SPECULAR REFLECTION FROM ATMOSPHERIC NONSPHERICAL PARTICLES

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Received June 8, 1994

The results of floodlight sounding of atmospheric layers with spatio–oriented nonspherical particles are represented in this paper. It is shown that components obeying the regularities of diffuse scattering and specular reflection occur in the scattered radiation as a result of interaction of the directional optical radiation with such a layer. Depending on observational conditions the intensity of specularly reflected component may be several times higher than the intensity of radiation diffusely scattered in the same direction.

The results of interaction between electromagnetic radiation and nonspherical atmospheric particles with anisotropic properties are of both scientific and practical interest. Of special importance is the interaction of the directional optical radiation with spatio–oriented atmospheric crystals of ice, whose ratio of dimentions to radiation wavelength is much more than unity. Such particles are of frequent occurrence in the Earth's atmosphere, they are classified as large (gigantic and supergigantic), they are characterized by variety of shapes, and they have large reflectances.[1] The laws of geometric optics, in addition to the wave theory, can be applied to them.[2,3]

The specific property of the Earth's atmosphere is the temperature inversions observed in different climatic zones in all seasons not only near the Earth's surface but in the free atmosphere as well. In the atmospheric layers related to temperature inversions the turbulence and vertical motions are substantially attenuated or absent.[4] The aspects of aerodynamics of atmospheric nonspherical particles are considered in detail in Ref. 5. It is shown that in a wide range of values of Reynolds number such particles can be steadily oriented with their largest radius perpendicular to the incoming flow, so that maximum aerodynamic resistance is provided. Ice crystals entering the layers related to temperature inversions and moving under the action of gravity and resistance to incoming air flow can be steadily oriented in space, with the largest aerodynamic radius parallel with the planet surface, giving anisotropic properties to the atmosphere as a medium of radiation propagation.

Taking into account what has been said above the hypothesis on specular properties of the layer of nonturbulent atmosphere containing many spatio–oriented ice crystals was formulated. In practice a specular reflection from this layer can be recorded in a rather simple and reliable way by the observer being in the same plane with optical radiation incident on the layer and reflected from it taking account of the law of equal angles of incidence and reflection. The temporal stability of specular reflection will depend on stability of spatial orientation of ice crystal clusters. In this case a virtual image of the light source must be observed against the background of diffuse scattering on molecules and aerosol. The variety of ice crystal shapes, variations of their concentration in the volume illuminated and the degree of orientation, and the presence of particles without the pronounced specular properties cause variations of reflecting properties of such a layer.

To check the hypothesis described the experimental scheme was developed, the observations over the area of examination with inversion layers were made, and the levels of brightness of diffuse scattering and specular reflection were estimated. The observation were made at night in fall and winter. The meteorological service information was used when estimating the observational conditions.

Figure 1 depicts a geometry of the experiment, where S is the radiation source; S' is its virtual image; N is the observer (recorder) position; and OO' is the conventional axis of the layer containing spatio–oriented nonspherical atmospheric particles.

