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The possibility of investigating aerosol layers by twilight method

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1. The existing twilight theory supposes that the scattering is produced by the air molecules only, and that a small contribution of large aerosol particles is negligible. But, as already stated in a previous paper (Megrelishvili 1956), the presence of aerosol particles of meteor origin in upper atmosphere is likely to be one of the causes of the additional twilight sky brightness. It is detected in comparing the twilight data with rocket ones.

Generally speaking, the particles of terrestrial origin can also be present in the stratosphere having penetrated there from the troposphere by vertical mixing.

Bigg (1956) suggests that this makes the detection of meteor dust by twilight observations difficult. As this was first noted by Staude (1936), it is of interest to study dust particles in the upper atmosphere by twilight observations. She is of the opinion that the additional brightness can be explained by the scattering of light by meteor dust particles in the upper layers.

Staude has suggested a method for the detection of meteor dust based on the integral twilight brightness determination.

Recently a number of publications appeared dealing with the study of dust in terrestrial atmosphere, on the basis of meteor and twilight data and of lunar eclipse observations, as well.

Mention should be made here of the papers by Grandmontagne (1941), Link (1953), Vaucouleurs (1951), Karandikar (1955), Svestka (1954) and Bigg (1956).

The authors of some of them give evidence of twilight curves discontinuities that could be interpreted as an indication of the presence of some strongly scattering dust layers in the upper atmosphere. Let us discuss it in a more detailed manner.

It must be said that we never observed the above-mentioned discontinuities on our numerous twilight curves (more than 1500 twilight curves having been observed during 15 years of observations). It can possibly depend in some way on the transparency stability of tropospheric layers. The atmosphere above the Abastumani mountain observatory where our observations are carried out is characterised by a high transparency stability (Kharadse 1947, Nikonov 1953 and Megrelishvili 1946). In this connection the results obtained by Karandikar (1955) are of great interest. According to his careful measurements with a photoelectric differential twilight photometer such discontinuities are not being observed during the twilight. Karandikar emphasizes the fact that the atmosphere of the place of his measurements is characterized by a high transparency. He estimated the maximum thickness of a dust layer that could have been left unnoticed at the sky photometry. If one assumes the uniform distribution of dust particles having the radii 10-100 μ in the 3-km thickness layer, one obtains only the value 10^{-8} to 10^{-9} particles/cm^3 as a maximum concentration.

It should be borne in mind, however, that the absence of discontinuities on twilight curves does not necessarily mean the absence of dust particles in the upper atmosphere. It only indicates the absence of sharply outlined dust layers. If, as was reported by Link (1953), the dust layer occupies the whole atmosphere more or less uniformly, the discontinuities would not take place.

2. The most interesting conclusions about dust layers in the atmosphere based on twilight observations have been recently published by Bigg (1956). This work draws one's attention by its stating of the question. But as it seems to us, the method of the interpretation of observations used does not, however, allow for certain twilight theory statements and should be made considerably more accurate.

Bigg carried out his observations in the Sun's vertical at a 20° altitude.

A temperature sounding with sounding-balloons has been done simultaneously. Its results were compared with twilight observations represented by Bigg as the $1/I \times dI/dt$ ratio in the dependence on h (I=twilight intensity, h=Earth shadow height, t=time). Maxima of this ratio about h=15 km and h=80 km appeared as a regular feature of the curves obtained by Bigg. Three $1/I \times dI/dt$ ratio maxima were obtained near 15-20 km heights, temperature inversions being located at the same altitudes. Hence Bigg concluded that dust accumulations associated with inversions occurred at these altitudes.

3. Let us consider two questions in respect to which Bigg's suggestions are in contradiction with the twilight theory. We would try to show on their examples what a correctly applied twilight method could give in this case. In so doing, we will not go beyond the limits of the conceptions associated with the $1/I \times dI/dt$ ratio used by Bigg.

