LATAN-3 sodar for investigation of the atmospheric boundary layer

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The design and operating principles of a new LATAN-3 sodar are described. The sodar is designed for measurements of vertical profiles of wind and the intensity of temperature fluctuations with high temporal resolution. The sodar can be used in investigations of atmospheric turbulence and coherent structures in the height range up to few hundreds of meters above the ground. The results of field tests of the sodar demonstrate a good agreement of the wind field characteristics measured by LATAN-3 and the local measurements on a meteorological tower.

Introduction

Modern commercial sodars are used to measure wind velocity profiles in the atmospheric boundary layer. The technique of such measurements is well developed[1,2] and allows the average (for 10–60 min) wind speed and direction profiles to be determined with the accuracy corresponding to meteorological standards. However, the technique of acoustic sounding can provide much more information about the structure of the atmospheric boundary layer.[3]

The LATAN-3 sodar was designed for investigation of coherent structures and turbulence in the atmospheric boundary layer along with traditional measurements of vertical profiles of the wind speed and direction. When designing LATAN-3, we tried to ensure its simplicity and reliability along with the possibility to control signals at any stage of their processing.

In the LATAN-3 sodar, the most operations on formation of a sounding pulse and processing of an echo signal are performed with the aid of specialized computer programs. A similar approach is successfully implemented in some other sodars, for example, in the Volna-3 sodar.[4] However, the design of Volna-3, despite the original processing algorithms, rather follows the tendencies of development of general-purpose sodars.

Below we describe the architecture and algorithms of the LATAN-3 sodar with examples of data obtained and present the results of LATAN-3 field tests at the Zvenigorod Research Station (ZRS) of the Institute of Atmospheric Physics.

1. Design

The hardware of the LATAN-3 sodar (Fig. 1) consists of a control computer, an amplifier of a sounding pulse power (Amp1), an antenna switch (SW), three acoustic antennas in soundproof screens (A1, A2, and A3), and a microphone amplifier (Amp2).

A sounding pulse through a linear output of a sound card (Line out) after amplification comes to the antenna. Once the transmission is completed, the switch connects the microphone amplifier to the antenna, and the signal from this amplifier comes to the linear input of the sound card for digitization. The microphone amplifier has a pass band of 500–10000 Hz, which allows us, on the one hand, to filter out the marked part of noise before digitization and, on the other hand, to avoid fixing instrumentally the sodar operating frequency. After the reception of the echo signal, the switch connects the following antenna to the power amplifier. After polling all the three antennas, the measurement cycle is repeated.

LATAN-3 operates with the antennas made as a parabolic reflector with a horn loudspeaker at the focus. By now the operation with antennas of the LATAN-1 and Echo1-D sodars with an aperture of 1.2 m, as well as the LATAN-2 minisodar with an aperture of 0.6 m, has been successfully tested.

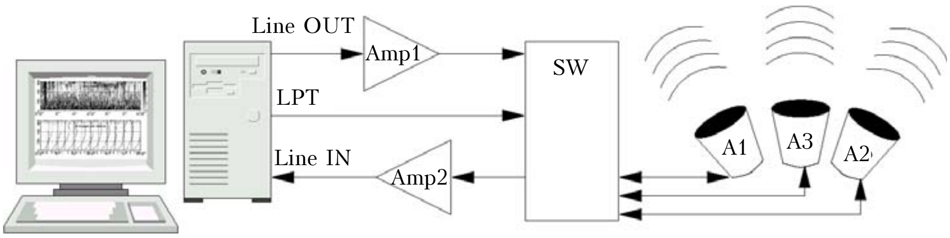

Fig. 1. Simplified block diagram of the LATAN-3 sodar.

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The temporal diagram of antenna polling is formed with the aid of a built-in timer of the sound card. The switch is controlled by the computer through the parallel port (LPT). The order and periodicity of antenna polling, as well as the sounding parameters, are program-specified.

The LATAN-3 sodar employs a personal computer with the GNU/Linux operating system. For sodar operation, the speed of an ordinary personal computer of the previous generation is sufficient.

The antenna poll, the primary processing of the echo signal, the data averaging, and the graphical representation of measured results are performed by individual programs. The parameters of sodar operation are specified through text configuration files. Besides the specially developed software, the sodar widely uses standard GNU tools and other free software.

Plots drawn by one of graphical programs developed for the sodar are exemplified in Fig. 2. Figure 2*a* shows the "reflectability" (intensity of the echo signal corrected for the spherical divergence of the sounding pulse), while Figure 2*b* shows the series of wind speed and direction profiles. Similar diagrams can be viewed in real time both directly on the display of the control computer and remotely.

