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The Atmospheric Aerosol Measurements at Maitri

Vimlesh Pant, Devendraa Siingh and A. K. Kamra

Indian Institute of Tropical Meteorology, Pune – 411008, India

ABSTRACT

Measurements of total concentration and the number size distribution of the atmospheric aerosol particles in the size ranges of 3 – 700 nm and 0.5 – 20 μm diameters were made at Maitri, during the 24th Indian Scientific Expedition to Antarctica. Observations showed that total number concentrations of particles in the submicrometer size range varied between 100 to 2000 particles cm^{-3}. Typical size distributions of submicrometer particles were observed to be either monomodal with a maximum in Aitken mode at 50 - 80 nm, or bimodal with maximum in Aitken mode at 20 – 40 nm and in Accumulation mode at ~100 nm diameters. However, total concentration of particles in the coarse particle size range remained nearly constant and very low (< 1 particle cm^{-3}) for most of the period. The number size distribution of coarse particles were monomodal with a maximum in coarse mode at 0.7 – 1 μm diameter. Their concentration increaseed when any cyclonic system revolving around the continent of Antarctica passeed near the Maitri station. The presence of ultrafine particles of < 10 nm diameter, observed on a few occasions, indicate the formation of new particles by the gas-to-particle conversion mechanism. Measurements made during a blizzard showed that blowing snow-particles can significantly scavenge the submicrometer particles in the lower atmosphere. Total aerosol number concentration decreased in the submicrometer particle size-range but increased in coarse particle size range with increase in wind speed after the blizzard.

INTRODUCTION

Aerosols play an important role in the radiation budget of the Earth as they interact, both directly and indirectly, with the solar radiation. The continent of Antarctica provides an ideal site to study the background aerosols as it has no or very little human activity and the air circulation over the continent prevents the direct transport of air from the lower latitudes through the lower atmosphere. Some of the earlier investigations of the aerosol properties at Antarctica are reported by Shaw (1979), Lal and Kapoor (1989), Harvey et al. (1991), Ito (1993), Hogan and Gow (1993),

Hall and Wolff (1998), Wagenbach et al. (1998), Kerminen et al. (2000), Mazzera et al. (2001), Deshpande and Kamra (2004), Gadhavi and Jayaraman (2004), Mishra et al. (2004), Hara et al. (2005) etc. and reviewed by Shaw (1988) and Fitzgerald (1991).

Submicrometer particles are suspended throughout the troposphere and lower stratosphere over the ice sheet of Antarctica. Their concentration shows a strong seasonal variation, being as low as a few cm^{-3} in winter to several thousands cm^{-3} in summer (Hogan, 1975). Most of the submicrometer Antarctic aerosol has been found to be sulfate. Coarse mode (> 1 µm diameter) aerosol particles, however, mostly consist of sea-salt particles, having their origin at coastal Antarctic sea and transported over the continent with prevailing winds. The circulating cyclonic storms around the continent of Antarctica enhance the concentration of aerosol particles at coastal Antarctic stations. Gadhavi and Jayaraman (2004) observed that about 63 % of total aerosol mass is contributed by particles of size greater than 1 µm diameter at Maitri. The individual particle analysis carried out at Syowa station (69.00°S, 39.58°E) by Hara et al. (2005) indicates that sea salt particles having their diameter between 0.2 – 2 µm are modified through heterogeneous reactions mainly with gaseous sulfur species in the summer and reactive nitrogen oxides (e.g. HNO_3 and N_2O_5) in the winter spring season at Antarctica. They found that, in addition to SO_2 and H_2SO_4, the volatile sulfur species such as CH_3SO_3H, DMS and DMSO derived from bioactivity on the ocean surface during summer months can modify the sea salt particles in coastal Antarctic atmosphere through various heterogeneous reactions.

The aerosol particles are removed from the Antarctic atmosphere mainly by precipitation in the form of snowfall and gravitational settling. The drifting snow particles can scavenge the submicrometer aerosols not only during their vertical fall but also during their horizontal advection with strong winds in the lower atmosphere, and thereby decreasing their concentration (Kamra et al., 2008).

