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The atmospheric electric conductivity and aerosol measurements during fog over the Indian Ocean

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Abstract

The atmospheric electric conductivity and aerosol size-distribution measurements made over the Indian Ocean on two occasions of fog occurrence during the XVI Indian Scientific Expedition, 1996–1997, are reported. The locations and the meteorological conditions associated with two fog episodes, one being a warm fog and the other a cold fog, are widely different. Values of both polar conductivities after showing a slight increase start decreasing about 1 h before the onset of fog, and then start increasing about 0.5–2 h prior to the dissipation of fog. The conductivity values then attain their fair-weather values in case of cold fog but continue to increase and give a maximum ~2 h after the dissipation of fog in case of warm fog. Total number concentration of aerosol particles (between 13- and 1000-nm diameter) increases during the warm fog period but only just after the dissipation of cold fog. Aerosol size distributions show an increase in concentration of all particle sizes in warm fog but mainly in concentration of the nucleation mode particles in cold fog. Possible causes of the changes observed in conductivity and aerosols and their utility in forecasting the onset and dissipation of fog are discussed.

Keywords: Electric conductivity; Aerosol; Indian Ocean

1. Introduction

The effect of fog on the basic atmospheric electrical elements has been a topic of considerable interest in view of the prospect of such measurements for forecasting the onset and dissipation of fog. Measurements of potential gradient and conduction current by Israel and Kasemir (1952) during widespread fogs show an increase in potential gradient and a decrease in conduction current; the corresponding average drop in conductivity value being

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about one third of its fair-weather value. Serbu (1958) and Serbu and Trent (1958) observe a decrease in conductivity and a consequent increase in potential gradient 1–2 h before the onset of fog and the reverse changes about 1 h before the dissipation of fog and pointed out to the possible use of the atmospheric electric parameters as a tool for forecasting the onset and dissipation of fog. Dolezalek (1962) and Ruhnke (1966) report a strong correlation between visibility and small ion concentration in an atmosphere with high amount of hygroscopic particles. In the measurements made at a high mountain peak observatory, Reiter (1992) observes an increase in electric field and a decrease in total conductivity 1–2 h prior to the onset of fog, and associates it with an increase in relative humidity during fog. His measurements of size distribution of fine aerosol particles of <1 μm show an increase by an order of magnitude during the fog.

In an overview of the departures observed in the atmospheric electric parameters related to fog or mist, Anderson (1974) points out that many of the published findings are ambiguous and/or even contradictory. Recent observations of Israelsson (1999) indicate that the space charge is negative and polar conductivity and potential gradient decrease about 1 h before the visual observation of radiation fog. He explains his results on the basis of decreasing conduction current but increasing negative sedimentation current due to gravitational settling of fog droplets in the radiation fog. Recently, Anisimov et al. (2003) have measured the vertical current with a 1-km-long wire antenna mounted in a circle at 4-m height and electric field with nine field-mills during six cases of fog. They observe that the current density smoothly decreases and even changes direction but then rapidly returns to the fair-weather value. However, the electric field shows no significant change when the current goes to negative values. The field has a significant increase in the fluctuations in the frequency range of 10^{-2}–1 Hz and increases by a factor of 2, several hours after the current becomes negative. Anisimov et al. (2003) explain their results in terms of the diffusive charging of fog particles. Above discussion shows clearly that the conclusion of Dolezalek (1963) that there are various problems in explaining the atmospheric electrical fog effect is still valid. This emphasizes the need for detailed study of changes in the atmospheric electric parameters with the meteorological and aerosol characteristics of fog.

Choice of an adequate site is important for investigating the atmospheric electric fog effect. The atmospheric electric measurements made over remote oceans certainly have a unique advantage of being least disturbed by the anthropogenically polluted air from continents. The measurements made over oceans, therefore, can provide more convincing evidence than those made over land for detecting any changes associated with the fog. For example, the atmospheric electric conductivity measurements made over the North Atlantic Ocean show it to decrease 2–6 h before the fog episode (Anderson and Trent, 1962). In this paper, we report measurements of the atmospheric electric conductivity and aerosol size distribution made during the periods of warm and cold fogs over the Indian Ocean and in the Antarctic environment, respectively.

