Extinction Variations at La Silla

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1. Introduction

The observations made in the seven-colour photoelectric photometry of Geneva Observatory are carried out in a very systematic mannner with equipment which allows a precise and stable definition of the passbands. During these last ten years, the Geneva observers have had permanent access to a small telescope installed at La Silla (altitude: 2,400 m; latitude: −29°). These circumstances have allowed us to undertake several programmes which we have already presented here (*The Messenger* No. 31, 1983). Retrospectively, this series of observations has been reexamined with the aim of extracting a precise appreciation of the atmospheric extinction in each passband as well as its evolution with time. Actually, during 4 nights out of 5 we do not measure the value of the atmospheric extinction: the reduction to outside the atmosphere of the measurements is then made by using the mean extinction values. Simplifying the problem, we can summarize the computation of the magnitudes outside the atmosphere by the following formula.

$$m_{o,\lambda} = m_{z,\lambda} - k_\lambda F_z + C_\lambda \qquad (1)$$

where:
- $m_{o,\lambda}$: magnitude reduced to outside the atmosphere for the mean wavelength λ.
- $m_{o,\lambda}$: magnitude for the same wavelength measured at ground level.
- k_λ: atmospheric extinction coefficient by unit of air mass.
- F_z: air mass expressed in units of zenithal atmosphere thicknesses passed through along the line of sight ($3 > F_z \geq 1$).
- C_λ: Constant allowing the adjustment of the scale of magnitudes.

The inconvenience due to the ignorance of the exact value of the extinction coefficient and its replacement by a mean coefficient ($\bar{k}_\lambda$) is much reduced if the observations are planned in such a manner that the air mass (F_z) passed through varies within very small limits from one measurement to another. This enables the main part of the error on k_λ to be compensated for by a corresponding adjustment of the zero point of the magnitude scale.

On the other hand, for about 1 night out of 5, a particular procedure is used which enables a precise estimate of the extinction to be made even if the latter is not absolutely stable over the night. This is the M and D method, the advantages and peculiarities of which have been described in detail by Rufener (1964, 1986). It differs from the classical Bouguer method which directly applies relation (1). This last case only requires the measurement of a given star at several air masses. The extinction k_λ is then obtained either graphically or by computation. The Bouguer method implicitly assumes the extinction to be stable during the time (4 to 6 hours) necessary for its measurement. This hypothesis is, however, seldom true. Without entering into the details discussed by Rufener (1964, 1986) we can state that the M and D method, which uses pairs of quasi-simultaneous observations of two stars, the one chosen ascending (M) and the other descending (D), allows a subsequent estimate of the instantaneous extinction prevailing at the time of the measurement of each pair to be made. Although this method allows the extinction to be slowly variable during the night it assumes, on the other hand, that it is isotropic at a given moment. This last condition is well confirmed during the clear nights qualified as "photometric". The application of the M and D method leads to a particularization of the extinction as a function of time during the night by interpolating between the moments when the 4 to 6 pairs of M and D measurements were made.

For the period situated between November 1975 and March 1985 we dispose of 452 M and D nights. For each night and for each one of the seven colours we have computed the monochromatic extinctions corresponding to the mean wavelength (λ_o) of each passband. The extinction k_λ adopted is the mean over the 8 to 12 estimates given by the M and D method. We also obtain for each night and each colour a standard deviation ($\sigma_{k\lambda}$ = r.m.s. deviation) which provides an estimate of the fluctuation of the nocturnal extinction. Figure 1 shows the chronological evolution of this estimation of the atmospheric extinction for 3 wavelengths corresponding to the filters

[U]: $\lambda_o = 3456$ Å
[B]: $\lambda_o = 4245$ Å
[V]: $\lambda_o = 5500$ Å

Some points earlier than November 1975 are visible in this figure. They correspond to M and D nights recorded with the aid of ESO telescopes equipped with photometers in which the filters of the Geneva system had been installed. Several remarkable features can be seen in Figure 1.

