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Aerosol Characteristics over Maitri-Antarctica and Their Impact on Radiative Forcing

Harish Gadhavi and A. Jayaraman
Physical Research Laboratory, Ahmedabad

Abstract

During the 20th Indian Antarctic expedition conducted in January-February 2001, a detailed study on the aerosol spectral optical depth, mass concentration and size-distribution along with columnar ozone and water vapour concentrations was made from the Indian station, Maitri (70.77° S, 11.73° E) by a single member team of Physical Research Laboratory, Ahmedabad. A low aerosol optical depth of about 0.03 at 400 nm wavelength and a dry aerosol mass concentration of about 7 ug/m^3 for the $PM_{,0}$ particles are found out of which 63% are greater than 1 urn radius. Average columnar ozone and total precipitable water-vapour content during the observation period were found to be 271.6 DU and 0.147 cm respectively. Estimation of aerosol radiative forcing over Maitri reveals a positive forcing of 0.95 W/m^2 at the top of the atmosphere and -0.83 W/m^2 at the surface.

Keywords: Aerosol, Antarctica, forcing, optical depth, size distribution, ozone, water vapour

Introduction

Aerosols are defined as colloidal solution of solid or liquid particle with air. Aerosol can affect the Earth's climate either by directly scattering and absorbing radiation received from the sun or by modifying the cloud properties (Haywood and Baucher, 2000). Antarctic region is unique. In the absence of any major local aerosol source, the air is generally pristine and is only influenced by the long-range transport of sub-micron-size particles and gaseous pollutants from other parts of the globe. The objective of the present study is to examine the characteristics of the aerosol particles found in the Antarctic and to estimate their radiative forcing. In the last few decades there has been a considerable increase in anthropogenic activities both in developed and developing nations, which is responsible for an overall increase in the aerosol burden around the globe. Aerosol and radiative-forcing studies over sites such as Antarctica will help in estimating the background-level aerosol forcing over a pristine

site, which could be compared with results obtained over polluted regions. Also, such a study helps in establishing a database that could be used in future for studying the long-term impact of continuous human activities in increasing the background-level aerosol concentration. Factors like high surface albedo and unique solar insolation cycle over Antarctica also make the study an interesting one. The present field study made at the permanent Indian Antarctic Station, Maitri (70.77°S, 11.73°E) during the 20th Indian Antarctic Expedition provides the continuity to aerosol optical-depth measurements made over Antarctica **by other** groups (Shaw, 1982, Herber et al., 1993 andl996, Sharma and Sharma, 1999). Also, by including results on aerosol size-distribution and radiative- transfer analysis, additional information is provided which is of use to global climate-change study.

Experiment

The 20th Indian Antarctic expedition was launched from Goa on 28 December 2000. The team arrived at Maitri on 14 January 2001. Aerosol studies were carried out from 18 January to 23 February 2001. A hand-held sun-photometer was used to measure the aerosol optical depth and a quartz crystal microbalance (QCM) cascade impactor was used to measure the surface-level aerosol mass-concentration and size-distribution. Measurements of columnar ozone and water-vapour were carried out using Microtops-II.

Aerosol optical depth

Aerosol optical depth (AOD) is a measure of the attenuation of direct solar radiation **that** occurred while passing through the atmosphere containing aerosols. A hand-held sun-photometer, built in-house at the Physical Research Laboratory (PRL), Ahmedabad has been used for AOD measurements. Optical interference filters are used to select the spectrum of interest from near-UV to near-IR region. Detail of principle, calibration, corrections applied, errors are explained in Gadhavi and Jayaraman, 2004. Prior to and after the expedition, the interference filters were calibrated in-house for changes, if any, in the filter-transmission characteristics and are included in the computation of the optical depth due to molecular gases. Measurements were made at five wavelength regions centred around 400, 497, 668, 875 and 1058 nm with a typical bandwidth of 10 nm **at** approximately 15 min interval, whenever clouds are not obscuring the sun or are not in the vicinity of about 30 degrees around the sun. A total of

