Atmospheric extinction and meteorological conditions: a long time photometric study

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Received April 14, accepted July 12, 1992

Abstract. A retrospective investigation covering about twenty years during which wide-band and intermediate-band photometry has been performed at Großschwabhausen observing station of the Jena University Observatory, allows an analysis of variations of atmospheric extinction at different time scales. A comparison with an earlier investigation by Wempe (1947) permits to draw conclusions about the evolution of air pollution by aerosols over nearly half a century. Parallel Mie calculations allow to interpret the variations of the measured extinction data in terms of size variations of water-rich aerosols.

Key words: atmospheric effects – techniques: photometric – methods: observational

1. Introduction

Nearly half a century is elaps since the first extinction measurements in Jena were carried out by Wempe (1947) during the years 1941 – 1943. Wempe determined monochromatic extinction coefficients for 45 wavelengths between 380 nm and 650 nm. He assumed an extinction law for aerosols of the form

\[ k_0(\lambda) = 2.5 \ln e^{-\beta_{\lambda} x}, \quad [\mu \text{m}]/\lambda \]

which was introduced by Ångström (1929). A justification for the applicability of this formula was given by Foitzik & Hinzpeter (1958). Wempe derived with this formula typical values for the wavelength exponent \(\alpha\) and the turbidity factor \(\beta\) for different low altitude sites in Europe on the basis of the observed aerosol extinction coefficient \(k_0\). He found that the \(\alpha\)-value for Jena (\(\alpha \approx 1.5\)) was significant higher than for the other sites (\(\alpha \approx 1.3\)) and supposed that this effect comes from a larger part of aerosols which originate from industrial dust emission. Generally in the recent literature a mean value of \(\alpha = 1.33\) is cited which was established by Siedentopf (1948).

Now again atmospheric extinction observations have been performed at Jena University Observatory with varying frequency and duration according to other programs and the quality of weather. Nevertheless, the data are now both sufficiently numerous and cover a time interval long enough to derive accurate

extinction quantities for the urban atmosphere of Central Europe. Complementary weather observations obtained at the meteorological observing station of the Jena University allow to find correlations between the variation of extinction parameters and the changing weather situations. The aims of the present paper are to establish characteristic extinction data for given weather situations, to study the evolution of air pollution by aerosols over long time scales, and to explain the measured extinction values in terms of Mie calculations for typical aerosol models. Additionally, we compare our results with long time extinction studies at other observing sites. We want to draw attention to the fact that many valuable data are hidden in long time photometric observations obtained for several years at astronomical observatories all over the world.

2. Observations and data reduction

Photoelectric photometry in three colour \(UBV\), four colour \(uvby\), and six colour standard IHW comet filters has been carried out since 1968 at Großschwabhausen observing station of Jena University Observatory (longitude 11° 29', latitude 50° 55', elevation 356 m). The observations were done at the 90-cm telescope using a single channel photon counting photometer. A full description of technical details of the used equipment was given by Reimann et al. (1984). The atmospheric extinction coefficients and the zero points of the transformation equations on each photometric night were determined from a sample of about 15 standard stars. The colour equations had been determined separately using a more numerous sample of about 30 to 50 stars. All of them were taken from the original lists of standard stars for the systems under consideration, for the \(UBV\) system from Johnson & Harris (1954), for the \(uvby\) system from the list of Crawford & Barnes (1970) including the revisions by Perry et al. (1987), and for the Hailey filter system from Pfau & Stecklum (1986). The final values for the extinction coefficients were derived in a complex iteration procedure between mean colour equations and nightly extinction coefficients described in detail by Reimann et al. (1989).

For the individual data sets according to the different photometric systems we obtained extinction coefficients \(k(\lambda)\) for the mean wavelengths of the filter passbands given in Table 1. Furthermore we adopted the normal decomposition for \(k(\lambda)\) as given by Siedentopf (1948).
\begin{equation}
k(\lambda) = k_R(\lambda) + k_O(\lambda) + k_D(\lambda)
\end{equation}

In this formula \(k_R\) means the Rayleigh scattering extinction coefficient at given atmospheric pressure, \(k_O\) is the extinction coefficient for standard ozone content (to correct for the Chappuis bands), and \(k_D\) is the extinction coefficient due to aerosols. The standard values for \(k_R\) and \(k_O\) were taken from Straizys (1977) and are also given in Table 1. Subtracting these quantities corrected for actual air pressure from the observational determined \(k(\lambda)\) we obtained for each night an estimation of \(k_D\).