In the first place it concerns that atmospheric height to which either twilight measurements should be assigned. The Earth shadow height is wrongly used in this sense by Bigg, since h is not the height of maximum scattered light for a given zenith distance. A brief statement of the known twilight theory is necessary for the discussion of this question.

The twilight method theory for the study of the upper atmosphere is elaborated by academician Fessenkov (1923, 1930, 1937).

According to this theory, if the observations are being done in zenith, the observed twilight brightness can be defined approximately by

$$I = C\ (1+\cos^2 Z_0) \int_h^\infty I_h\ F(h)\ dh,$$

where Z_0 is zenith distance of the Sun, $F(h)$ scattering power of the air, I_h intensity of the solar rays lighting the zenith of the place and dependent on light absorption. Earth shadow height defines the lower limit of the integral, and the infinity—the upper one. Practically, only a comparatively thin layer contributes to the scattering so far as the scattering is insignificant in the upper layers of small density, and the low layers do not act because of a strong absorption in them. Thus, as was suggested by Staude, it seems as if only one sun ray surrounding the Earth at about 20 km distance from its surface takes part in the twilight phenomena. The height of an effectively scattering layer where we have a maximum scattered light is obtained from the formula —

$$h_{\text{eff}} = h + \frac{H_0}{\sin Z_0}$$

where h is the earth shadow height. H_0 is the same height equal to 20 km and present at all zenith distances. When applying the twilight method, the height h_{eff} becomes solely correct relative to which we should consider all phenomena occurring in the Earth's atmosphere and detected by twilight observations.

As can be seen from the above formula, even with the Earth shadow height being equal to zero, the effectively scattering layer height is about 20 km. Consequently, when the twilight method is applied this height is the least one of the atmospheric layers accessible to investigation, as was shown so long ago as in 1934 by Fessenkov (1937).

Having obtained maxima on curves $(1/I \times dI/dt, h)$ with 15-20 km Earth shadow height, Bigg compared them with temperature data at the same heights, as well.

But as a matter of fact, in comparing the twilight data with those obtained by other methods, we should take not the Earth shadow height (15-20 km in this case) but the height of the effectively scattering layer-in this case 35-40 km. Therefore, either using of Earth shadow heights or comparing them with the data obtained at the same height by other methods, is erroneous.

4. The second question in respect to which the results of Bigg seem objectionable to us, deals with the resolving power of the twilight method (in the sense of a more or less accurate determination of the height).

As it was said before, the twilight phenomena is produced at every given moment for each layer or as it can be said otherwise by a twilight ray some tens of kilometres thick.

Consequently, it can be supposed beforehand that two thin dust layers situated not far apart and compared with layer thickness cannot be detected by twilight method. The resolving power of this method in height is a value of the order of tens of kilometres. If closely disposed one to another maxima are observed on curves $(1/I \times dI/dh, h)$, — these maxima cannot be interpreted as literally reflecting the real changes of the atmospheric optical features at a given height.

Basing upon the twilight theory, one can demonstrate that two really existing sharply outlined layers, closely disposed (for instance, at 5 km apart), would not appear separately on twilight curves owing to a very thick twilight ray.

Let us assume that only sunlight molecular scattering determines the twilight sky brightness and take Rocket Panel data (*Phys. Rev.*, **88**, 5, 1952) for density distribution in height. Then, as it was already shown, it will result in the change of the ratio $1/I \times dI/dh$ with height (Megrelishvili, *Rep. Acad. Sci.*, USSR, **116**) represented in Fig. 1, curve 1. Let us further suppose that a sharply outlined 10-km layer is situated at 60-70 km height and is producing an additional glow equal in brightness to sunlight molecular scattering by the air in the same layer.

The estimations do not reveal in the ratio $1/I \times dI/dh$ (Fig. 1, curve 2) run any local features either in the 60-70 km layer or close to it. Significant deflections are seen from 30 to 90 km. The 65-km level (average height of a 60-70 km layer) is distinguished only by a changing of the sign of the differences between 'normal' and disturbed values of $1/I \times dI/dh$.