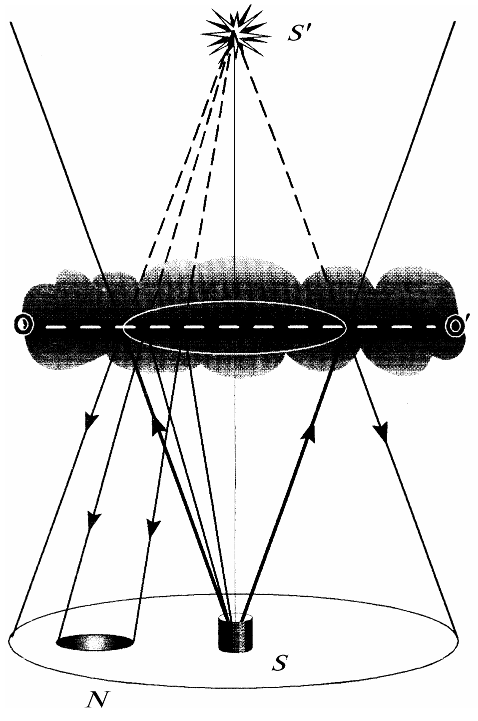
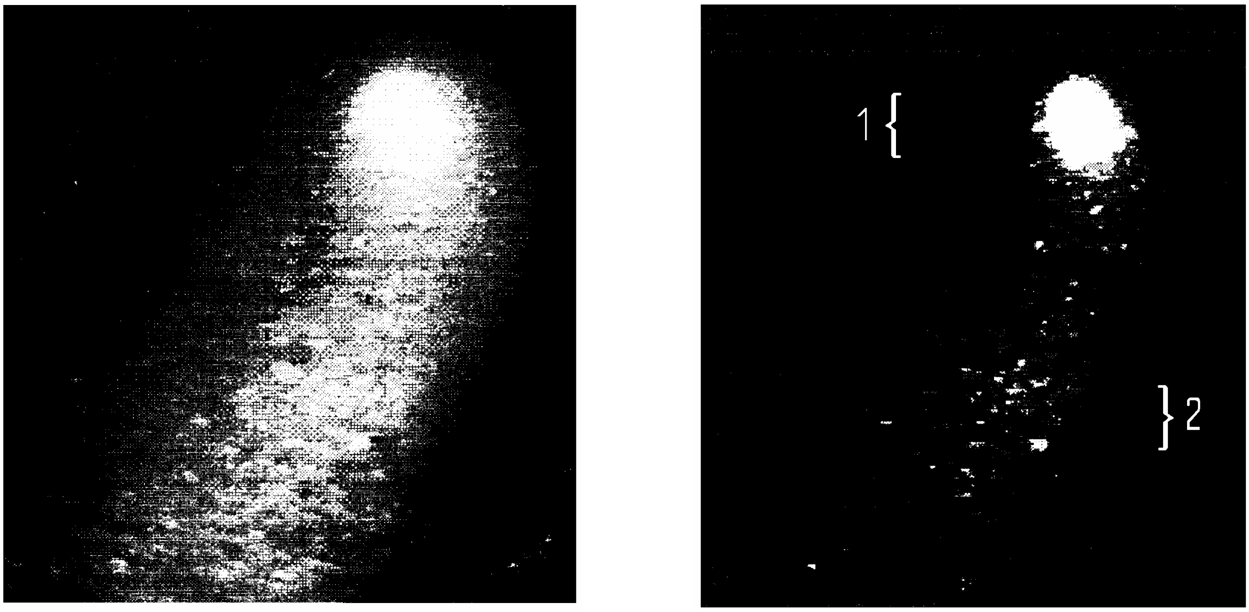


FIG. 1.

In this experiment we used a floodlight setup in which arc xenon superhigh–pressure lamps DKSSh–4000 were used as an emitter. The spherical mirror was 500 mm in diameter. It was possible to retune the polar diagram within 1 to 30° with variation of sounding direction within 25° out of the vertical and 90° in horizontal plane. The spectral characteristics of the lamp DKSSh–4000 and the Sun in the visible spectral range practically coincided. The video camera HITACHI–600 was used as a recording device. The emitter and recorder were positioned according to a bistatic scheme of sounding with a variable base (from 1 to 100 m). The scanning with a field of view with respect to a floodlight beam was accomplished using the video camera.

In the experiments carried out during two years in fall and winter we observed regularly a specular reflection from the layers of spatio–oriented crystals related to temperature inversions of both frontal and ground types. A luminous cone of diffuse scattering of radiation on atmospheric particles was usually observed during operation of the setup (with the floodlight beam directed toward the zenith and constant characteristics of the emitter). But in some cases the observer, when moving away horizontally from the floodlight at a distance up to 100 m, could visually observe a bright <star–shaped> spot in the direction of sounding. The effect was stable during some hours. Depicted in Fig. 2*a* is the image specific for this situation which was obtained using a video camera positioned horizontally 2 m from the floodlight. Figure 2*b* gives the results of image processing to find maxima of the brightness structure.



a *b*

FIG. 2.

There are two areas of increased brightness in the image: a virtual image of the source (number 1 in Fig 2*b*) in the upper part of the pattern and a region of elevated brightness (number 2) due to diffuse scattering on atmospheric particles below. The shape and brightness of the spot (1, Fig. 2*b*) depended on meteorological situation and changed from bright and star–shaped to blurred, slightly differing by brightness from the diffusely scattered radiation in the direction to the observer (2, Fig. 2*b*).

