CONTRIBUTION OF INDIVIDUAL ATMOSPHERIC LAYERS TO OPTICAL INSTABILITY OF THE ATMOSPHERE OVER SOME REGIONS OF THE COMMONWEALTH OF INDEPENDENT STATES ACCORDING TO DATA OF AEROLOGICAL OBSERVATIONS

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Large-scale characteristics of the optical instability of the Earth's atmosphere (OIEA) up to the height of 30.5 km *are being studied as calculated using data acquired at the aerological network throughout the CIS territory. The contributions of the boundary layer and free atmosphere to the OIEA over various regions during a year are estimated. Average duration of the optically calm periods of the atmosphere is determined. It has been established in this study that two cycles of the OIEA oscillations are observed over Yakutia and Far East during a year.*

Studying of the astronomical climate over the localities intended for mounting high resolution telescopes requires, first of all, estimation of the optical instability of the Earth's atmosphere (OIEA) and its individual layers. By OIEA it is usually meant the degree of inhomogeneity of the refractive index along a line of sight. The atmospheric stability is normally estimated with highly sensitive telescopes. Besides, some layers of the air are estimated comprehensively by use of tall meteorological masts, sodars, sounding balloons, airborne laboratories, etc. Most of these experiments have been carried out during a limited time and refer to one, or only sometimes to several points. We believe it to be more expedient to complete and generalize the results of these studies by studying larger-scale background characteristics of the optical instability obtained at the network of aerological observations.

To determine characteristics of the optical instability of the Earth's atmosphere over the CIS, we have used 10-year data from 50 aerological stations on the root-mean-square values of the day-to-day differences in temperature, average air temperature, and atmospheric pressure at 15 standard baric levels starting from the surface and up to 10 hPa (~ 30.5 km) level.[1] The contribution of calculated root-mean-square deviations, in percent, of the refractive index is determined at each level with respect to the mean sum for all the levels. The mean vertical profile of these deviations is also determined for all the stations. It characterizes the OIEA over the entire CIS territory thus being a certain scale for this territory.[2]

Of course, the contributions coming into the OIEA from individual atmospheric layers over that large territory are different. The averaged estimates demonstrate that optical activity of the boundary layer which is most turbulized (BL up to the height of ~ 3 km) compares to the entire upper layer which is called the free atmosphere (FA). Here FA is considered as the layer from ~ 3 to ~30.5 km. Optical instability of the BL and FA for a given territory is often compared in the investigations. This makes it possible to find regions with low level of optical instability of FA and BL in some seasons.

Figure 1 presents annual mean contribution of different air layers to the optical instability of the atmosphere. It has been obtained by averaging data from 50 stations over 10-year period. Curve *1* in the figure reflects the contribution of lower layers relative to the upper ones; curve *2* reflects the contribution of the upper layers relative to the lower ones. The contribution of FA and BL is 51 and 49%, respectively. For some stations, this relation has a considerable spread and depends on season. For instance, for the "Leningrad" station, the ratio is 75 to 57% in winter, and 45 to 35% in summer; at the "Yakutsk" station, the ratio is 56 to 45 and 39 to 35%, respectively, and so on. The data from this figure enable one to estimate the mean contribution of a layer (e.g., a 1-km thick layer) at any height below 30.5 km for a given territory. For instance, the lower 1-km layer yields ~ 18%, the next 1-km layer yields ~ 10%. To "reduce" the action of optical inhomogeneities, for instance, by 95%, one should go up to ~ 16 km.

In our opinion, a point with lower value of optical instability of FA is preferable, as it follows from a comparison of estimated contributions of FA and BL. These are "Aldan" (34% in February), "Tashkent" (37% in May), "Dushanbe" (37.3% in October), "Alma-Ata" (37.8% in September), and "Ashkhabad" (37.1% in October). Note that optical activity of the BL at these stations, in the same months, is also weak.