Measurements of total concentrations and number size distributions of the atmospheric aerosol particles in the size ranges of 3 – 700 nm and 0.5 – 20 µm diameters have been made at Maitri during the 24th Indian Scientific Expedition to Antarctica. The results are reported here and interpreted in terms of local meteorological conditions and wind flow at the station. The effects of the cyclonic systems revolving around the continent of Antarctica and the drifting snow particles during a blizzard on the aerosol number size distributions were also studied.

INSTRUMENTATION AND SAMPLING

The Scanning Mobility Particle Sizer (SMPS, Model 3936 of TSI) and Aerodynamic Particle Sizer (APS, Model 3321 of TSI) systems have been used to make measurements of total number concentration and highly resolved number size distributions of aerosol particles in the size ranges of 3-700 nm and 0.5-20 μm diameters, respectively **(Figure 1)**.

Fig. 1 : The Aerodynamic Particle Sizer (APS) and Scanning Mobility Particle Sizer (SMPS) systems installed inside the Kamet hut at Maitri

Both instruments were kept inside Kamet hut, which is located approximately 300 m upwind of the prevailing wind from the living modules and generator complex (see **Figure 3** of Siingh et al. in this volume). Therefore the chances of air samples being contaminated by human activities at the station are minimized.

The ambient air for the SMPS and APS systems was sampled at a height of 2 m from the ground level, through two inlet-tubes of 0.5 cm diameter each. Both tubes were projected out through a wall of Kamet hut and air was sucked at flow rates of 3.3 / 6.6 liter per minute (l pm) and 5 l pm for the SMPS and APS systems, respectively. The inlets were cleaned from time-to-time to avoid accumulation of sea salt, dust or snow in the inlet. Further the instruments were not operated during the periods of snowfall and blizzard to prevent ice entering the sizing- and optics-parts of the instruments. The aerosol data were recorded continuously from January 1 – February 28, 2005 and 10-minutes averaged samples were stored in computer.

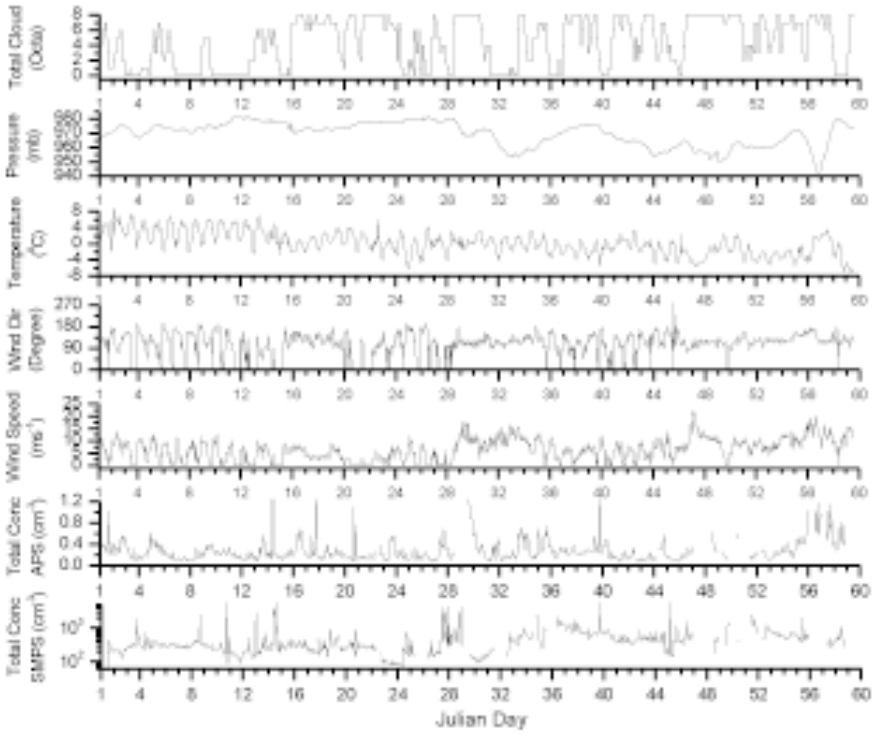

Fig. 2 : Variations in total number concentration along with the meteorological parameters recorded at Maitri

