27A2

# RUSSIAN SPACE LIDARS AND STATIONARY LIDAR COMPLEXES FOR SUPPORT OF SATELLITE OBSERVATIONS

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## INTRODUCTION

The first announcement on the NASA spaceborne lidar development program was reported at special session of the 9-th ILRC in Munich, 1979 [1]. In recent years the corresponding ESA programs have been reported. In the former Soviet Union and nowadays in the Russian Federation a special program on spaceborne lidars was unavailable and remains yet to be unavailable. On the initiative of the Institute of Atmospheric Optics stimulated by the announced in due time by Dr. McCormick scheduled in late 1987 or early 1988 launching of the first spaceborne lidar, in the Soviet Union in 1986 the joint work has begun on creation of the first Soviet spaceborne lidar "BALKAN-1". The work was done on a contract with the scientific and production association (SPA) "ENERGIA" with participation of the SPA "RADIOPRIBOR". In 1989 the Institute of Atmospheric Optics gave the prototype of this lidar to SPA "ENERGIA" to be installed on board the module "SPEKTR" of the Russian orbital station "MIR". The module "SPEKTR" was scheduled to be launched in late 1992 or early 1993 but the launching did not take place up to now because of the lack of funding. The "BALKAN-1" lidar potentialities are rather modest due to unsatisfactory funding.

We reported on the above lidar at the 15th ILRC held by the Institute of Atmospheric Optics in Tomsk, July 1990. At present the Institute Of Atmospheric Optics together with SPA "Mashinostroenie" and the Scientific Research Institute of Space Instrument Manufacture are developing a new spaceborne lidar "BALKAN-2" to installed at the unique space platform "ALMAZ". Simultaneously a question is considered on the development, creation and launching of a spaceborne lidar "BALKAN-3". This lidar should be installed at the platform "ALMAZ" when launching the platform in future.

Since 1986 the Institute of Atmospheric Optics has been developing and creating a unique multipurpose ground-based lidar station aimed at calibration and validation of spaceborne lidars as well as to the other means of spaceborne remote sounding of the atmosphere and underlying surface.

## LIDAR "BALKAN-1"

The "BALKAN-1" spaceborne lidar is briefly described in Ref.2. Here we enumerate the problems which may be solved using the above lidar: a). identification of scattering objects like, e.g., clouds against the background from underlying surface;
b). determination of the upper boundary height, and optical properties of clouds;
c). investigation of the statistical structure and optical parameters of underlying surface, and in particular, sea and ocean surfaces. The main specifications of the lidar are as follows: energy of frequency doubled radiation of Nd:YAG laser is ~ 0.15 J per pulse; its repetition rate 0.2 Hz; receiving objective has the diameter of 270 mm; transmitting beam expander aperture is 100 mm in diameter; sounding beam divergence is 30′ and the receiver's field of view is 90′.

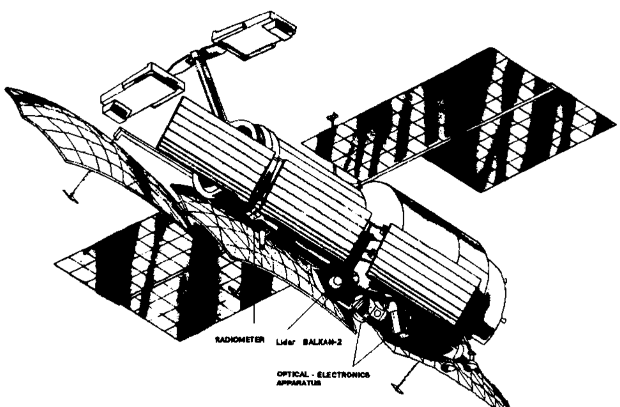
As it was mentioned above, the "BALKAN-1" lidar is scheduled to be launched on board the "SPEKTR" module of the manned space station "MIR" whereas the lidar "BALKAN-2" and "BALKAN-3" are aimed at operation on board the unique space platform "ALMAZ". For this reason we shall briefly describe below the platform "ALMAZ" and its advantages as compared with those of station "MIR".

## SPACE PLATFORM "ALMAZ"

This exceptional platform was launched to orbit twice, first as a satellite "Kosmos-1870" (1987) and "ALMAZ-1" (1990). A number of instruments, including radars, radiometers, spectral optoelectronic apparatus were installed on board this platform. all of them are very essential and effective for the purpose of remote sensing of the Earth's surface.

At present the work is underway on widening the scope of potentialities of the platform both in respect to improvement of its parameters and as regards an enlargement of the number of the used technical means, first of all, for purposes of remote sensing of the Earth's surface, including the lidar "BALKAN-2". In this case the platform itself is known as "ALMAZ-1B" (see figure) and its improved technical data are the following:

1. Orbit: height is 335-400 km; flight path angle is 73°.
2. Power supply unit: average power per one revolution is 2300-3300 W; maximum power (under peak loading for 15-20 min) is 8600 W.
3. Data sampling rate: directly at the SIR - 122.8 Mbit/s; through a retranslating satellite - 10 Mbit/s.