2. Weather conditions during fog episodes

Two occasions of fog—the first over the Indian Ocean (34.5°S, 48.9°E) on December 25, 1996 and the second at the Antarctic coast (69.8°S, 11.9°E) on January 5, 1997—were

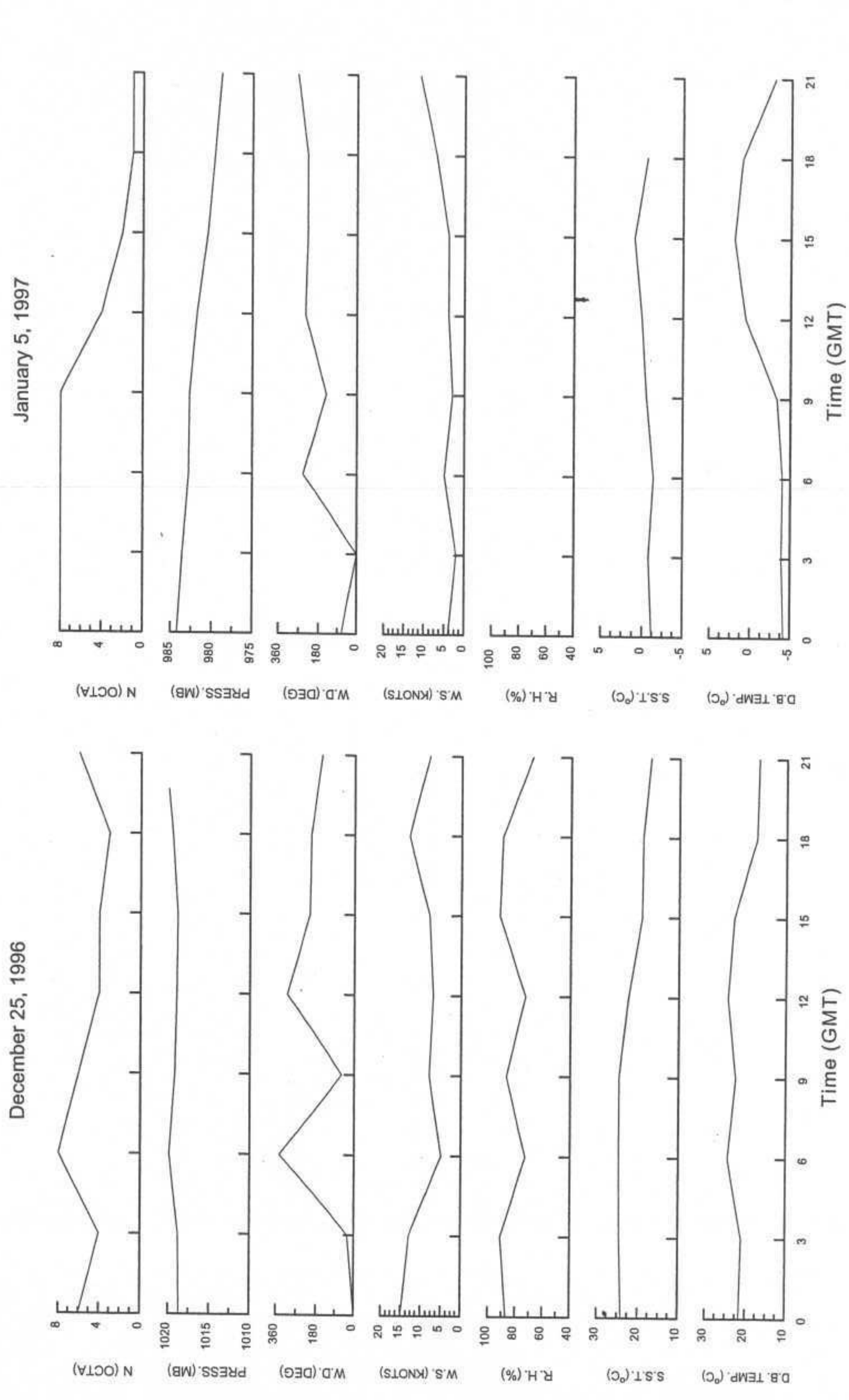

Fig. 1. The 3-h meteorological data taken on the ship at 34.5°S, 48.9°E on December 25, 1996 and at 69.8°S, 48.9°E on January 5, 1997.