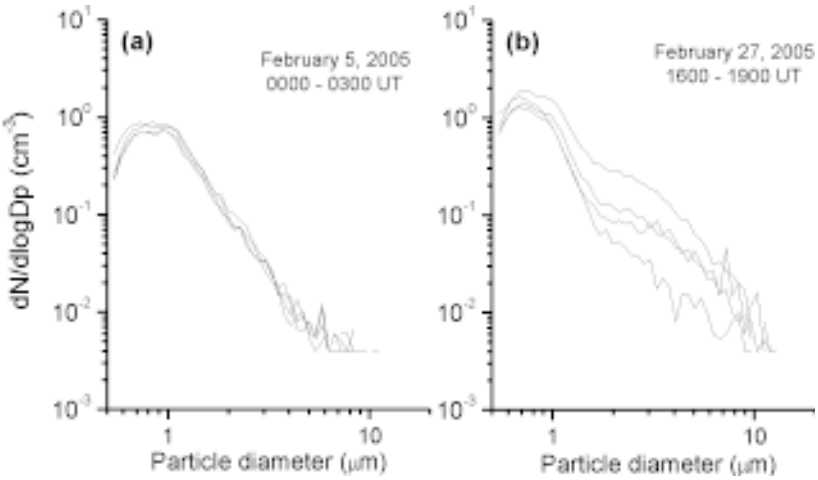

Fig. 3 : Hourly averaged number size distributions of micrometer aerosol particles (0.5 – 20 μm diameter) normally observed in (a) fair weather, and (b) during the passage of cyclonic system around the continent of Antarctica

TOTAL NUMBER CONCENTRATION OF AEROSOL PARTICLES

To compute total number concentrations of the micrometer (0.5 – 20 μm) and submicrometer (collective range of 3 – 700 nm) size particles, each size distribution measured by the APS and SMPS systems, respectively at 10-minutes interval, was integrated. **Figure 2** shows variations of total number concentration of micrometer and submicrometer particles alongwith those of atmospheric temperature, pressure, wind speed and direction and cloud coverage as recorded at Maitri, throughout the period of observation.

(a) Micrometer particles

Aerosol particles in the size range of 0.5R-20 μm diameter have very low and almost constant concentrations (0.1 – 0.8 particle cm^{-3}) throughout period of observations at Maitri. However, some peaks in the coarse particle concentrations exceeding 1.2 particles cm^{-3} and generally associated with the passage of cyclonic systems, revolving around the continent of Antarctica, are observed.

(b) Submicrometer particles

Values of total number concentration of aerosol particles in the collective size range of 3 – 700 nm diameter during this period generally ranged between 100 and 2000 particles cm^{-3}. Occasionally, however, some peaks, lasting for a few hours, of as high concentration as ~ 5000 particles cm^{-3} were also observed. The concentrations of these submicrometer particles were generally below 800 particles cm^{-3} in January but increased 2 to 5 times in the month of February. Concentrations of condensation nuclei of the same order have also been reported at different coastal Antarctic stations during summer months by several investigators such as Ito (1993) at Syowa (69°S, 39.6°E) and Gras and Adriasseson (1985) at Mawson (67.6°S, 62.9°E). Aerosol measurements made at Maitri by Lal and Kapoor (1989) and by Deshpande and Kamra (2004) also showed similar concentrations of submicrometer aerosol particles during January – February months. However, comparatively lower concentrations of the order of few hundreds of condensation nuclei cm^{-3} have been reported by Voskresenskii (1968) at coastal station 'Mirny' (66.6°S, 93°E).

Although the occurrence of some peaks in the concentrations of micrometer and submicrometer sized particles coincided with each other, variations in the two categories of particles were not always similar.

NUMBER SIZE DISTRIBUTIONS OF AEROSOL PARTICLES

(a) Micrometer particles

Number size distributions of coarse particles in the size range of 0.5 -20 μm diameter mostly exhibited a single maximum between 0.7 and 1.0 μm. Height of the maximum in the dN/dlogDp representation of the distribution was generally ~ 1 cm^{-3} . Typical number size distributions of hourly averaged concentrations of aerosol particles in this size range during clear weather conditions is shown in **Figure 3 (a)**. Size distributions in this size range did not change much during the period of measurements at Maitri. However, the concentration of particles with > 2 μm diameter undergo appreciable variations and showed another maximum at ~ 3 μm. The coarse sea-salt particle mode was observed at approximately 2 μm diameter in earlier studies carried out in summer by Kerminen et al. (2000) and Jourdain and Legrand (2002) at coastal Antarctic stations.