We are now particularly interested in the case when, save the discussed layer disposed at 60-70 km there is a second one 5 km below, having the same thickness and intensity as the first layer. The calculations show that the obtained ratio run in this case is such as represented in Fig. 1, curve 3. The comparison of curves 2 and 3 in Fig. 1 shows that curves having one and two layers differ only in greater value of the ratio $1/I \times dI/dh$ in the second case. Thus, twilight observations do not make it possible to separate the closely disposed layers. The reported evaluations indicate that individual maxima closely situated at 10-20 km heights obtained by Bigg (Fig. 2) cannot correspond to the real layers with additional scattering power (for instance, to dust layers), and accordingly comparison of these maxima with temperature data can give only fictitious results. The incorrectness of such comparison caused by the fact of these two data ranges belonging to different heights was noted above.

5. Certain considerations resulting from our observations are given below—

We have chosen a pair of twilight curves measured simultaneously (in the morning of

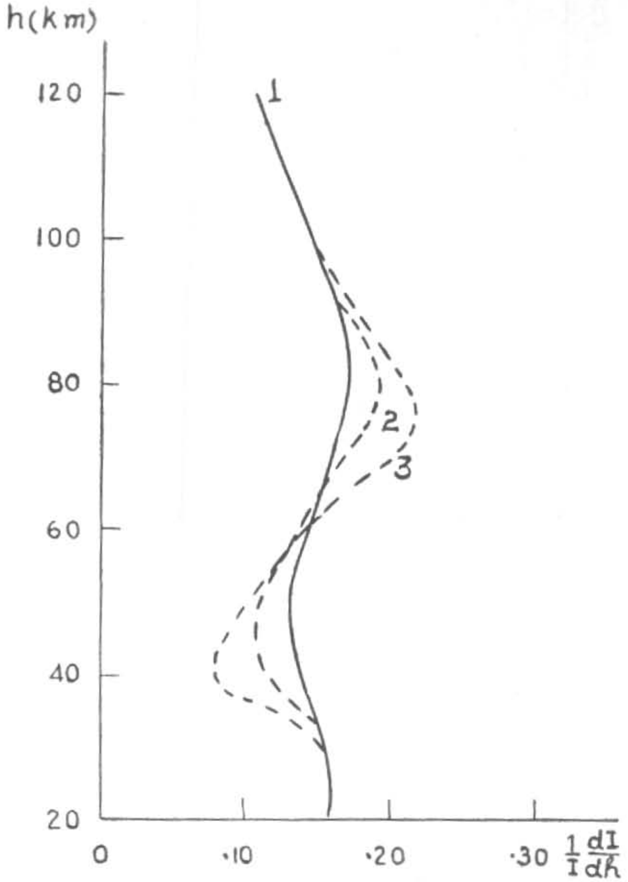
h(km)
120
100
80
60
40
20
0
·10
·20
·30
$\frac{1}{I}\frac{dI}{dh}$
1
2
3

Fig. 1

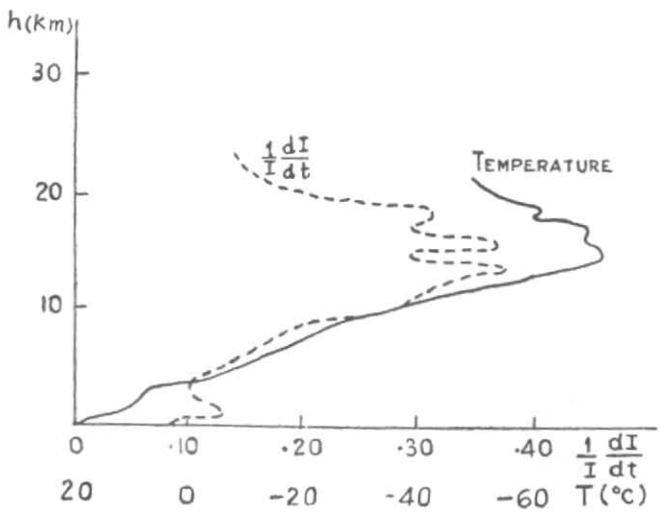
h(km)
30
20
10
$\frac{1}{I}\frac{dI}{dt}$
TEMPERATURE
0
·10
·20
·30
·40
$\frac{1}{I}\frac{dI}{dt}$
20
0
−20
−40
−60
T(°C)

