VISIBILITY AND TELEPHOTOMETER

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Received April 29, 1984

ABSTRACT

This paper discusses the possible error of the calculation of the atmospheric extinction coefficient by the Koschmieder visibility formula. An analysis of the problem shows that an error of 10% can be introduced in the measurement if the target used is a non-blackbody. By using the telephotometer as a tool of measurement, such an error can be markedly reduced.

The concentration and characteristics of atmospheric aerosols are the key factors influencing the meteorological visibility. In recent years, visibility has been considered as one of the monitoring factors of air pollution and more attention has to be paid to it.

The early theory of visibility was developed by Koschmieder (1924)[1]. Koschmieder's formula showed that, for a homogeneous atmosphere, the meteorological visibility range R is inversely proportional to the extinction coefficient

$$R=\frac{3.91}{\beta_{ex}}. \tag{1}$$

But there are restrictions on using this formula. When using visibility as a factor of monitoring, one must take this point into consideration. There have been some works discussing about it[2,3]. In this paper, the concept of contrast transfer function will be discussed in brief.

Telephotometer is an instrument for measuring the meteorological visibility[4]. Differing from other visibility meters, this instrument measures the contrast directly. In this paper, we will discuss the telephotometer constructed by our department, together with some measuring results.

I. THE THEORY OF VISIBILITY

For one to distinguish any target from its background, the contrast, which is in most cases the brightness contrast, must be larger than the contrast threshold of eye

$$C=\left|\frac{B-B'}{B'}\right|, \tag{2}$$

where C is the brightness contrast, B and B' are the intrinsic brightness of the target and background respectively. If a target located at distance L is observed, the measured brightness varies with the atmospheric condition and the apparent contrast C_L is given by

$$C_L=\left|\frac{B_L-B_L'}{B_L'}\right|=\left|\frac{B-B'}{B'}\right|\left(1+\frac{D_L}{B'\cdot T_L}\right)^{-1}$$
$$=C\cdot Y, \tag{3}$$

where, $B_L=B\cdot T_L+D_L$, $B_L'=B'\cdot T_L+D_L$, T_L is the transmissivity of the atmosphere through distance L, D_L is the brightness of atmosphere cone within distance L, and $Y=\left(1+\frac{D_L}{B'\cdot T_L}\right)^{-1}$ is the transfer function of contrast. In general,

$$T_L=\exp[-\int_0^L \beta_{ex}(l)dl], \quad (4)$$

$$D_L=\int_0^L A(l)\exp[-\int_0^l \beta_{ex}(l')dl']dl, \quad (5)$$

where, A (l) is the brightness of volume element. If the target is surrounded by horizontal sky,

$$B'=\int_L^\infty A(l)\exp[-\int_L^l \beta_{ex}(l')dl']dl, \quad (6)$$

and the contrast transfer function

$$Y=\frac{\int_L^\infty A(l)\exp[-\int_0^l \beta_{ex}(l')dl']dl}{\int_0^\infty A(l)\exp[-\int_0^l \beta_{ex}(l')dl']dl}. \quad (7)$$

According to the concept of meteorological visibility, the target must be a blackbody against the horizontal sky and assume the contrast threshold of the observer's eye to be $\varepsilon=0.02$, the Koschmieder forumla can then be deduced.

Normally the target is a non-blackbody. The extinction coefficient calculated from the visual range by Koschmieder formula will be overestimated. If the brightness of the target is $B=\zeta\cdot B'$, then $C=|1-\zeta|$, the estimated extinction coefficient is given by

$$\beta'_{ex}=\beta_{ex}\frac{\ln\varepsilon}{\ln\varepsilon-\ln C}. \quad (8)$$

For a common target, $\beta'_{ex}>\beta_{ex}$, and when $\zeta<0.3$ the error of overestimation will not be over 10% (Fig. 1).

II. A TELEPHOTOMETER FOR MEASUREMENT OF THE METEOROLOGICAL VISIBILITY

Telephotometer is an instrument for measurement of the meteorological visibility. The main part of this instrument is a telescope in conjunction with a photometric measuring unit. The long focal length of the telescope's lens provides a small view angle of the instrument, so the brightness of target and its background can be measured separately.

