A LIDAR FOR SUBSATELLITE INVESTIGATIONS OF CLOUDS

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An M2M airborne lidar designed to imitate the operation of a spaceborne lidar as well as to carry out subsatellite cloudiness sensing is described. The choice of its design and specifications is justified. The lidar has been flight - tested.

After a number of theoretical investigations of the possibilities in spaceborne laser sensing, a report was published to the effect that a spaceborne lidar has already been constructed.[1] Naturally enough, the problem the of reliability of the results derived from such a lidar has arisen. The main factors which affect the measurement error can be enumerated as follows. The first and traditional one concerns reduction of the signal–to–noise ratio on paths of several hundred kilometers in length. The second reason, which is more important from our viewpoint, is a change in the geometry of photon scattering.

Let us now study the phenomena associated with a change in the geometry of the experiment. We shall assume that the lidar has a transmitter with a beam divergence of 1 mrad, pulsewidth 15 ns (equivalent spatial resolution 4.5 m), and a receiver with field – of – view angle $\theta = 2$ mrad. Then, in the first approximation, the configuration of the light scattering volume can be represented in the following way: for the lidar located at a distance of 1 km from the cloud, a glowing cylinder 4.5 m and 1 m in diameter is "inserted" into the observation cylinder of the same length but 2 m in diameter, i.e., their diameter–to–length ratios are equal to 0.222 and 0.444. For the same lidar located at a distance of 300 km, the glowing cylinder 300 m in diameter and the observation cylinder – 600 m in diameter (they are now flat as "pancakes" since their length remains the same). The diameter–to–length ratios now grow up to 66.7 and 133.3, respectively. Naturally, the trajectories of the multiply scattered photons in the cloud layer will radically differ for such a change of the configuration of the light scattering system, and, consequently, the contribution of multiple scattering in the laser sensing equation will also be different.

Only theoretical estimates of the magnitude of the signals of the spaceborne lasers and the results of inversion of these signals into the optical parameters of the cloud mass were given in Refs. 2 and 3. Therefore, it is necessary to support them experimentally. The M2M lidar was developed and tested onboard an AN–30 aircraft to this end. The lidar configuration shown in Fig. 1 allows one to judge its features. Here we do not consider to the information system of the lidar, i. e., the computer system, the ADC devices, the signal visualization system, etc.

A feature of the telescope is its relatively large field–of–view angle, which reaches 70 mrad. In the event that the altitude of the aircraft flight is 4.5 km greater than the height of the cloud top, the diameter of the light spot on the upper boundary of the cloud field (UBC) is equal to 300 m. This is quite sufficient for a comparison with the satellite data. The working flight altitude of an AN–30 aircraft–laboratory was equal to 7.5 km. This fact makes it possible to perform the sensing of clouds located at lower altitudes for such an imitation.

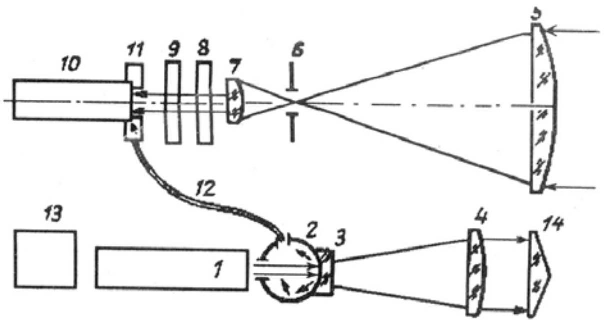

FIG. 1. The M2M lidar configuration: 1) laser, 2) light scattering cavity, 3 and 4) the collimating lenses, 5) detector objective lens, 6) field diaphragm, 7) ocular lens, 8) interference filter, 9) polaroid filter, 10) photomultiplier, 11) glass ring for transporting the radiation from the light guide, 12, 13) power supply, and 14) conical lens.

The receiving telescope of the lidar is formed by the spherical lens *5* with 0.2 m diameter and 750 mm focal length and by the ocular lens *7*. A commercial YAG laser provides pulses at a wavelength of 532 μm with pulsewidth 15 ns and 30 mJ per pulse. The pulse repetition frequency onboard the aircraft is adjusted up to 10 – 12 Hz and, in this case, is limited by the rate of data sampling using the available information system. The continuous operation time of the laser is limited to 2.5 h in flight, since the heat generated by the laser is eliminated with the help of the intrinsic heat capacity of the refrigerant.

