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Study Of Mass Distribution Of Near Surface Aerosols At Maitri, Antarctica

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Abstract: ***A Quartz Crystal Microbalance (QCM) Impactor was operated at Indian Antarctic Station, Maitri for measurement of total and size segregated mass concentration of near surface aerosols. The observations were carried out for one year (December 2011-November 2012). The mean value of the total mass concentration (M_t) is 12.0±3.4 μg/m^3, which is consistently higher than previously reported values for short durations from Antarctica. Other derived parameters such as mass of super micron (M_c) and sub micron (M_a) particles, number concentration (N_t), and particulate matter ($PM_{2.5}$, PM_{10}) from QCM observations are reported for the first time for Maitri station.***

Keywords: Near surface Aerosol, Sub micron and Super micron particles, Number concentration, Mass concentration.

I. INTRODUCTION

Atmospheric aerosols are tiny particles in solid or liquid phase, suspended in the gaseous medium, the atmosphere. Produced by a variety of natural and anthropogenic processes, the aerosols are polydispersive with sizes ranging from 10^{-3} μm to 10^{2} μm. Although only a minor constituent of the Earth's atmosphere, they have appreciable influence on the air quality, the chemistry of the troposphere and stratosphere, Earth's radiation budget, clouds and precipitation. The geographically localized sources and sinks and relatively short atmospheric life times give aerosols high spatial and temporal inhomogeneity in the atmosphere.

Near surface aerosols are those that reside within the Earth's boundary layer (~500m to 2000 m) or the so called well mixed layer. Characteristics of near surface aerosols are very important from Geosphere - Biosphere perspective as the aerosol abundance is highest in this region. The convective turbulence and winds cause a thorough vertical mixing of aerosols within the boundary layer, giving a vertical homogeneity. The land and sea breeze regimes lead to horizontal advection of continental aerosols offshore and on shore transport of marine aerosols. The Optical effects of aerosols include: scattering and absorption of solar and infra red radiation, altering of cloud properties acting as cloud condensation nuclei. No single technique or group of techniques is adequate for a complete characterization of aerosol properties.

Antarctica is a unique continent at the extreme south, separated from the other populated continental masses, making it one of the most pristine places on the Earth (Wall, 2005). Due to the pristine characteristics (compared to other snow covered regions like the Arctic or the high altitude mountains in the Northern Hemisphere), it provides an excellent environment to examine the natural and background aerosols in the atmosphere over snow and ice. Not only that, the large ice sheet of the Antarctic continent affects atmospheric circulation patterns over this region, which affects the transport and removal of the aerosols particles (Shaw, 1979). In the recent years, with the increase in human interventions (exploratory, scientific and tourism) there is an

increase in the emissions of anthropogenic species arising from fossil fuel combustion, both at the research stations as well as those associated with transport. These include atmospheric particles as well (Shaw, 1979; Tomasi et al., 2007; Weller et al., 2008; Chaubey et al., 2010). Antarctic aerosols comprise of mainly sea salt, sulphate, dust, nss sulphate, NH^{+4} , NO^{-3} , Methane Sulphonate (Niemi et al., 2005; Virkkula et al., 2006; Tomasi et al., 2007) and a small amount of efficient absorbing aerosols like black carbon (Bodhaine, 1995; Hansen et al., 2001; Hara et al., 2008; Chaubey et al., 2010). Even small quantity of absorbing aerosols (anthropogenic or natural) over the highly reflecting snow might enhance the warming of the atmosphere (Chylek and Coakley, 1974; Randles et al., 2004) and the deposition of these particles over the surface of the snow or ice reduces the albedo (Russell et al., 2002; Hansen and Nazarenko, 2004). As such, there is an increased interest and need to investigate the properties of Antarctic aerosols, and their spatial temporal and microphysical properties to understand their climate forcing potential (Valero et al., 1983; Herber et al., 1993; Schwartz and Andreae, 1996; Hatzianastassiou et al., 2004; Gadhavi and Jayaraman 2004; IPCC, 2007; Chaubey et al, 2011).

The present investigation uses in-situ technique for the measurement of total and size segregated mass concentration using Quartz Crystal Microbalance (QCM) Impactor. This gives measurement of total Mass (M_t) and size segregated mass of near surface aerosols.

II. METHODS

LOCATION OF OBSERVATIONS AND PREVAILING METEOROLOGY

The observations were taken at the Indian Antarctic station, Maitri (Geographic Latitude 70.77^o S, Longitude 11.75^o E), situated in an ice free area of Schirmarchar Oasis of central Drauning Maud Land (ScODML), East Antarctica. The surface aerosol observations were taken for the period December 2011 to November 2012. The observation location was away from Diesel Generator power house, so as to avoid concentration of fine particles from the exhaust.

