*Kodaikanal Obs. Bull. (1986)* **5**, *201 - 209*

# ATMOSPHERIC EXTINCTION AT KAVALUR OBSERVATORY DURING 1980-85

B.S. SHYLAJA AND J.C. BHATTACHARYYA

## ABSTRACT

From a series of photoelectric scanner observations during 1980-85, the atmospheric extinction at Kavalur has been analysed. The variation of this appears to follow $\lambda^{-4}$ law. There is a general increase in the aerosol absorption during 1980-85. An attempt made to compare the meteorological data on ozone and water vapour measures, shows that the absorption due to ozone was marginally higher during 1980-81. The absorption due to water vapour appears to be varying during the night, making such comparisons very difficult.

**Key Words :** atmospheric extinction, ozone and water vapour, spectrophotometry

## 1. Introduction

The seeing conditions at Kavalur (-78° 49' 53.9" longitude, +12° 34' 32.2" latitude, 725m altitude) have been well studied and the seasonal variations estimated from standard observations (Bappu, Mohin and Unnikrishnan, 1978). From a series of photoelectric scanner observations during 1980-85, it has been possible to estimate the extinction introduced by the atmosphere over the visible spectral band. The present report brings about the role of minor constituents in the atmosphere in extinction variations.

## 2. Theory

Let us consider a monochromatic beam of wavelength $\lambda$ entering the atmosphere at a zenith distance z with reference to the observer. The observed intensity will be a function of the optical depth $\tau$ as,

$$I(\lambda,\tau) = I(\lambda, 0) \exp[-\tau(\lambda, z)] \qquad (1)$$

The optical depth is defined as,

$$\tau(\lambda, z) = K(\lambda) \; X(z) \qquad (2)$$

where $K(\lambda)$ is the extinction coefficient and X(z) is the airmass. The optical depth at z=0 is,

$$\tau(\lambda, 0) = K(\lambda) \qquad (3)$$

Thus we can rewrite (1) as,

$$I(\lambda,\tau) = I(\lambda,0)\ \exp[-K(\lambda)\ X(z)]$$

$$\text{or,}\quad \ln\ I(\lambda,\tau) = \ln\ I(\lambda,0) - K(\lambda)\ X(z)$$

$$\text{or,}\quad \partial/\partial x\ [\ln(\lambda,\tau)] = -K(\lambda) \tag{4}$$

Thus a plot of the natural logarithm of the intensity with airmass gives the slope as K( λ), the extinction coefficient. The knowledge of I( λ, 0), the intensity prior to entry into atmosphere is not necessary.

The model of the atmosphere described by Hayes and Latham (1975) was used for the calculation for airmass extinction. The main contributors are (a) the Rayleigh scattering by molecules, (b) aerosal scattering and (c) molecular absorption.

The absorption due to Rayleigh scattering can be calculated as,

$$A(\lambda, h) = 9.4977\times10^{-3}\ \times\ \frac{1}{\lambda^4}\left[\frac{(n-1)_\lambda}{(n-1)_{\lambda=1}}\right]^2 \exp\ \frac{-h}{7.996} \tag{5}$$

assuming n = 0 at p = 760 tor and at altitude h = 0. The index of refraction n, is given by,

$$\frac{(n-1)_\lambda}{(n-1)_{\lambda=1}} = 0.2345 + \frac{1.076\times10^2}{146 - \frac{1}{\lambda^2}} + \frac{0.93161}{44 - \frac{1}{\lambda^4}} \tag{6}$$

The absorption due to ozone may be calculated as,

$$A_{oz}(\lambda) = 1.11\ T_{oz}\ K_{oz}(\lambda) \tag{7}$$

where $T_{oz}$ is the total ozone above the observatory in atm. cm. and $K_{oz}(\lambda)$ is the absorption coefficient in $cm^{-1}$.