**Table 1.** Mean wavelengths and extinction parameters for standard atmospheric conditions (1013.25 mb and 3 mm \(O_3\)) according to the used photometric systems

<table>
<thead>
<tr>
<th>System</th>
<th>Filter</th>
<th>(\lambda_0) [nm]</th>
<th>(k_R) [mag]</th>
<th>(k_O) [mag]</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBV</td>
<td>(U)</td>
<td>364</td>
<td>0.533</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(B)</td>
<td>443</td>
<td>0.234</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(V)</td>
<td>550</td>
<td>0.098</td>
<td>0.030</td>
</tr>
<tr>
<td>uvby</td>
<td>(u)</td>
<td>345</td>
<td>0.665</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>(v)</td>
<td>410</td>
<td>0.335</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(b)</td>
<td>468</td>
<td>0.185</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>(y)</td>
<td>547</td>
<td>0.100</td>
<td>0.029</td>
</tr>
<tr>
<td>C0</td>
<td>(C_U)</td>
<td>365</td>
<td>0.527</td>
<td>-</td>
</tr>
<tr>
<td>CN</td>
<td>(C_N)</td>
<td>387.1</td>
<td>0.413</td>
<td>-</td>
</tr>
<tr>
<td>C3</td>
<td>(C_3)</td>
<td>406</td>
<td>0.339</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>(C_O)</td>
<td>426</td>
<td>0.278</td>
<td>-</td>
</tr>
<tr>
<td>CB</td>
<td>(C_B)</td>
<td>484.5</td>
<td>0.163</td>
<td>0.009</td>
</tr>
<tr>
<td>C2</td>
<td>(C_2)</td>
<td>514</td>
<td>0.128</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Taking this extinction coefficient for aerosols \(k_D(\lambda)\) for the individual mean filter wavelengths we followed the same data handling procedure as described by Wempe (1947). In this way we are able to compare our \(x\) and \(\beta\) with those obtained earlier by Wempe. We adopt the same extinction quality classes as introduced by Wempe.

- class I : \(k(V) < 0.53\) mag
- class II : \(0.53\) mag \(\leq k(V) \leq 0.68\) mag
- class III : \(0.68\) mag < \(k(V)\)

In the mentioned time interval we obtained 184 extinction measurements. In Table 2 we list the individual numbers of observations with respect to the different photometric systems and quality classes.

After rejecting uncertain extinction determinations and days with \(k(V) \geq 1\) mag there remain data for 172 nights. For these measurements the histogram for the distribution of the visual extinction coefficient \(k(V)\) is shown in Fig. 1. It is evident that all the observations with \(k(V) > 0.800\) mag (very bad observing conditions) are not statistically significant. In most of these cases only standard stars were observed to obtain the extinction coefficients for the nights. The frequency of these observations may be strongly biased compared to normal observations. Therefore, we refer generally to class I and class II in drawing conclusions from the photometric data.

**Table 2.** Extinction measurements according to photometric systems and quality classes

<table>
<thead>
<tr>
<th>System</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBV</td>
<td>53</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>uvby</td>
<td>59</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Halley</td>
<td>11</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>total</td>
<td>123</td>
<td>30</td>
<td>31</td>
</tr>
</tbody>
</table>

We have fitted the histogram of the \(k(V)\) values with a Poisson distribution and obtained a mean value of \(k(V) = 0.355\) mag. This mean extinction value is comparable with the value \(k(V) = 0.370\) mag given by Papoušek et al. (1984) for the observing station of the University of Brno ČSFR (elevation 303 m).

**Fig. 1.** Histogram of the observed visual extinction coefficients at Großschwabhausen observing station for the years 1968–1991

The lowest values of the visual extinction coefficient \(k(V) \leq 0.150\) were observed in November 1980, February 1990 and July 1991. These measurements confirm the observations of Paetzold (1952) who found some weather conditions for low altitude sites in Central Europe nearly identical with the theoretical limit of pure Rayleigh scattering.

The \(\alpha-\beta\)-diagram for all observations is drawn in Fig. 2 were each photometric quality class is marked by a different symbol. All \(\alpha\) values from nearly pure Rayleigh scattering up to completely grey light scattering occur. There is even one night (1983 May 15th) included where the wavelength dependence of the extinction was reverse, a scarce effect known as the phenomenon of the blue sun. The classes are well separated and arranged in stripes along the mean relations given by the dashed lines. The best fits for the classes were obtained with logarithmic regressions which are most adequate to the physics invoked:

\begin{equation}
\alpha(\text{class I}) = -0.567 \ln(\beta) + 1.55
\end{equation}

\begin{equation}
\alpha(\text{class II}) = -0.709 \ln(\beta) + 0.63
\end{equation}
\( \alpha_{\text{class III}} = -0.723 \ln(\beta) + 0.09 \)

The constant terms in Eqs. (3) are related to the mean values for \( \alpha \) in the different quality classes but strongly weighted by the few nights with the greatest \( \beta \) values i.e. the poorest observing conditions. As mentioned above these values are not conclusive for further discussion.