1. An important dispersion of the daily values, with a pronounced seasonal trend.

2. A slow decrease before the El Chichón event and a more rapid trend following the discontinuity.

3. A marked discontinuity in October 1982. It is a consequence of the eruptions of the El Chichón volcano in the Mexican state of Chiapas on March 23 and April 4, 1982.

Let us examine in more detail these three observational facts and their significance.

2. Mean Extinction and Seasonal Variations

Our observations of the mean daily extinctions show a dispersion $\sigma_{k\lambda}$ (r.m.s. deviation) which varies from night to night. A typical value of this dispersion is 0.007; this implies peak to peak variations of the extinction of 0.02 to 0.03 per night. We quite often (10% of the M and D nights) find amplitudes of variation of twice these values. The dispersion observed over the series of daily values is larger, clearly more pronounced for the ultraviolet than for the visible. Figure 1 shows peak to peak variations ranging from 0.05 for $k_{[V]}$ to 0.10 for $k_{[U]}$. It is readily apparent that this dispersion is seasonal. By taking into account the 321 m and D nights preceding the El Chichón event and by subtracting the slow decrease we obtain the annual variation depicted in Figure 2. The full line is the result of a sinusoidal fit with a period of one year. This same sine curve is plotted in Figure 1 after addition of the slow decrease.

It is generally assumed that the atmospheric extinction is the result of three main causes which add together:

$$k(\lambda_o) = k_{RC}(\lambda_o) + k_{03}(\lambda_o) + k_p(\lambda_o) \qquad (2)$$

- $k_{RC}(\lambda_o)$ for the Rayleigh-Cabannes molecular diffusion.
- $k_{03}(\lambda_o)$ for the selective absorption by molecular bands which in our case are restricted to those of ozone.
- $k_p(\lambda_o)$ for the extinction due to aerosols, dust and condensations of various natures.

Each of these 3 components varies as a function of several parameters; let us point out the main ones: For $k_{RC}(\lambda_o)$ these are the atmospheric pressure and temperature, for $k_{03}(\lambda_o)$ it is the reduced height of ozone and for $k_p(\lambda_o)$ the quantity of aerosols, whose vertical distribution and origin can be variable.

