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L E T T E R S

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AEROSOL OPTICAL THICKNESS OVER INDIAN ANTARCTICA STATION MAITRI

1. Antarctica is a unique continent at South Pole, separated from the continental habitations. Due to its immaculate characteristics, it provides an excellent environment to study the natural and background aerosols in the atmosphere over snow and ice. Circulation patterns associated with ice sheet of the Antarctica affects the transport, dispersion and removal of the aerosol particles. During the last decade, there is an increase in the emissions of anthropogenic species arising from the fossil fuel combustion, associated with increase in man made activities, in the context of regular scientific explorations and logistic operations related to them. (Tomasi *et al*., 2007; Chaubey *et al*., 2010) Antarctica aerosols comprise of mainly sea salt, sulphate, nss sulphate, dust, NH_4^+, NO_3^-, Methane Sulphonate, (Tomasai *et al*., 2007; Virkkula *et al*., 2006) and black carbon (Hara *et al*., 2008; Chaubey *et al*., 2010). Presence of absorbing aerosols over the highly reflecting snow not only, may enhance the warming of the atmosphere, but also deposition of these particles over the surface of the snow / ice reduces the albedo. Climate effects of aerosols depend strongly on their optical properties and therefore the study of AOT, Angstorm exponent and size distribution parameters of aerosols over Antarctica, make possible, to assess the influence of the aerosols on the climate. Lack of extensive and reliable measurements in most regions makes it difficult to quantify the global impact of aerosols on Earth's climate (Hansen *et al*., 1997) and Antarctica is one such region. To fill this gap, a Microtops II Sunphotometer, to measure aerosol optical depths, has been supplied to 20th Indian Antarctica Expedition team during 2008 and regular reliable data are available since February 2009 at Indian Antarctica Station Maitri. Aerosol optical thickness (AOT) and Angstorm Exponent over Antarctica Station Maitri, based on the measurements with a Microtops II Sunphotometer are studied in the present investigation. The Microtops II is a hand-held multi-band Sunphotometer capable of measuring the aerosol optical thickness and direct solar irradiance in five different bands at central wavelengths 368, 500, 675, 778 and 1028 nm (FWHM : ± 2-10 nm). The instrument advantages, limitations and calibration procedures involved for Microtops II have been detailed in Morys *et al*. (2001).

2. Microtops II Sunphotometer instrument measures the total columnar optical thickness (AOT) from the direct Sun radiation and subtracts the Rayleigh scattering component. Contributions to the total optical thickness by trace gases such as ozone O_3 and NO_x are neglected by the instrument build in software. Therefore in the equation $\tau_t(\lambda) = \tau_a(\lambda) + \tau_g(\lambda) + \tau_R(\lambda)$, where τt, τa, τg and τR stand for total, aerosol, gases (molecular absorption) and Rayleigh (molecular scattering) optical thickness, $\tau_t(\lambda)$ become equal to $\tau_a(\lambda)$.

Applying Angstorm Law (Angstrom, 1929), we can write,

$$\tau_a(\lambda) = \tau_{a0}(\lambda)\,\lambda^{-\alpha}$$

where,

α is the so called Angstrom exponent.

$\tau_a(\lambda)$ is the AOT for wavelength λ and τ_{a0} is the AOT at a reference of 1 nm. If we choose two bands λ_1 and λ_2 and take the slope of the linear fit to the logarithm of λ_1 *vs* the logarithm of λ_2 then we obtain a very useful expression as given below and used in the present investigation.

$$\alpha = \frac{\ln\left[\tau_a(\lambda_2)\ \ \tau_a(\lambda_1)\right]}{\ln(\lambda_1) - \ln(\lambda_2)}$$

3. The Indian Antarctica Station, Maitri (70º45'57" S, 11º44'09" E, 123 m m.s.l.) is located in the Schirmacher Oasis, near continental ice, 75 km away from the open ocean in east Antarctica (Fig. 1). There are only two seasons in Antarctica, winter and summer. Winter is almost continuously dark and summer it mostly light. Raise in maximum and fall in minimum temperatures occur from February to August and September to January respectively. Average annual temp is - 9.5 ºC, annual average wind speed is 17.5 kt and speed is more during February to May / June (16 to 20 kt). In summer the weather can be calm and clear for several days, sometimes there are blizzards that last days. Frequency of blizzards is more in summer particularly during April to August. Occurrence of rain is very rare and only snow fall occurs. (Annual snowfall is 182.1 mm). Total global solar radiation is maximum in November, December and January due to long period of cloud free sky, insolation and high solar elevation > 45º.