From the viewpoint of theoretical calculations it is more convenient to consider the absolute value of the extinction at wavelengths shorter than 1 \( \mu \)m (basis for \( \beta \)). Then, we can obtain further information concerning the aerosol size from this quantity. We will select here the wavelength of the \( V \)- or \( y \)-band, respectively. In Fig. 3 we give the \( \alpha-k_D(V) \)-relation of the observations. We marked different time intervals of the observations by different symbols. We see that most of the observations seem to follow one general law: with increasing \( k_D(V) \) \( \alpha \) increases. A exponential fit with \( \alpha = 4 \) for \( k_D(V) = 0 \) is drawn.

### 3. Mie calculations of aerosol extinction

#### 3.1. Quantities determining the extinction spectra

We want to investigate a possible interpretation of the measured extinction spectra in terms of theoretical calculations of scattering and absorption by ordinary atmospheric aerosol particles.

To calculate the extinction by the aerosol particles we will apply the formalism of the Mie theory for light scattering by homogeneous, spherical particles (van de Hulst 1957). The importance of deviations from spherical shapes and inhomogeneities for atmospheric aerosols was discussed by Shettle (1979) and found to be low for the aerosol types and within the limited spectral range we will consider here.

Typical models for the aerosol distribution above Europe assume three main components (Koopke & Hess 1988). They contain a water-soluble component (optical constants: \( n = 1.52, k = 0.005 \ldots 0.006 \) in the considered wavelength region), a soot component (\( n = 1.76, k = 0.48 \ldots 0.42 \)), and a dustlike component (\( n = 1.52, k = 0.008 \)). The optical constants are taken from Twitty and Weinman (1971) and Volz (1973). The size spectra of all three components are given by a logarithmic normal distribution.

\[
\frac{dN}{da} = \sum_{j=1}^{3} \frac{N_j}{\sqrt{2\pi} a \ln \sigma_j} \exp \left( -\frac{(\ln a - \ln \rho_j)^2}{2 \ln \sigma_j^2} \right)
\]

Here, \( N \) is the particle number density and \( a \) the particle radius. The parameter \( N_j \) characterizes the number density contribution of each component, \( j \), \( \rho_j \) its most probable radius, and \( \sigma_j \) the logarithmic standard deviation of its size distribution. The standard parameters for two typical situations in Central Europe are given in Table 3 (from Koopke & Hess 1988).

<table>
<thead>
<tr>
<th>Model</th>
<th>Components</th>
<th>( \rho_j [\mu m] )</th>
<th>( \sigma_j )</th>
<th>( N_j/N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental</td>
<td>Water-soluble</td>
<td>0.0285</td>
<td>2.239</td>
<td>0.93876</td>
</tr>
<tr>
<td></td>
<td>Soot</td>
<td>0.0118</td>
<td>2.00</td>
<td>0.06123</td>
</tr>
<tr>
<td>Urban</td>
<td>Water-soluble</td>
<td>0.0285</td>
<td>2.239</td>
<td>0.5945</td>
</tr>
<tr>
<td></td>
<td>Soot</td>
<td>0.0118</td>
<td>2.00</td>
<td>0.4055</td>
</tr>
<tr>
<td></td>
<td>Dustlike</td>
<td>0.471</td>
<td>2.512</td>
<td>2.27e-6</td>
</tr>
</tbody>
</table>

Considering the sets in terms of the slope of the extinction curve \( \alpha \) we find that these two quite different models show very similar \( \alpha \)-values of 1.02 and 1.04, respectively. Looking at our observations we find that 80\% of them exhibit \( \alpha \)-values above 1.1. Hence, the proposed aerosol models are not appropriate to interpret the observed data. At first we will discuss the influence of the size distribution of the aerosols. As an additional limiting aerosol type we will consider pure water droplets (\( n = 1.52, k = 0 \)).

We will concentrate on the comparison of the shape and the slope \( \alpha \) of the calculated extinction curves with those of the measured extinction. The total magnitude of the extinction expressed by \( \beta \) or \( k_D(V) \) is not only determined by the aerosol...
type but also influenced by the uncertain column density of the aerosol particles.

In Fig. 4 we show the \( \alpha \)-values of the extinction spectra produced by the four aerosol types depending on their radii without any distribution of sizes. Because of the similarity of the optical constants of the water-soluble and the dustlike component the extinction behaviour is nearly identical in a broad range of aerosol sizes. Therefore, we will consider in the following only the water-soluble component knowing that the conclusions may be the same for dustlike grains which are, however, much less abundant in Central Europe. The spectra exhibit a number of oscillations produced by interferences between transmitted and diffracted light in the range of aerosol radii between 0.2 and 2 \( \mu \)m. In the case of the soot grains these oscillations are strongly damped due to the high grain absorptivity. The maximum value of \( \alpha \) is 4 for the pure water. The realistic aerosol types exhibit maximum values of 3.5 for the water-soluble component but only 1.95 for the soot. Looking at the observed values only the water-soluble component may explain a wide range of the data. The values between 3.5 and 4 may be explained only by a “cleaner” aerosol, e.g. the pure water without any pollution. In general high \( \alpha \)-values are related to relatively small particles.