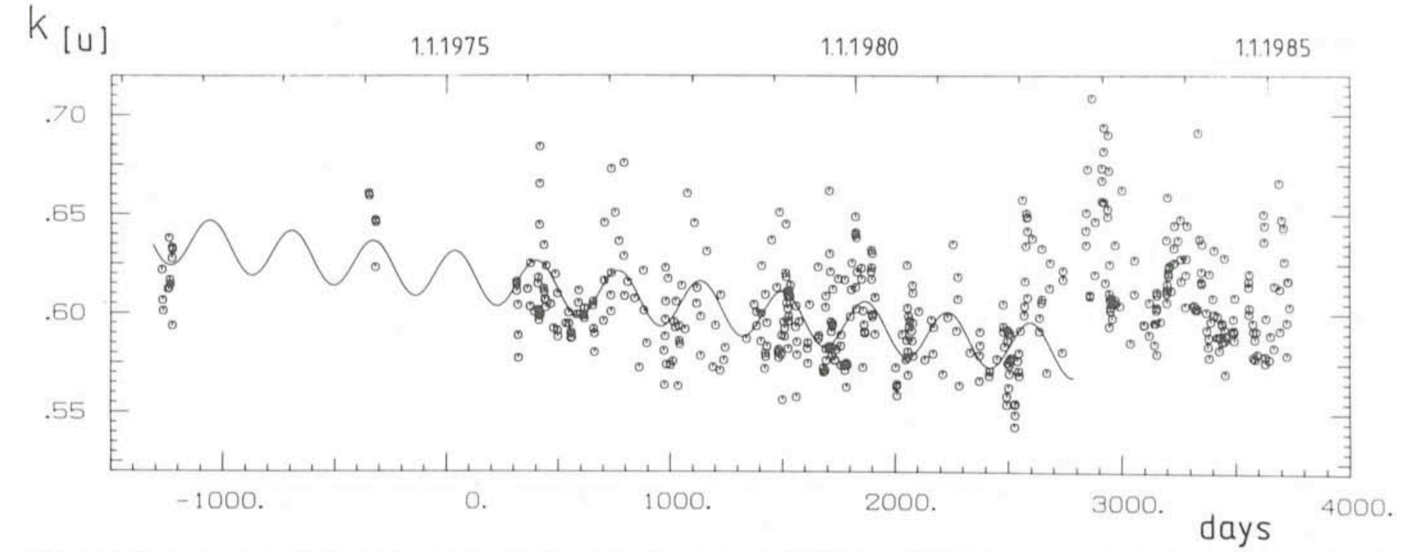

Figure 1a: *Chronological variation for the colour [U] of the mean atmospheric extinction coefficient ($k_{\lambda o} = k_{[U]}$) computed for each M and D night (see text for details). The discontinuity at the abscissa 2800 is due to the eruption of the El Chichón volcano. A slow decrease of the minimum and maximum values is clearly visible over the 2500 preceding nights. This is also the case for the mean value $\bar{k}(t)$. The sine curve represents the annual variation of $\bar{k}(t)$ as obtained in Figure 2a. The site of the observations is the ESO observatory at La Silla (Chile). The zero point of the abscissa corresponds to 1.1.1975.*

