Atmospheric extinction at the Brno and Skalnaté Pleso Observatories

I. Instrumentation, observations and review of data

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Abstract.
Two extensive collections of *UBV* photoelectric measurements of atmospheric extinction obtained at the Skalnaté Pleso Observatory and at the Masaryk University Observatory in Brno from 1962 to 1995 were analyzed for the nature of extiction and for seasonal and long-term variations as well. In the present paper (Paper I) the instrumentation used, observations, and general characterizations of the data are discussed. Interpretation of the data is the subject of the Paper II that will occur in one of the next volumes of the journal.

Key words: extinction: atmospheric

1. Introduction

The fact is that at least two effects steadily diminish the efficiency of the astronomical measurements done through the atmosphere - the deterioration of the transparency of our Earth air envelope (i.e., increasing extinction) and the growing light pollution of the night sky. The first effect can be relatively and unbiasedly well documented by the behavior of the extinction coefficients which are usually obtained as by-products of photoelectric measurements made in various photometric systems and from this point of view it deserves a detailed analysis.

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A number of observatories have analyzed their photometric measurements for the atmospheric extinction and published the data describing the effect statistically concerning its time variations and nature. At this time it is impossible to give a complete bibliography of all the studies focused on understanding all the processes affecting the optical properties of the Earth's atmosphere and their changes. We will refer to some of these studies, performed in the last two or three decades.

The main carriers of atmospheric extinction, i.e. the molecules, the aerosol and dust particles are well studied in papers by Hodge et al. (1972), Hodge and Laulainen (1973), Laulainen et al. (1977), Taylor et al. (1977), Laulainen (1977). In particular, the last paper is very interesting because it compiles the measurements from 31 observatory sites.

Some of the papers are oriented towards studies of atmospheric turbidity in different meteorological environments (Alkezweeny and Laulainen, 1976; Laulainen et al., 1978; Michalsky et al., 1982; Reimann et al., 1992), the other come out of the measurements made at different astronomical sites. Together with his collaborators, Krisciunas investigated the atmospheric extinction and the sky brightness at two altitude levels in Hawaii and the results of their efforts are published in two papers (Krisciunas et al., 1987; Krisciunas, 1990). Their two-colour measurements obtained in the time period from 1985 to the end of 1989 made it possible not only to derive the scale height of atmospheric aerosols but also to display an increase of atmospheric turbidity caused by the volcanic eruptions of distant Mount St. Helen and El Chicón. The impact of volcanic eruptions on the northern hemisphere's aerosol burden during the last few decades is the subject of solar radiometric studies by a series of investigators (Lockwood and Thompson, 1986; Michalsky et al., 1989 and 1990).

A number of additional contributions can be found in the references to all the papers mentioned above. We would like to mention that the most complete survey of the publications on the subject of the atmospheric extinction and atmospheric optics are involved in papers and posters presented at the IAU/ICSU/UNESCO Exposition on the Adverse Environmental Impact on Astronomy held in Paris in 1992 (Laulainen, 1992; Sullivan III, 1992).

This short summary of contributions devoted to the study of the optical properties of the Earth atmosphere is certainly not complete even though we would also add our papers published or presented as posters during the last two decades (Papoušek et al., 1984; Papoušek et al., 1992). Above all the first paper presents an extensive collection of long-term observations enabling scientists to study the physical processes of the atmospheric extinction in detail. Especially noteworthy is the behaviour of the coefficient describing the bizarre exponential dependence of the extinction on the wavelength, i.e. the dependence or the exponential coefficient α on the level of the total amount of the particle pollutants in the Earth atmosphere. The multi-wavelength observations given in this paper have indicated that the carriers of extinction may form diverse components characterized by different size and types of particles and, in this way, also with different spectral properties.

2. Instrumentation and observations

The present papers (I and II) should be considered as a continuation and an up date extension of our investigations of atmospheric extinction made in the last two decades. Its main goal is to introduce an as simple as possible model of the carriers well describing the physical processes that produce atmospheric extinction and to search for seasonal as well as long-term variations of it, that will allow us to do some predictions concerning extinction. Two observatories were chosen for obtaining the experimental data, both in former Czechoslovakia and situated at a distance of about 265 kilometres from each other. The first one, the high-altitude Skalnaté Pleso Observatory of the Slovak Academy of Sciences can be generally characterized as having good observational conditions. It is especially valid during the winter season when the atmospheric temperature inversion lays under the level of the observatory, the local altitude of which is 1 783 metres. It is satisfactorily remote from any industrial developments and some remote urban lights on the horizon do not interfere with its night observations.