The meteorological parameters like relative humidity (RH), wind speed and wind direction are taken from the automatic weather stations (AWS) operated regularly by the Indian Meteorological Department (IMD) at Maitri. The monthly mean RH at Maitri during the observation period is shown in fig.-1a. Figure.-1b shows the monthly mean wind speed and wind direction over this location. The data are taken into consideration only during normal clear sky days.

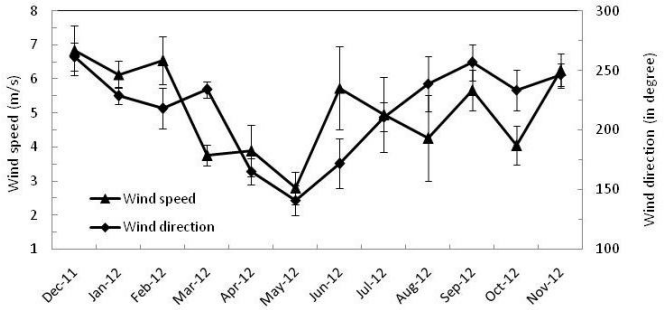

Figure 1a: Monthly mean Variation of Relative Humidity (RH) (December 2011 – November 2012)

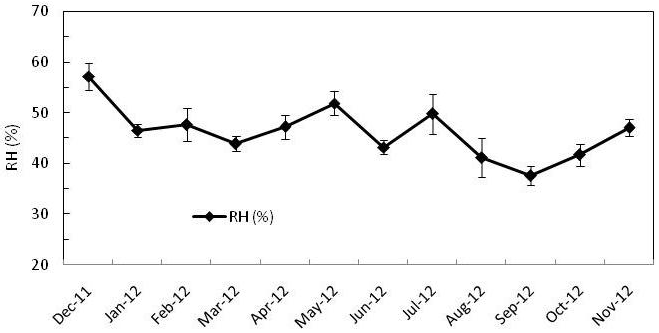

Figure 1b: Monthly mean Variation of wind speed and wind direction (December 2011 – November 2012)

MEASUREMENT OF MASS CONCENTRATION

In this study QCM Impactor (Model PC-2 California Measurements, Inc) has been used. The photograph of the instrument is shown in Fig.2. It has two sub assemblies: a sensing stack and a control unit which is detachable. Each stage of a cascade impactor has a certain size range over which the capture efficiency is high. The diameter at which it falls to 50% of the maximum value (unity) is considered as the lower cut off diameter for that stage so that all particles with sizes above that cut off diameter is expected to be captured by that stage. For QCM the 50% cut off sizes for the 10 stages are given based on a particle density of 2 g cm $^{-3}$.

Measurement were carried out manually at a flow rate of 0.24 l min^{-1} and data are collected every hour with a sampling time of 5 min. Measurement were restricted to periods when the ambient Relative Humidity (RH) was less than 75% (as a view of the affinity of Quartz crystal changes in RH at higher RH levels). This condition was normally met at the station except during blizzards.

Figure 2: Photograph of the Quartz Crystal Microbalance Impactor. The sensing stack is kept over the control unit.

III. ANALYSIS OF QCM DATA

During each measurement, the QCM provides direct information on two parameters:

- ✓ The total mass concentration (M_t) which is the mass of aerosols in the size range 0.05 to 25 µm (stage Nos. 1 to 10 in inverse order) in unit volume of the sampled air, and
- ✓ The mass concentration (m_{ci}) in each of the size bins i=1 to 10 which gives the mass-size distribution. These constitute the raw data, which in itself is useful. M_t and m_{ci} are related by

$$M_t = \sum_{i=1}^{10} m_{ci} \qquad (1)$$

However, in practice only channels 2 to 10 are used in the above summation as the first channel includes particles with size >25 µm.

