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Atmospheric water vapour and its effect on aerosol extinction at a coastal station — Visakhapatnam

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सार — प्रत्यक्ष रूप से संचारित सौर फ्लक्स के प्रक्षेणों से 800, 935 और 1025 ना० मी० पर जल वाष्प के $\rho\sigma\tau$ बैंड के आस-पास स्पैक्ट्रमी प्रकाशीय गहनताओं से समाकलित वायुमंडलीय जल वाष्पन अंश का मूल्यांकन किया गया । कुल वर्षणीय जल वाष्प के सामयिक परिवर्तन, पूर्व मानसून और मानसून के महीनों में अधिकतम और शीत के महीनों में न्यूनतम मान के साथ उल्लेखनीय ऋतुविक विविधताएं प्रकट करते हैं। समाकलित अंश का सतही आर्द्रता प्राचलों के साथ रचनात्मक सहसंबंध प्रकट हुआ है तथा यह सहसंबंध अन्य ऋतुओं की तुलना में मानसून के महीनों में बेहतर पाया गया है । प्रायोगिक रूप से व्युत्पन्न जलवाष्प की विविधताओं की तुलना रेडियोसौंदे आंकड़ों के प्रयोग से सूत्रित मॉडल की विविधताओं के साथ की गई। दृश्य और निकटवर्ती इन्फ्रारेड (आई आर) क्षेत्रों में बहुत स्पैक्ट्रमी सौर फ्लक्स मापों से व्युत्पन्न वायुविलय (एरोसोल) के विलोपन परिवर्धित वायुमंडलीय जल वाष्प के साथ बढ़ते हैं । यह वृद्धि ऋतुविक निर्भरता प्रकट करती है । सतही तापमान संभवत: इसके प्रभावों के माध्यम से मिश्रित ऊंचाइयों पर वायु विलय (एरोसोल) के विलोपन को भी प्रभावित करता है ।

ABSTRACT. Integrated atmospheric water vapour content has been evaluated from the spectral optical depths around the $\rho\sigma\tau$ band of water vapour by making directly transmitted solar flux measurements at 800, 935 and 1025 nm. The temporal variation of the total precipitable water vapour shows significant seasonal variation with maximum during pre-monsoon and monsoon months and minimum during winter months. The integrated content shows a positive correlation with surface humidity parameters and the correlation is better during monsoon months compared to other seasons. The experimentally derived variations of water vapour are compared with the model variations formulated using radiosonde data. The aerosol extinctions derived from the multi-spectral solar flux measurements in the visible and near IR regions increase with increasing atmospheric water vapour and this increase shows a seasonal dependance. The surface temperature also seems to affect the aerosol extinction probably through its effect on the mixing heights.

Key words—Aerosol extinction, Aerosol optical depths, Mixing heights, Relative humidity, Water vapour content, Monsoon.

1. Introduction

One of the important and all pervasive components of the earth's atmosphere is water vapour, which plays an important role in the radiation balance. There are various ways to express the water vapour content of the atmosphere like, dew point temperature, water vapour partial pressure, absolute humidity, relative humidity and precipitable water vapour. Of all these, the precipitable water vapour or the integrated water vapour content has got wide applications in microwave communication problems, for example in satellite tracking by microwave radars and for microwave propagation studies and in remote sensing (Bliss 1961, Goldfinger 1980, Parameswaran and Rose 1982, etc). Water vapour exhibits intensive and widest absorption bands and so affects both the incoming solar radiation and also longwave radiation emitted by the earth into space. Therefore, an accurate and reliable assessment of the effects of water vapour on the attenuation in the path of propagation is essential to the design of the systems operating in this spectral region.