The observer, first being outside the zone of the effect visibility, observed the aforementioned phenomenon when increasing the polar diagram of radiation or changing the zenith angle and the sounding azimuth in its direction. As the floodlight was inclined to the observer, the latter observed variations in the beam brightness accounted for by the scattering phase function and geometry of beam section with atmospheric layers. With specific tilt of the floodlight the observer noticed sharp increase of brightness at some angular departure in the upward direction from the anomaly scattering layer (i.e., out of the beam axis). The <spot> brightness increased as the width of the polar diagram of radiation decreased and attained its maximum with minimum divergence of the beam. In the following we give the brightness level relations caused by specular reflection and diffuse scattering which were obtained during observations of the effect of specular reflection from the 2–m distance and 60 m from the floodlight axis when direction of radiation changed. Brightnesses of the light source virtual image are reduced to the same level (255) in the scale of conventional units (0–255).

Remoteness of the observer from the light source (observation base), m	2	60
Virtual image brightness B_* (relative units)	255	255
Diffuse scattering brightness $B_{\rm d}$ (relative units)	240	12
Brightness ratio $B_*/B_{\rm d}$	1.06	21(!)

The analysis of the results reveals that in both these cases the brightness of the light source virtual image exceeded that of diffuse scattering. This clearly demonstrates the importance of specular reflection in interaction of optical radiation with the atmosphere which contains spatio–oriented ice crystals. In the observed situations, with ground temperature inversion and vertical direction of sounding, the observer was in the cone of reflected radiation at distances not more than 30 m. At frontal inversions, this remoteness was larger than 100 m that enabled us to assess the layer height being less than 800 and 3000 m, respectively. Several spots of different brightness located on the same line and sometimes connected with a relatively bright connector were often observed in place of single bright spot. This may be related to several sublayers in the reflecting layer which contain spatio–oriented ice crystals of different shape and size.

Figure 3 depicts the image and scheme which presumably accounts for the observed phenomenon.

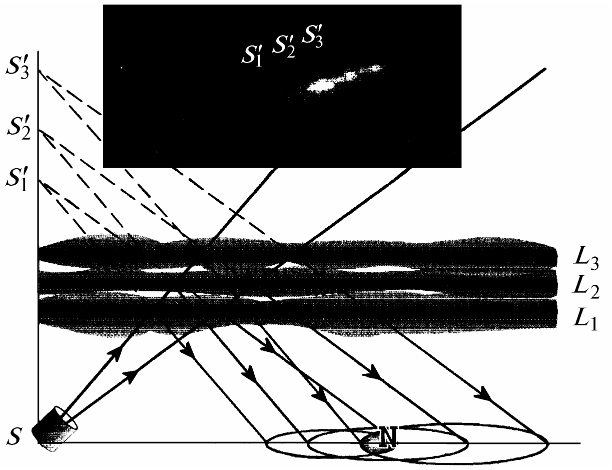


FIG. 3. Fragment of video frame (removed at a 100 m *distance from the floodlight) and scheme of complicated reflection formation during slant sounding: S – floodlight, N – observer,* S_1', S_2', *and* S_3' *are virtual images of the floodlight on the reflecting layers* L_1, L_2, *and* L_3.

Neglect of specular reflection of optical radiation from a cluster of spatio–oriented nonspherical atmospheric particles (ice crystals) can distort the model representations, make interpretation of the results too difficult, and result in incorrect elucidation of some phenomena observed in the atmosphere (e.g., appearance of UFOs). In particular, in slant optical sounding a portion of radiation can be drawn aside from the direction of sounding. In this case it is impossible to correctly take account of the level of energy supplied to the sounded volume located above the inversion layer. In vertical sounding a portion of radiation reflected towards the receiver can cause light overload of the photoreceiver since the appearance of specular component in diffusely scattered radiation manifestes itself as sharp increase of the optical signal amplitude. Moreover, the specular component should be taken into account in calculation of radiation balance of the <Earth–atmosphere> system.

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