DERIVED PARAMETERS

The QCM raw data can be effectively used to retrieve various physically meaningful parameters of aerosols, which are called derived parameters. These are:

Volume Concentration

$$v_{ci} = \frac{m_{ci}}{\rho_a} \quad , \qquad \rho_a = 2\ g/cm^3$$

The number concentration in each of size bins

$$n_{ci} = \frac{v_{ci}}{\frac{4}{3}\pi r_i^3} \qquad (2)$$

Sub micron (M_a) and super micron (M_c) range aerosol mass concentration estimated separately from the size segregated mass concentration (m_{ci}) are given by

$$M_a = \sum_{i=7}^{10} m_{ci} \qquad (3)$$

$$M_c = \sum_{i=2}^{6} m_{ci} \qquad (4)$$

Similarly the total number concentration of atmospheric aerosols (N_t) can also be estimated as:

$$N_t = \sum_{i=2}^{10} n_{ci} \qquad (5)$$

Particulate matter smaller than about 10 micrometers (channels 3 to 10), referred to as PM_{10}, can settle in the bronchi and lungs and cause health problems. Particulate matter smaller than 2.5 micrometers (channels 5 to 10) referred to as $PM_{2.5}$ tends to penetrate into the gas exchange regions of the lungs and damage the respiratory system. Hence it is essential to study these two parameters quantitatively. PM_{10} and $PM_{2.5}$ can be estimated as

$$PM_{10} = \sum_{i=3}^{10} m_{ci} \qquad PM_{2.5} = \sum_{i=5}^{10} m_{ci} \quad (6)$$

IV. RESULTS AND DISCUSSION

The observations were carried out for one year (December 2011-November 2012). The size segregated mass concentration of different size bins of yearly mean are listed in Table -1 and the plot shown in fig. 3. The average mass concentration at all size ranges is very low ≤ 3.3 µg/m^{-3}. Total mass concentration (M_t) is 12.0 ± 3.4 µg m^{-3}. Gadhavi and Jayaraman (2004) reported a value of 7.0 µg m^{-3} (after correcting for humidity effects) during Jan-Feb, 2001 at Maitri. Chaubey et al (2011) reported M_t of 8.2 ± 2.9 µg m^{-3} at Maitri during the International Polar Year 2007-2008. This suggests M_t seems to be increasing with years in the Antarctic atmosphere.

Channel No.	Yearly Mean Mass concentration (µg/m^3)	Standard error
2	1.7	±0.1
3	2.1	±0.2
4	1.1	±0.1
5	3.3	±0.8
6	1.1	±0.2
7	1.3	±0.2
8	1.1	±0.2
9	1.8	±0.4
10	1.8	±0.8

Table 1: The size segregated mass concentration of different size bins of yearly mean during observation period December 2011 to November 2012

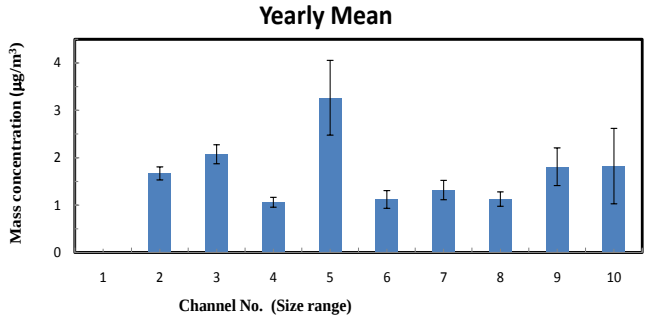

Figure 3: Distribution of yearly mean mass concentration in different channel listed in Table 1.

The average aerosol mass in two different size groups: PM_{10} and $PM_{2.5}$ as defined in equation (6) are calculated and presented in Table 2.

Month	N_t (m^{-3})	M_t ($\mu g/m^3$)	M_a($\mu g/m^3$)	M_c($\mu g/m^3$)	PM2.5 ($\mu g/m^3$)	PM10($\mu g/m^3$)
Dec-11	3.3E+09	16.0	7.4	8.6	11.7	14.7
Jan-12	2.5E+09	11.2	4.1	7.2	6.3	9.9
Feb-12	1.8E+09	10.9	4.4	6.4	5.9	9.5
Mar-12	3.5E+09	15.8	6.0	9.8	10.1	13.6
Apr-12	3.8E+09	16.2	7.7	8.4	9.1	14.2
May-12	3.0E+09	4.9	4.3	0.6	4.9	4.9
Jun-12	1.8E+09	8.4	2.1	6.3	4.6	7.1
Jul-12	2.0E+09	13.1	2.6	10.6	9.9	11.8
Aug-12	4.3E+06	10.3	0.6	9.7	9.6	10.3
Sep-12	2.8E+10	12.0	10.7	1.3	10.7	10.7
Oct-12	7.2E+09	14.6	5.1	9.5	8.9	11.9
Nov-12	5.2E+09	10.4	3.5	6.9	6.3	8.6

Table 2: Monthly mean values of derived parameters for the observation period December 2011 to November 2012

Certain larger size ranges are removed from $PM_{2.5}$ and hence it is less than PM_{10}. This indicates that there is significant contribution of larger size particles to the total Mass M_t. Similar results were also reported by Gadhavi and Jayaraman (2004) who observed that 63% of the particles were of supermicron mode (>1 µm).