encountered on the onward cruise of MV Polarbird during the XVI Indian Scientific Expedition to Antarctica. Fig. 1 shows variations of different meteorological parameters recorded at 3-h intervals on the ship. During the first episode, the ship was sailing at a speed of 25 km h^{-1} and experienced fog from 1430 to 1630 UT. If the surface area covered by fog is assumed circular, its diameter can be roughly estimated from the average speed and direction of wind and ship's movement as ~ 75 km. Inside the fog zone, the atmospheric temperature dropped from 24 to 17 °C and the sea surface temperature from 24.5 to 17.1 °C; the relative humidity increased from 70% to 92% and remained high (~ 90%) even after its dissipation at 1800 UT; the wind speed decreased from 2–7 to 2–4 m s^{-1} and changed from the northeasterly to southwesterly direction; and the atmospheric pressure remained almost constant at about 1018 mb. Meteorological features point this out to be an advection fog formed due to the flow of moist air from warm regions to cover the colder surface.

During the second fog episode, the ship was idle at the Antarctic coast. The fog, consisting of ice particles, set in at 1000 UT and existed up to 1500 UT. The weather conditions during this period were much different from those during the warm fog. The fog area as roughly estimated from the average wind speed and direction is a circle of diameter equal to ~ 30 km. The atmospheric temperature during the fog period increased from −4.2 to 2.0 °C and the sea surface temperature from −1.2 to 1.0 °C. Southerly winds of 2–4 m/s continued throughout the fog period. The sea surface temperature was less by up to 2 °C than the atmospheric temperature so that a warmer air existed over the colder water during the fog period. The atmospheric pressure kept decreasing from 988 to 980 mb throughout the day. Finally, the fog began to dissipate due to increase in wind speed.

3. Instrumentation and recording of data

Electric conductivity of both polarities is measured with a Gerdien's apparatus described in detail by Deshpande and Kamra (2001). Apparatus consists of two identical cylindrical condensers of stainless steel joined with a U-tube and has a common fan to suck the air through two tubes. Critical mobility of each condenser is adjusted at 3.60×10^{-4} m^2 V^{-1} s^{-1}. An Analog Device 311 K amplifier is used to amplify the signal separately from each condenser. Gerdien's apparatus is vertically installed with its inlets at 24 cm above platform and ~ 10 m above sea level on the port-side deck of the ship. Gerdien's apparatus is placed upwind of the ship's chimney and its position is so selected that exhaust of the ship, when it is in motion, travels away from the apparatus and does not contaminate the measurements. When the ship is stationary, only those observations when wind direction is such that the ship's exhaust is carried away from the apparatus are considered. Amplifier boxes are placed near to sensors and a conical cap is fixed over the air-suction fan to avoid accumulation of snowfall or rain on it. A PC-based data acquisition system kept inside a living cabin is used to store data from Gerdien's apparatus. The system can sample 10^5 samples s^{-1} and store and average the data at different time intervals. The 1-min-average and 30-min-average data are stored during the entire period of measurements. Maintenance of Gerdien's apparatus, especially cleaning of its insulators, was done at least daily. The zero shift which was checked every 3 h did not show any appreciable value during these periods.

