SPECTRAL DEPENDENCE OF THE ATTENUATION OF BRIGHTNESS CONTRAST BY THE ATMOSPHERE

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ABSTRACT

A study has been made of the effect of wavelength on the attenuation of brightness contrast by the atmosphere. The results of the study have been expressed in terms of the variation in meteorological range with wavelength and indicate a linear relation between meteorological range and wavelength rather than a fourth power law, which might be expected on the basis of Rayleigh scattering. This linear relation has been found to hold for black objects and white objects for a wide range of transparencies of the atmosphere. From this result, it is concluded that even on the clearest of days there is in the atmosphere always an abundance of scattering nuclei of a size greater than molecular dimensions.

1. Introduction

It is the purpose of this paper to describe a study of the influence of wavelength on attenuation of brightness contrast by the atmosphere. Such a dependence might be expected to involve the fourth power of the wavelength, on the basis of Rayleigh [5] scattering. The result of a survey of the literature on this topic, by Middleton [4], would indicate that the attenuation coefficient β, upon which atmospheric attenuation depends, is of the form

$$\beta = A\lambda^{-\alpha}, \tag{1}$$

in which α ranges from 0.81 to 2.09. More recently, Schmolinsky [6] reported measurements for landscapes and forests, leading to a value of 0.92 ± 0.25 for α. The data reported by Middleton [4] indicate that α might approach the value given by Rayleigh for highly pure air, and that it would therefore vary with the transparency of the atmosphere. The results of the study presented in this paper show that α is very nearly unity for a rather wide range of transparencies of the atmosphere. The details upon which this conclusion is based are set forth below.

2. Apparatus and procedure

The apparatus and procedure used in this study are based on a law governing the attenuation of brightness contrast by the atmosphere. This law, derived by Koschmieder [3], may be expressed, in the form given by Duntley [2], as

$$C_R = C_0 e^{-\beta R}. \tag{2}$$

It gives the apparent contrast C_R, of an object of inherent contrast C_0, at a range R from a point of observation, at a time when the atmosphere has an attenuation coefficient β. From a practical point of view, it is often convenient to express the attenuation coefficient in terms of a quantity referred to as the "meteorological range." The meteorological range R_m has been defined by Duntley [2] as the range at which the contrast transmittance equals two per cent, and, therefore, would be related to the attenuation coefficient by

$$R_m = \beta^{-1} \ln (1/.02) = 3.91\beta^{-1}. \tag{3}$$

The meteorological range, thus defined, is a measure of the state of the atmosphere from the point of view of the range at which objects of different contrast would be visible, using a photosensitive receptor having a contrast threshold of two per cent.

In the present study, measurements were made by means of which the dependence of the meteorological range on wavelength could be determined. A photoelectric telephotometer and seven black and seven white visibility targets, located along a horizontal path over a range approximately eight miles long, were used. Each of the targets subtended an angle of 1.86 minutes of arc from the point of observation. For purposes of this description, the targets can be imaged as rectangular planes, one half white and the other half black, arranged normal to the line of observation. The smallest target was 6 × 12 inches and was at a range of 300 yards. The largest was 33 × 66 feet and was at a range of 15,267 yards.

The apparent contrast C_R of each of the targets was measured with respect to the sky background against which they were viewed. This contrast was defined in terms of the apparent brightness of the sky B_H, and the apparent brightness of a target B_R, as

$$C_R = (B_H - B_R)B_H^{-1}. \tag{4}$$

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A similar definition may be given for the inherent contrast C_O, in terms of the inherent brightness of the target (*i.e.*, at zero range) B_O, and the horizon brightness, which would not change appreciably over the eight-mile range. This latter definition is

$$C_0 = (B_H - B_0)B_H^{-1}. \tag{5}$$

The brightness quantities in (4) were measured for each of the seven black targets and each of the seven white targets by means of the photoelectric telephotometer mentioned, the details of which have been described elsewhere [1]. These brightness measurements were made as a set of seven runs. One set of runs consisted of making brightness measurements for each of five different filters inserted in the telephotometer and two runs in which no filter was used. The characteristics and designations of these filters are presented in table 1.

TABLE 1. Filter designations and characteristics.

Designation	Effective wavelength (Å)
A	4200
B	4530
C	5400
D	5770
E	6720
F	No filter

The time required to make the seven runs was approximately twenty-five minutes. Measurements of this type were made over a wide range of weather conditions, in which the meteorological range varied from a few thousand yards to about a quarter of a million yards. The measurements were made during periods in which the state of the atmosphere remained fairly constant over the twenty-five minute period required for the complete set. Whether or not the state of the atmosphere had changed was determined by comparing the meteorological ranges obtained with the telephotometer with no filter at the beginning and at the end of each set of runs.