The particles with size <1 µm are termed submicron (M_a) and those with size >1 µm are called supermicron (M_c). The number concentration of particles in these categories are calculated by equations 3 & 4 and shown in Table-2. The mass of the submicron (M_a) particles is less than that of supermicron (M_c) particles in all the months except the month of May 2012. It may be due to domination of submicron particles on super micron particles.

Fig.4 shows the monthly variation of different parameters listed in Table 2. Large variation was noticed in Month-to-Month observation of M_t (4.9 μgm^{-3} to 16.2 μgm^{-3} with mean12.0 μgm^{-3}) at Maitri. Troposphere-stratosphere exchange process of aerosols is very less effective over Antarctica due to the low pressure in the upper stratosphere that makes wind flow always towards the oceans. Only when the polar vortex breaks down, the exchange of the stratosphere and troposphere air takes place and the aerosols are brought down to the lower troposphere and that too mainly at high latitudes region (Hogan et al., 1979). These aerosols are then transported towards the coastal Antarctica by the katabatic wind and strength of this cycle may contribute significantly in the day to day variation in the ambient mass concentration.

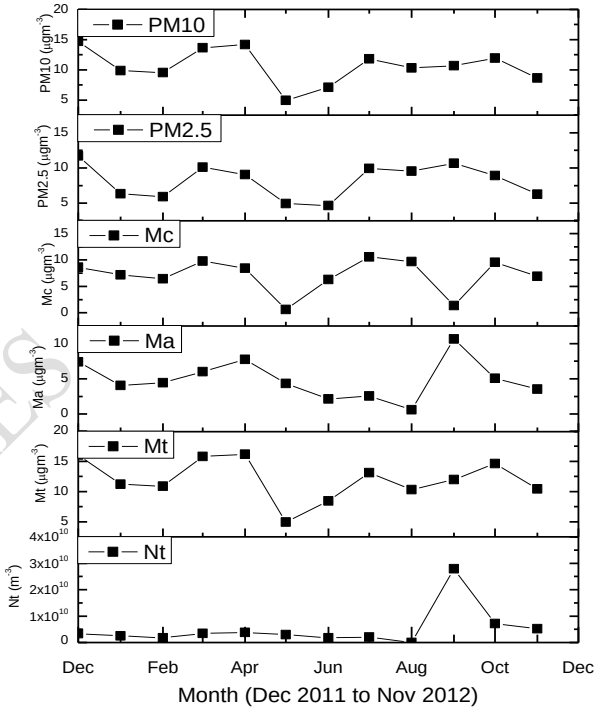

Figure 4: Monthly mean Variation of different parameters listed in Table-2 (December 2011 – November 2012)

Values of M_t reported for different Antarctic location by other studies are included in Table 3. The mean values of M_t reported in our study were significantly higher than the values reported for distinct regions of Antarctica as listed in Table 3, showing spatial variation of M_t over different location of Antarctica.

Antarctic locations	Period of observation	M_t (μgm^{-3})	References
Maitri (71^0 S, 11^0 E)	Jan-Feb 2008	8.2±2.9	Chaubey et al., 2011
Larsemann Hills (69^0 S, 76^0 E)	Feb-Mar 2008	6.0±1.3	Chaubey et al., 2011
Maitri (71^0 S, 11^0 E)	Jan-Feb 2001	7.0	Gadhavi and Jayaraman., 2004
Mc	Dec 1995-	3.5 to 4.2	Mazzera et

Murdo(78^0 S, 167^0 E)	Feb 1996		al., 2001
Maitri (71^0 S, 11^0 E)	Dec 2011-Nov 2012	12.0± 3.4	Present Study

Table 3: Comparison of total mass concentration (M_t) reported for various Antarctic locations by other studies with present result

Looking at Table 3, the value of M_t for the location Maitri during 2001, 2008 and 2011-12 show an increasing trend with time, which may be an indication of long term changes in Antarctic atmosphere. Moreover Fig.4 also confirms that the values during the months Dec-Feb (same months as reported by previous measurements) at Maitri are $>10 \mu g m^{-3}$, thus the increasing trend is not affected by seasonal differences in the different measurements.

Detailed analysis in the light of the meteorological conditions during the observation period is under progress. The preliminary results show that the observed aerosols are primarily of local in nature as there is no significant change in the wind speed and direction during the observation period.

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