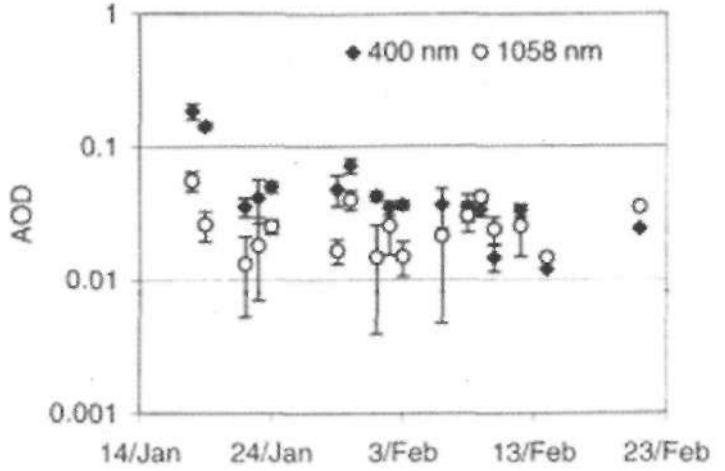

Fig. 1: Daily mean aerosol optical depth observed over Maitri-Antarctica at 400 and 19058 nm

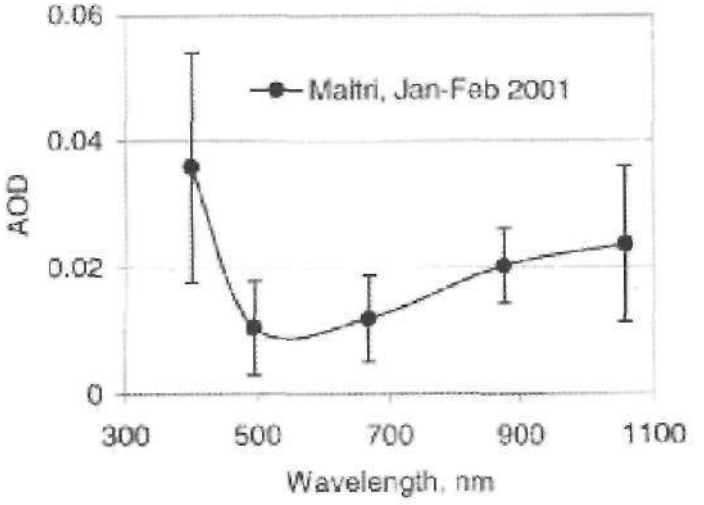

Fig. 2: Mean AOD spectrum during entire campaign period excluding 18 and 19 Jan AOD values. Vertical bars over data points show the standard deviation from mean

about 220 measurements were made for each wavelength region during the campaign period.

Aerosol mass concentration

A QCM, California Measurements Inc, USA is used to measure the mass size-distribution of aerosols at the surface level. The instrument has

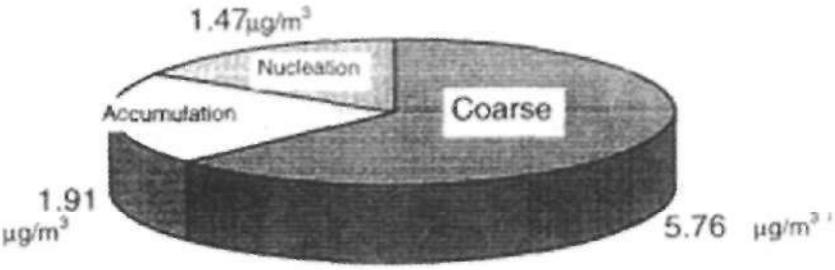

Fig. 3: Average mass concentration of aerosol (PM_{10}) particles at Maitri during the campaign period was 9.14 pg/m^3, of which the coarse particles (r>l pm) contribute 5.76 (63%); the accumulation (0.1 < r < 1 pm) particles 1.91 (21%); and the nucleation (r < 0.1 pm) particles 1.47 (16%) pg/m^3