A TSI 3030 Electrical Aerosol Analyzer (EAA) System is used to measure aerosol size distribution of particles of diameter 3 to 1000 nm in 10 different size ranges, at the atmospheric relative humidity. Accuracy of the contributions from the lowest two channels, i.e. for 3- and 7-nm diameter ranges, is not sufficient due to limitation of operating the instrument where the rate of generation of the photo-chemically generated aerosols is highly variable, and hence the contributions from these channels are not considered in this analysis. Five size-distribution samples are collected at 3-h intervals and the data are stored in a PC. Average of five samples taken at an interval of 3 h is used in this analysis. Inlet of the EAA-system is cleaned at least once a day to minimize the accumulation of sea salt, snow or dust at the inlet. This cleaning frequency was found to be adequate and effective as no appreciable difference was observed in the measurements taken before and after the cleaning.

The air is sampled at a height of 12 m above mean sea level through a 1-cm diameter stainless steel tube of 1-m length, which is projected outward from a cabin and is properly grounded. The EAA-system is installed inside the cabin. Position of the inlet to collect the air sample is so selected that the ship's exhaust does not contaminate the aerosol measurements.

4. Observations

4.1. Effect of fog on conductivity

On December 25, 1996, the ship entered the fog zone at ~ 1430 UT and came out of it at ~ 1630 UT. It was a warm fog and consisted of water droplets. Fig. 2 shows the changes in polar conductivity and total aerosol concentration before, during and after crossing the zone of fog. Also shown in Fig. 2 are the curves for polar conductivities averaged for 5 fair-weather days during the same expedition. Standard deviations of the half-hourly averaged values are also shown. We define a fair-weather day, as the day with wind speed <5 m s^{-1}, no precipitation on the ship, and low level clouds <3 octas. Further, the minimum distance of the ship from coastline should be >200 km. Electric conductivity of both polarities after showing slight increase starts decreasing 1–2 h before the ship entered the fog zone. Total electric conductivity experiences a change of 71% during this period and decreases from 2.25×10^{-14} to 0.65×10^{-14} S m^{-1} (Fig. 2). Conductivity attains the minimum value at about 1600 UT and starts increasing again about half an hour before coming out of the fog zone. It continues to increase and attains its maximum value about 2 h after coming out of the fog zone and then decreases to its normal value. To the best of author's knowledge, the increase in conductivity before entering and after coming out of the fog zone is not reported earlier. Deviations in polar conductivity around and within the fog zone are significantly higher than standard deviations from its mean value on other fair-weather days. The departures in atmospheric electric conductivity during fog start much earlier in observations of Anderson and Trent (1962) over the North Atlantic Ocean than in the present observations over the southern Indian Ocean.