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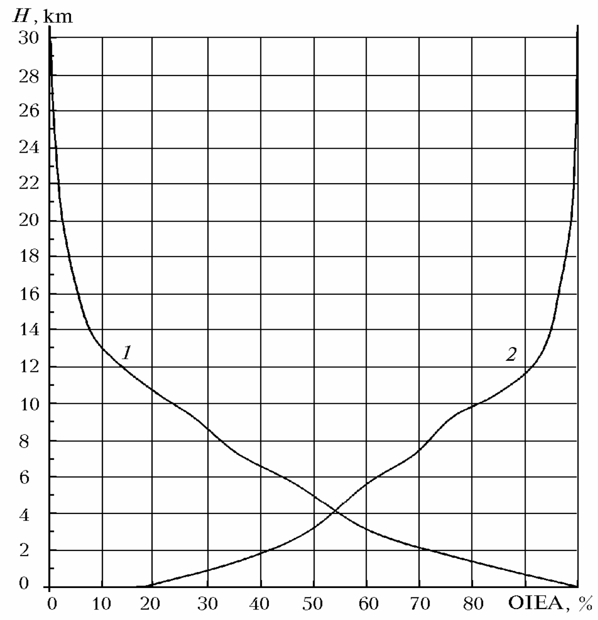

FIG. 1. The annual mean contribution of different air layers to the optical instability of the atmosphere according to 10-year aerological data of 50 stations.

Estimates of contributions from the FA and BL to the OIEA have been done in several Russian and foreign papers. In the La Palma observatory,[3] according to observations with a monitor of the Sun's image quality, as well as from measurements of temperature pulsation at the mast and captive balloons, the FA and BL contributions were estimated as 41 and 56%, respectively. Besides, the contribution from the surface layer to the OIEA was also determined (3%). The authors of this paper have arrived at a conclusion that the contribution of the free atmosphere is approximately the same as at Mauna Kea and La Silla. The boundary layer there is more turbulized than at La Silla.

As shown in Refs. 4 and 5 the contributions of the boundary layer (0–3 km) and free atmosphere (> 3 km) to the turbulent optical factor ($\int_0^\infty C_n(h)\mathrm{d}h$) are approximately the same as it follows from observations of stars with a shift interferometer and scidar. The problem on determining the height of atmospheric layers with the largest contribution to image jitter was studied in a series of Russian papers. According to facts presented in Ref. 6, the jitter of star images is caused by lower layers of the troposphere. Observations of the Sun, the Moon, and stars[7–9] in Pulkovo demonstrate that optically active layers of the atmosphere are at heights from 200 m to 2.5 km (in some cases, up to 8.5 km) in the afternoon, and from 600 m to 6.5 km at night. On some nights, those were observed at the height of 9 km. At the same time, according to the results of cinematography of the Sun,[10] the most probable height of optically active layers does not exceed 70 m. In Ref. 11, according to observations of star images' jitter, the efficient thickness of optical inhomogeneities does not exceed 500 m. The same height is presented in Ref. 12.

In more recent papers, the heights of the efficient optically unstable layers are higher and in fact begin to coincide with the OIEA estimation presented in Fig. 1. In Ref. 13 there is presented vertical profile of C_n^2 estimated from the star images jitter. Depending on C_n^2 near the Earth's surface, the boundary 1-km layer contributes 84, 75, and 50%. From that it follows that the overlying atmospheric layers contribute 16, 25, and 50%, respectively. The values of C_n^2 presented in Ref. 13 demonstrate that atmospheric layers above 1 km heights start to bring the main contribution at the improved quality of star images. Note that, according to our data at the station "L'vov," nearest to Uzhgorod, the atmosphere is rather stable in summer, and the contribution from FA also increases with the OIEA decrease. This is characteristic of almost all the stations.

In Ref. 14, based on a large bulk of observation data on the star image jitter obtained with a FEP device, the image quality is shown to be mainly determined by the layers above 0.5 km height. From the measurement data on the star jitter at Assy-Turgen plateau (H = 2700 m), the contribution of the surface layer of thickness 25 m is estimated to be 11–18%.[15]

It should be noted that numerical estimates in the above cited papers keep within the limits of our data in the majority of cases, regardless of a considerable spread. Besides, one should keep in mind that the conclusions in almost all the papers are drawn based on relatively short observation series of the duration about few days and only rarely up to one year and longer.