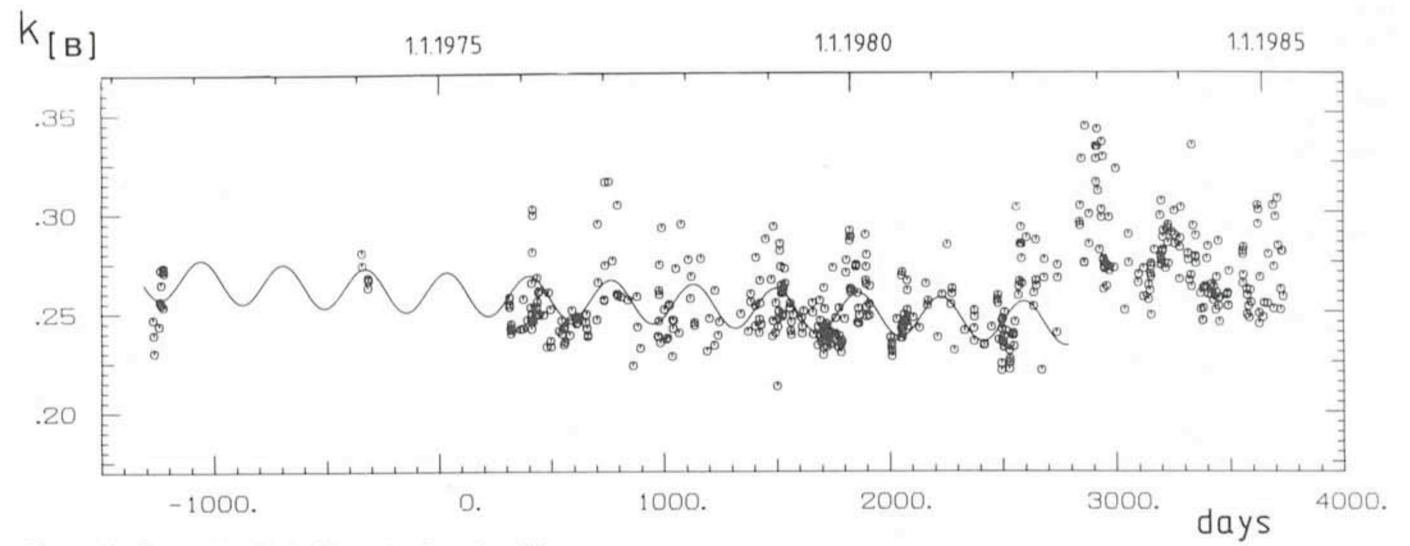

Figure 1b: *Same remarks as Figure 1a, for colour [B].*

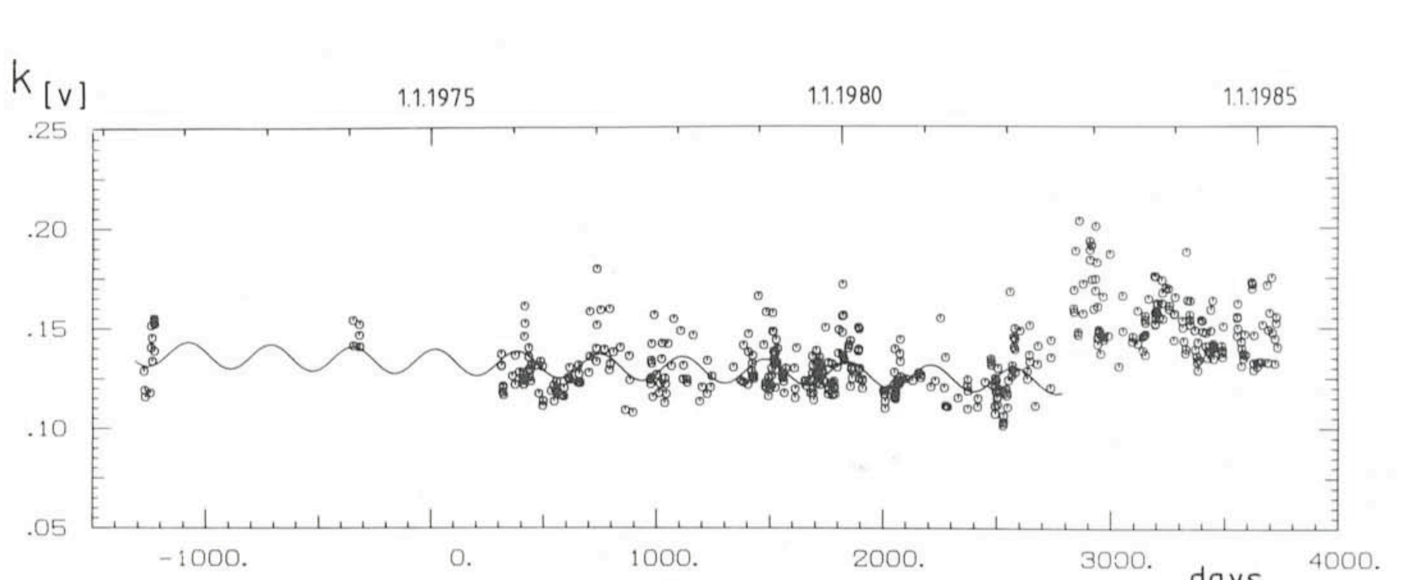

Figure 1c: *Same remarks as Figure 1a, for colour [V].*

The mean values and minima shown in Figure 2 are characteristic for the period preceding the El Chichón eruption; they are given in Table 1. The interpretation of these values enables an appreciation of the minimal effect of aerosols possible at La Silla. Indeed, by subtracting probable estimates of k_{RC} (λ_o) and k_{03} (λ_o), taken from Penndorf (1957), Van Allen (1976), Gast (1960) we get for k_p (λ_o) the values of Table 1. The mean minimum extinction by aerosols can then be expressed by

$$k_p(\lambda_o) = b\,\lambda_o^{-\alpha} = 0.006\,\lambda_o^{-1.3} \qquad (3)$$

(k_p in magnitudes per unit of air mass, λ_o in μm). The value of the coefficient b = 0.006 is exceptionally small if one considers the work of Siedentopf (1948). The important fluctuations of the observed extinctions, be they seasonal or not, result on the one hand from the variation of the physical parameters which control molecular diffusion and, on the other hand, from seasonal variations of the reduced thickness of ozone and of the various aerosols present in the lower atmospheric layers. The altitude reached by the latter is clearly greater during the southern summer, its upper limit being situated above La Silla.