The divergence of the laser beam after collimating is equal to 1 mrad under ordinary conditions. However, the lenses *3* and *4* can be moved relative to each other thereby changing the divergence of the probing beam until the value is reached which is required for the conditions of our experiment.

The fraction of the radiative power reflected from the frontal surface of the lens *3* is averaged in the spherical cavity 3. This eliminates the unfavorable effect of jitter of the energy center of gravity of the beam consisting of the biharmonic of the YAG laser as well as the effect of polarization. The optical synchronizing pulse is incident on the photocathode of the photomultiplier after passing through the light guide *12* and the glass ring *11* and provides triggering of the recording system and monitoring of the energy of the probing beam.

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Another source of error is associated with a curvature of the wavefront, when the beam of large diameter enters the cloud. So, as can be seen from Fig. 2, for the plane UBC the echo signal from the axial region of the beam starts to arrive at the detector earlier than the echo signal from the peripheral region of the beam, which introduces a certain error in the measurement of H. Its value is $\Delta L = H\cos^{-1}\theta_0(1 - \cos\theta_0)$. For the foregoing spaceborne lidar with $\theta_0 = 1$ mrad, $\Delta L = 0.06$ m, while for the subsatellite airborne lidar it is equal to 1.8 m, i.e., 12 ns temporal resolution. It is evident that this error can be neglected in most practical situations, the more so taking into account the UBC spreading.

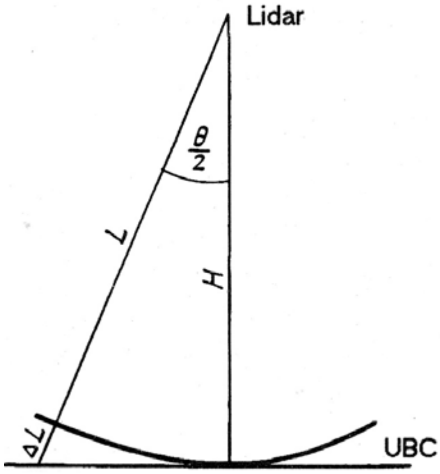

FIG. 2. Influence of wavefront curvature of the laser beam on the error in the measurement of the distance to the UBC. H is the altitude of the lidar above the cloud field, θ_0 is the divergence of the laser beam, and ΔL is the error in determining the distance.

It is natural that the larger field – of – view angle of the lidar is intended for imitation of the operation of a spaceborne lidar and also for determining the distance to the clouds averaged over a circle with diameter θH (it is desirable that this circle agree with the observation circle of the spaceborne lidar). It is necessary to perform the test determination of the cloud scattering coefficient using an airborne lidar with small field–of–view angle in order to reduce the contribution of multiple scattering and thereby improve the measurement accuracy.

In the case in which it is necessary to monitor only the distance from the aircraft to the UBC, it is expedient to employ a laser beam with annular cross section. Toward this end the collimator, which comprises lenses *3* and *4*, is adjusted to the rated regime and the conical lens *14* is inserted into the beam. After passing through this lens the laser beam has the shape of a hollow cone with outer divergence equal to the field–of–view angle of the receiving telescope in the far diffraction zone The field diaphragm *6* is not of the ordinary circular form: there is a nontransparent axial region whose diameter corresponds to the diameter of the interior nonradiative zone of the hollow laser cone. Such a configuration significantly decreases the background irradiation of the photodetector and preserves the averaging over the circle with diameter θH.

The positive conical lens *14* makes it impossible to increase the laser radiative power, since an electric breakdown of the air can occur in the caustic region. It is difficult to fabricate a negative lens. Therefore, a reasonable approach should be to employ a kinoform with the properties of a negative conical lens with preset parameters.

Thus, the ground–based and airborne experiments have shown that sensing of clouds located at distances up to 10–15 km can be performed. All kinds of underlying surfaces can be observed at the limiting flight altitude of the AN–30 aircraft– laboratory. The range of sensing of the cloudless atmosphere in the current regime of operation of the photodetector is about 1–2 km, and aerosol emissions (dust and smoke plumes) can be detected from a flight altitude of 5–6 km.

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