10 stages with each stage sensitive to a specific size range of particles. The radii at which the collection efficiency is maximum are 8.64, 4.26, 2.24, 1.08, 0.55, 0.29, 0.16, 0.07 and 0.03 prn respectively, for the stages 2 to 10 and the respective full width at half maximum changes from about

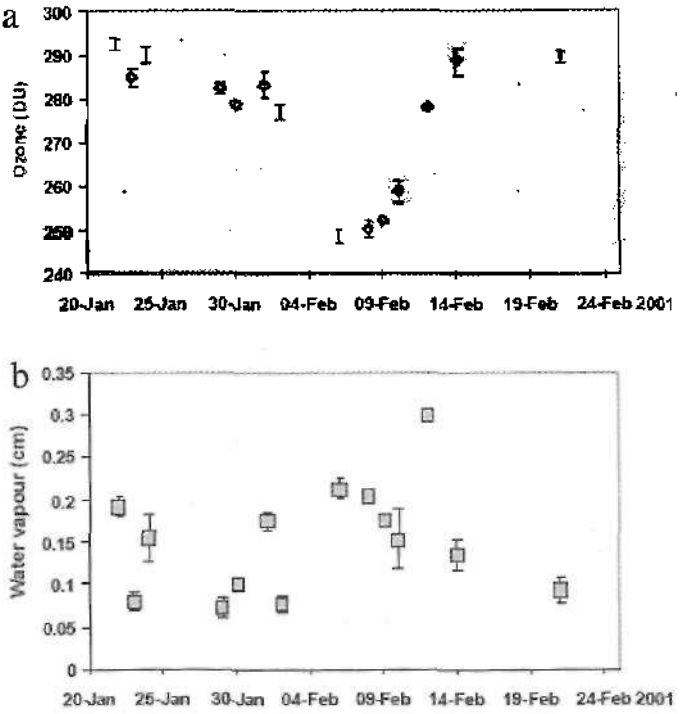

Fig. 4: Daily mean columnar ozone (a) and total precipitable water-vapour (b) over Maitri, Antarctica. Vertical bar over data points represents standard deviation for that day

7 to 0.03 |im. The instrument was kept around 225 m away in a wooden hut, in a northward direction from the main station to avoid contamination from any localized sources such as power generator, kitchen, etc. Air sample was drawn at a height of 2 m from the ground level. The sampling arrangement is configured vertically such that there is negligible loss of particles within the sampling tube. About 3 to 4 measurements were taken every day. Prior to the starting of the measurement, drift if any, in the crystal frequency was checked each day, and was found to be negligible and random. No special correction has been done for this variation. Error in the measurement of total mass is estimated to be within 25%, found earlier by simultaneously operating this instrument with others like Anderson impactor (Jayaraman et al., 1998).

Columnar 0_3 and H_20 concentrations

Microtops-II sun-photometer, manufactured by Solar Light Co, USA is used for measurements of the column concentrations of ozone and water-vapour. The accuracy of the ozone and water-vapour measurements is better than 2%. More details of the instrument and measurement accuracy can be found in Morys et al. (2001).