The distribution of aerosols with altitude can be assumed to be exponential. The dependence of this on wavelength is given by,

$$A_{aer}(\lambda) = A_0\ \lambda^{-\alpha}\ \exp(-h/H) \tag{8}$$

where λ is in microns.

Ozone is known to absorb in two bands - Huggins band, with the peak at about 2600 Å and the weaker Chappius band, with the peak at 6000 Å (Allen, 1976). It has been shown by Dunkelman and Scolnik (1959) that the ozone absorption is strong in the range $3000<\lambda<3400$ Å, compared to that in Chappius band. They have measured the ozone content in the atmosphere and compared with measurable absorption in Huggins band. They have also shown that the region of $3400 < \lambda < 4650$ Å, which is free of absorption due to ozone, shows the absorption variation nearly parallel to the Rayleigh curve, but approximately 15% above that.

The aerosol extinction is calculated by subtracting the Rayleigh scattering and ozone absorption from the measured total extinction (Hayes and Latham, 1975). Tug et al.(1977) have used this as a tool for assessing the quality of transparency.

## 3. Procedure

The spectrophotometric data obtained with good sky conditions, from the automated spectrum scanner (Bappu, 1977) were used for estimating the absorptions. Stars with similar magnitudes and spectral classes were chosen for this analysis. In fact, one of the many standards observed on any night itself was used for estimating the absorptions. Measurements made at zenith distances not exceeding 30° have been used in this analysis. Four such observations with the best conditions of sky are shown in Table 1. The errors in magnitude estimates as computed from such standard star observations were 0.004 at 5000 Å and 0.006 at 7400 Å.

Table 1. Data Used for Extinction Analysis & Results

| Date | Prog. star | Std. star | Z | A | B | α | Abs. due to ozone per cent | Ozone* measures (atm. cm) |
|---|---|---|---|---|---|---|---|---|
| 1980 Oct 29 | ε Aqr | γ Gem | 24°.73 | 0.063 | 0.0141 | 1.33 | 15 | 269 |
| 1981 Feb 27 | η Hya | γ Gem | 30°.03 | 0.050 | 0.0132 | 1.31 | 12 | 246 |
| 1983 Feb 4 | $\xi^2$ Cet | ζ Pup | 23°.93 | 0.051 | 0.158 | 1.14 | 6 | 243 |
| 1984 Dec 13 | ρ Leo | ζ Pup | 26°.96 | 0.075 | 0.0142 | 0.92 | 7 | 241 |

* Measurements from IMD, made at Kodaikanal

Following van den Bergh and Henry (1963), the measured total absorption was fitted the equation,

$$K(\lambda) = A + B/\lambda^4 \tag{9}$$

re K(λ) is the absorption in magnitude per unit airmass. This expression is found to show tter validity in the longward region of 4000 Å.

Figure 1 shows the total measured absorption and that due to pure Rayleigh scattering. vertical shift between the two is accounted for by the factor A in equation (9). This be taken as representative of other contributors, because within the accuracies of measures, a better fit of other higher order Rayleigh coefficients may not be realistic.

As mentioned earlier, the Chappius band of ozone affects the absorption in the wave- th range 5000 < λ <7000 Å. The water vapour absorbs strongly in the longer wavelength ons; only the band at 7100 Å is included in our coverage. The range of wavelength 0 < λ <4800 Å can be considered to be free of both ozone and water vapour. The residual