Correlation between the columnar content of water vapour in the air and the humidity or moisture parameters at the surface has long been established. There have been many a report on the relation between total moisture content and surface moisture (Shands 1949, Goss and Brooks 1956, Reitan 1963, Smith 1966, Karalis 1974, Lowry and Glahn 1969, Reber and Swope 1972, Parameswaran 1988). A study on the temporal variation and total precipitable water vapour derived from the spectral extinction measurements at 800 nm, 935 nm and 1025 nm centred around the $\rho\sigma\tau$ band of water vapour absorption has been carried out. The relative variation of the columnar content of water vapour with respect to the surface humidity parameters like relative humidity and dew point has also been attempted for the first time using spectral extinction data at this station.

Research in the past two decades has shown the importance of humidity as a factor controlling the optical state of the matter dispersed in air. These studies have indicated that there is a pronounced trend

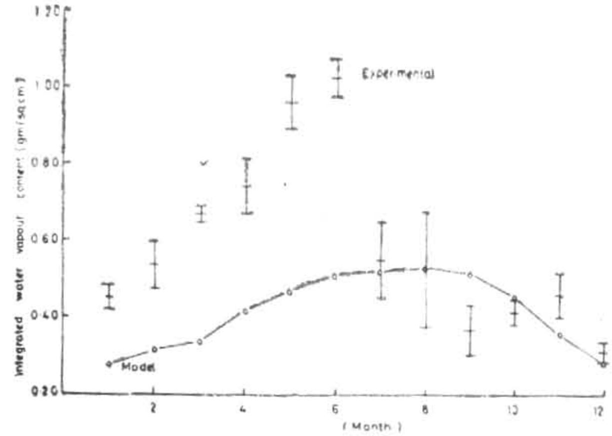

Fig. 1. Annual variation of mean precipitable water vapour with the standard error bars and the model variation (solid line) of Parameswaran (1988)

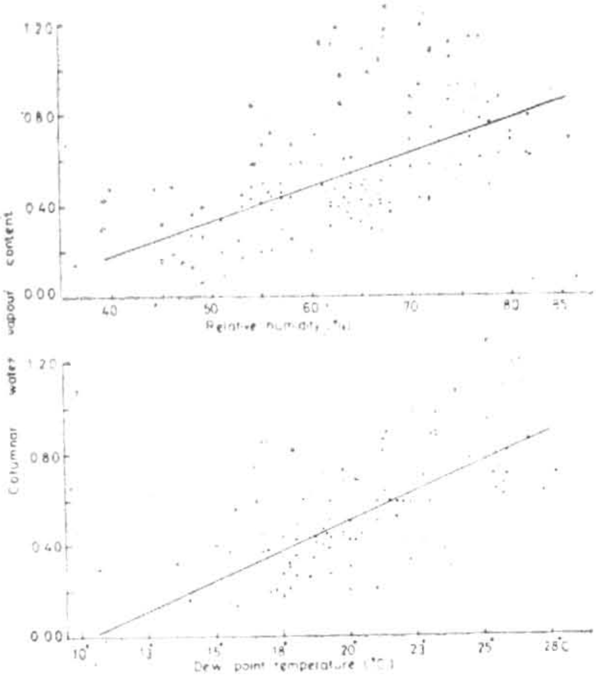

Fig. 2. Mass plots of relative humidity and surface dew poin against the columnar water vapour content (gm cm^{-2}) alongwith regression lines.

for lower visibilities as the humidity in the atmosphere increases (Filippov and Mirumyants 1972 and the references therein). The atmospheric extinction due to water vapour could be either due to absorption at the particular wavelength under consideration or due to the growth of the aerosol particles in size. The size changes alter the scattering characteristics of the aerosol system and thus effect the optical depths. Visakhapatnam (17.7°N, 83.3°E) being a coastal station, it is expected that the atmospheric humidity plays an important role in determining the transparency and the aerosol size distributions. Also it is believed that the local temperatures may also effect the turbidity of the atmosphere through affecting the mixing heights. A study has been carried out on the effect of relative humidity, precipitable water vapour and the surface temperature on the aerosol extinction at different wavelengths and the results are reported here.