3. Slow Variations of the Extinction

If we consider the 2,500 days preceding the El Chichón eruption we notice, in spite of the strong dispersion of the points in Figure 1, a slow and regular decrease of the mean as well as the extreme values (minima and maxima). This decrease is strongly chromatic, more pronounced for [U] than for [V]. For the values observed in the seven colours and calling this decrease over 2,500 days $d_{\lambda o}$, we find the relation

$$d_{\lambda o} = 0.002\,{}_{\lambda o}^{-2.3} \qquad (4)$$

($d_{\lambda o}$ in magnitudes by unit of air mass, λ_o in μm). This decrease cannot be related with a drift of the parameters which control molecular diffusion or the absorption by ozone, since no variation of that nature is known. On the other hand, if we compare our observations with those of Moreno and Stock (1964) and Gutierrez-Moreno et al. (1982), we are led to the conclusion that this decrease is the continuation of the diminishing diffusive and absorbant effects caused by the aerosols emitted in March 1963 by the Mt. Agung volcano (Bali, latitude −8°). Indeed, that volcano was responsible for an exceptional stratospheric load of aerosols with a probable maximum in the southern hemisphere. According to Lamb (1970), the contamination of the stratosphere could have reached an altitude close to 50 km. The

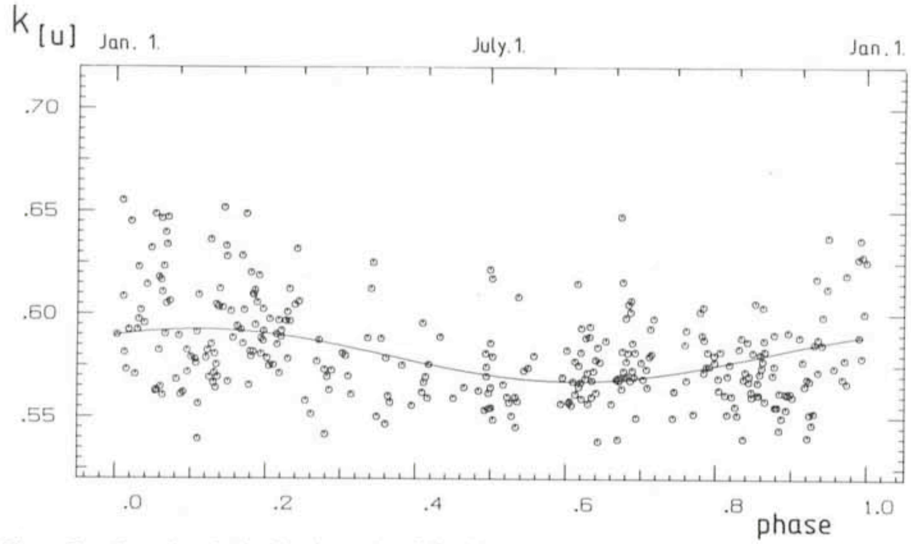

Figure 2a: *Annual variation for the colour [U] of the atmospheric extinction coefficient ($k\lambda_o$ = $k_{[U]}$) observed during the 321 M and D nights preceding the eruption of the El Chichón volcano (positive abscissa in Figure 1a). The slow decrease has been subtracted. The scale of the ordinates therefore corresponds to the period 2800 in abscissa in Figure 1a. The full line is the fitted sine curve.*