The calculated extinction spectra often do not follow the ideal power law presumed by Wempe (1947). In Fig. 5 we show the spectra for different sizes of water-soluble aerosol calculated at the central wavelengths of all filters of observation (\( UBV \), \( uby \), cometary filters). The plotted quantity \( Q_{av} \) represents the efficiency for extinction of an incoming photon. For small aerosol sizes (\( a < 0.2 \mu \)m) the ansatz is well fulfilled, but larger particles often show nonmonotonic behaviour or discontinuities in the slope of the extinction as they are also observed. To quantify this effect we have plotted in Fig. 6 \( \alpha \) and the statistical error of \( \alpha \) from the regression as a measure for the deviation of the calculated extinction curve from the power law. Especially, in the range of the oscillations these deviations are important. The same diagram for soot shows much smoother extinction spectra. This result is in a good agreement with the observations where all curves except four with \( \alpha \geq 2.5 \) are smooth with correlation coefficients above 0.8.

All together, a change of aerosol radii of the water-soluble aerosol might explain most of the observed extinction curves. Nevertheless, single sizes are not very realistic. In Fig. 7 we show \( \alpha \) depending on the standard deviation for a logarithmic size distribution of water-soluble aerosols with a constant mean radius of 0.06 \( \mu \)m. Already for relatively low widths of the distribution no high \( \alpha \)-values are possible. The extinction becomes more and more grey. When we assume the same width of the size distribution for the water-soluble aerosol as in the standard models the maximum value of \( \alpha \) is 1.3. Hence, the observations clearly indicate the occurrence of much narrower size distributions.

The proposed optical constants of the aerosol types seem to be physically reasonable orientation points. The given values for the soot component are quite typical for amorphous carbon soot and it is hard to imagine an aerosol component which is more absorbing. Water droplets condensed on any nucleation core will form the main component in tropospheric aerosol. Their refractive index \( n \) will be always at about 1.52, but it is possible that the absorptivity \( k \) characterizing the “dirtiness” of the droplets differs from 0.005. Every realistic aerosol has to show an inter-
mediate behaviour between that of pure water droplets without any absorption and the pure soot grains.

3.2. Aerosol evolution and the observed $\alpha - k_\nu(V)$ diagram

At first we want to investigate the effect of particle growth. This process is daily evident in the formation of clouds, fog and so on. We assume a relatively narrow size distribution with a logarithmic standard deviation of 1.2 to enable the high $\alpha$-values.

We will now include the absolute values of the extinction curves represented by $k_\nu(V)$ in our considerations. To obtain a translation from the computable extinction cross sections of the aerosols into the observable $k_\nu(V)$ we need a factor describing the number column density of the particles. We select this factor for a special particle radius which is according to an $\alpha$-value of 0.5 in such a way that the resulting extinction $k_\nu(V)$ is 0.95, the same value as in the fit of the observational data. This normalization is relatively arbitrary and only necessary for a better comparison of the general behaviour between calculated and observed extinction data. The column density for particles of other radii must then be related to this factor. There are two limiting cases possible with respect to the evolution of an aerosol population: number conservation and mass conservation. In the first case the column density is independent from the particle radii, in the second case it decreases with $\rho^{-3}$.

Physically, number conservation would describe a process of aerosol growth by condensation from the gas. Mass conservation is representative for a growth process driven by aggregation of the aerosols. Both processes are possible and will combine in reality.

In Fig. 8 we have plotted the evolution of a distribution of water-soluble particles within the $\alpha - k_\nu(V)$ diagram assuming a number conserving growth process on the one hand and a mass conserving growth process on the other hand. The lines mark the way of growth connecting points of particles with neighbouring mean radii. The number conservation graph shows only one branch and the large particles have such a high extinction that they do not fit the figure. The mass conservation graph contains not only the branch of increasing $k_\nu(V)$ with size but also another branch with decreasing $k_\nu(V)$ but lower $\alpha$-values. A comparison of this diagram with the $\alpha - k_\nu(V)$ plot of the observations shows that it is possible to explain most of the observations by the same number density of aerosols but different radii. Therefore, the different points of the observations may be caused by aerosols which have started with a similar value of the number density but have grown to different sizes due to their different history.

A broadening of the size distribution with constant mean radius is another possible process changing the picture of the aerosols in the $\alpha - k_\nu(V)$ plot (see Sect. 3.2). The curve produced by this process is very similar to the mass conservation curve of the grain growth investigation and, hence, does not fit the sample of observations. Moreover, it is difficult to find a realistic mechanism driving this process. In combination with particle growth, however, it might occur and slightly modify the growth process since aerosol growth is probably connected with an enhancement of the width of the distribution.