2. Experiment and methodology

A multi-wavelength solar radiometer system employing nine narrow band interference filters at 400, 450, 500, 590, 700, 750, 800, 935 and 1025 nm is used to measure the direct solar flux at these wavelengths from which aerosol optical depths are evaluated after removing the optical depths due to Rayleigh scattering and molecular absorption. This experiment is conducted as a part of the Indian middle atmosphere programme and the details of the experimental system and analysis are available from Krishnamoorthy *et al.* (1989). The aerosol optical depths thus evaluated during the period December 1987 to May 1989 are used in the present study. The wavelength at 935 nm coincides with the peak of the strong $\rho\sigma\tau$ absorption band of water vapour, while at 800 and 1025 nm, there is no significant absorption by water vapour. Thus, from the spectral extinction measurements at 800, 935 and 1025 nm, estimation of integrated columnar content of water vapour can be made following the method suggested by Krishnamoorthy *et al.* (1989) and the data for the above said period is used for the study of the atmospheric water vapour and its effect on aerosol extinction.

3. Temporal variation of columnar water vapour content drived from spectral extinction measurements

The columnar water vapour content has been evaluated for each day of observation from the spectral extinction measurements at 800, 935 and 1025 nm as described in the earlier section. The monthly mean values of the columnar water vapour content alongwith the standard error bars for one the year 1988 are shown in Fig. 1. From this figure, it can be seen that the water vapour content shows two distinct seasonal characteristics, namely, the low water vapour content in the winter season say from mid-October to the end of February and higher water vapour content in the premonsoon and monsoon seasons, *i.e.*, during the months of April, May, June and July. The model derived values (solid line) of the precipitable water vapour content from Parameswaran (1988) are also shown in the figure. It may be noticed from the figure that though the seasonal trends are similar in both the cases, the agreement is good in the later half of the year compared to the earlier half of the year. The model derived from the radiosonde data is expected to show a deviation of about 20% during the summer months (Parameswaran 1988) and this being a coastal station, the variability is expected to be high. However, as the data considered is just for one year, some more data is required before any statement could be made about the validity of the model. Also efforts are on to compare individual days data from both the experiment and radiosonde.