The second observatory, the Masaryk University Observatory in Brno (now in the Czech Republic), is a genuine contrast with the firstt one. It is an urban astronomical observatory site with the atmosphere highly polluted by products of industry, public transport, and other human activities. It is situated in the middle of the town, on the top of the hill Kraví hora at a height of 310 metres above sea level. From this point of view, it represents a site where the interference of urban lights with astronomical observations is particularly appreciable. The relative number of good nights is small there and the observing season is restricted from the spring to autumn period from May to September.

The photometric measurements at both the observatories were performed in the *UBV* system using two independent 60-cm telescopes equipped with standard type photoelectric photometers. A full description of the instruments, their photometric properties as well as the basic methods of data processing can be found in the papers published previously (Horák et al., 1976; Klocok et al., 1986 and 1987; Papoušek and Vetešník, 1990).

The mean atmospheric extinction coefficients for 332 nights were measured at Brno Observatory in 1962-92 and for 407 nights at Skalnaté Pleso Observatory in 1962-95. As the analysis of the measurement dated up to 1980 have already been published (Papoušek et al., 1984), we do not give the details of the observing procedures here, we only repeat a brief basic information about it.

The whole set of the observations is expressed in the broad band standard *UBV* photometrical system. The observation method can be divided into two groups according to the two periods in which the observations were obtained.

The first part of the measurements, made up to the end of 1974, was performed within the framework of the observational programs directed at studying variable stars. These observations were generally not accompanied with special extinction measurements and this is why only mean extinction coefficients could be derived from them for each observing night using the common method of Bouguer's straight lines. Although the majority of the observations was provided under stable atmospheric conditions, some of them could have been affected by some short-time variations of the atmospheric transparency, in a few cases even resulting a negative extinction.

In 1975, the methodology of obtaining the observations was changed and replaced by the numerical computations of the extinction coefficients from the colour system measurements. From time to time, the more reliable determinations were supplemented with special extinction measurements based on a list of selected standard stars. Thus, these extinction coefficients are based on four stars of different spectral types, two observed near zenith and two at large zenith distances. After having analyzed the photometrical data as a whole, one can state that the reliability of the measurements was increased substantially. As a result the corresponding extinction coefficients are about four times more accurate than those obtained in the previous period.

The extensive set of the measurements dated up to 1980 has already been published (Papoušek et al., 1984), which is why we do not intend to repeat them again. The rest of the original measurements is also not included in this paper because they have been included as a part of the total observational material discussed here on INTERNET pages of the Skalnaté Pleso Observatory where they can be easy accessible (*http://www.ta3.sk/~ziga/ftp/extin*).

3. General characterizations of the data

Observational data acquired in the Masaryk University Observatory in Brno represents 1013 extinction coefficients measured in the international photometric system *UBV* carried out in 400 observations on 332 different nights. Measurements were performed during a time interval of 32 years (from 1962 to 1994). Treated data taken at the Skalnaté Pleso Observatory consists of 766 *UBV* extinction coefficients measured in 443 observationss on 407 different nights. Unfortunately, the atmospheric extinction in all three colours of the photometeric system used were measured in only one third of the cases. Skalnaté Pleso extinction data cover a time interval of 33 years (from 1963 to 1995).

The whole set of the extinction coefficients is far from a guarantee of homogenous information about the wavelength dependency and the time variations of the atmospheric extinction at Brno and Skalnaté Pleso. Only 71% and 32% of the observations made at the observing sites involve all three extinction coefficients in the *UBV* system, respectively (see Table 1). The information about their global variations of atmospheric extinction seems to be even more incomplete and scarce: only 3% of all nights can be photometrically characterized in this way. Moreover, the observations at both observatories are not distributed over the three decades under review uniformly (see Fig. 1a). Finally, in particular, the data is tainted with a well-pronounced selection effect: only the photometrically good nights characterized with clear and stable sky were used for photoelectric observations. On the other hand, the observations represent a relatively homogenous set describing the time development of such a specific "atmospheric situation".