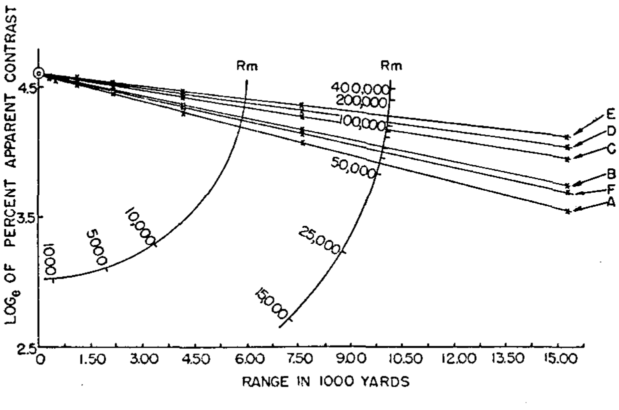

FIG. 1. Log$_e$ of per cent apparent contrast *vs.* range data obtained using various filters for black targets.

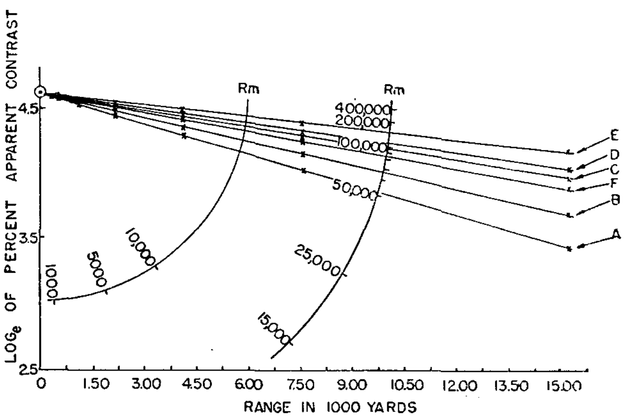

FIG. 2. Log$_e$ of per cent apparent contrast *vs.* range data obtained using various filters for white targets.

3. The data

A sample of the basic data obtained in the study of the dependence of the meteorological range upon wavelength is shown in figs. 1 and 2. The data in these figures have been plotted on a semi-logarithmic scale which, according to (2) and (3), should result in a straight line if Koschmieder's law were found to hold for the conditions under which the measurements were made. Fig. 1 shows typical data obtained for black targets and fig. 2 shows typical data obtained

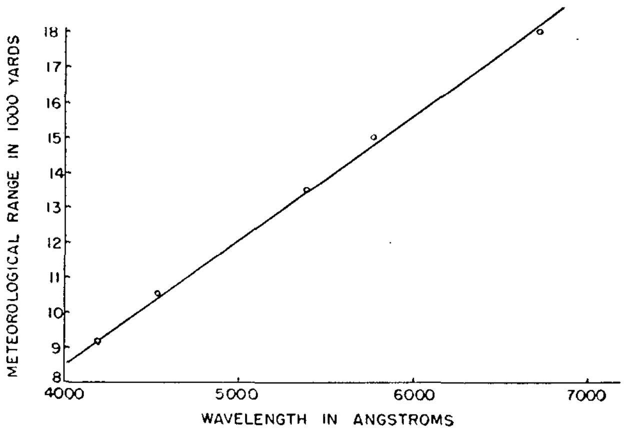

FIG. 3. Meteorological range *vs.* wavelength for black targets on a day when the maximum meteorological range was approximately 20,000 yards.

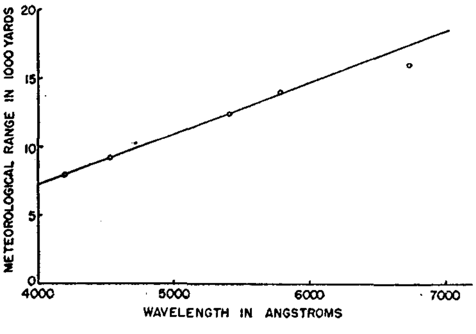

FIG. 4. Meteorological range *vs.* wavelength for white targets on a day when the maximum meteorological range was approximately 20,000 yards.

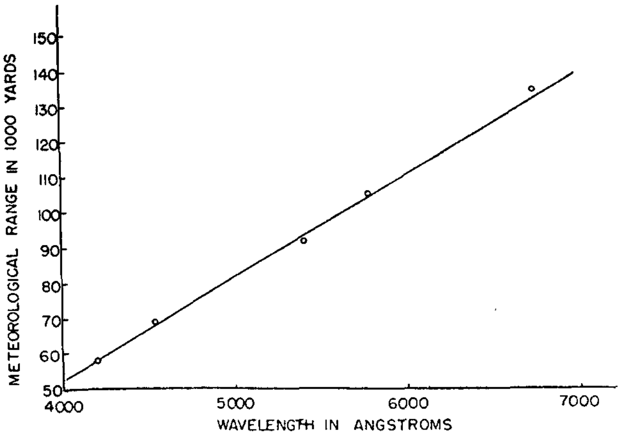

Fig. 5. Meteorological range *vs.* wavelength for black targets on a day when the maximum meteorological range was approximately 150,000 yards.

for white targets. Nomographic arcs, by means of which the meteorological range can be read directly from the markings, have been included in these two figures.