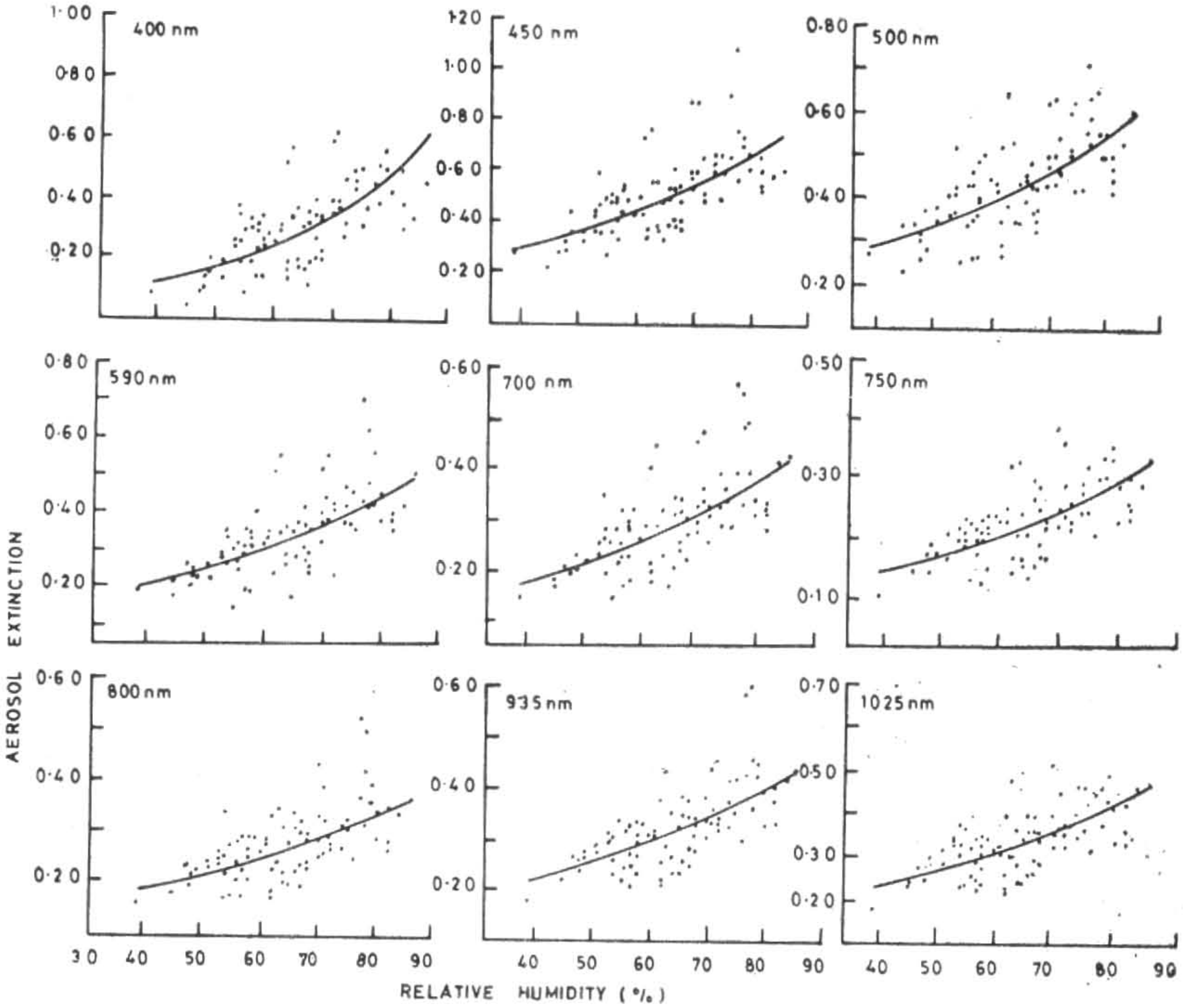

Fig. 3. Mass plots of aerosol extinction *versus* the relative humidity (%) at different wavelengths. The solid lines are the best fit lines

Over the last several years, many attempts have been made to relate the surface weather parameters to the precipitable water vapour content of the atmosphere. Reitan (1963) proposed a linear relationship between the natural logarithm of the total precipitable water vapour and surface dew point temperature. Tomasi (1977) reported that correct estimates of water vapour content can be made only by the use of proper coefficients in the relationship with surface parameters for various periods of each day. According to Rebber and Swope (1972), a widely variable relationship exists between total precipitable water vapour and surface absolute humidity and their results also demonstrated that estimates of total precipitable water vapour from surface humidity measurements are not valid. In light of these reports, an attempt has been made to study the variability of integrated water vapour content as a function of the surface relative humidity and dew point temperature.

Fig. 2 shows the mass plot of the surface relative humidity and dew point temperature against the integrated water vapour content, for one year data of 1988. By and large the integrated water vapour content shows a linear relationship with both the surface relative humidity and dew point and regression lines have been fit for the data which yielded a correlation coefficient of 0.39 for surface RH and 0.54 for dew point for the whole data. With a view to see the seasonal variation in the dependance of the total precipitable water vapour on these surface parameters, the data for the year 1988 has been divided into the three seasons, namely, winter (November-February), summer (March-June) and monsoon (July-October) seasons and standard regression analysis has been carried out for the three seasons separately and the results are tabulated in Table 1. It can be noticed from this table that the integrated water vapour content shows highest dependance on the surface humidity parameters during the monsoon season followed by winter and minimum dependance in summer. The low correlation in summer could possibly due to the prevailing local weather conditions in summer at Visakhapatnam. The summer weather at the observing site is typical with high probability for the occurrence of sea breeze and also high probability for the formation of the stable layers in the atmosphere (Kumar 1984). During this period the mixing heights are less than 400 metres and this stability precludes any large scale mixing. During the rest of the