Fig. 2

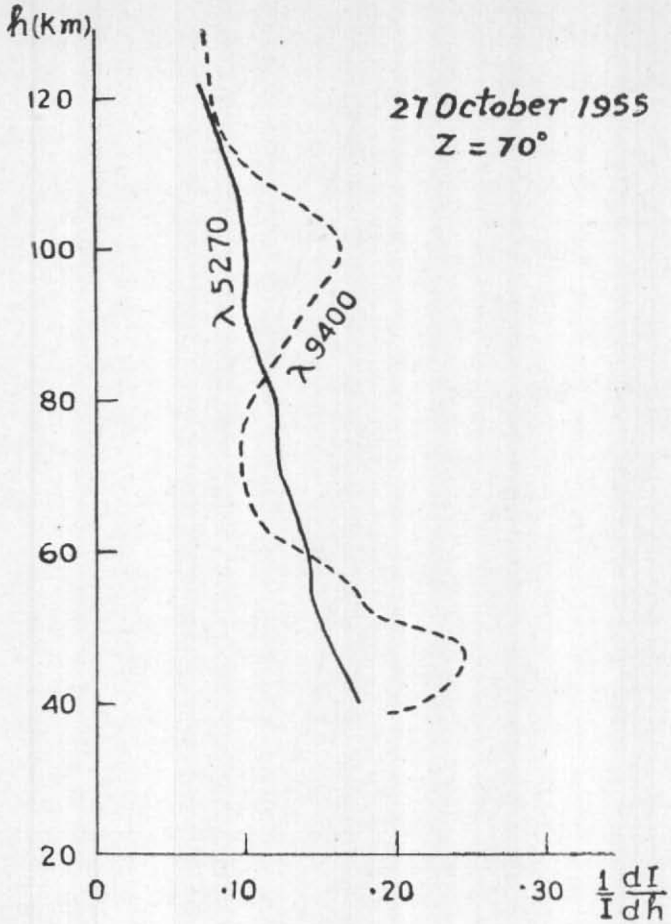

Fig. 3

27 October 1955) in two different spectral regions (for λ = 5270 Å and λ = 9400 Å).

The curves ($1/I \times dI/dh$, h_{eff}) represented in Fig. 3 were traced basing on our observations. The curve for λ = 5270 Å shows a continuous value $1/I \times dI/dh$ fall. That obtained in infra-red rays has, however, a quite different run. Both curves are constructed in relations to the effectively scattering layer height and not to the Earth shadow height.

The following can be said on account of the curve for λ = 9400 Å. Its real characteristics might be the maximum value of $1/I \times dI/dh$ at about 47 km; then, a decreasing and a second maximum at about 100-km height. The presence of evident maxima on curves ($1/I \times dI/dh$, h_{eff}) at about 45-50 km and 100 km, only in spectral region λ = 9400 Å with a continuous run of the curve for λ = 5270 Å permits to attribute these maxima to the fluorescence phenomena, and not to the contribution of dust particles, though we do not believe in the complete absence of dust particles influence.

Bigg has carried out his observations in the infra-red spectral region. He explains the maxima at h = 15-20 km (h_{eff} = 35-40 km) and h = 80 km (h_{eff} = 100 km) by the existence of dust layers. This conclusion would appear more well-grounded to us there being analogous maxima obtained from observations in other spectral regions. But with observations available only from one spectral region, these maxima might be explained, generally speaking, not only by aerosol particles action but by the fluorescence as well.

The fact of an approximate coincidence of maxima heights reported in Bigg's paper with maxima in our curves, is of interest.

6. We take this opportunity to express our sincere thanks to Prof. I.A. Khvostikov for his valuable advice and the discussion of our results.

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