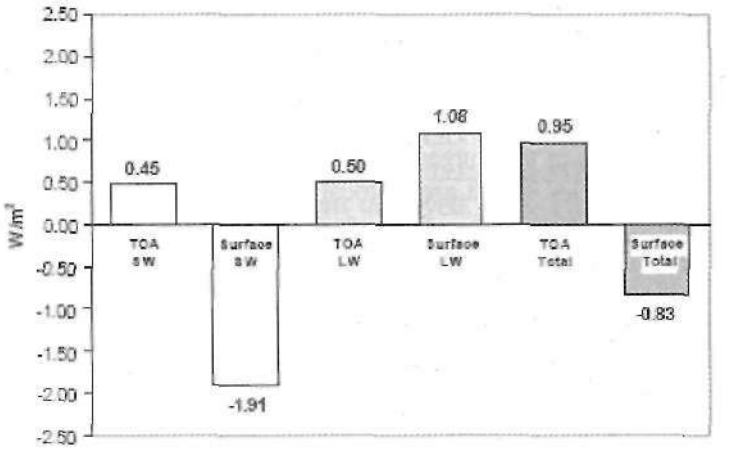

Fig. 5: Diurnally averaged mean aerosol direct radiative forcing over Maitri, Antarctica for the observation period

Results and Discussions

Daily variation in the mean AOD for the campaign period is shown in **Error! Reference source not found.,** for two selected wavelengths of

400 and 1058 nm. Except for the two high values recorded on 18 and 19 January, during the remaining days the values were in the range 0.01 to 0.1 for all wavelengths. High values of AOD and high day-to-day variations are seen in the extreme wavelengths of 400 and 1058 nm compared to the intermittent region.

Error! Reference source not found, shows the average AOD spectrum obtained for the whole period. Vertical bars over the data points represent the standard deviation for that day. The high values recorded on 18 and 19 January are not included for the estimation of the average spectrum. The AOD value at 400 nm is the maximum compared to those at longer wavelengths, with a mean value of 0.036 ± 0.018 and also exhibiting larger daily variability. The average AOD spectrum shows distinctly two modes, one peaking at a lower wavelength of 400 nm or below and the other at a higher wavelength of 1058 nm or above. This kind of feature is typical of an optically clean region where the AOD at the visible wavelength region is the minimum. The higher AOD at lower wave-length is caused due to nucleation-mode particles, which are of sub-micron size. These particles are produced mainly *in situ* within the atmosphere by gas-to-particle conversion mechanism from precursor gases such as oxides of sulphur, nitrogen, etc. Owing to their small size, they have a higher residence time in the atmosphere compared to bigger particles. Also, the residence time increases with increasing altitude and in the free troposphere, these submicron particles have residence time of the order of a few weeks to a month, sufficient to sustain long-range inter-continent transport from their source origin to the polar region. Higher AOD values seen in the longer wavelength region is produced mainly by bigger size particles which are of local and natural origin and composed mainly of sea-salt particles from the ocean and dust debris from the underlying land.

The average mass concentration of the ambient aerosol particles of size less than 10 um (denoted as PM_{10} particles) at Maitri for the entire campaign period was 9.14 ug/m^3, with a standard deviation of 6.0 ug/m^3. The relatively large variation shows the extent of the day-to-day variability in the surface-level aerosol mass concentration over Maitri. Of the average total mass, the coarse particles having a size between 1 and 10 um contribute 5.76 ug/m^3, which is 63% of the total **(Error! Reference source not found.)**- Similarly, the accumulation-mode particles having a size between 0.1 and 1 um contribute 1.91 ug/m^3, which is 21% of the total and the nucleation-mode particles having a size less than 0.1 um contribute 1.47 ug/m^3, which is 16% of the total. The mass values shown are for the ambient measurements, meaning that they also contain water. If we correct

for the water content, the dry (0% RH) PM_{10} aerosol mass becomes 6.97 ug/m^3 and at 50% RH, it becomes 7.87 ug/m^3. The major contribution to the total aerosol mass is from the coarse particles which have local origin, such as the sea-salt particles brought from the nearby ocean region as well as dust from the underlying surface. The aerosol mass concentration over Maitri is at least an order of magnitude low compared to those in other polluted parts of the world (Jayaraman et al, 2001, Ramachandran and Jayaraman, 2002). However, in comparison with other Antarctic stations such as McMurdo (77°51'S, 166°40'E), the Maitri value is high. Mazzera et al. (2001) have found average PM_{10} in the range 3.21 to 4.81 ug/m^3 between the years 1995 and 1997, at two different locations over McMurdo station. Also over Maitri, an increasing trend is observed in the total mass value from January to the end of February. Increase in surface level aerosol concentration as austral winter progresses has also been observed by other explorers (Hall and Wolff, 1998 and references therein). Hall and Wolff (1998) have explained this seasonal increase by the effect of temperature on salinity of brine formed over newly-formed sea-ice surface. *Richardson* (1976) has demonstrated through laboratory experiments that original sea-water salinity of *35%c* increases to 122‰ when temperature decreases from 0 to -8°C, and the surface brines formed are much better sources of sea-salt aerosol than sea-water.