The meteorological range, as determined from data such as shown in figs. 1 and 2, has been plotted as a function of wavelength for black targets and for white targets. Samples of such plots are shown for the data obtained on two different days, one on which the maximum meteorological range was approximately 20,000 yards, and one on which the maximum meteorological range was approximately 150,000 yards. These are shown in figs. 3, 4, 5, and 6.

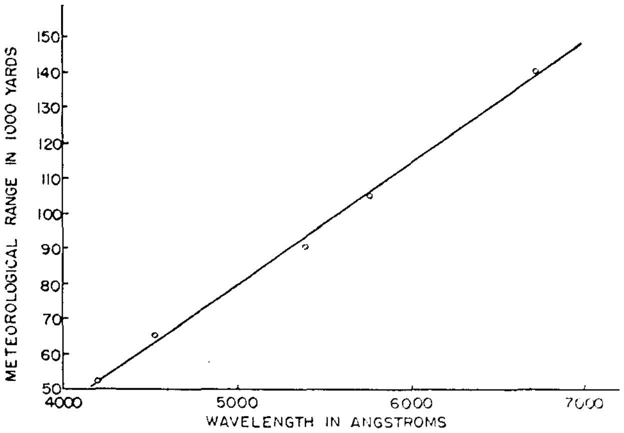

Fig. 6. Meteorological range *vs.* wavelength for white targets on a day when the maximum meteorological range was approximately 150,000 yards.

4. Discussion and conclusions

It is evident from the data presented in this paper that the dependence of meteorological range on wavelength is a linear, rather than a fourth-power function, over a rather wide range of transparencies of the atmosphere. This may be interpreted as indicating that molecular scattering is not the predominant factor in the atmospheric attenuation of brightness contrast, and that even on the clearest of days the atmosphere contains an abundance of scattering nuclei of some size greater than molecular. This would appear to indicate a need for a review of the theoretical studies of the mechanism upon which the spectral dependence of atmospheric scattering depends. It may be possible that from such data as presented in this paper, a better idea could be gained as to the sizes and distribution of the scattering nuclei in the atmosphere. Specifically, it may be possible to use the general, empirical equation relating meteorological range to wavelength,

$$R_m = a + b\lambda^{\alpha}, \tag{6}$$

as experimental guidance in such theoretical work. It is suggested that the significance be considered of a, defined as the "invisibility index," b, defined as the "spectral coefficient," and α, defined as the "spectral exponent." As an example of the line such considerations might follow, fig. 7 has been prepared. In this figure, the spectral coefficients, determined at various atmospheric transparencies, have been plotted for a wavelength of 4670Å. Somewhat unexpectedly, this appears to be a linear function and a clear explanation of the cause would be of practical value.

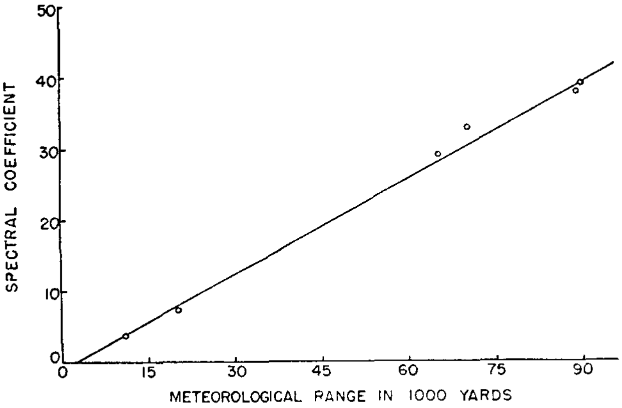

Fig. 7. Spectral coefficient *vs.* meteorological range at an effective wavelength of 4670Å.

In conclusion, it should be indicated that perhaps the reason such linear relations, as presented in this paper, have not been established before, is inadequate experimental designs and facilities. In this regard, having targets whose inherent size and luminance can be determined is important. The earlier investigators used natural objects, such as various terrains, for which such inherent properties cannot be accurately specified. In addition, the apparatus used to make the measurements described in this paper was rigidly constructed and the telephotometer measurements were known to be free from stray light, which may not have been the case in the earlier experiments mentioned. Also, the effect of atmospheric optical haze (shimmer) was likely neglected by the early investigators. This quantity can account for as much as at least half of the atmospheric attenuation of brightness contrast. The measurements presented in this paper were made only when such optical haze was negligible.

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