ALMAZ - 1B AUTOMATIC SPACE STATION

## LIDAR "BALKAN-2"

The lidar "BALKAN-2" is single frequency lidar, which uses the backscattering in the atmosphere, ocean and from ground surface. Its main parameters are cited in Table.1.

The lidar "BALKAN-2" is used for many technical applications, verified by modeling and tests of lidar "BALKAN-1"[1]. This allows to accelerate "BALKAN-2" manufacture.

In comparison with "BALKAN-1" lidar "BALKAN-2" potentialities are extended in the following directions: pulse repetition rate is increased, scanning is created, photon counting is appeared for signal processing unit. Besides, there is a polarization analysis of lidar returns.

Table 1.

| | |
|---|---|
| Output wavelength (nm) | 532 |
| Output energy (mJ) | 200 |
| Laser pulse length (ns) | 10 |
| Beam divergence (sek. arc.) | 30 |
| Repetition rate (Hz) | 1 |
| Primary mirror diameter (mm) | 275 |
| Field of view (sec. arc.) | 90 |
| Digitizing rate (MHz) | 50 |
| Digitizer accuracy (bits) | 6 |
| Strobe duration of photon counter (μs) | 2.0<br>6.67<br>20 |
| Number of strobes | 26 |
| Scanning angle (degrees) | ±10 |
| Power consumption (W) | 600 |
| Lifetime (shots) | $2 \cdot 10^5$ |

Suggested novelties extend significantly the sphere of problems, solved by the lidar "BALKAN-2". Atmospheric parameters measured by "BALKAN-2" are listed below:

1. Stratosphere (night side of the planet): aerosol backscatter ratio, aerosol scattering ratio, tropopause height, temperature and density profiles.
2. Troposphere: aerosol backscatter cross section, planetary boundary layer (PBL) height, PBL optical depth.
3. Strong ecological danger in tropo- and stratosphere (day and night sides): aerosol backscatter cross section; geographic distribution.
4. Clouds (day and night sides): top and base (for thin heights clouds); scattering cross section, phase composition; geographic distribution, albedo.
5. Ocean (day and night sides): albedo, transparency subsurface layer; height of powerful waves; depth of bottom at the sea shelf; searching of bioproductivity areas (fish shoals, plankton, etc.).
6 .Surface (day and night sides): average height of the forest cover; height of the desert barkhans; precise orbit altitude.

## LIDAR COMPLEX "BALKAN-3"

The lidar complex is an active optical system, which makes it possible to solve the problems of remote sensing of the Earth independently and in combination with the other systems of the station "ALMAZ-2".

The multifrequency lidar "BALKAN-3" is intended for remote sensing of atmospheric parameters and different types of underlying surface. The lidar applications are the following: ecological monitoring and observation of natural and anthropogenic disasters; climatology; weather service of flight of spacecraft-platform; software of land, forest and water cadastres.

The planned problems should be solved using the lidar and data processing techniques. the following parameters of the atmosphere and underlying surface are determined:

1. Altitude of the upper boundary of cloudiness and its optical density (water content), its selection against the background of snow.
2. Vertical distribution of aerosol scattering coefficient in the atmosphere, aerosol particle size spectrum and particle mass concentration.
3. Density and phase composition of cirrus, nacreous clouds, noctilucent (including polar stratospheric) clouds.
4. Vertical distribution of ozone concentration in the atmosphere.
5. Variations of total concentration of gas molecules at orbit altitude along the flight trajectory.
6. Vertical distribution of temperature in the upper troposphere, stratosphere and mesosphere.
7. Density of the stratosphere.
8. Spectral albedo of separate parts of the Earth's surface.
9. Height of sand-hills in the desert and trees in large forest areas.
10. State of vegetation according to peculiarities of its fluorescence.
11. Depth of shallow parts of sea shelves.
12. Height of energy carrying waves in the sea.
13. Turbidity of the marine upper layer.
14. Chlorophyll content in the marine upper layer.
15. Presence of oil products contamination in water surface.
16. Density of bioactive surface layer of the ocean.

Widening of the scope of potentialities of this lidar as compared with the "BALKAN-2" lidar ones is connected with the use of large number of wavelengths of a sounding emitter and with the increase of energy potential. This is manifested in qualitative increase of the number of measured characteristics of the atmosphere, sea and dry land as well as in the increase of measurement accuracy.

## SPECIFICATIONS OF THE LIDAR

The lidar consists of a laser multiwave transmitter based on a solid Nd:YAG laser, second-, third-, fourth-harmonic generators and a radiation frequency converter in the hydrogen cell at the expense of stimulated Raman scattering, a mirror receiving antenna, a lidar return spectral selector, polarizers, photoreceivers and lidar return detectors. The specifications of the lidar and its main parts are given in Table 2. The measured parameters and body of data are listed in Table 3.