In spite of the pristine atmosphere, large day-to-day variations in both the aerosol parameters as well as the column concentrations of ozone and water-vapour are recorded over Maitri. Though the ozone and water-vapour measurements were made to correct the AOD for the estimation of the radiative forcing over Maitri, which is the main objective of the present study, because of the large variations observed in the column ozone and water-vapour, it is interesting to present the results here. **Error! Reference source not found,** shows the daily average values of the measured integrated vertical columnar ozone and water-vapour concentrations, and the vertical bar over data points are standard deviation for that day. During the period from 3 to 11 February 2001, an episodic decrease in the ozone concentration by about 40 DU was observed from the normal background value of about 285 DU. Comparison of this observed decrease with *TOMS* satellite data revealed that the decrease was localized mainly over the Maitri region. Atmospheric dynamics plays a major role in controlling the ozone concentration over this region, located at the edge of the polar vortex.

Diurnally averaged radiative forcing calculations at top of the atmosphere (TOA) and surface level are shown in **Error! Reference source not found.** (Gadhavi and Jayaraman, 2004). The forcing is positive

at TOA for both shortwave (SW; 0.25 to 2.5 urn) and long wave (LW; 2.5 to 40 urn), but at the surface it is negative for SW and positive for LW. The net forcing is 0.95 W/m^2 at **TOA and** -0.83 W/m^2 **at the** surface, with absorption of 1.78 W/m^2 within the atmosphere. Positive radiative forcing at TOA over Maitri is due to high surface albedo, typical of the polar region. In comparison to regions of high anthropogenic activity, the observed aerosol radiative forcing over Antarctica is low. Jayaraman (2001) has reported TOA SW aerosol forcing of about -6.9 W/m^2 over coastal India, -4.7 W/m^2 over the Arabian Sea and -1.45 W/m^2 over the tropical Indian Ocean. Ganguly et a1, (2005) has found -8.4 to -10.6 W/m^2 **net** aerosol radiative forcing over the Bay of Bengal. Higgnet et al., (1999) have found -9 W/m^2 over the Atlantic Ocean.

Conclusion

AOD over Antarctica is low, with the average value lying between 0.01 and 0.1 for **all** wavelengths during the observation period from January to February 2001. This is lower than the value obtained earlier over clean oceanic regions like the southern Indian Ocean. Surface-level ambient aerosol mass concentration is also low with an average value of **9.14** ug/m^3, which when corrected for the humidity (dry mass) becomes 6.97 ug/m^3. Coarse mode particles are found to contribute about 63% to the total mass. The dominance of coarse-mode particles is also reflected in the obtained AOD spectrum, which is more or less flat. Calculations of aerosol radiative forcing show that though the optical depth values are **low,** they contribute to a net positive forcing of about 0.95 W/m^2 because of the high surface reflectance. Model computations repeated for the same aerosol amount but for different surface types reveal that for an unit AOD change, **the TOA** SW forcing values are + 22.5 W/m2, -43.9 W/m2 **and** -72.9 W/m2 respectively, for snow, sand and sea-water types of surfaces (Gadhavi and Jayaraman, 2004). Another interesting observation is that because of the strongly varying sun-earth geometry over the polar region, the radiative forcing exhibits strong seasonal dependence, varying from a positive value of 0.7 W/m^2 in December to -0.15 W/m^2 in April, and becomes zero during no sunshine days in June and July (Gadhavi and Jayaraman, 2004).

