AIRBORNE LIDAR APPLICATION TO SOUNDING OF THE SEA WATER AREAS

V.S. Shamanaev

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received December 4, 1992

Several prototypes of domestic and foreign airborne laser radars harnessing the elastic scattering of light are considered from the standpoint of their application to the estimate of water optical parameters. The results of measurement of the hydrooptical characteristics are analyzed.

The lidars have been in use for sounding of the upper layer of the sea more than ten years. This lead got under way as applied to fundamental (in climatology) and applied problems (bathymetry of shoal, search for bioproductive zones in the ocean, monitoring of oil and other pollutants).

The main merit of an aircraft as a platform for a lidar is obvious: the high speed of observation of the water areas. In addition, it is capable of operation over shoal, where navigation is dangerous. In many cases this compensates for the demerits: high cost of flights and the dependence on weather conditions.

Much attention is paid to the fluorescent sounding, since it can be used to reveal relatively simply the organic compounds in water, namely, various chlorophylls, oil products, etc. The problem of their identification and quantitative measurements is still far from being completely solved due to the complicated chemical–physical composition of these substances. (Many organizations, in particular, the members of the European Association of Laser Sounding Laboratories,[1] deal with this problem.) However, the sounding depth for the luminescent signal reception reaches only several meters, since this radiation lies in the red spectral region for which the absorption by water is high. For this reason we consider the results obtained by harnessing the elastic scattering of green radiation, for which the maximum sounding depths can be reached.

In the applied aspect of hydrooptical laser sounding, the greatest success has been achieved in the solution of the bathymetric problem in Australia.[2] There the necessity of determination of the water light scattering characteristics arose, since the multiple scattering of light affects the accuracy of bathymetric measurements. Evidently, the light scattering parameters have their own significance, since all the peculiarities of the scattering phase function and scattering matrix of water are determined by its microphysical and chemical composition. The authors of a number of papers (see, for example, Ref. 3) succeeded in the identification of the underwater lidar signals, although there is a long way to the quantitative solutions of the inverse problems.

Thus, in 1980 Hoge et al.[4] could achieve the sea water sounding depth of several meters with a lidar on the basis of low–power laser (generating "hot" green band of neon) and revealed the presence of near–bottom hydrosol layers producing detectable power signals.

The layered structure of water to a depth of 12 m was also revealed in Lagoon of Venice.[6] A laser radiation with a wavelength of 450 nm was used for sounding. The signal of Raman scattering was received at a wavelength of 533 nm. This signal is of greatest interest now. The extinction coefficient was determined from it with a resolution of 1 m. The accuracy of reconstruction of ε was not very high, but it made it possible to follow the variations of the water properties at distances up to 25 km.

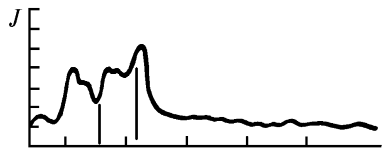

FIG. 1. The WRELADS–II lidar echo–signal obtained from under water. The zero depth corresponds to the air–water interface. The depth resolution is 0.6 m.

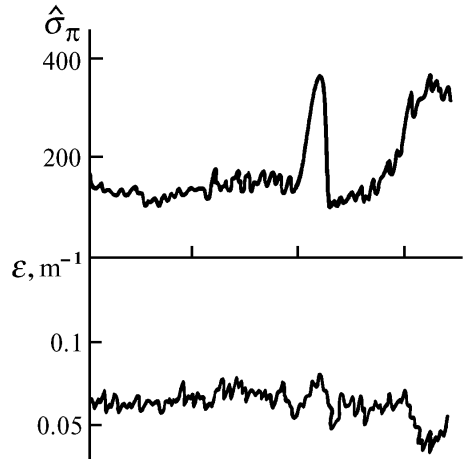

FIG. 2. Horizontal sectional view of the upper sea layer. L is the flight distance, ε is the extinction coefficient of water, and $\hat{\sigma}_\pi$ is the backscattering coefficient in relative units.