## GROUND-BASED LIDAR STATION

Since 1986 at the Institute of Atmospheric Optics a unique stationary ground-based lidar station has been created providing calibration and validation of lidars and other spaceborne facilities for sounding atmospheric parameters. At present this station makes possible sounding at six laser wavelengths: 1064, 578, 532, 511, 353 and 308 nm generated simultaneously. Lidar-returns are received by the six independent channels to the receiving mirror 2.2 m in diameter. In 1991-1993 this station allowed for obtaining and analysis of data on ozone profiles, aerosol particle size spectra and concentration, including aerosol emitted to the stratosphere during Pinatubo volcano eruption. At present the work is in progress on future development of this station in the following directions:

1. The increase of the number of sounding wavelengths (with the use of Au-vapor laser with $\lambda = 628$ nm and Pb-vapor laser with $\lambda = 723$ nm).
2. Modification of all components of the optical path to improve the efficiency of sounding.

## REFERENCES


1. J.E. Harris and R.V. Greco, Abstracts of Papers 9th IRLC, Munich, FRG, p.178, 1979.
2. Yu.S. Balin, V.V. Burkov,I.V. Znamenskii, V.E. Zuev et al., Abstracts of Papers 15th IRLC, Tomsk, USSR, p. 12-14, 1990.

Table 2.

| Parameter | Values | | | | |
|---|---|---|---|---|---|
| *Laser transmitter* | | | | | |
| Radiation wavelength, nm | 1064 | 532 | 355 | 266 | 299 |
| Output power, J | 0.15 | 0.35 | 0.2 | 0.15 | 0.15 |
| Pulse duration, ns | 3 | 3 | 3 | 3 | 3 |
| Radiation divergence, mrad | 0.25 | 0.20 | 0.20 | 0.20 | 0.25 |
| Pulse repetition rate, Hz | < 50 | < 50 | < 50 | < 50 | < 50 |
| Diameter of transmitting collimators, mm | 120 | 120 | 120 | 120 | 120 |
| *Optical receiver* | | | | | |
| Band width of interference filter, nm | 4.0 | 3.0 | 1.5 | 1.0 | 1.0 |
| Polarization analysis | - | + | - | - | - |
| Diameter of receiving telescope, mm | 300 | 300 | 700 | 700 | 700 |
| Viewing angle, mrad | 0.5 | | | | |
| *Photoreceiver* | | | | | |
| Current mode | + | + | + | + | + |
| Photon counting mode | - | + | + | + | + |
| *System of lidar return processing* | | | | | |
| Transmission band of amplifier, MHz | 40 | | | | |
| Amplitude resolution of A/D converter, bit | 10 | | | | |
| Time resolution of A/D converter, ns | 20 | | | | |
| Strobe duration, μs | | 2.0 | 6.67 | 20 | |
| Number of strobes | 26 | | | | |
| *Lidar* | | | | | |
| Power consumption, W | 1500 | | | | |
| Weight, kg | 1200 | | | | |
| Time for full-load condition, min | 40 | | | | |
| *Resource characteristics* | | | | | |
| Maximum number of radiation pulses | $10^8$ | | | | |
| Time of standart operation, hour | 5000 | | | | |
| Maximum number of lidar switching | 2000 | | | | |

Table 3. List of measured parameters and body of data (parameter, indicated by *, are measured at the night side of the Earth).

| Measured parameter | Range of parameter variation | Measurement error | Space resolution vert./horiz. |
|---|---|---|---|
| *Cloudiness* | | | |
| Altitude of upper boundary | 50...12000 m | 50 m | 3/320 |
| Vertical profile of scattering coefficient | 5...100 km$^{-1}$ | 20% | 3/320 |
| *Atmospheric aerosols* | | | |
| Altitude of upper and lower boundaries of aerosol plumes | 50...5000 m | 50 m | 3/320 |
| Vertical profile of scattering coefficient (mass concentration for the visible range in the lower troposphere)* | 2...10 km$^{-1}$ (0.5..5 mg/m$^3$) | 30% 40% | 300/1600 |
| Particle size spectrum in the upper troposphere and stratosphere* | 0.4...1.5 μm | 50% | 300/1600 |
| *Atmospheric gases** | | | |
| Atmospheric density fluctuations at orbit altitude | 50 % | | 5000/16000 |
| Vertical profile of ozone concentration | 0.3...10.0 ppm | 10...60% | 500... 5000/16000 |
| Density and temperature of the air* | 20...0.003 g/m$^3$ -50...+5°C | | 200... 2000/16000 |
| *Underlying surface* | | | |
| Spectral albedo for 1064, 532, 355 nm | 0.3...0.9 | 15% | -/320 |
| Height of sand-hills | 5...50 m | ± 0.5 m | -/320 |
| Height of trees | 5...50 m | ± 0.5 m | -/320 |
| Depth of shallow carrying waves | 3...30 m | ± 0.5 m | 0.5/320 |
| Height of energy carrying waves | 0.7...8 m | ± 0.5 m | 0.5/320 |
| Extinction coefficient of the sea upper layer at λ=532 nm | 0.5...0.15 m$^{-1}$ | 30% | -/320 |
| Presence of chlorophyll in the sea upper layer above the threshold level | yes/no | | -/320 |
| Presence of oil products on the sea surface | yes/no | | -/320 |