Time series of monthly averages of the aerosol optical thickness τ_{500} at 500 nm and the Ångström exponents (α) observed at Maitri in the period between February 2009 and November 2011 are shown in Fig. 2. Ångström exponents α are calculated from optical thickness values at wavelengths 368 and 675 nm as explained above. Higher Ångström exponents indicate smaller aerosol particles and *vice versa*. A total of 359 daytime averages (average of individual measurements in each day) are analyzed. As instrument measured values may be spurious occasionally for various reasons, extreme outliers are rejected through a simple statistical technique. Data points outside three times of standard deviation, on either side of long term mean (τ_{500} and α) were excluded. All τ_{500} values are within the range but only about 3% of 359 α data points fell outside the range, therefore these were not considered for study. It was found that daily average τ_{500} values to have a high fluctuation between 0.01 and 0.67 whereas monthly average values were between 0.05 and 0.44 in the study period (Fig. 2). The sources contributing to these might be (*i*) marine particles (sea salt) and dust particles from the oasis, both produced and transported by winds and (*ii*) produced by activities at Maitri and its surroundings. In order to understand the aerosol size distribution over Maitri, Ångström exponent values were estimated. Ångström exponent values generally range from greater than 2.0 for particles near combustion sources to values close to zero for coarse-mode-dominated desert dust aerosols. In general, $\alpha > 1$ indicate an increased abundance of fine and accumulation mode aerosols (size < 1 μ) in the aerosol size spectrum and $\alpha < 1$ is considered indicative of a coarse mode aerosol (size > 1μ) dominance. At Maitri it is found that daily average α values ranging from - 0.94 to 1.48 and monthly values ranged from 0.02 to 0.74 (Fig. 2). Occasional occurrence of negative values indicate coarse mode dominance. Monthly variation of Aerosol Optical Thickness and Angstorm Exponent for the years 2009 to 2011 shown in Figs. 3(a&b) respectively, indicate an inverse relation between the two. Post monsoon and winter seasons of all the three years showed higher optical thickness values and lower values of Ångström exponents in general. The lower values of optical thickness and highest values of Ångström exponents are observed during April/May. This indicates higher concentrations of coarse aerosols during post monsoon and winter months and fine and accumulation mode particles during summer in general. The dominance of fine and accumulation particles at Maitri might be due to (*i*) enhanced station activities (*ii*) pre existing accumulation mode dominant background aerosols in the coastal Antarctic atmosphere as suggested by Hara *et al*. (2008) and (*iii*) biogenic species (methane sulphonate, non sea salt sulphate etc.) which have been reported during Antarctic summer (Weller *et al.*, 2008). Also an increase in the AOT values throughout 2011 year and during post-monsoon and winter seasons in the year 2010, compared to the AOT values of the year 2009 is conspicuous from the Fig. 3(a). This may due to increase in the emissions of anthropogenic species as explained earlier (Tomasi *et al*., 2007; Chaubey *et al*., 2010). Another interesting pattern observed from the variation of mean monthly Ångström exponent in the years 2009 to 2011 is that, cycle of mean monthly Angstrom exponent over a year, has reversed in most part, in the succeeding year in the study period [Fig. 3(b)], although this feature is not prominent in AOT monthly variation. The change in mean monthly Angstrom exponent cycle over the three years and increase in AOT values as described before, implies not only that dominance of fine or coarse mode aerosols varied significantly and continuously but also increase in aerosols occurred throughout the study period over Maitri.

4. To understand physically interpretable cluster regions for different size ranges of aerosols, the scatter plot of daily averages of aerosol optical depth *versus* Angstrom parameter is drawn and shown in Fig. 4. This is normally considered as a fingerprint of the aerosol at a given location (Nakajima *et al*., 1996; Holben *et al*., 2001). Although no obvious cluster discrimination is evident, a wide range of Ångström exponents from -0.94 to high value of 1.48 are associated with aerosol optical depth ranging from small value of 0.01 to 0.67. Maitri therefore has no characteristics typical to an urban site. This could be due to the fact that the periods influenced by convective activities are not influenced by accumulation mode particles due to local pollution or transport.

5. *Conclusion* - Daily average τ_{500} values to have a high fluctuation (0.01 and 0.67) compared to monthly averages (0.05 and 0.44) in the study period.

At Maitri, the daily average α values ranged from -0.94 to 1.48 with negative values occurring occasionally indicating coarse mode dominance. The monthly average values were between 0.02 to 0.74. An inverse relation between α and AOT is witnessed.

Higher values of AOT and lower values of Ångström exponents are observed during post-monsoon and winter seasons and *vice versa* during April / May months. This indicates higher concentrations of coarse aerosols during post-monsoon and winter months and fine and accumulation mode particles during summer.

Increase in AOT values throughout the year 2011 and during post-monsoon and winter seasons of 2010 compared to values of 2009 indicate increase in the emissions of anthropogenic species during 2009 to 2011.

Continuous variation in mean monthly Angstrom exponent during 2009 to 2011 is witnessed suggesting significant and continuous variation in the dominance of fine or coarse mode aerosols over Maitri in the study period.

No cluster discrimination is evident in the size distribution of aerosols.

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