2. Primary processing of signal

The LATAN-3 sodar employs the algorithm, which analyzes the echo signal from every sounding pulse separately. This allows the data with the maximal temporal resolution to be obtained. For every height interval, three parameters are determined: the intensity of the signal with noise, the noise intensity (dB), and the radial component of the wind with respect to the frequency of the received signal f:

$$V_R = \frac{c}{2f_0}(f_0 - f),$$

where c is the acoustic speed; f_0 is the frequency of the sounding pulse. These data are then used to determine wind velocity components and their variances.

At every height interval, the Fourier spectrum is calculated for the power of the echo signal complemented with zeros to the squared number of readings so that the total number of readings increases several times. The spectra are processed consequently from lower levels to upper ones. The Doppler frequency is estimated in two stages. The primary estimate for the lower frequency interval is obtained as a centroid of the spectrum in the interval ±10 m/s around a frequency. (Here we measure frequencies in units of the radial velocity).

For the following height intervals, the centroid is calculated in the interval ±3 m/s around the last *reliable* estimate. Finally, the radial velocity is calculated as a centroid of the spectrum in the "signal" band of ±1.5 m/s around the primary estimate, while the signal intensity is calculated as a mean power in the same band around the ultimate estimate. The noise intensity is estimated as mean power in two bands each 6 m/s wide adjacent to the signal band.

The estimate of the Doppler frequency is considered as reliable, if the intensity in the signal band exceeds the noise intensity by no less than 4.5 dB. This algorithm ensures the high noise immunity compared to the simple calculation of the spectrum centroid.

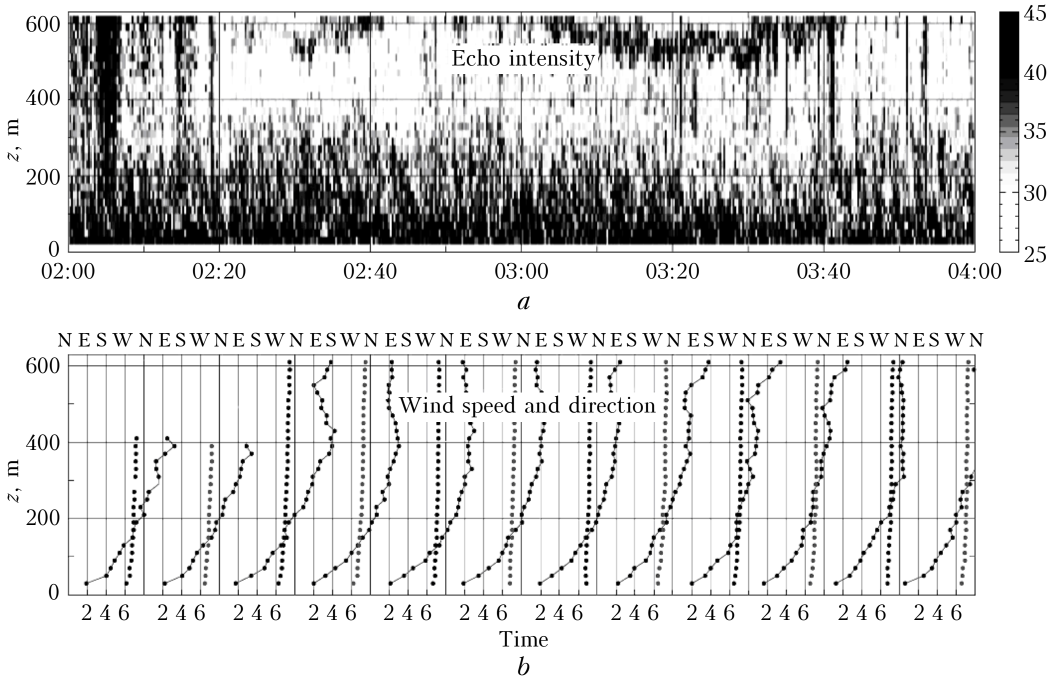

Fig. 2. Echogram (signal level, dB) (*a*) and series of 10-min wind speed (line with dots, lower scale, m/s) and direction (dots, upper rhumb scale) profiles (*b*). July 2 of 2005, ZRS, local time.

To illustrate the algorithm operation, we selected the echo signal obtained at an inclined antenna (zenith angle of 30°) with a signal having a frequency of 1700 Hz and a pulse duration $\tau = 100$ ms. In this case, the range resolution is $\Delta h = c\tau/2 = 17$ m, and the Doppler sensitivity is $\Delta f/V_R = 10$ Hz/(m/s). The spectra corresponding to different height intervals are shown in Fig. 3. The band of tentative search is indicated by the bold line, and the signal band is shown by black.

The mean wind and scattering efficiency profiles are calculated from the data of a series of individual sounding events. For averaging, the data with the signal-to-noise ratio exceeding a certain value selected for a particular problem are used.