The above–mentioned Australian group obtained interesting data with the help of the WRELADS–II lidar.[2] Figure 1 illustrates the depth behavior of the echo–signal recorded from a clear sea water in the coastal region of Australia from a flight altitude of 500 m. The signal was recorded with a depth resolution of 0.6 m in water to a

0235-6880/93/02 101-03 $02.00

depth of about 15 m. The layers located at depths of 5 and 11 m can be quite distinctly identified by the spikes of the received power. The horizontal sectional view of the sea extended for about 30 km was obtained in one run of experiments (Fig. 2). The lidar was not calibrated against the power; therefore, the backscattering coefficient $\hat{\sigma}_\pi$ is given in relative units. The extinction coefficient ε was obtained by the logarithmic derivative method and needed no calibration.

Water has the fluctuating optical characteristics at a flight distance of about 19 km. The increase of reflectance of the water column is clearly pronounced at distances between 20 and 22 km. Backscattering is anticorrelated with extinction at larger distances. In this case we have the example of identification of three different sections of the sea. The same method of identification of these sections in the Saint Vincent Gulf[6] is illustrated by Fig. 3 in the ε–$\hat{\sigma}_\pi$ coordinates.

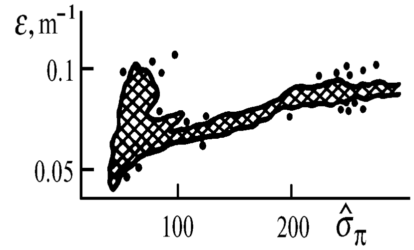

FIG. 3. Interrelation between backscattering and extinction of radiation in water from the data obtained along one flight line.

Side by side with the section of linear regression, there is a section (on the left) where the dependence $\varepsilon = \varepsilon(\hat{\sigma}_\pi)$ is not clearly manifested. One can suppose the presence of two water types along this flight line, the more so as the flight was carried out over slope water whose depth varied from 35 m to 6 km, i.e., the role of the near–bottom mineral hydrosol fraction changed. (As is well known, the scattering phase functions of the fine mineral and coarse organic fractions are essentially different.)

Processing of signals obtained with a relatively high depth resolution has been considered above. Another approach was stated in Ref. 7. There the power of the echo–signal received from two depths spaced at a distance of 11 m were recorded for each laser shot. The data obtained along two flight lines are shown in Fig. 4. The echo–signal power averaged over the laser pulse train is shown in relative units for both depths. The correlation coefficient B was calculated for each flight line. In this case the approach to the diagnostics of the water masses was the following. In Fig. 4*a* the signals received from depths of 11 and 22 m fluctuate strongly, but there is a positive correlation between them. In Fig. 4*b* the signal powers recorded along the flight lines fluctuate weaker; however, the correlation coefficient between them changes its sign.

We also obtained the horizontal sectional views of the sea with depth resolutions of 2.8 (see Ref. 8) and 1.1 m (see Ref. 9). The instability of the parameters of the upper water layer was observed along the flight line under conditions of the gradient of the sea surface temperature. The example of such an instability[8] is shown in Fig. 5, where N is the portion of the echo–signals with underwater pulses in the trailing edge (similar to those shown in Fig. 1) in the total pulse train. The sea depth was several hundreds of meters, i.e., that could not be the signals reflected from the bottom. In any case the deterministic, though implicit, relation between the inhomogeneities of the upper sea layer and its thermal structure is manifested here.

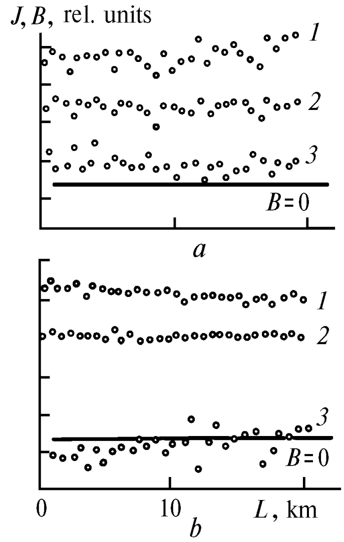

FIG. 4. The results of water sounding along two flight lines (a and b). 1) and 2) powers of signals received from depths of 11 *and* 22 m *in relative units, and 3) coefficient of correlation B between the signals.*