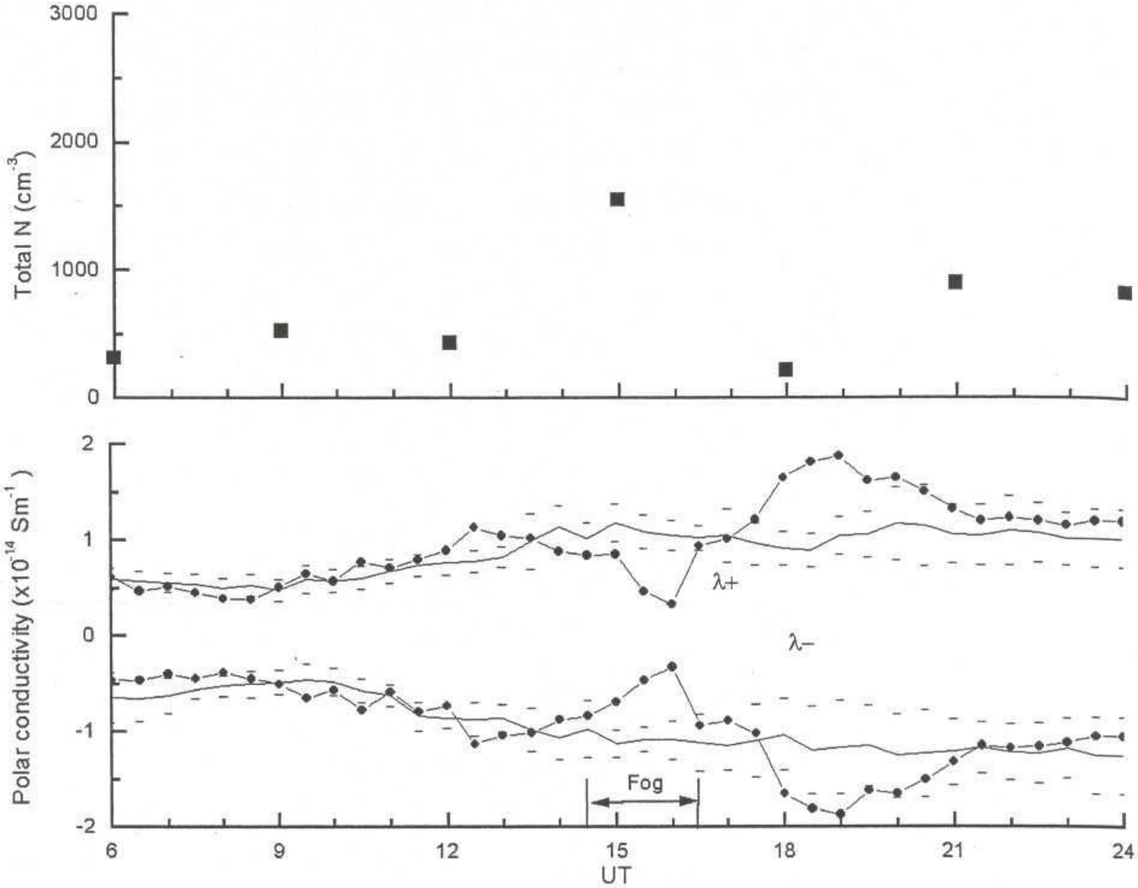

Fig. 2. The variation of the electrical conductivity of both polarities and total aerosol concentration on December 25, 1996 (–●–). The continuous line (—) shows the average conductivity values alongwith their standard deviations shown by dashes for each half-hourly average values for 5 fair-weather days on the same cruise.

Unfortunately, our aerosol observations have been made only at 3-h intervals and this frequency is not enough to satisfactorily examine the conductivity–aerosol concentration relationship. However, we have plotted the aerosol concentrations in Fig. 2 to see the possible trends in two parameters. Total aerosol concentrations of 10 to 1000 nm in diameter particles are obtained by adding the measured concentrations in respective channels of the EAA-system. Total aerosol concentrations before entering and after passing through the fog zone are at normal background levels in the Indian Ocean but increase by three times to 1500 particles/cm^3 at 1500 UT when the ship is inside the fog zone. Aerosol concentration attains the minimum value at 1800 UT, i.e. immediately after coming out of the fog zone but recovers back to its ambient value at 2100 and 2400 UT.

Fig. 3 shows the conductivity and total aerosol concentration values before, during and after the fog on January 5, 1997 when the ship was idle at the Antarctic coast. The fog sets in at ~ 1000 UT and dissipates at ~ 1500 UT. It also shows the curves of polar conductivities averaged for 5 fair-weather days during the cruise period. It was a cold fog and consisted of ice crystals. The values of electrical conductivity of either polarity increase to $\sim 1.2 \times 10^{-14}$ S m^{-1} at 0900 UT, start decreasing ~ 1 h before the fog sets in,