References

Gadhavi and Jayaraman (2004), Aerosol characteristics and radiative forcing over Maitri-Antarctica, *Current Science, 86(2),* 296-304.

Ganguly, D., A. Jayaraman and H. Gadhavi (2005), In situ ship cruise measurements of mass concentration and size distribution of aerosols over Bay of Bengal and their radiative impacts, *J. Geophys. Res., 110,* D06205, doi:10.1029/2004JD005325.

Hall, J. S., and E. W. Wolff (1998), Causes of seasonal and daily variations in aerosol sea-salt concentrations at a coastal Antarctic Station, *Atmos. Environ., 32,* 3669-3677.

Haywood J. and O. Baucher (2000), Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: a review, *Rev. Geophys., 38(4),* 513-543.

Herber, A., L. W. Thomason, V. F. Radionov, and U. Leiterer (1993), Comparison of trends in the tropospheric and stratospheric aerosol optical depths in the Antarctic. *J. Geophys. Res., 98,* 18441-18447.

Herber, A., L. W. Thomason, K. Dethloff, P. Viterbo, V. F. Radionov, and U. Leiterer (1996), Volcanic perturbation of the atmosphere in both polar regions: 1991-1994. *J. Geophys. Res., 101,* 3921-3928.

IPCC (2001), The Intergovernmental Panel on Climate Change, Climate Change 2001: The Scientific Basis. *Cambridge University Press,* Cambridge. 896pp.

Hignett, P., J. P. Taylor, P. N. Francis, and M. D. Glew (1999), Comparison of observed and modeled direct aerosol forcing during TARFOX, *J. Geophys. Res., 104,* 2279-2287.

Jayaraman, A., D. Lubin, S. Ramachandran, V. Ramanathan, E. Woodbridge, W. Collins, and K. S. Zalpuri (1998), Direct observations of aerosol radiative forcing over the tropical Indian Ocean during the January-February 1996 pre-INDOEX cruise. *J. Geophys. Res., 103,* 13827-13836.^

Jayaraman, A., S. K. Satheesh, A. P. Mitra, and V. Ramanathan (2001), Latitude gradient in aerosol properties across the inter tropical convergence zone: Results from the joint Indo-US study onboard Sagar Kanya, *Cum Set, 80,* 128-137.

Jayaraman, A. (2001), Aerosol radiative forcing over the tropical Indian Ocean. *Proc. Indian Natl. Sci. Acad., 67,* 385-394.

Mazzera, D. M., D. H. Lowenthal, J. C. Chow, J. G. Watson, and V. Grubisic (2001), $PM_{,0}$ measurements at McMurdo Station-Antarctica, *Atmos. Environ, 35,* 1891-1902.

Morys, M., F. M. Mims III, S. Hagerup, S. E. Anderson, A. Baker, J. Kia, and T Walkup (2001), Design, calibration, and performance of Microtops II handheld ozone monitor and sun photometer. *J. Geophys. Res., 106,* 14573-14582.

Ramachandran, S., and A. Jayaraman (2002), Pre-monsoon aerosol mass loadings and size-distributions over the Arabian Sea and the tropical Indian Ocean, *J. Geophys. Res., 107,* doi:10.1029/ 2002JD002386.

Richardson, C. (1976), Phase relationships in sea ice as a function of temperature, *J. Glacioi, 17,* 507-519.

Sharma, S. D., and M. C. Sharma (1999), Erythemal and aerosol studies at Maitri, Antarctica during austral spring of 1995, *Indian J. Phys., 73B,* 463-472.

Shaw, G. E. (1982), Atmospheric turbidity in the polar regions. *J. Appl. Meteorol, 21,* 1080-1088.

lOMS, Total Ozone Mapping Spectrometer data available at following website: http:// toms.gsfc.nasa.gov/