Table 1. Review of extinction observations obtained in various colours of *UBV* system.

Observatory	Color	V	B	U	$V+B$	$V+U$	$B+U$	$U+B+V$	Total
Brno	V	53			41	0		285	**379**
	B		16		41		2	285	**344**
	U			3		0	2	285	**290**
Sk. Pleso	V	192			30	2		142	**366**
	B		69		30		7	142	**248**
	U			1		2	7	142	**152**

The median of the Brno observations is at 1985.4, the distribution of frequency of measurements is rather asymmetric with a main peak at the end of eighties and a secondary one around 1975 (see Fig. 1a). The distribution of extinction measurements taken at Skalnaté Pleso is more symmetric, but far from uniform. There are two apparent maxima in aquisition of data: 1968-70 and 1980-2, the median of the time distribution is at 1978.2.

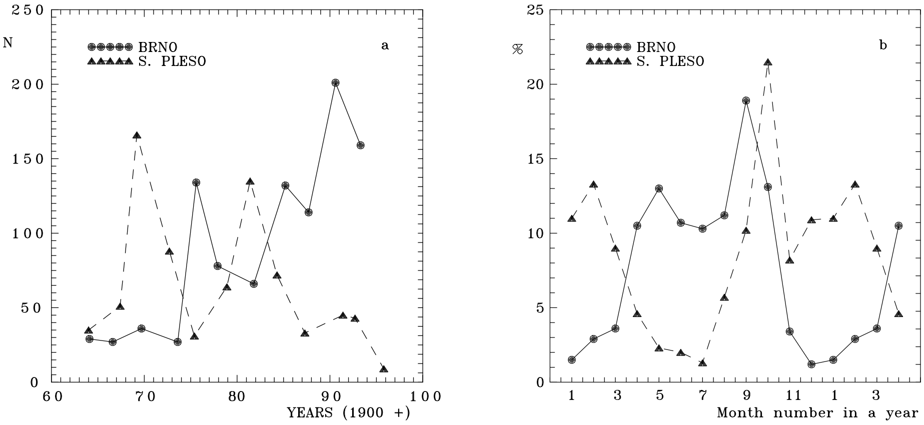

Figure 1. a) The distribution of the extinction measurements at the Skalnaté Pleso and Brno observatories in the time period 1962-95. Each point represents measurements done in a time interval of three years, the x-coordinate of which corresponds to the median of measurements within this interval, N is the number of individual measurements. b) The distribution of measurements during a year.

Extinction coefficients in the B and U colours of the UBV system had not been measured consistently before the end of seventies. Consequently, all our conclusions referring to the relationship of them to extinction in V are based on measurements done in the second half of the reviewed time interval.

The histograms of Skalnaté Pleso and Brno observations during the year differ strongly (see Fig. 1b). Although the observations at Skalnaté Pleso show a concentration in the autumn and winter months (74% of the measurements were performed from October to March), the ones in Brno were made predominantly during the spring and summer time (77% of them were obtained from May to October). Such an almost alternating time distribution of the observing nights corresponds with the different climatic conditions of both observatory sites. The climate of the lowland Brno observatory is strongly influenced with the proximity of the Austrian Alps and with a warm alpine stream of persistent winds in summer. The meteorological conditions of the mountain observatory at Skalnaté Pleso are determined by the position of a temperature inversion resulting in a number of clear nights during the winter season.

The scarcity and unevenness of the numbers of measurements of extinction in the course of the reviewed time interval and during the year urge us to be very cautious in the interpretation of the observed seasonal and long-term extinction variations.

4. Distribution functions of the extinction coefficients at the Skalnaté Pleso and Brno observatories

The analysis of the distribution function of extinction is indisputably an important tool for an appraisal of the quality of an observing site. Recognizing the function in details, one can analyze all the extra circumstances that could affect the true values of the extinction coefficients, as the interference of the meteorological conditions as well as the selection effects connected with the actual observations. The distribution functions of the extinction coefficients K in the V, B and U colours of the UBV system at Skalnaté Pleso and Brno are plotted in Fig. 2. In a rough estimate, they pronounce a similar asymmetric course with a fast increase and a slower descend, the feature that is common for the majority of all astronomical sizes (Reimann et al., 1992). Some global characteristics of individual distribution functions are given in Table 2.