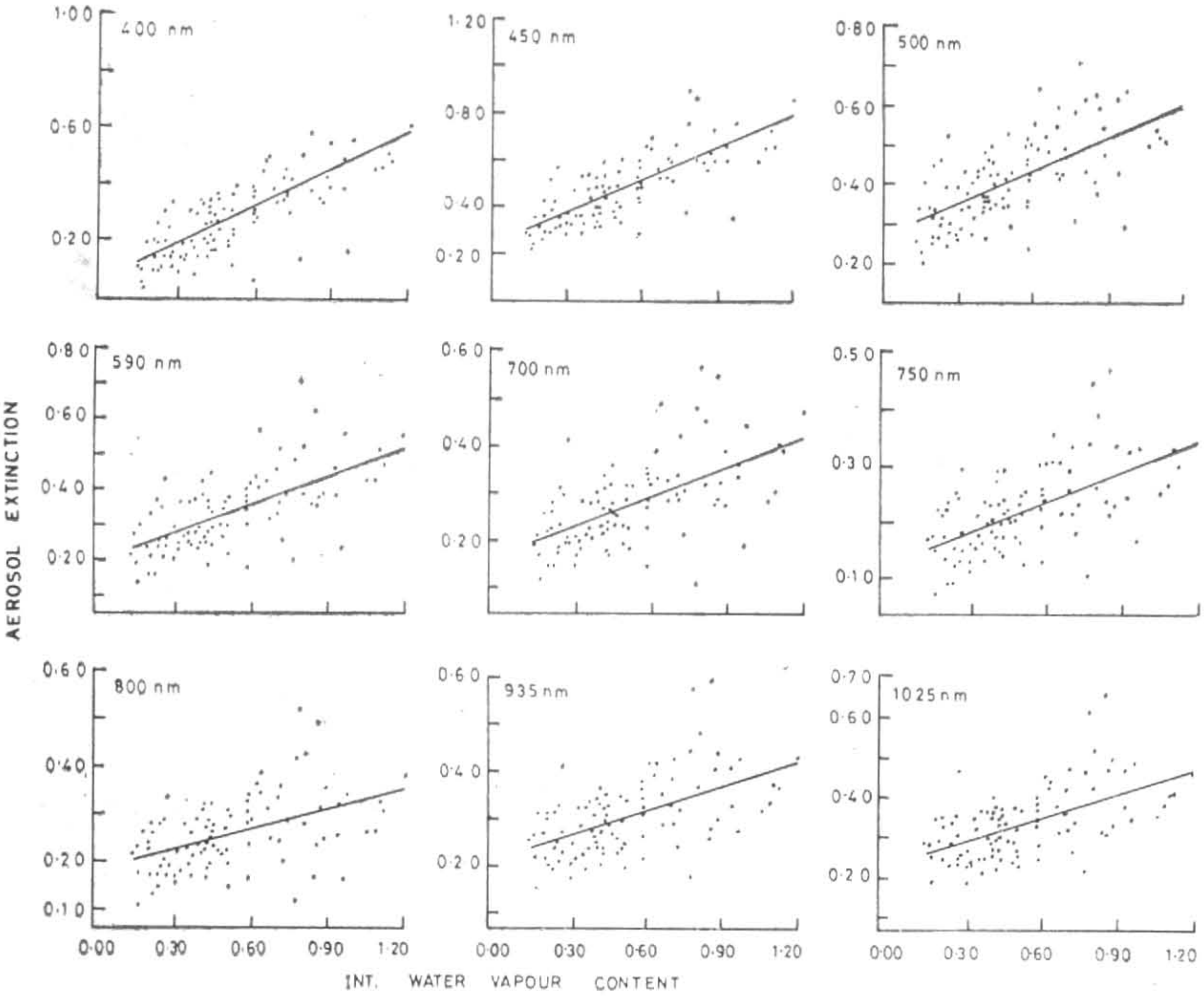

Fig. 4. Mass plots of aerosol extinction *versus* integrated water vapour content ($gm\ cm^{-2}$) derived from the spectral extinction measurements alongwith the regression lines

TABLE 1

Regresson coefficients for relative humidity, surface dew point *versus* columnar water vapour content

Season	Relative humidity	Dew point
Summer	0.1118 (0.006)	0.0958 (0.025)
Monsoon	0.6574 (0.002)	0.5821 (0.010)
Winter	0.4203 (0.019)	0.4709 (0.011)
Total data	0.3938 (0.002)	0.5438 (0.005)

The numbers in the parenthesis give the standard error of the coefficients.