Significant increase in the coarse particle concentrations was mostly observed when some eastward propagating cyclonic system circulating around the coast of Antarctica passed close to the Maitri station and influenced the wind flow over it. **Figure 3 (b)** shows change in size distribution under the influence of a cyclonic system passing over the coastline near the Maitri station on February 27, 2005. Concentrations of particles of all sizes increased, the increase being as much as an order of magnitude for particles of > 2 μm diameter. The increase in particles was most probably associated with enhanced generation of sea salt particles at the coastal Antarctic sea surface during the passage of cyclonic system and their subsequent transport by winds over Maitri.

(b) Submicrometer particles

All the three modes, nucleation, Aitken and accumulation, can be observed in the size distribution curves of submicrometer particles at Maitri. **Figure 4** shows typical shapes of aerosol number size distributions generally observed at Maitri. The number size distributions in this size range are mostly either monomodal **(Figure 4 a)** with an Aitken mode maximum at 50 - 80 nm, or bimodal with an Aitken mode maximum at 20 – 40 nm and the accumulation mode maximum at ~100 nm **(Figure 4 b)**. The heights of the maxima are of the order of 10^2 – 10^3 cm^{-3} in the dN/dlogDp representation. Positions and heights of the maxima keep changing in response to different meteorological conditions. Sometimes, however, the

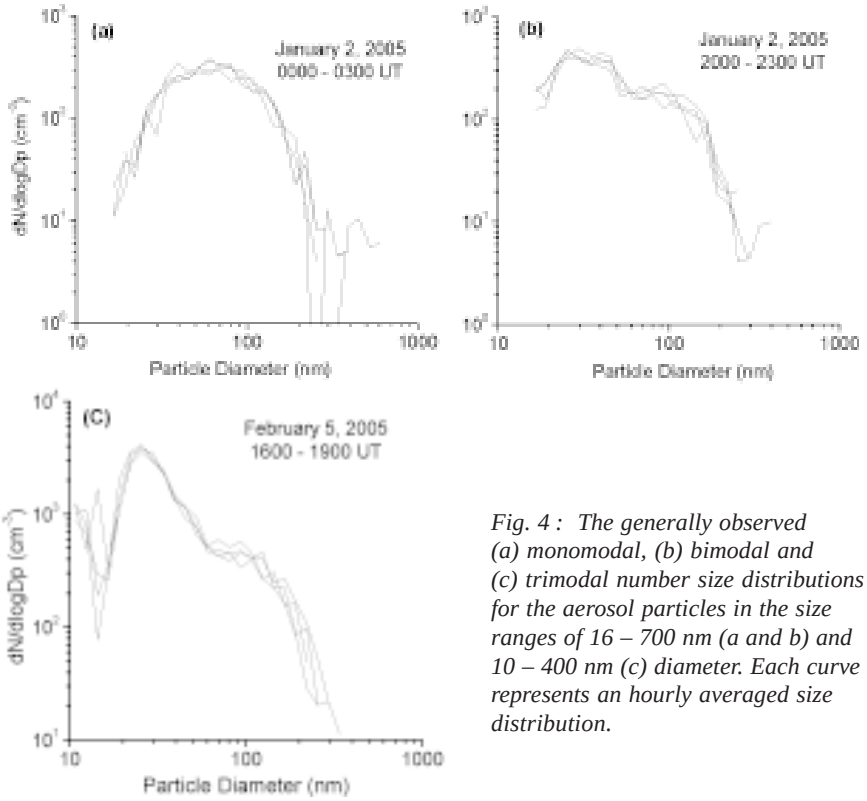

Fig. 4 : The generally observed (a) monomodal, (b) bimodal and (c) trimodal number size distributions for the aerosol particles in the size ranges of 16 – 700 nm (a and b) and 10 – 400 nm (c) diameter. Each curve represents an hourly averaged size distribution.

accumulation mode maximum is preceded by another maximum in nucleation mode at < 20 nm diameter **(Figure 4 c)**.