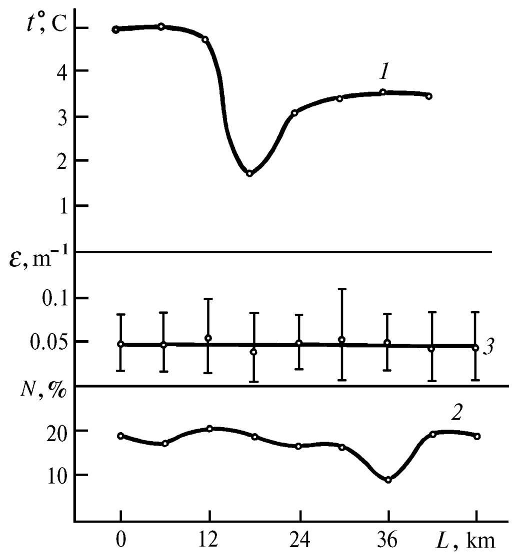

FIG. 5. Horizontal sectional view of the upper sea layer. L is the flight distance, 1) profile of the water surface temperature, 2) normalized frequency N of the appearance of the underwater pulses, and 3) extinction coefficient at the wavelength λ = 532 nm *with its standard deviation.*

The results of sounding of the water area with an increased salinity at depths of 5–10 m were reported in Ref. 9.

The horizontal size of this local inhomogeneity reached 30 m. Up to 40% of all signals had spikes in the trailing edges at depths of 10–15 m. Their distribution (grouping) indicated the presence of the inhomogeneity cells with the size of several tens or hundreds of meters.

Cellular structure of the light scattering properties of water along the flight lines was also pointed out in the experiment of Hoge et al.[10] The layers with the enhanced values of the extinction coefficient were observed at depths varying from 6 to 24 m.

The available experimental data of laser sounding of the light scattering structures in the upper sea layer are still insufficient for creating any models. Such experiments are very expensive. However, it is evident that lidars are capable to investigate fast the degree of inhomogeneity of subsurface sea layer to depths as great as tens of meters. One can also classify the underwater inhomogeneities using either the statistical analysis of signals, as in some papers considered above, or the polarization analysis.[11] For these reasons the airborne lidar method of monitoring of the upper sea layer can be recommended for use not only for the purely scientific purposes, but also for solving various applied problems.

REFERENCES

1. M.M. Krekova, G.M. Krekov, and V.S. Shamanaev, Report presented at the *Workshop on Lidar Remote Sensing of Land and Sea,* EARSEL, Florence, 1991 (unpublished).
2. M.E. Penny, R.H. Abbot, D.M. Phillips, et al., Appl. Opt. **25**, No. 13, 2046–2058 (1986).
3. B.A. Kargin, G.M. Krekov, and M.M. Krekova, Atm. Oceanic Opt. **5**, No. 3, 191–195 (1992).
4. F.E. Hoge, R.N. Swift, and E.B. Frederick, Appl. Opt. **19**, No. 6, 871–883 (1980).
5. D. Diebel–Longohr, T. Hengstermann, and R. Penner, in: *Abstracts of Reports at the Seventh Int. Congr. Laser 85 Optoelectron.,* Munchen (1985), pp. 648–651.
6. B. Billard, R.H. Abbot, and M.F. Penny, Appl. Opt. **25**, No. 13, 2080–2088 (1986).
7. D.V. Vlasov, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **50**, No. 4, 724–735 (1986).
8. I.E. Penner, I.V. Samokhvalov, and V.S. Shamanaev, Atm. Opt. **1**, No. 12, 60–66 (1988).
9. I.E. Penner and V.S. Shamanaev, Atm. Oceanic Opt. **6,** No. 1, 65–67 (1993).
10. F.E. Hoge, C.W. Wright, W.B. Krabill, et al., Appl. Opt. **27**, No. 19, 3969–3977 (1988).
11. M.V. Kabanov ed., *Remote Monitoring of the Upper Oceanic Layer* (Nauka, Novosibirsk, 1991), 149 pp.