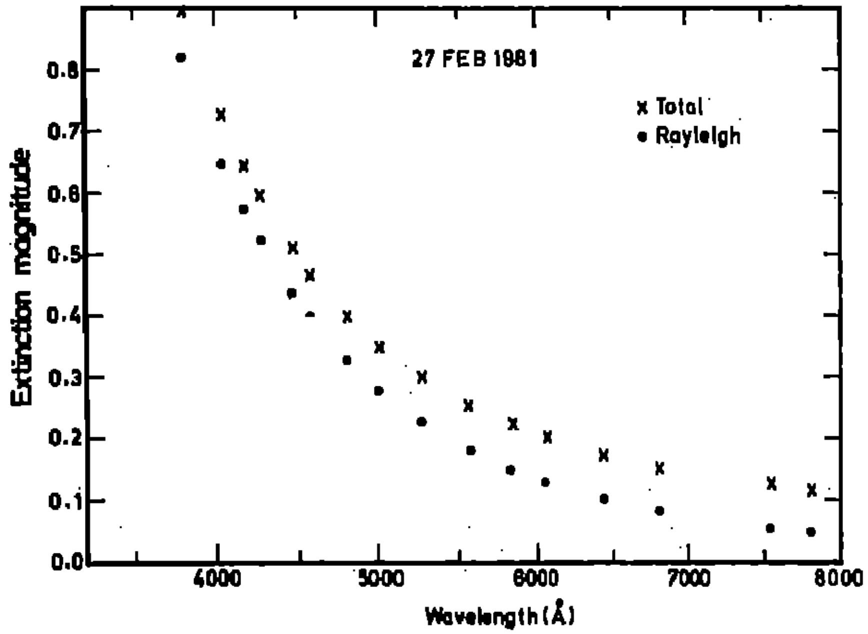

**Fig. 1** The measured total absorption and that due to pure Rayleigh scattering per air mass, given as K (λ) in magnitudes.

orption in this range was used to calculate the constant α in equation (8). Its value been tabulated in Table 1. It is known that this can have a range 0.9 < α < 1.5 Vaucouleurs, 1965).

The residual absorptions have been plotted on an expanded scale in Figure 2, which ngs out two important points :

The contribution from ozone is higher in the Oct 1980 and Feb 1981 measurements

There seems to be a general increase in the total absorption from 1980 to 84

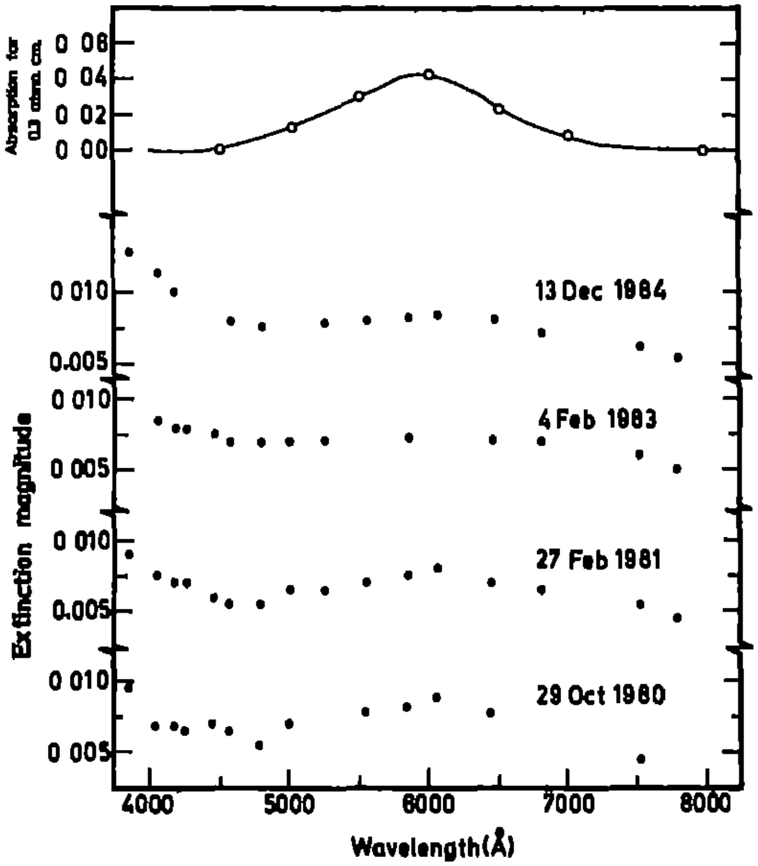

Fig. 2 Residual absorptions after removing the Rayleigh effect. The ozone absorption coefficient (Allen, 1976) also is shown in the top curve