(c) Ultrafine particles

Occasional measurements of ultrafine particles in the size range of 3 – 160 nm diameter showed that aerosol particles of < 10 nm diameter were also observed under favorable meteorological conditions. An example of the ultrafine aerosol particle number size distribution, in the size range of 3 – 160 nm diameter, observed on February 2, 2005 is shown in **Figure 5**. Each curve is an average of six size distributions obtained in one hour. Observations of particles in this size range indicate formation of new particles at the continent. These ultrafine particles are generally formed by the gas-to-particle conversion mechanism. These particles subsequently grow in size by condensation and coagulation processes and contribute to the enhancement of the Aitken mode (40 – 60 nm) particles. Covert et al. (1996) and Ito (1985) have shown that the formation of new particles by

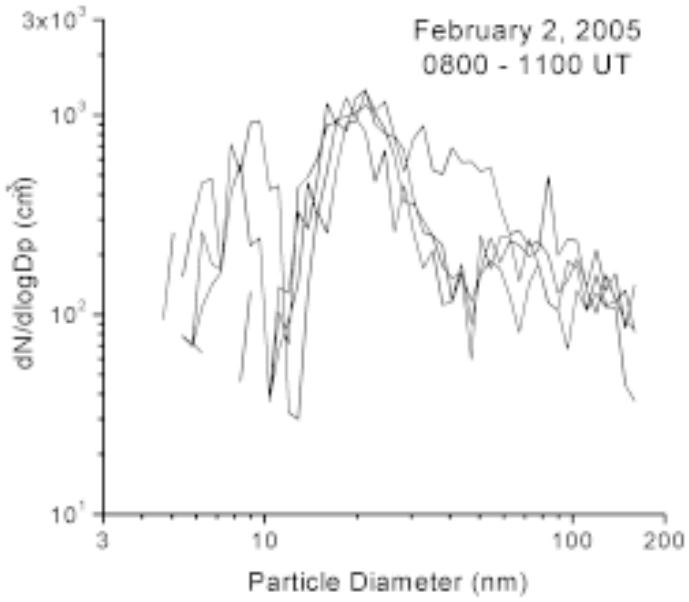

Fig. 5 : A typical example of new particle formation (< 10 nm diameter) in the size range of 3 – 160 nm diameter, at Maitri

the photo-oxidation process can occur in a clean environment with low aerosol surface area if plenty of solar radiation is available. Such conditions for formation of new particles are frequently met at Maitri. The rate of new particle formation is strengthened by the higher emissions of dimethyl sulphide (DMS) in the ice-melt regions around the continent of Antarctica (Davison et al., 1996; O'Dowd et al., 1997).

SCAVENGING OF AEROSOL PARTICLES BY DRIFTING SNOW

Our observations made on February 20, 2005 provided a unique opportunity to study the changes in aerosol concentrations and their size distributions due to the passage of a blizzard on February 18 – 19, 2005. Maitri station was covered by a sheet of fresh snow after the blizzard. Instruments were kept off during the blizzard period but observations were soon after resumed on February 20, 2005. **Figure 6** shows that total number concentration of aerosol particles in the size-range of 3 – 160 nm diameters. The concentration in this size range decreased from ~ 1800 to ~ 800 cm^{-3} as the wind speed increased from 5 to 10 ms^{-1} between 1700 and 2200 UT. On the contrary, total number concentration of particles in the size-range 0.5 to 20 µm diameter increased from 0.2 to 0.4 cm^{-3} in the same time period.