Optical instability of the boundary layer and free atmosphere is governed, in a certain sense, by different factors. Turbulence of the boundary layer is formed directly under the influence of the underlying surface and outer thermodynamic factors.[16] Turbulence in the free atmosphere is formed only by the thermodynamic factors. In this connection, the optical instability of the BL is more unsteady than that of the FA.

An attempt to obtain the minimal height above sea level below which one must not build observatories was undertaken in Ref. 17 based on the C_n^2 measurements by use of radiosondes. According to our estimates, the rise to isolated mountain tops may provide for an average improvement of 10–20% per 1 km what well agrees with the estimates in Refs. 17 and 18. However, to find the optimum height, the data on optical instability of the BL are yet insufficient. Estimates of optical instability of the FA are also needed. As follows from qualitative reasoning in Ref. 19, the optical instability of the FA sets, say it so, the "background" of an image quality which varies little from place to place. This is true to life only for a limited territory, while the seasonal variation of the optical instability can be considerable in this case too.

Contribution of the atmosphere to image distortion decreases with increasing height and, according to data of optical observations,[20] it is 12–28% from the layers above 9 km. Returning to Fig. 1, where curve *2* demonstrates annual mean contribution coming to the optical instability from the upper atmospheric layers as compared to that from the lower ones, we see that the interval mentioned in Ref. 20 agrees with the data presented in this figure.

As was established in Refs. 21 and 22 by use of micro-temperature radiosonde observations, turbulence in the free atmosphere is similar in different observation points (observatories in Sacramento Peak, Canary Islands, and other). Based on this fact, the authors suppose that the FA turbulence has a similar effect upon the image quality throughout the globe. But, our data make us to argue this statement for at least two reasons. First, optical instability of the FA is subject to seasonal variations, at least in the midlatitudes (according to our data it may reach 15–20%). Second, the FA instability varies from station to station, and the difference can be from 20 to 30% in some seasons.

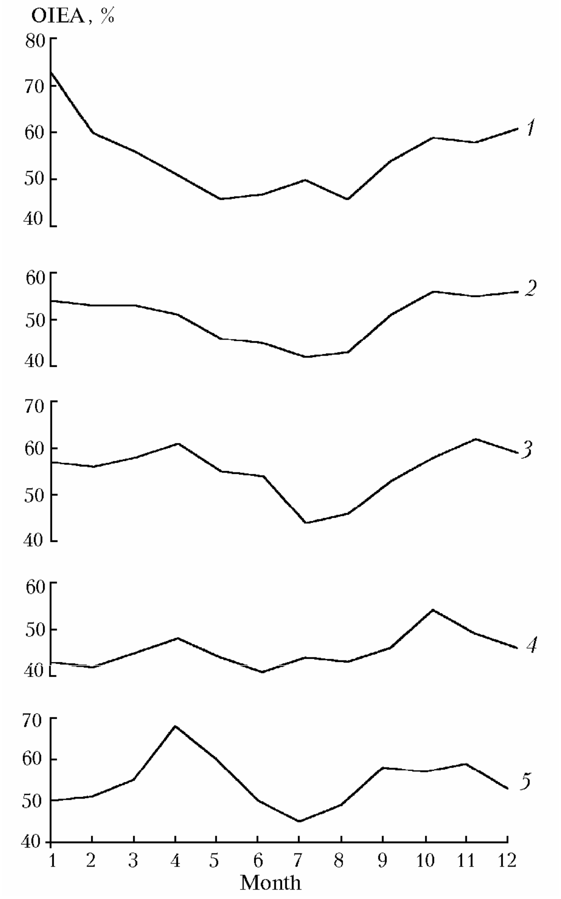

FIG. 2. The month-to-month variations of the optical instability of the 3–30.5-km *layer within one year over different regions: the western coast (1), Central European Russia (2), the West Siberian Plain (3), Yakutia (4), and the eastern coast (5).*

It should be noted that variations of optical instability of the FA are the lowest in summer over the whole CIS territory (5–10%) excluding "Arkhangelsk" station where the difference is 19%. Besides, seasonal variations are small in some regions, e.g., over Southern Kazakhstan, Central Asia, and over the Arctic Ocean coast. Thus, in particular, at "Cape Chelyuskin", "Olenek", and other stations the seasonal variations may account only a few percents. Since the problem on the optical structure of the inhomogeneities is important for astroclimatic conceptions, it is worth considering it in a more detail.