These values correspond well with the climatic conditions of the observational sites and demonstrate the apparent advantage of mountain observatories over urbane ones. It is useful to introduce a special function of extinction K, $H(K)$ characterizing the relative quality of a night of given extinction K. If $f(K)$ is a normalized distribution function of extinction, then:

$$H(K) = \int_{-\infty}^{K} f(t)\mathrm{d}t.$$

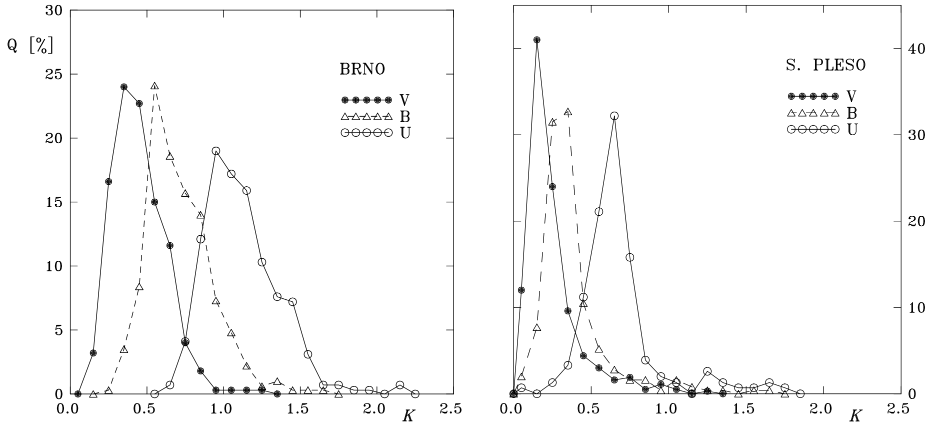

Figure 2. The distributions of the observed extinctions in the U, B and V colours at the Brno and Skalnaté Pleso observatories. The quantity Q [%] means the percentual portion of the extinction in the interval of 0.1 mag/air mass. In all the cases the distribution functions are evidently asymmetric.

Table 2. Characterization of extinction in individual colours.

colour	V		B		U	
effective vawelength	550 nm		440 nm		365 nm	
station	Brno	Sk. Pl.	Brno	Sk. Pl.	Brno	Sk. Pl.
median year	1985.3	1973.8	1985.7	1979.9	1986.8	1982.1
number of measurements	379	366	344	248	290	152
average extinction	0.447	0.246	0.708	0.378	1.118	0.681
K of "good" nights	0.287	0.119	0.520	0.230	0.900	0.500
K of "medium" nights	0.420	0.190	0.690	0.315	1.082	0.634
K of "poor" nights	0.609	0.350	0.897	0.480	1.340	0.770
"width" – W	0.322	0.231	0.377	0.250	0.440	0.270
"asymmetry" – z	0.170	0.390	0.100	0.320	0.170	0.010

As the function $H(K)$ is a smooth monotonic function, we can explicitly state its inversion function $K(H)$. If the relative quality of the night $H = 1/2$, we speak about a "medium" night. The corresponding extinction $K(1/2)$ is the median extinction in the set. We will call the night characterized by $H = 1/6$ a "typical good night", or simply a "good night", the "typical poor night" or simply a "poor night" corresponds to $H = 5/6$. In the case of a good night only one sixth of nights of the set studied exhibit extinction less than $K(1/6)$, in the case of a poor night only one sixth of nights have their extinction larger than $K(5/6)$.

Using the quantities $K(1/2)$, $K(1/6)$ and $K(5/6)$ we can define the "width" W and the "asymmetry" z of the distribution function as:

$$W = K(5/6) - K(1/6), \quad z = \frac{K(5/6) + K(1/6) - 2K(1/2)}{K(5/6) - K(1/6)}.$$

It is instructive to compare the wavelength dependence of extinction of three types of night of the mountain and urban observatory, as is plotted on Figure 3. We found the maximum discrepancy of extinction observational conditions at near ultraviolet (U colour), where the difference between the extinctions of Brno and Skalnaté Pleso atmosphere is enormous (0.45 mag/air mass). The difference between them decreases with increasing wavelengths, but only from 500 nm, so we can say that the Brno good nights are better than the Skalnaté Pleso poor ones. As we have fair reasons for assuming the discussed trend proceeds in red and near infrared colours we arrive at a very strong recommendation for all lowland and urban observatories: to abandon observations in the U and B colours as fast as possible and replace them with observations in red and infrared (e.g. in the colours R and I). The general switching from photomultipliers to CCD techniques sensitive in red and IR is the second factor supporting this consequential decision.