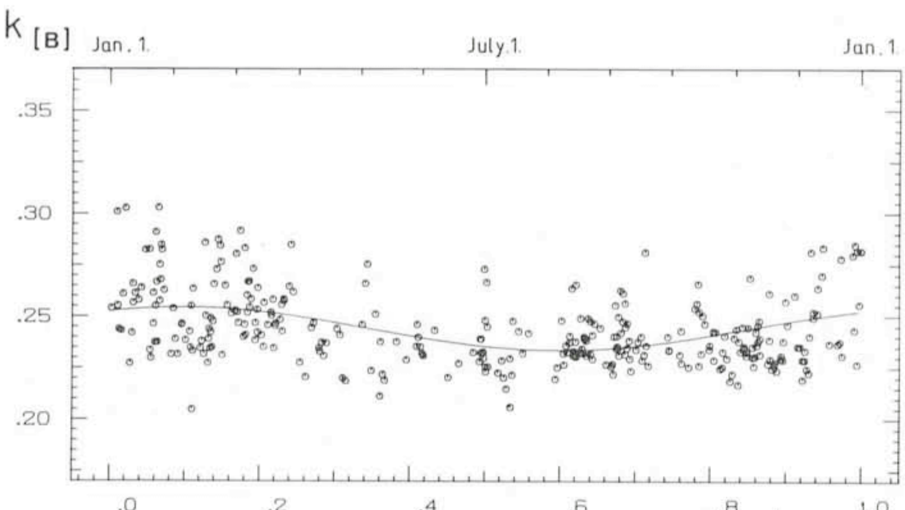

Figure 2b: *Same remarks as Figure 2a, for colour [B].*

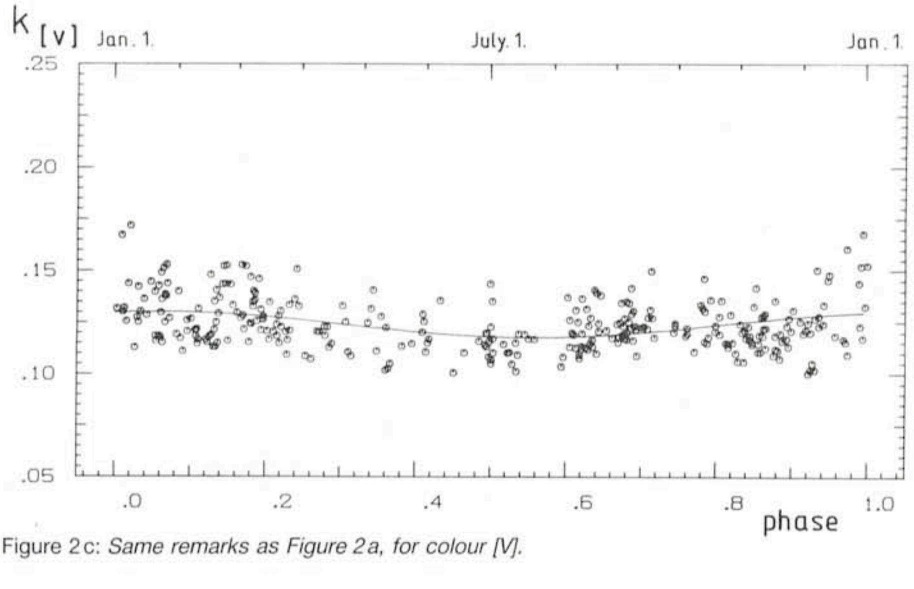

Figure 2c: *Same remarks as Figure 2a, for colour [V].*

TABLE 1

Filters	U	B_1	B	B_2	V_1	V	G
λ_o [nm]	345.6	402.4	424.5	448.0	540.5	550.0	580.0
k_{RC} (λ_o) [magn. air mass^{-1}]	.550	.289	.230	.185	.085	.080	.065
k_{O3} (λ_o) [magn. air mass^{-1}]	.016	.000	.000	.001	.025	.030	.039
$< k >$ [magn. air mass^{-1}]	.589	.308	.246	.206	.126	.124	.114
k_p (λ_o) [magn. air mass^{-1}]	.023	.019	.016	.020	.016	.014	.010
Slope $d_{\lambda o}$ [magn./2500 d]	.034	.012	.015	.013	.008	.009	.010
El Chichón discont. $\varepsilon_{\lambda o}$ [magn.]	.070	.053	.055	.050	.048	.048	.040