Figure 2 presents variations of the FA optical instability over the regions from the western coast (curve *1*) to the eastern coast (curve *5*) within a year. The main features of the optical instability fluctuations are the amplitude and periodicity of the fluctuations. Stations that are situated at the coast have larger amplitude of fluctuations (22–27%) as compared to those at the continental ones (12–19%) and higher (annual mean) optical instability. It is of a certain interest that two cycles (second harmonics) appear in the annual variation of the optical instability over Yakutia (curve *4*) and eastern coast (curve *5*). The second harmonic is already clearly seen over the West Siberian Plain (curve *3*). The double cycle of annual fluctuations is followed up to the tropopause (H ~ 12 km).

Figure 3 presents annual variations of the optical instability throughout the whole layer (0 – 30.5 km), in accordance with Fig. 2, over the western coast, Central European Russia, West Siberian Plain, Yakutia, and the eastern coast (they are designated by figures *1–5*, respectively). Here the fluctuations have larger amplitude and, consequently, are better pronounced.

The dual cyclic recurrence during a year is probably caused by a stabilizing effect of the Asian anticyclone in winter.[23] Its effect can be seen up to the tropopause.

The optically more calm period in July can be observed not only at western stations. For instance, if we take 90% OIEA level (denoted by dashed lines in Fig. 3), i.e., better than the average one by 10% for a chosen territory, the longest period (7.5 months) is observed over Yakutia. Corresponding periods over Central European Russia, Far East, the western coast, and the West Siberian Plain are 3.8, 2.6, 3, and 2 months, respectively. Let us note one salient feature. In July, optical instability is 68% of the average value characteristic of Central European Russia, i.e., it is the most optically quiet atmosphere among the regions presented in Fig. 3. Perhaps, this fact made it possible to obtain test photographic pictures of the Sun from the ground near Volsk with a high resolution. In terms of quality, the pictures are almost on a par with the pictures taken with the stratospheric sun telescope from Pulkovo (quoted from the oral presentation by Doctor V.N. Karpinskii, State Astronomical Observatory, Russian Academy of Sciences, Pulkovo, 1990).

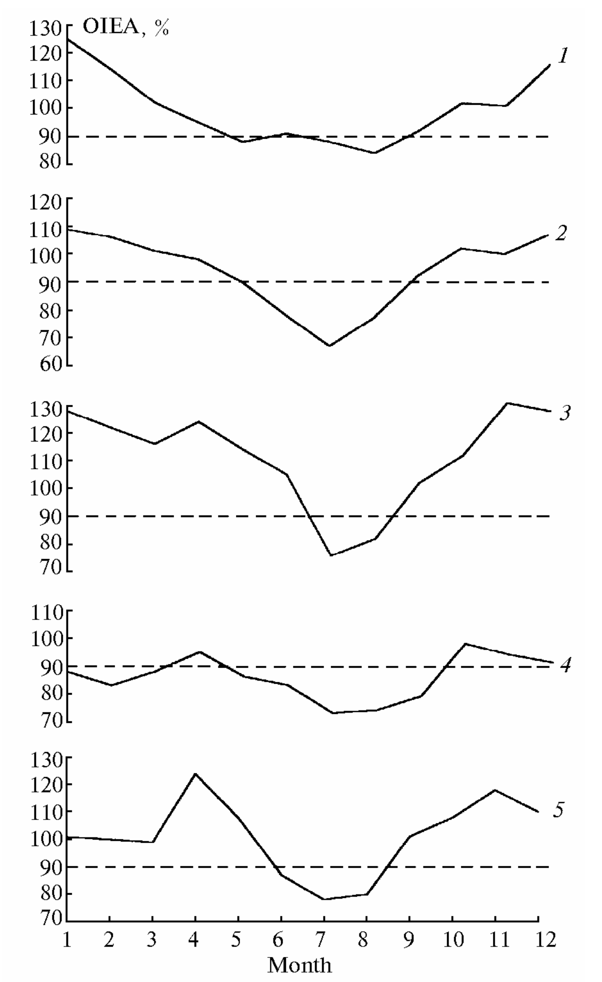

FIG. 3. Annual OIEA variations over different regions: the western coast (1), Central European Russia (2), the West Siberian Plain (3), Yakutia (4), and the eastern coast (5).