This paper refers to only four observations, but the total number of such observations eds 40 The coefficients A and B are indicated in Figure 3 Since A corresponds he variable aerosol and dust content, the scatter can be easily explained The almost tant value of B permits its extrapolation to nights for which the extinction could be determined Generally it is found that, although the observing season extends ı November to March, both the extinction and seeing are minimum in February and sky conditions are favourable for photometry and spectrophotometry

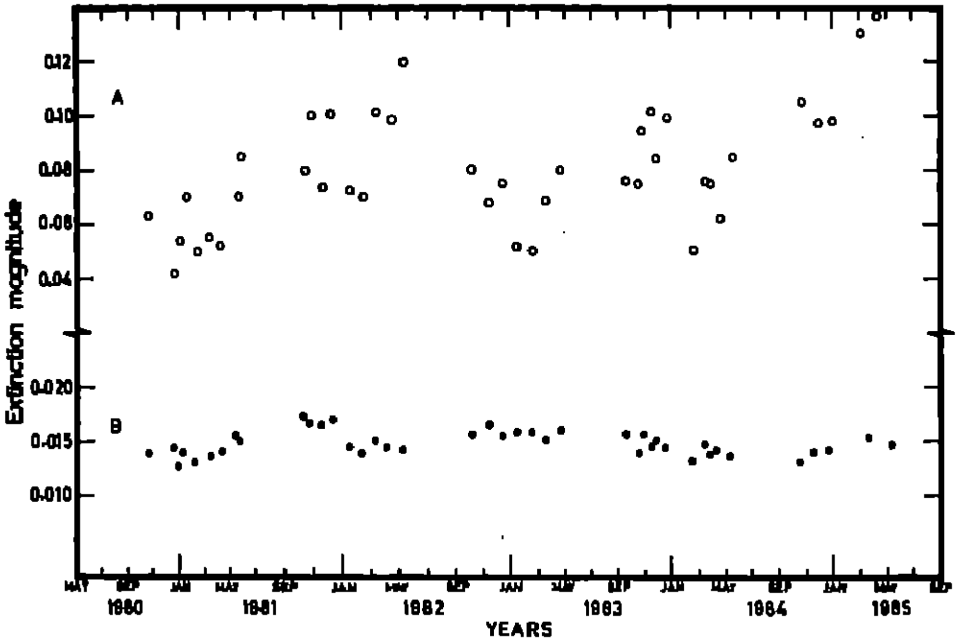

Fig. 3 The variation of coefficients A and B during 1980-85 (See Text).

## 4. Comparison with Meteorological Data

We obtained the ozone measurements and T-$\phi$ grams from the meteorological department for four dates of observations of Table 1, with the idea of comparing our estimates with their measurements. The nearest ozone measuring station is Kodaikanal (lat. 10° 14' alt. 2343 m) and the ozone measures are included in the Table 1.

It appears that there has been a general increase of ozone during 1980-81, from both measures. A similar effect may be inferred from Figure 2, although the large errors prevent quantitative comparisons. Moreover the hourly variation of ozone on time scales as short as a few hours also has been taken in deriving that the measured ozone represents only a mean value (Hayes and Latham, 1975). Hence only simultaneous measures of ozone content at the site may reveal any possible direct relationship, as has been pointed out by Dunkelman and Scolnik (1959).

The $H_2O$ band at 7100 Å was used for deciding the water vapour absorption. The percentage of absorption can be estimated by knowing the continuum energy distribution of the particular star. Since this band was covered on almost all nights, it was possible to notice that the band structure itself appears to have changed during the night. To study this more carefully, stars of similar spectral type, observed at similar zenith distances, on the same night, were chosen (Table 2). Their energy distributions are shown in Figure 4, which clearly indicate the variation in $H_2O$ band during the night.