TABLE 2

Regression coefficients for relative humidity, columnar water vapour and surface temperature with aerosol extinction at 400 nm

Season	Correlation coefficient with		
	Relative humidity	Columnar water vapour	Surface temperature
Summer	0.1435 (0.005)	0.1388 (0.038)	0.1743 (0.06)
Monsoon	0.8978 (0.008)	0.6461 (0.088)	0.2841 (0.07)
Winter	0.4967 (0.008)	0.4609 (0.067)	0.3589 (0.08)

The numbers in the parenthesis give the standard error of the coefficients.

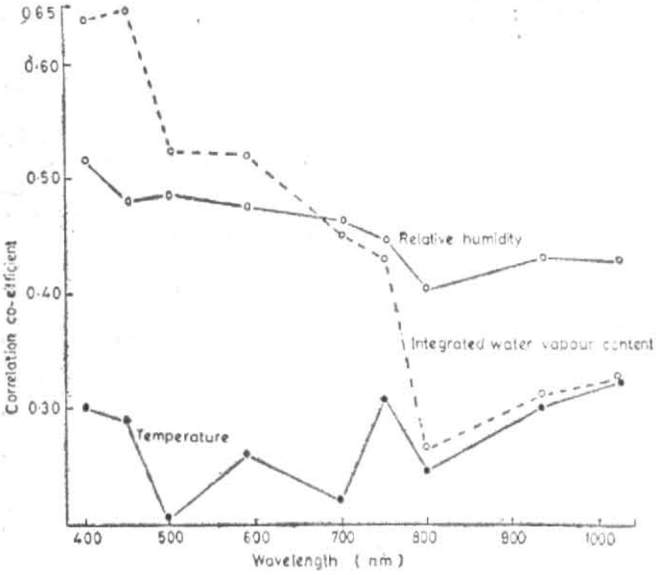

Fig. 5. Spectral variation of regression coefficients of aerosol extinction with surface temperature, relative humidity and columnar water vapour at 400 nm

year, cyclonic activity, disturbed weather and conditions that favour vertical mixing in depths are quite common. These may account for the low correlations in summer in the present data set.

4. Dependance of aerosol extinction on surface weather parameters

Aerosol extinction as it depends to certain extent on the humidity and temperature, is known to show a significant dependance on certain atmospheric weather parameters like, humidity, temperature and precipitable water vapour. Filippov and Mirumyants (1972) have reported that there is a stong effect of relative humidity on the optical state of matter and that it can be quantified. Ben Mohamed and Frangi (1983) have reported higher turbidity in the humid seasons compared to the other seasons. Krishnamoorthy *et al.* (1988) have reported that the particulate extinction remains more or less steady at lower relative humidity values (45 to 55%) but increases rather sharply at higher RH values. In order to see the effect of humidity on the optical state of matter and to infer whether the surface humidity parameter can be used to quantify the effect of humidity on the particulate extinction, a study has been carried out on the effect of surface relative humidity and the total precipitable water vapour on the spectral distribution of aerosol extinction. Also a study has been carried out if the surface temperature in any way effects the aerosol extinction.