A change of optical constants of the involved media during the aerosol evolution or at different weather situations is also possible when a soot grain serving as condensation nucleus is surrounded by a shell of water with growing thickness. The resulting effective optical constants for the whole aerosol particle are then dependent on the mantle thickness and can change between those of pure soot and pure water. We have calculated the effective optical constants using conventional Maxwell-Garnett rule and found that the evolution curve of such a model agrees very well with the curve of water-soluble aerosols except for the smallest grains ($\alpha < 0.04\mu m$). This is what one would expect since the water-soluble aerosol represents particles with few inclusions within a water droplet.

4. Correlation between weather conditions and extinction parameters

Lockwood & Thompson (1986) tried to find correlations between locally recorded meteorological data and the observed extinction for the site of Flagstaff. Their results suffer from the fact that the authors tried to correlate each meteorological observable separately with the extinction. But, several meteorological parameters act together and lead in their sum to properties which are related to certain meteorological conditions. We will base these meteo-
rological conditions on the type of atmospheric circulation and the air-mass.

An air-mass is a body of air of uniform temperature, humidity, and aerosol distribution. Its properties are determined by the source region and the route it has taken. This implies quite natural a range of the distinct parameters. A circulation type (general weather situation) is characterized by the large scale distribution of atmospheric pressure. The circulation types can be derived from the upper-air maps distributed by the German Federal Weather Service (Deutscher Wetterdienst). In dependence on the previous weather period a range of air-masses may occur at one and the same circulation type.

For each meteorological condition we calculated mean values of $a$ and meteorological parameters which were then related to each other. For all meteorological conditions with more than three observations we list the mean weather and extinction parameters in Table 4. In the first column the abbreviations of the meteorological conditions are given. The first capitalized letters characterize the circulation type, the following letters denote the air-mass. The next columns refer to the parameters $k_0(V)$, $x$, $\beta$, water-vapour partial pressure ($P_{H_2O}$), and the mean temperature ($T$) followed by their respective r.m.s. errors. The last column contains the number of nights $n$. An explanation of the abbreviations used for the meteorological conditions is given in the appendix.

In Fig. 9 we present the relation between the mean $a$-values and the mean visual extinction due to aerosols $k_0(V)$ in terms of meteorological conditions. It is significant that there exist at least three different groups in the arrangement of the data points following the same tendency of decreasing $a$ with increasing $k_0(V)$ as already shown in Fig. 3. However, it is not possible to find a simple relation between extinction and meteorological conditions.

The circulation type alone cannot serve as a criterion of extinction conditions. E.g., the extinction conditions corresponding to the "HM-situation" cover the whole scope possible according to the different types of air-masses present. Best observing conditions occur in air-masses carrying low air-moisture (cTP, cP, altmP) while more humid maritime air-masses produce high extinction and a low wavelength exponent $x$.

A clear separation also exists between meteorological conditions which belong to the same circulation type and source region of air-mass but which differ in the route the air-mass has taken. If one compares the types HMcP, HMcPT, HFmP, HFmPT, respectively, the air-mass which has taken the direct way leads in both cases to lower extinction values. On the other hand the same air-mass may lead to more or less extinction depending on the circulation type. This is to be seen at the example of the air-mass mPT. Here the "NW-situation" produces the lowest absolute extinction values but still relatively low $a$-values. The diagram underlines a general tendency: Air-masses which come directly from higher latitudes (letter symbol on second position "P") contain smaller particles than those directly transported from lower latitudes (letter symbol on second position "T").

The three points on the lower right hand-side of the diagram stand for bad observing conditions. As discussed in Sect. 3.2, these high $k_0(V)$ and low $a$ clearly indicate that they are produced by large particles. This may be explained by the extremely high moisture of HMnP and SWmP producing large condensates and by dust grains always being relatively large contained in the air of ScT.

One constellation differs considerably from all other meteorological conditions: lowest extinction and highest $a$ due to very small particles. This effect occurs when maritime polar air-masses come under the influence of an anticyclone over Central Europe, become stationary and have time to mature.

Although nothing can replace nightly measurements of extinction for all-sky observations the mean values for given weather conditions may yield a predictive value for a better organization of different types of photometric observations. Furthermore, our mean extinction parameters for specified meteorological conditions could be of value for a more precise atmospheric correction of remote sensing images than the commonly used mean values (see also Khosraviani & Cracknell 1987, Mukai et al. 1990).

5. Nightly variations of the extinction coefficients

Nightly time dependent extinction changes have been known for some times and are one of the main sources of errors in all-sky photometry. An erroneous extinction coefficient can arise from mainly four causes:

- too few standard stars,
- instrumental instabilities,
- not exactly determined airmass,
- temporal changes in the atmosphere.