Table 2 Details of Observations of Five Stars of Figure 4

| Name | HR Number | Spectral type* | Declination | Zenith Distance | Effective temperature obtained |
|---|---|---|---|---|---|
| 73 Vir | 5094 | A4m | - 19° 40' | 46° | 0.64 |
| λ Vir | 5359 | A m | - 13° 19' | 39° | 0.50 |
| 60 Hya | 5591 | A m | - 28° 00' | 49° | 0.59 |
| | 5762 | A m | - 19° 38' | 40° | 0.53 |
| | 5875 | A m | - 3° 48' | 25° | 0.50 |

* From Hoffleit (1964)

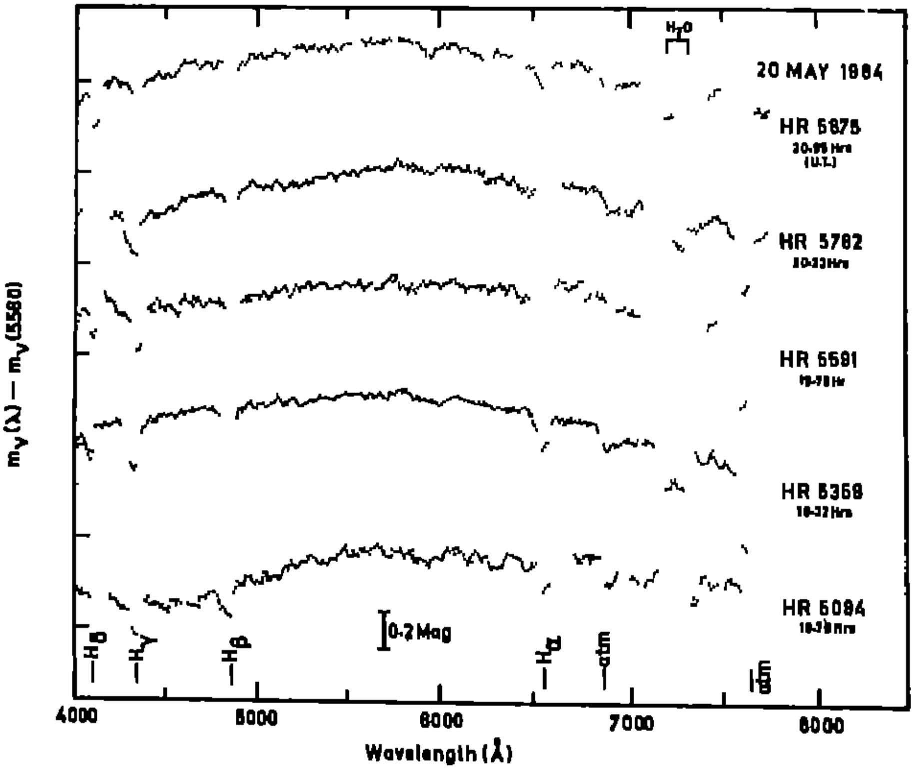

Fig. 4 Energy distributions of five stars of similar spectral type as observed on the same night at similar zenith distances. The difference in $H_2O$ absorption with UT is noticeable. Details of observations are in Table 2 (from Shylaja et al., 1985).

The T-ϕ grams were used to estimate the amount of precipitable water in the atmosphere. These measurements were available for Bangalore (lat 12° 55' and alt. 921 m) and Madras (lat 13° 04' alt. 7 m). Since Madras is situated at sea level, we decided to compare with the measurements from Bangalore only, which is at a similar altitude as Kavalur (725 m). These measurements are obtained from balloons at 5.30 am ($0^h$ UT) and 5.30 pm ($12^h$ UT).