The mass plots of aerosol extinction against the surface relative humidity (in %) for all the nine wavelengths under consideration are shown in Fig. 3. It can be seen from the figure that there is a definite increase in the aerosol extinction with increase in relative humidity. Regression lines fitted to the data yielded a correlation coefficient which varied between 0.41 and 0.52 at different wavelengths (Fig. 5). However, a close examination of the data has been made to evaluate the type of variation the aerosol extinction is showing in relation to the surface relative humidity. The solid lines shown in Fig. 3 are the best fit lines for the total data set of one year. From this figure it can be immediately noticed that the increase in aerosol extinction for an increase in the RH is relatively small up to 60% RH and thereafter it shows a sharp increase with increasing RH beyond 60%. This sharp increase is more significant at 400, 590 and 750 nm compared to the other wavelengths. Secondly the one year data set has been divided into the three seasons to see if there is any seasonal effect on the relative variation of aerosol extinction at 450 nm (the wavelength which shows highest dependance on the relative humidity with a correlation coefficient of 0.52) and the results are tabulated in Table 2. From this table, it can be seen that the aerosol extinction is more sensitive to surface relative humidity in the monsoon season compared to the other seasons. Similar seasonal behaviour is seen at all the other wavelengths.

Similarly, the mass plots of the aerosol extinction at different wavelengths as a function of columnar content of water vapour or the total precipitable water vapour derived from the spectral extinction measurements around the $\rho\sigma\tau$ band of water vapour are shown in Fig. 4. It can be seen that the aerosol extinction increases also with an increase in the precipitable water vapour and this dependance also shows a seasonal behaviour similar to surface relative humidity with maximum in monsoon followed by winter and minimum in summer (Table 2). The humidity at the present location is high during the pre-monsoon summer months and the correlation of aerosol extinction with surface relative humidity and the columnar water vapour content deteriorates during these months. Probably it is due this reason large scatter of points is observed at high humidity values in Figs. 3 and 4.

The results of the regression analysis carried out on the response of aerosol extinction to surface temperature are plotted in Fig. 5. It may be noticed that the surface temperature also tends to increase the aerosol extinction at all the wavelengths and the effect is by and large uniform at all the wavelengths. The effect of surface temperature to increase the aerosol extinction could be through its effect on the mixing heights.

Also in order to see the spectral dependance of RH and the total precipitable water vapour content on aerosol extinction the correlation coefficients derived from the regression lines of aerosol extinction at different wavelengths *versus* the relative humidity and the total precipitable water vapour for one year data are plotted against the wavelength in Fig. 5, which shows that the total precipitable water vapour and the surface relative humidity significantly effect the aerosol extinction at all the wavelengths compared to surface temperature. The effect of the surface temperature by and large is constant at all the wavelengths whereas the surface relative humidity and precipitable water vapour shows a spectral dependance with higher correlation coefficients at lower wavelengths and the correlation decreases with increasing wavelengths. Highest correlation is seen at 450 nm and minimum correlation at 800 nm.

Water vapour in the atmosphere effects the opticael depths in two ways, *i.e.*, either due to absorption at the particular wavelength under consideration or due to the growth of the aerosol particles size. Such growth changes the size distribution which results in a change in the overall refractive index. These changes effect the scattering characteristics affecting the optical depths (Shettle and Fenn 1979, Krishnamoorthy *et al.* 1988). Shettle and Fenn (1979) have theoretically estimated the effect of water vapour on the aerosol extinction and found that at higher relative humidity values the extinction increases very significantly. Krishnamoorthy *et al.* (1988) have plotted the dependance of aerosol extinction with RH for maritime aerosol from the tabulated values of Shettle and Fenn (1979) at two typical wavelengths for non-winter months which shows a near exponential variation with RH and the trends shown in Fig. 3 by and large follow the exponential trends as given by Krishnamoorthy *et al.* (1988).

The higher correlations in monsoon clearly demonstrate the increase in aerosol extinction with an increase in the humidity. Closest correlation between variations of visibility and humidity was observed immediately after heavy precipitation and in periods with alternating clear weather conditions. Under these conditions we obtain high correlations as during these periods, aerosols are finely dispersed in the atmosphere and high relative humidity conditions prevail for longer duration of time (say more than 12 hours) which aid the growth of the particles size due to capture of moisture. This is less probable during the other seasons in which humidity varies through a wide range over the course of the day and there will be insufficient time for such changes in the aerosols (Filippov and Mirumyants 1972).

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