3. Results of field tests

The field tests of the LATAN-3 sodar were carried out in July, 2005 at the Zvenigorod Research Station 50 km westward from Moscow. In the tests, the antennas of the LATAN-1 sodar were used. The sodar was installed 50 m far from a 56-m meteorological tower, at the roof of a two-storey laboratory building. A USA-1 (METEK, Germany) sonic anemometer, referred from here on as a sonic, was set on the tower.

The data of the both devices were recorded round the clock. The sounding was carried out by 100-ms pulses having a frequency of 1700 Hz in the height range 20–610 m with a height resolution of 20 m. The period of the sounding cycle was 15 s; the zenith angles of the inclined antennas were 30 and 25°.

To estimate the accuracy of sodar measurements, the data of the second height interval (40–60 m plus a height of the laboratory building of 10 m) were compared with the data of contact measurements at a height of 56 m. Since the technique of wind measurements by a sonic anemometer is well developed now, the sonic data were taken as reference ones.

For the comparison, we used the sodar data after the rejection: data with the signal-to-noise ratio lower than 4 dB were rejected, and only reliable averages, which made up more than 80% of successful measurements for wind and more than 90% for variances, were included in the consideration. The wind direction (for both the sodar and the sonic) was calculated from the average values of radial components. When estimating the agreement between the measured wind directions, we ignored points with the mean speed lower than 2 m/s (according to the sodar data). In general, about 10% of averaged data were neglected. Such a high percentage is caused by the fact that the test field was close to a highway. The correlation plots for the measured parameters are shown in Fig. 4. The linear regression and the mutual correlation coefficients are indicated on the plots.

The sodar data on the radial components of wind are in a good agreement with the data of the sonic. For the absolute value of the horizontal speed V, the agreement is somewhat worse although still within the meteorological accuracy. This is caused by the fact that the error in V at the zenith angles used two to three times (depending on the direction) exceeds the error of determination of the radial velocity. The wind direction determined by the sodar is in a good agreement with the sonic data.

The sodar systematically overestimates the variance of the vertical component of the wind velocity σ_w^2. The nearly unit linear regression and correlation coefficients for σ_w^2 indicate that the error w has a random character. It is likely caused by the principal impossibility of more accurate determination of the frequency of an incoherent signal at a short sample (about 200 periods). The standard deviation of the vertical component was calculated as

$$\sigma_w = \sqrt{\sigma_w^2 - \delta},$$

where $\delta = 0.07$ m^2/s^2 is the smallest σ_w^2 value measured by the sodar. It can be seen from Fig. 4 that the values calculated in this way fall well on a straight line. This confirms the validity of this method of correction of the measurement error.

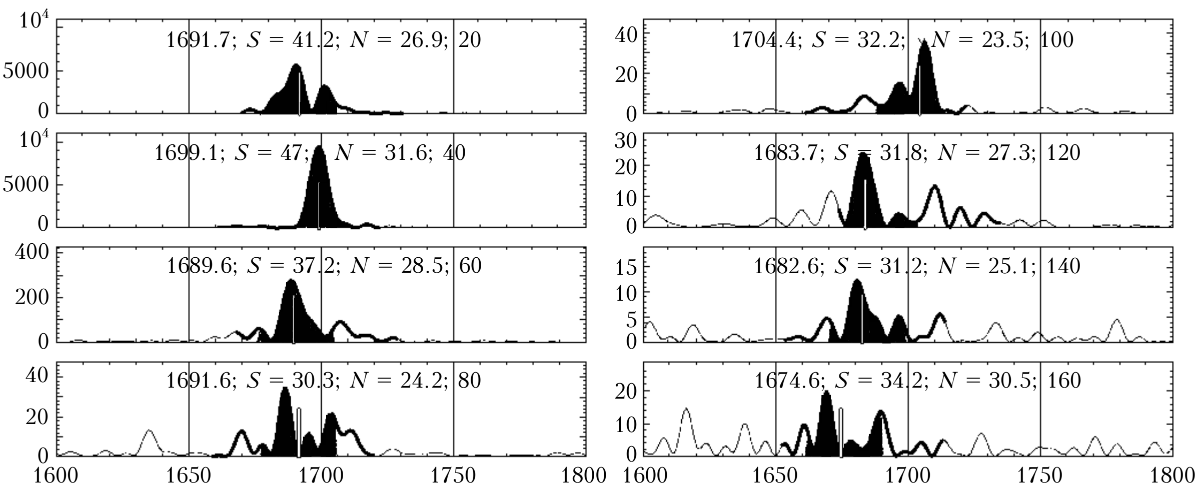

Fig. 3. Spectra of echo signal from a single sounding pulse received by an inclined antenna from consecutive height intervals. Signal frequency (Hz), signal + noise intensity S and noise intensity N (dB), as well as the lower boundary of the height interval, in m, are indicated.