From the T-ϕ gram it is possible to measure the mixing ratio (defined as the ratio of mass of water vapour to the mass of dry air) by superposing the isohygrics. This measurement is done for every 50 mb variation of pressure. It is further assumed that the specific humidity (defined as the ratio of mass of water vapour to mass of moist air) differs from the mixing ratio by a small amount (0.1) and the mean specific humidity is calculated. Then the total amount of precipitable water in cm is available from

$$W = \frac{1}{g} \bar{q} \, (p_o - p) \tag{10}$$

where $g$ = acceleration due to gravity,

$\bar{q}$ = mean specific humidity and

$p_o - p$ = difference in pressure chosen for measurement of $q$, in this case 50 mb.

Table 3. Comparison of Water Vapour Measurements

| Precipitable water measurements | | | Water vapour absorption measurements | | |
|---|---|---|---|---|---|
| Date | Time UT | Amount Cm | Name of star | Time UT | Absorption % |
| 1980 Oct 29 | 12.00 | 1.46 | ε Agr | 13:45 | 65 |
| | | | HR 8216 | 14:10 | 56 |
| 1981 Feb 27 | 12.00 | 0.96 | γ Gem | 17:55 | 38 |
| | | | HR 1732 | 18:03 | 42 |
| 1983 Feb 4 | 00.00 | 0.80 | - | - | - |
| 1983 Feb 4 | 12.00 | 1.37 | $\xi^2$ Cet | 14:18 | 47 |
| | | | HR 1732 | 14:45 | 38 |
| 1984 Dec 13 | 00.00 | 0.47 | ζ Pup | 23:38* | 42 |
| | | | φ Leo | 23:55* | 46 |

* Times of Dec. 12.

Since the time of observation of star and the measurement of water vapour do not coincide, we decided to restrict our comparison to stars observed as close to the balloon launch time as possible. Such results are shown in Table 3. No apparent relation is noticeable between the two. This is not altogether unexpected, considering the rapid variation of water vapour absorption, as mentioned earlier, and the differences in the distribution of water vapour content over geographically separated locations. This, again, emphasizes the necessity of simultaneous water vapour measures at the site for deriving meaningful relationship.

## 5. Conclusion

The spectrophotometric observations during 1980-85, indicate that an approximation to $\lambda^{-4}$ variation for the atmospheric extinction appears quite reasonable. A general increase in aerosol absorption is noticed from 1980 to 1985. A comparison with meteorological data on ozone shows possible relations, which cannot be established quantitatively. The effect of water vapour on extinction is not apparent. This study implies the necessity of simultaneous meteorological measurements at the site, for evaluating the role of minor constituents in atmospheric extinction.

## Acknowledgements

We wish to thank G.S.D. Babu for valuable guidance in observation and reduction. The India Meteorological Department is acknowledged for providing the ozone data and the T-$\phi$ grams. We are grateful to Drs. B.K.Sridhar and C.V.V.Bhadran of IMD, Bangalore, for useful discussions on the IMD data. We thank an anonymous referee for helpful suggestions.

## References

Allen, C.W., 1976, Astrophysical Quantities, Athlone Press, London, p.127

Bappu, M.K.V., Mohin, S. and Unnikrishnan, K.G., 1978, Kodaikanal Obs. Bull., Series A, **2**, 168

Bappu, M.K.V., 1977, Kodaikanal Obs. Bull., Series A, **2**, 64

de Vaucouleurs, G., 1965, Publ. Astr. Soc. Pacific, **77**, 5

Dunkelman, L. and Scolnik, R., 1959, J. Opt. Soc. America, **49**, 356

Hayes, D.S. and Latham, D.W., 1975, Astrophys. J., **197**, 593

Hoffleit, D., 1964, Catalogue of bright stars, Yale Observatory Publication

Shylaja, B.S., Babu, G.S.D., Ghosh, T., Indulekha, K., Joarder, P.S., Karbelkar, S.N. and Shanbag, S., 1985, Bull. Astr. Soc. India, **13**, 87

Tug, H., White, N.N. and Lockwood, G.W., 1977, Astr. Astrophys., **61**, 679

van den Bergh, S. and Henry, R.C., 1962, Publ. David Dunlop Obs., **2**, 281