For a comparison, Fig. 4 presents annual variation of the optical instability over island stations "Barentsburg", Heis island, Bering Island, Simushir Island, and "Yuzhno-Sakhalinsk." Note that the atmosphere is more quiet over west islands near to the pole, what is especially true in the case with the FA layer. This fact must be taken into account when selecting promising places for polar astronomical stations.

Let us now consider the region of Central Asia, South Kazakhstan, and Caucasus. Here (Fig. 5) the optical instability during a year is the lowest one, as compared with the other regions considered. The best time for observations here is August. The free atmosphere contributes from 35 to 45% of the OIEA. The duration at the 90% level is 12 months. According to observations at the Pamir solar telescope[24] mounted at the Shorbulak pass, image quality sharply deteriorates in winter (in December) and duration of the periods with resolution better than a second of arc decreases to 0.14%. At the same time, in summer, the duration reaches 20%. These estimates qualitatively agree with the OIEA variations over Central Asia (~ 80% in winter and ~ 60% in summer).

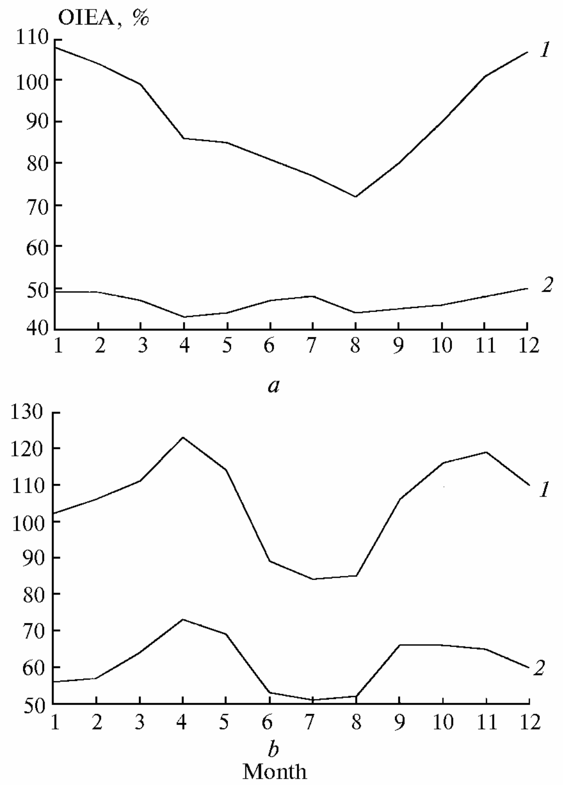

FIG. 4. Annual OIEA variations in the layers: 0–30.5 km *(1) and* 3–30.5 km *(2) over island stations: North-West part of Russia (a); Russian Far East (b).*

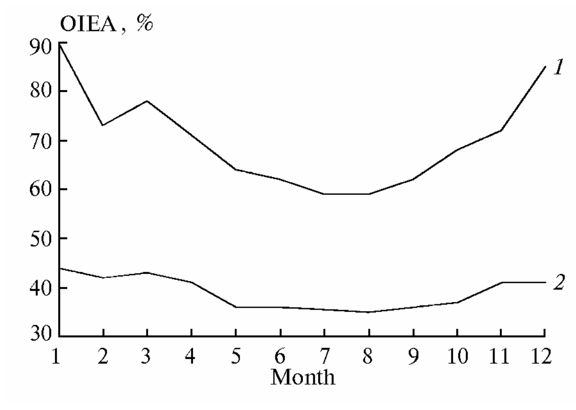

FIG. 5. Annual OIEA variations in the layers: 0–30.5 km *(1) and* 3–30.5 km *(2) over Central Asia, Southern Kazakhstan, and Caucasus.*

In summer, the OIEA level is less than 80% practically over the entire territory considered (except the western coast). However, the duration of this period is longest over the Central European Russia and Yakutia. This fact should be taken to account when developing the search astroclimatic programs.