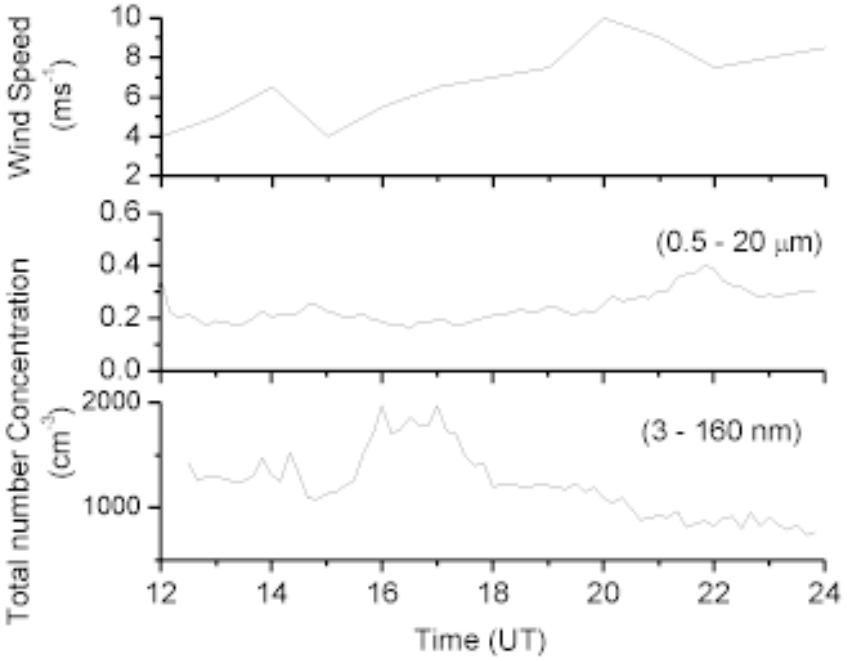

Fig. 6 : Total aerosol number concentration in the size range 3 – 160 nm and 0.5 – 20 μm diameter along with wind speed on February 20, 2005

Ice-particles are raised from the fresh snow with winds and traverse in the lower atmosphere. These ice-particles are mostly coarse particles of micron / supermicron size. When airborne, these ice particles drift with a lower velocity than that of aerosol particles because of their higher inertia. As a result of the relative velocity, ice-particles scavenge smaller aerosol particles in submicrometer size range and therefore decrease their concentration.

Figure 7 shows number size distributions of ultrafine particles observed on February 20, 2005 and their evolution with time. All curves show a dominant maximum at ~ 30 nm diameter in Aitken mode and the height of maximum decreased as the wind speed increased from 1700 to 2200 UT. However, another maximum appeared at ~ 11 nm diameter in nucleation mode in the afternoon hours when the solar radiation was high. Moreover, the particle size distributions obtained at these hours showed the presence of particles as small as 4.6 nm diameter. Since such small particles can not be transported from long distances, their presence indicates the formation of new particles of nanometer size near this locality and

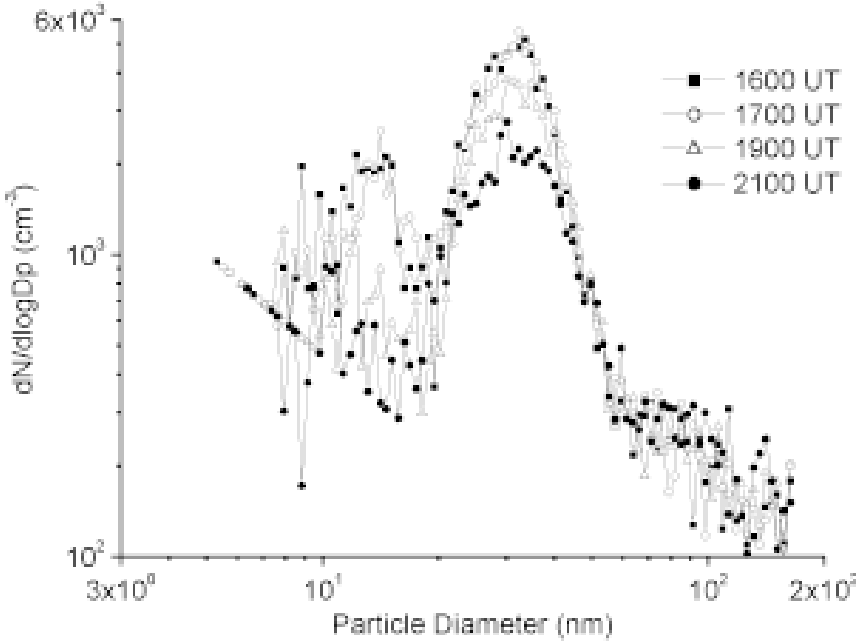

Fig. 7 : Aerosol number size distributions in the size range 3 – 160 nm on February 20, 2005

their subsequent growth to these sizes (Koponen et al, 2003; Kulmala and Kerminen, 2008).

