of identifying the thickness of the mixing layer according to the character of the received signal (see Fig. 3). As in the previous example, one of the files, which was "inconvenient" for interpretation since it was stored under conditions of strong convection, was selected for the demonstration.

Figure 3*a* shows the facsimile recording of the signal, in which the characteristic convective "feathers" ascending up to an altitude of 250 m can be seen. Figure 3*b* shows this recording in which the FAXTOOLS.EXE program has separated out the volume where a more intense mixing of air mass takes place. The remaining space of the figure is colored by the "sand" shading what is one of the possible procedures of the program which was used in this paper for the purpose of clear presentation. In actual work it is more convenient to use solid lines for showing the upper boundary of the mixing layer. The thickness of the mixing layer is stored in the file on the hard disk. Special algorithm makes it possible to identify the thickness of the mixing layer under conditions of a strongly fluctuating signal, in the presence of noise and so on. The algorithm used in the FAXTOOLS.EXE program does not require preliminary acquisition of the statistical data on noise, or local reflectors as well as other information like these.

The sodar "ZVUK–1" has been tested. These tests showed its sufficient reliability and convenience of operation. It can identify the type of stratification (the class of the atmospheric stability), the altitude of the mixing layer, the altitudes and the power of the temperature inversions, and the structure characteristic of the temperature field. In 1990 one sample of the sodar was delivered to the Center of Hydrometeorology and Environmental Protection in Kemerovo. Another sample regularly operates for the SATOR program carried out at the Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences and aimed at studying the atmospheric ozone and other gas constituents of air.

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