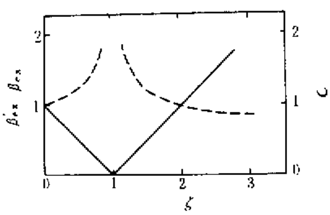

Fig. 1. Variation of C (solid lines) and β'_{ex}/β_{ex} (dashed lines) with ζ.

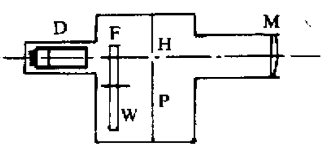

Fig. 2. Schemetic diagram of the telephotometer.

Fig. 2 is the schematic diagram of the telephotometer constructed by the Peking University.

An objective lens (M) with a focal length of 300 mm forms a real image on the plane P. The light through a small hole (H) enters the instrument and is detected by a filter–photo–multiplier system (F and D). A wheel (W) with 8 filters is turned by a motor at one cycle per min. The specification of the filters is shown in Table 1.

Table 1 The Specification of Filters

Channel	1	2	3	4	5	6	7	8
λ_{max} (Å)	4048	5000	5940	7195	7620	8815	9340	10600
Band Width (Å)	105	110	75	135	115	100	140	205
Transmission (%)	51	52	67	48	52	57	54	52

If one, by using the telephotometer, measures a blackbody target and its surrounding sky, the extinction coefficient can be calculated from

$$\beta_{ex}=\frac{1}{L}\ln\left(\frac{I_0}{I_0-I_1}\right), \tag{9}$$

where, I_0 is the measured brightness of sky and I_1 is the measured brightness of the target at distance L.

If the target is not a blackbody, one can select two targets at different distances with similar intrinsic brightness. If the brightness measured by the telephotometer are I_1 and I_2 respectively, we have

$$\beta_{ex}=\frac{1}{L_1-L_2}\ln\left(\frac{I_2-I_0}{I_1-I_0}\right). \tag{10}$$

The instrument was installed on the top of the Physics Building of Peking University. The distances from the building of two targets were 730 and 30 m respectively. Both targets were parts of some gray wall.

Fig. 3 shows a comparison between the visibility derived from measured extinction coefficients and the weather report by the Haidian Meteorological Station (one kilometer southwest from the observation point). It is evident that they are in good agreement with each other. Considering the error caused by the non–blackbody target, we calculate the extinction coefficient for one target (I_1) by

$$\beta'_{ex}=\frac{1}{L_1}\ln\left(\frac{I_0}{I_0-I_1}\right). \tag{11}$$

By reason of the intrinsic brightness of the target, β'_{ex} usually gives an overestimated value of β_{ex}. But there exists a linear relation between β_{ex} and β'_{ex} (Fig. 4). Assuming $B=\zeta\cdot B'$, we have

$$\zeta=a+b\beta'_{ex}, \tag{12}$$

and, consequently,

$$\beta_{ex,1}=\beta'_{e}+\frac{1}{L_1}\ln(1-a-b\beta'_{ex}), \tag{13}$$

where $\beta_{ex,1}$ is the extinction coefficient calculated from I_1 and corrected by the use of Eq. (12). Fig. 5 shows the relation between β_{ex} and $\beta_{ex,1}$. Almost all the points are in the same, the inclination of which is 45°.

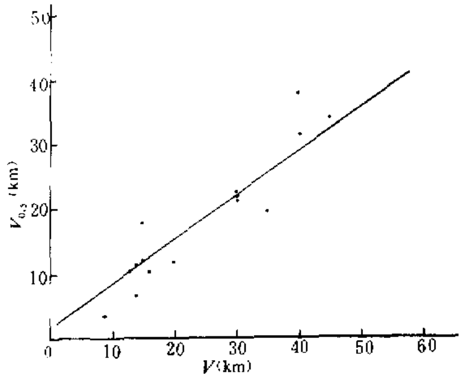

Fig. 3. Comparison between the visibility ($V_{0.5}$) derived from measured extinction coefficients and the weather report (V) by the Haidian Meteorological Station. $V_{0.5}=1.672\ \ 0.682V$, and the correlation coefficient $\gamma=0.81$.