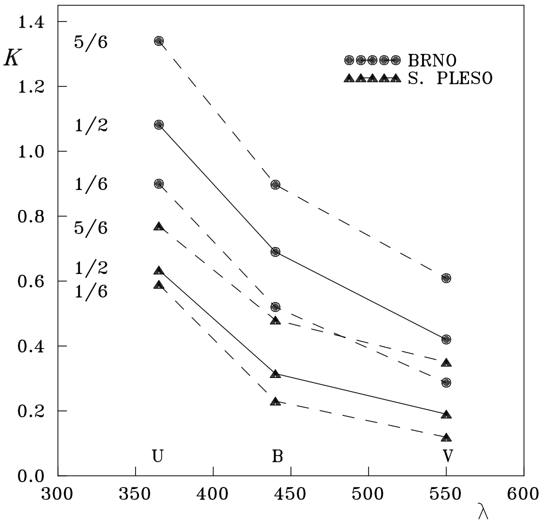

Figure 3. Comparison of the extinction K (in mag/air mass) at Brno and Skalnaté Pleso in different wavelengths (in nm). "Poor" (5/6), "medium" (1/2) and "good" (1/6) nights are distincted.

5. Relationships between extinction coefficients

The last item discussed in this paper is the relationship between extinction coefficients simultaneously measured in different colours. All graphs displaying the relation between extinction coefficients obtained in V, B and U (see Figs. 4a and 4b) prove:

1) There exists a very strong correlation among simultaneously established extinction coefficients ($r \cong 0.9$).

2) The scatter of these relationships is apparently less than mutual variations, consequently observed variations of extinction are very probably real.

3) The observed relationships among extinction coefficients can be satisfactorily represented by simple straight lines, which do not intersect the origin.

4) The observed relationships among the same colours for Brno and Skalnaté Pleso stations are within the uncertainty of the determination of their course parallel.

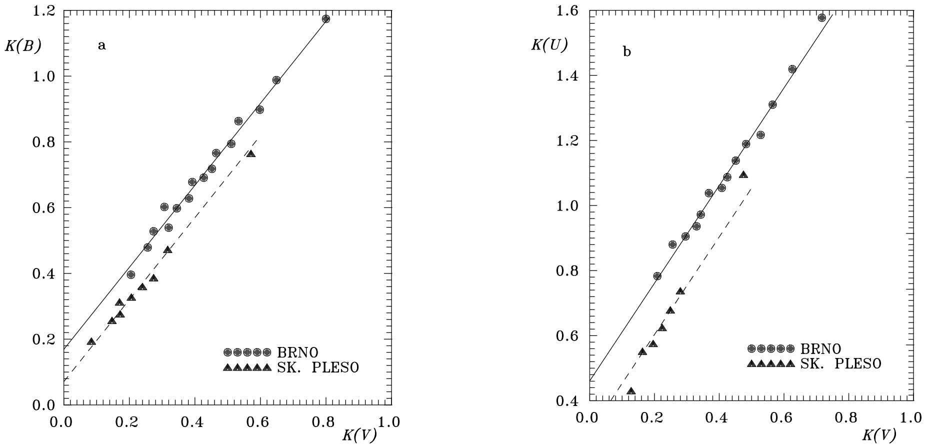

Figure 4. a) The correlation between the extinction coefficients K_V and K_B following from the measurements made in Brno and at Skalnaté Pleso. Each of the points is an average of about 20 neighbouring doubles of measurements. The solid line represents the conversion between K_V and K_B for Brno, the dashed line for Skalnaté Pleso. Parameters of both conversions are given in the text. b) The same as a), but for K_V and K_U.

We believe that such a behavior of relationships tell us crucial information about the nature and properties of extinction. Their thorough analysis will serve as a starting point for construction of adequate models, which is the subject of the adjoining Paper II which will be published in one of the following volumes of this journal.

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