The first source of error can easily be avoided if one measures at least 10 to 15 extinction stars before and after the program stars which bracket the observations with regard to time, airmass, and colour. To check the influence of the second error source we investigated the stability of our photometer performing three basic types of measurements. We tested the constancy of the pulse height distribution, the temperature dependence of the dark current, and the time dependence of the counting rates measuring a temperature-stabilized LED. During a typical 5 h run we find the variations below the 0.2 % level. However, if the phototube is illuminated before the tube voltage is switched on the dark current during the first 60 minutes of measurements decreases exponentially to the normal level. Contrary to Rosen & Chromey (1985) we find no evidence for photomultiplier fatigue after exposing the photometer to different input intensities (for details see Reimann et al. 1984).
Table 4. Mean values of weather and extinction parameters for meteorological conditions in Central Europe

<table>
<thead>
<tr>
<th>Weather condition</th>
<th>$k_0(V)$</th>
<th>r.m.s.</th>
<th>$\alpha$</th>
<th>r.m.s.</th>
<th>$\beta$</th>
<th>r.m.s.</th>
<th>$P_{H_2O}$</th>
<th>r.m.s.</th>
<th>$T$</th>
<th>r.m.s.</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMaltmP</td>
<td>0.132</td>
<td>0.026</td>
<td>3.725</td>
<td>0.176</td>
<td>0.050</td>
<td>0.013</td>
<td>5.500</td>
<td>0.876</td>
<td>5.178</td>
<td>2.838</td>
<td>9</td>
</tr>
<tr>
<td>NWmpT</td>
<td>0.194</td>
<td>0.023</td>
<td>2.203</td>
<td>0.217</td>
<td>0.504</td>
<td>0.153</td>
<td>6.200</td>
<td>0.987</td>
<td>4.957</td>
<td>3.243</td>
<td>7</td>
</tr>
<tr>
<td>HMcP</td>
<td>0.224</td>
<td>0.068</td>
<td>2.543</td>
<td>0.371</td>
<td>0.249</td>
<td>0.061</td>
<td>4.083</td>
<td>0.917</td>
<td>2.383</td>
<td>3.250</td>
<td>6</td>
</tr>
<tr>
<td>HMcTP</td>
<td>0.229</td>
<td>0.066</td>
<td>2.299</td>
<td>0.305</td>
<td>0.275</td>
<td>0.055</td>
<td>6.791</td>
<td>1.134</td>
<td>8.527</td>
<td>3.159</td>
<td>11</td>
</tr>
<tr>
<td>HFmP</td>
<td>0.255</td>
<td>0.044</td>
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<td>0.049</td>
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<td>1.705</td>
<td>10.950</td>
<td>3.819</td>
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<td>0.032</td>
<td>1.920</td>
<td>0.154</td>
<td>0.367</td>
<td>0.041</td>
<td>4.600</td>
<td>0.357</td>
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<td>0.207</td>
<td>0.372</td>
<td>0.102</td>
<td>7.350</td>
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<td>12.025</td>
<td>1.225</td>
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<td>8.671</td>
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<td>SEcT</td>
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<td>0.283</td>
<td>0.251</td>
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<td>3.840</td>
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<td>1.520</td>
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<td>0.247</td>
<td>0.037</td>
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<td>14.229</td>
<td>2.559</td>
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<td>0.125</td>
<td>1.172</td>
<td>0.303</td>
<td>0.352</td>
<td>0.041</td>
<td>8.700</td>
<td>1.259</td>
<td>12.220</td>
<td>3.508</td>
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<td>SwmT</td>
<td>0.688</td>
<td>0.093</td>
<td>1.301</td>
<td>0.159</td>
<td>0.232</td>
<td>0.033</td>
<td>7.840</td>
<td>1.854</td>
<td>9.400</td>
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<td>0.170</td>
<td>0.439</td>
<td>1.256</td>
<td>1.013</td>
<td>0.286</td>
<td>6.250</td>
<td>1.905</td>
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<td>5.431</td>
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Due to components with changing scale heights a modelling of the extinction is quite difficult. Even in a simple but somewhat realistic model the air mass $X$ (the optical path of light in the atmosphere) depends not only on the zenith angle $\alpha$, but also on the sum of the scale heights of the different constituents of the atmosphere $h_0(T)$. Using the formula given by Young (1974),

$$X = \frac{1}{\cos \alpha} - h_0(T) \frac{\sin^2 \alpha}{R \cos^2 \alpha},$$

which is valid up to $X = 3$ we can estimate the first order influence of changing water vapour and aerosol content in the atmosphere as well as the temperature dependence of $h_0(T)$. Here, $T$ means the temperature and $R$ is the radius of the Earth. Assuming changing values of the scale heights of water vapour and aerosols as given by Goitzik & Hinzpeter (1958) or Angione (1984) of 1 – 2 km and 0.5 – 1.5 km, respectively and with the mean visual extinction of $k(V) = 0.355$ mag derived above this would induce a photometric error of 1 – 2 thousandth of a magnitude and is therefore negligible for zenith angles $\alpha < 60^\circ$. However, this situation can change dramatically during times of perturbed atmospheric conditions (e.g. volcanic eruptions or burning oil wells) if a large part of the aerosol is situated in the stratosphere.