REFERENCES

1. *The New Aerological Handbook of the Free Atmosphere*, Vol. 1; 11 (Gidrometeoizdat, Moscow, 1980).
2. P.G. Kovadlo, in: *Abstracts of Reports at the Third International Symposium on Atmospheric and Oceanic Optics*, Tomsk (1996), pp. 41–42.
3. S. Vernin and C. Minoz-Tunon, Astron. and Astrophys. **257**, No. 2, 811–816 (1992).
4. C. Roddier and J. Vernin, Appl. Opt. **16**, No. 8, 2252–2256 (1977).
5. R. Barletti, G. Ceppatelli, L. Paterno et al., J. Opt. Soc. Am. **66**, No. 12, 1380–1383 (1976).
6. N.I. Kucherov, in: *Proceeding of the Conference on Star Scintillation* (Academy of Sciences of the USSR, Moscow – Leningrad, 1953), pp. 183–202.
7. A.N. Demidova, in: *Atmospheric Optics* (Nauka, Moscow, 1968), pp. 8–12.
8. A.N. Demidova, in: *Sun Data. Bulletin No. 2* (Nauka, Moscow, 1976), pp. 102–105.
9. N.V. Bystrova and A.N. Demidova, Izv. Gl. Astron. Obs. Pulkove **22**, issue 4, No. 169, 89–98 (1961).
10. U.I. Il'yasov, in: *Sun Data. Bulletin No. 1* (Nauka, Leningrad, 1973), pp. 92–96.
11. I.T. Kolchinskii, *Optical Instability of the Earth's Atmosphere According to Observations of Stars* (Naukova Dumka, Kiev, 1967), 230 pp.
12. M.A. Kallistratova, in: *Atmospheric Optics* (Nauka, Moscow, 1968), pp. 12–22.
13. V.Ts. Klimik, I.I. Motrunich, and I.V. Shvalagin, in: *Atmospheric Instability and the Adaptive Telescope* (Nauka, Moscow, 1988), pp. 120–122.
14. A.S. Gur'yanov, M.A. Kallistratova, A.S. Kutyrev, I.V. Petenko, P.V. Shcheglov, and A.A. Tokovinin, Astron. and Astrophys. **262**, No. 1, 373–381 (1992).
15. B.I. Demchenko and E.G. Mychelkin, in: *New EGuipment in Astronomy*, issue 6 (Nauka, Leningrad, 1979), pp. 175–182.
16. A.M. Obukhov, *Turbulence and Dynamics of the Atmosphere* (Gidrometeoizdat, Leningrad, 1988), 414 pp.
17. C.E. Coulman, Techn. Rept. LEST Foundat. No. 28, 205–211 (1987).
18. O.B. Vasil'ev, in: *Atmospheric Optics* (Nauka, Moscow, 1974), pp. 31–34.
19. V.G. Khetselius, in: *Astroclimate and Telescope Efficiency* (Nauka, Leningrad, 1984), pp. 142–150.
20. J.L. Bufton, Appl. Opt. **12**, No. 8, 1785–1793 (1973).
21. R. Barletti, G. Ceppatelli, and L. Paterno, Astron. and Astrophys. **6**, No. 54, 649–659 (1974).
22. G.C. Loos and C.B. Hogge, Appl. Opt. **15**, No. 18, 2654–2661 (1979).
23. I.V. Maksimov and V.P. Karklin, Izv. All-Union Geofiz. Obs. **101**, No. 4, 320–330 (1969).
24. Kh.I. Abdusamatov, A.G. Zlatopol'skii, G.V. Komissarov, and N.N. Lakshin, in: ATS, No. 1466, pp. 1–3 (1986).