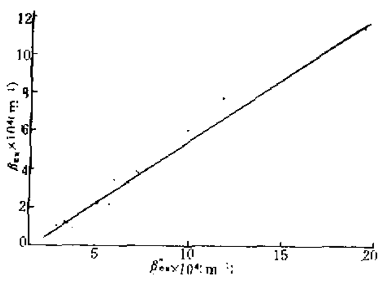

Fig. 4. The linear relation between β_{ex} and β'_{ex}.
$\beta_{ex}=-1.10\times10^{-4}--0.66\beta'_{ex}$. and the correlation coefficient $\gamma=0.99$.

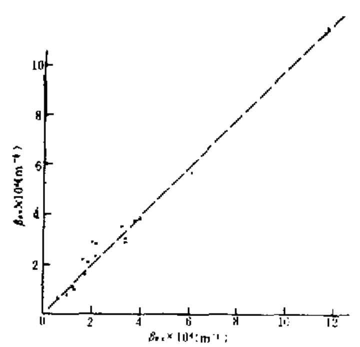

Fig. 5. The relation between β_{ex} and $\beta_{ex,1}$.
$\beta_{ex,1}=-6.16\times10^{-7}+\beta_{ex}$, and the correlation coefficient $\gamma=0.99$.

From the above discussion, it is evident that if the telephotometer can be used to make an observation for a period of time with a pair of targets and to obtain the empirical relation (12), then the following measurement of extinction coefficient by using the telephotometer with single target can be accomplished without appreciable error.

Another advantage of telephotometer is that it can be used to measure the spectrum of extincition coefficient without absolute calibration, so we can inverse the aerosols size distribution from the extinction spectrum. Fig. 6 gives the measured spectrum of extinction. Fig. 7 shows the inversed size distribution of atmospheric aerosols with the randomized–minimization–search–technique provided by Heintezenberg[5]. It is evident there is a secondary concentration maximum near the particle radius of 0.5 μm.

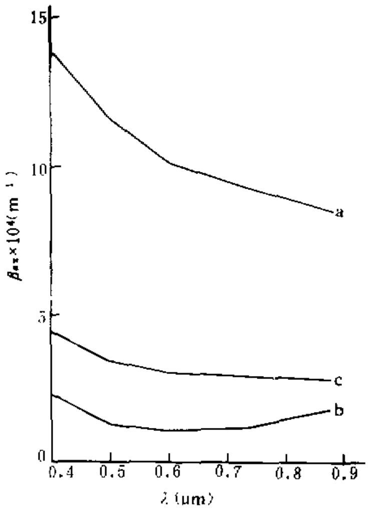

Fig. 6. The measured spectrum of extinction.
a—May 7, 1982; b—May 18;
c—May 17.

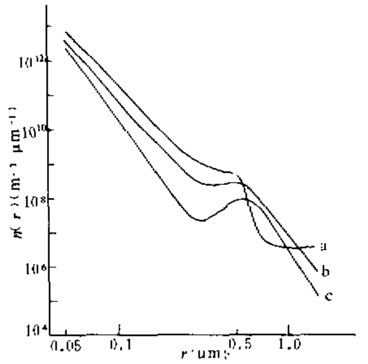

Fig. 7. The inversed size distribution of atmospheric aerosols.
a—May 7, 1982; b—May 18;
c—May 17.

III. DISCUSSIONS

The theory and observation results have shown that the non-blackbody target will give rise to an overestimation of extinction coefficient of not over 10 %. Using a telephotometer together with empirical relations, we can get a simple method to measure the extinction coefficient spectrum. It is used for many purposes.

The main problem of using the telephotometer is the inhomogeneous illumination of the sky light. An error over 100 % may be introduced. If the brightness of the target and that of the background are measured simultaneously this difficulty may be overcome.

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