In intermediate band and narrow band photometry it is customary to use a linear extinction correction for the star magnitudes of the form

$$m_* - m_{\text{obs}} = L(\lambda_0) - k(\lambda_0)X,$$

because the deviations from a monochromatic behaviour are small. In this classical Bouguer line the quantity $m_*$ means the standard magnitude of the star, $m_{\text{obs}}$ the ground-based measurement at zenith distance $\alpha$, and $L(\lambda_0)$ the instrumental zero point at some photometric passband characterized by its mean wavelength $\lambda_0$. The reliability of this method rests upon three hypotheses:

- the stability of the photometer,
- the constancy of the observed standard stars,
- the stability of the extinction properties determined by the aerosol content and the isotropy of the atmosphere during the whole observing time.

Whereas the technical precautions and the choice of the standard stars ensure that the first two of these hypotheses are fulfilled, there is only a minority of cases where the third one is satisfied too. We replace this hypothesis by the more realistic assumption that the extinction is not constant but varies slowly and isotropically in the whole azimuth angle considered. We have to replace Eq. (6) by

$$m_* - m_{\text{obs}} = L(\lambda_0) - k(\lambda_0)X + D(\lambda_0)t,$$

where $D(\lambda_0)$ represents a drift coefficient to account for linear changing extinction with time $t$ (see Reimann et al. 1989; Figueras et al. 1991). Whereas the visual drift coefficient can reach relatively high values the drift coefficients in the colour indices remain generally low. Main sources for the visual drift coefficient, $D(y)$, seem to be the process of dust settling at night, shrinking or swelling of the aerosols due to water vapour variations, and changing ozone concentration during day and night. Angione (1984) reported ozone variability up to 25% per night. At $\gamma$ where the ozone accounts for 0.029 mag of extinction this could lead to a change of 0.007 mag during the night. A statistical analysis of the visual drift coefficient $D(\gamma)$ reduced with Eq. (7) is given for all nights with why photometry in Table 5. From this data it seems evident that we need additional mechanisms to explain the large values of $D(\gamma)$ in the group of variable and strongly variable nights. We will consider only the absolute values of $D(\gamma)$ since most processes can lead both to an improvement and a deterioration of the observing conditions.

The first two categories in Table 5 are comparable to the behaviour of nights at mountain stations as Calar Alto Ob-
Table 5. Statistical analysis for the absolute value of the visual drift coefficient $D(y)$

<table>
<thead>
<tr>
<th>Night quality</th>
<th>$D(y)$ [mag/h]</th>
<th>% of nights</th>
</tr>
</thead>
<tbody>
<tr>
<td>stable nights</td>
<td>0.000 – 0.010</td>
<td>25</td>
</tr>
<tr>
<td>normal nights</td>
<td>0.010 – 0.030</td>
<td>50</td>
</tr>
<tr>
<td>variable nights</td>
<td>0.030 – 0.100</td>
<td>20</td>
</tr>
<tr>
<td>strongly variable nights</td>
<td>0.100 – 0.300</td>
<td>5</td>
</tr>
</tbody>
</table>

Separated from the first there exists a second group of meteorological conditions connected with high $D(y)$ values which does not seem to show any trend with moisture. It turned out that in these cases the high values of the drift coefficient are caused by the exchange of different air-masses over the observing site in a relatively short time interval. A closer look at the different meteorological conditions in this group shows that in most cases the air-mass exchange starts in higher tropospheric layers when warm and moist air is rising and being driven over the older air which is stationary under high pressure. A rapid condensation and aerosol growth occurs. This results in increasing extinction values.

A rapid decrease of extinction can be observed when a rest of a front or an air-mass border moves off and, particularly, when the influence of a moving upper-air low ("cold-air drop") gets lost. Stickland et al. (1987) reported similar strong nightly extinction variations at the Roque de los Muchachos Observatory during the summer months when the appearance of extensive Saharan dust clouds over the Canary Islands is a frequent event.

Our observations of the last years have shown that during nights of the first group all sky photometry leads to good results if one carefully reduces the measurements taking into account the time dependence using Eq. (7). Under the conditions of the second group with $D(y)$ values between 0.100 and 0.200 mag/h one should generally avoid absolute photometric observations even if the sky looks relatively nice.

6. Seasonal and longterm variations of extinction

To analyze a possible seasonal variability inherent in our visual extinction data the $k(V)$ values of all 184 observations are plotted in Fig. 11 modulo one year beginning on the first of January. Again we marked the different photometric quality classes by different symbols. Only the values in class I show a shallow seasonal variation. We find the same effect as Rufener (1986) in his photometric study of the La Silla site that the minimum values of $k(V)$ do not show any significant seasonal modulation. The maximum class I extinction values occur in March and April. We suppose that this effect is connected with the ascent of air from south, south-east or east, caused by large low-pressure areas over the Mediterranean Sea or South-East Europe typical for these months.