Figure 8 shows the evolution of the size distributions of particles in the size range 0.5 – 20 μm diameter from 1600 – 2300 UT on February 20, 2005. All size distributions show a broad maximum in coarse mode between 0.7 and 1.0 μm diameter. However, contrary to the trend of the maxima height decreasing with the wind speed in case of the nucleation and accumulation modes, the height of maxima in this coarse mode increased with the increase in wind speed.

DISCUSSION

The aerosol concentrations at Maitri are largely governed by two sources, viz. by gas-to-particle conversion of trace gases and by the breaking of waves on the surrounding ocean surface. The baroclinic disturbances generated over the Southern Ocean regions and katabatic winds flowing down-slope the higher polar plateau significantly alter the aerosol size distributions. The processes responsible for various modes observed in

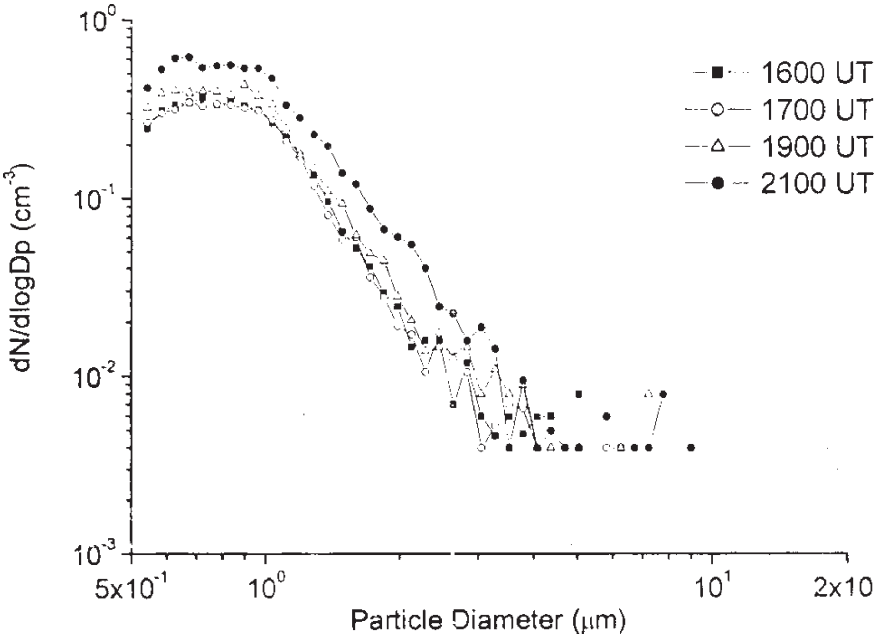

Fig. 8 : Aerosol number size distributions in the size range 0.5 – 20 μm on February 20, 2005

submicrometer size particles are different. The nucleation mode particles (< 20 nm diameter) are mainly formed due to nucleation of precursor gases and they have a short lifetime in the atmosphere. Most of these particles have been reported to consist of sulfate or droplets of sulphuric acid and are produced photochemically by gas-to-particle conversion process and act as condensation nuclei. Our observations show that generation of such nucleation mode particles can occur frequently at Maitri. These particles then grow in size by condensation and give rise to the Aitken mode (40 – 60 nm diameter) particles. The process of coagulation of small particles to form large particles dominantly contributes to the formation of the accumulation mode (100 – 1000 nm diameter) particles.

The wave-breaking and bubble bursting mechanisms at the surrounding sea surface are well recognized processes for sea salt particle generation in coarse mode (> 1 μm diameter). Our observations efficiently demonstrate the penetration of coarse particles with the winds associated with the cyclonic systems revolving around the continent of Antarctica. Our aerosol observations made in strong winds after a blizzard effectively show that scavenging of aerosol particles by snow particles being

horizontally advected with the winds making significant reduction in aerosol concentration.

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