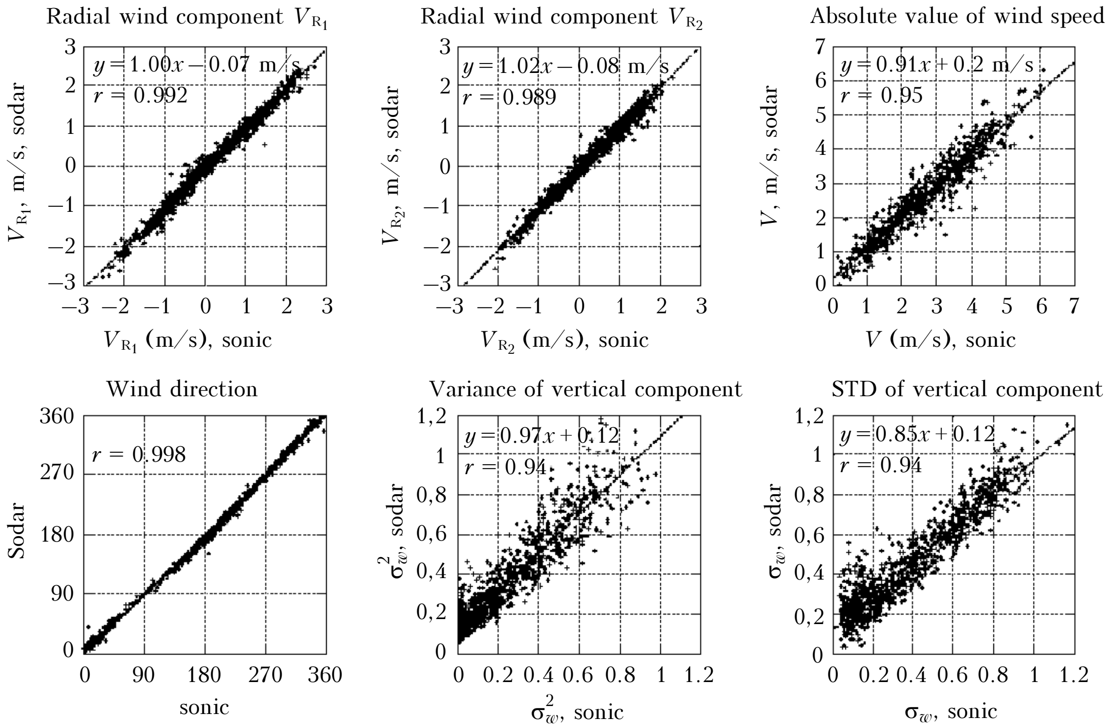

Fig. 4. Comparison of 30-min averaged remote (z = 60 m) and contact (z = 56 m) measurements.

Conclusions

The described algorithm of processing of the primary echo signal, despite its simplicity, turned out to be quite efficient even under the urban conditions. It does not provide for rejection of narrowband noises and reflections from local objects from the data obtained. For a research device, this rather is an advantage, because the use of simple algorithms makes the operation clear and facilitates identification of artifacts in results of measurements during the following processing.

The approach employed in the LATAN-3 sodar (minimum of specialized electronics, simplicity of algorithms) has demonstrated its promises. The accuracy of sodar measurements is sufficient for solution of many problems. The analogical tests of other sodars[5,6] demonstrate the quite comparable and, in some cases, higher measurements errors than in LATAN-3. Individual measurements of radial velocities have an accuracy of about 0.3 m/s. This is much lower that the characteristic velocities in convective formations (1–2 m/s), which indicates the possibility of using the LATAN-3 sodar for investigation of coherent structures in the atmospheric boundary layer.

The sodar is very flexible in use. Nearly all sodar parameters can be adjusted in arbitrary ranges. The sodar can operate with different types of antennas.

Two LATAN-3 sodars are now used for long-term measurements within the program of investigation of atmospheric turbulence and wind velocity field over Moscow. One of them is installed at the center of Moscow on the roof of the Institute of Atmospheric Physics, while another is set near suburbs, on the roof of the building, where the Physical Department of the Moscow State University resides.

Acknowledgements

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References

1. M.A. Kallistratova, Int. J. Remote Sens. **15**, No. 2, 251–266 (1994).
2. N.P. Krasnenko, *Acoustic Sounding of the Atmospheric Boundary Layer* (IOM SB RAS, Tomsk, 2001), 278 pp.
3. R.L. Coulter and M.A. Kallistratova, Meteorol. and Atmos. Phys. **85**, 3–19 (2004).
4. V.A. Gladkikh, A.E. Makienko, and V.A. Fedorov, Atmos. Oceanic Opt. **12**, No. 5, 422–429 (1999).
5. J.E. Gaynor, Int. J. Remote Sens. **15**, No. 2, 313–324 (1994).
6. Atmospheric Research Company web site, http://www.sodar.com