There is no doubt about the fact that the state of the atmosphere as well as its changes is influenced by anthropogenic activity contaminating the air with strange kinds of gaseous or dusty aerosols. But also natural catastrophes as large volcanic eruptions could induce long-time perturbations of the normal distribution of stratospheric aerosols. The use of photometric observations for studies of atmospheric pollution is not new (see e.g. Angione & de Vaucouleurs 1986, Rufener 1986, and Lockwood & Thompson 1986). All these authors found a considerable increase of the visual extinction after the eruption of El Chichon in 1982. From subsequent reports it became evident that this eruption had caused one of the largest measured atmospheric disturbances. Spinhirne & King (1985) showed that the maximum of the stratospheric optical depth occurred at latitude 50° N based on airborne measurements during May 1983 (see Fig. 12).

In the class I data an increase of the visual extinction with the maximum in 1983 is clearly to be seen. We give also a polynomial fit for the time interval since 1975 which underlines this effect obviously. Taking the time interval since 1989 with
Fig. 11. The seasonal variation of the visual extinction $k(V)$. The symbols are the same as in Fig. 2.

Fig. 12. The long-time behaviour of the visual extinction $k(V)$ (class I data). The dashed line is a seventh order polynomial fit to the data since 1975.

Fig. 13. The long-time evolution of the wavelength exponent $\alpha$. The circles with crosses inside are the mean values of the class I and class II observations by Wempe 1947. The two straight lines are regressions for all observations before 1970 (a, open circles) and all observations since 1985 (b, dots).

The tendency is clearly present and probably a result of a slow change of the chemical constituents of the anthropogenically induced aerosols.

7. Conclusions

The long time span covered by our photometric observations and the recorded weather data from the meteorological station of the Jena University allow us to draw conclusions about the influence of the meteorological conditions on photometric observations in Central Europe and the evolution of air-pollution.

1. The analysis of the visual drift coefficient $D(y)$ shows that the main part of variable nights is caused by swelling or shrinking aerosols due to the changing water vapour content in connection with certain meteorological conditions. As we have shown this is not only restricted to the lower tropospheric layers and, therefore, also conclusive for mountain observing stations. Even during clear weather conditions qualified as photometric we highly recommend frequent observations of standard stars to detect nightly variable extinction using Eq. (7). We emphasize strongly never to reduce photometric measurements in sets of more than one night using mean extinction values! It is necessary to iterate several times between extinction coefficients and colour equations to avoid strong zero point errors!

2. An improved relation between meteorological conditions and extinction parameters as we have found could have predictive value for a better organization of different types of photometric observations and the reverse approach – the extinction correction of remote sensing images. An interdisciplinary teamwork between astronomers and meteorologists could lead to a better understanding of the dynamics of aerosol evolution in terms of meteorological conditions and at least to a higher accuracy in extinction correction.

3. A theoretical explanation of the observed extinction data is possible when one assumes that the main part of the aerosol extinction is contributed by an aerosol with optical constants typical for the water-soluble type. Almost the full
range of the observed points in the $x - k_{D}(V)$ diagram can be reproduced with nearly the same number density of scatterers but different sizes. This indicates condensation as the main process of aerosol growth.

4. Several analyses of volcanic produced aerosols (e.g., Cardelli & Ackerman 1983) show that dust and ash aerosols are considerably larger than aerosols associated with gas-to-particle conversion. In analogy, we would interpret the long-time increase in the $x$-values as a historical shift of the composition of the antropogenic atmospheric pollutants from the more dust/soot-like types to the gaseous types producing aerosols by gas-to-particle conversion. This requires, of course, further confirmation by direct aerosol measurements.

Acknowledgements. We express our gratitude to all observers especially to Prof. W. Pfau and Dr. B. Stecklum which have carefully carried out and reduced the $UBV$ and $IHW$ filter observations.

Appendix

The classification of the European Atmospheric Circulation Patterns briefly described in this appendix is based on Heyer (1988).

Circulation types

$HM$ High pressure over Central Europe
$BM$ High pressure ridge over Central Europe
$NW$ Northwest circulation type
$SW$ Southwest circulation type
$HB$ High pressure over the British Islands
$NE$ Northeast circulation type
$HF$ High pressure over Fennoscandian
$HNF$ High pressure over the Norwegian Sea and Fennoscandian
$SE$ Southeast circulation type (High pressure over North East Europe, low pressure over West and South Europe)
$S$ South circulation type (Low pressure over the Atlantic, high pressure over East Europe)

In the following we give a short description of main types of air-masses based on Critchfield (1960).

Air-masses

$altmP$ matured maritime polar air-mass
$mPT$ maritime subpolar air-mass first deflected to the south and then returned back
$cP$ continental subpolar air-mass
$cTP$ air-mass with its source region in middle Europe
$mP$ maritime polar air-mass
$cPA$ continental arctic air-mass
$cPT$ continental subpolar air-mass first deflected to the south and then returned back
$cTS$ continental tropical (saharan) air-mass
$mT$ maritime tropical air-mass
$cT$ continental subtropical air-mass

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