eruptions of Mt. Agung and El Chichón are conspicuous by their very strong emissions of sulfuric gases such as sulfur dioxide. In the presence of water vapour this gas can condense in the form of fine droplets of sulfuric acid (Robock, 1983; Keen, 1983). The altitude reached by these droplets and their small size can explain their very slow decantation through the stratosphere. Durations of 10 to 20 years are estimated as possible by Lamb (1970). On the other hand, the fact that these droplets were still in suspension more than 12 years after the Mt. Agung event is consistent with the strong chromaticity of the slow decrease observed. Indeed, the chromatic nature of this type of diffusion is all the more pronounced if the dimensions of the droplets are smaller than the wavelength of the observations. An order of magnitude of the typical dimension of these residual aerosols is ≤ 0.1 µm. On the basis of our observations, we can also conclude that for negative latitudes the period 1978–1982 was the most transparent during these last 20 years.

4. The Discontinuity Following the El Chichón Eruption

We notice no appreciable increase of extinction until the second of July 1982, i.e. three months after the El Chichón eruption. A difference in latitude of 46° separates the volcano from the site of our observations. The strongest extinction is recorded on November 3, 1982, seven months after the eruption. These delays are longer than those recorded at Cerro Tololo (latitude −30°) by Moreno and Stock (1964) following the Mt. Agung eruption. Indeed, they detected a significant increase after only 6 weeks and measured the highest extinction after 5 months. The difference in latitude between Mt. Agung and Tololo is only 22°. The amplitude of the discontinuity was also much larger (about 5 times!). The longer propagation time is certainly due to the greater separation in latitude, whereas the smaller discontinuity following the El Chichón event may reflect the combination of an intrinsic difference between the stratospheric loads injected by each volcano with the effect of difference in latitude or hemisphere. The size of the discontinuity that we have estimated $(\varepsilon\lambda_o)$ over the extinction measured in each colour is observed as well for the mean values as for the minima and maxima. It is remarkable that the amplitude of the dispersions computed each night $(\sigma_{k\lambda})$ as well as the night-to-night dispersions are not significantly increased after the discontinuity. This tends to prove that at the latitude −29° the stratospheric load was already well distributed and sufficiently isotropic not to alter these estimators. From the $\varepsilon_{\lambda o}$ values of the discontinuity given in Table 1 we can deduce a chromatic dependence of the form

$$\varepsilon_{\lambda o} = 0.024\,\lambda^{-1} \quad (5)$$

($\varepsilon_{\lambda o}$ in magnitudes, λ in µm). The exponent of the wavelength in this relation suggests that the size distribution of the supplementary particles has a distinctly larger modal value (0.5 µm) than that of the particles responsible for the slow decrease of § 3. This is consistent with the fact that this additional stratospheric load decreases rather rapidly during the first two years. The largest particles decant most rapidly.

5. Conclusion

This retrospective analysis over ten years of atmospheric extinction observations at La Silla allows one to better understand the nature of its variations. We were able to calculate the sizes of its short, mean and long term fluctuations. We confirm the advisability of taking the necessary precautions to control this parameter which is essential for the precise reduction to outside the atmosphere of ground based photometric observations. Events such as El Chichón induce variations of extinction which are locally quasi isotropic but nevertheless variable in time. Due to the restricted number of its assumptions, the M and D method is very useful for the correct estimation of atmospheric extinction. The analysis of the measured values shows the high quality of transparancy of the best nights at La Silla and the great frequency of nights during which photometric measurements are feasable.

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The trail of a meteor is captured on this 20-minute exposure of the La Silla night sky with the meteo mast in the foreground. Photograph by R. Lukas on Kodak 400 ASA film with a 50-mm f/1.8 lens.