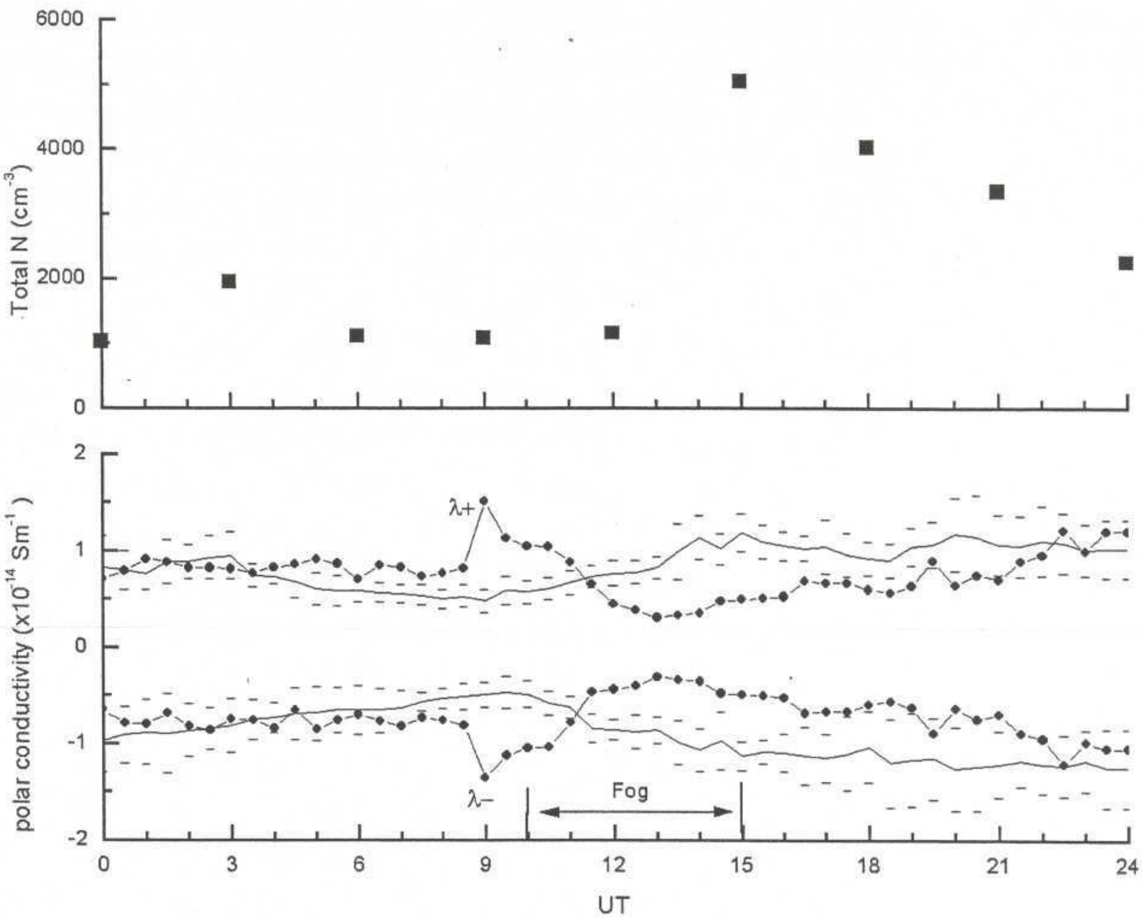

Fig. 3. Same as in Fig. 2 except on January 5, 1997.

attain the minimum values at 1300 UT, and start increasing slowly even before the fog dissipates. Finally, the conductivity attains its ambient value at ~1900 UT. The change in total conductivity in this case is 78%. The rate of change in the conductivity values after fog is faster when the ship passes through a warm advection fog on December 25, 1996 than on January 5, 1997 when the ship is stationary at a point and the fog sets in and dissipates there. In this case, total aerosol concentrations of ~1000 particles/cm^3 observed at 0900 UT before the setting in of fog remain almost the same at 1200 UT during the fog but increases at 1500 and 1800 UT, i.e. after the dissipation of fog.

5. Change in aerosol size distribution associated with the fog

Fig. 4 shows the aerosol size distribution observed before, during and after the fog on December 25, 1996 and January 5, 1997. The size distributions observed before the fog are trimodal and are open-ended with a peak at 133 nm and two minima at 75 and 420 nm. These are typical of the size distribution observed near the Antarctic coast in fair-weather situations. Concentrations of particles of all sizes increase with the onset of fog on December 25, 1996 and drop to almost its previous level after the fog. On January 5, 1997, however, particle concentrations increase only near the dissipation stage of fog and remain

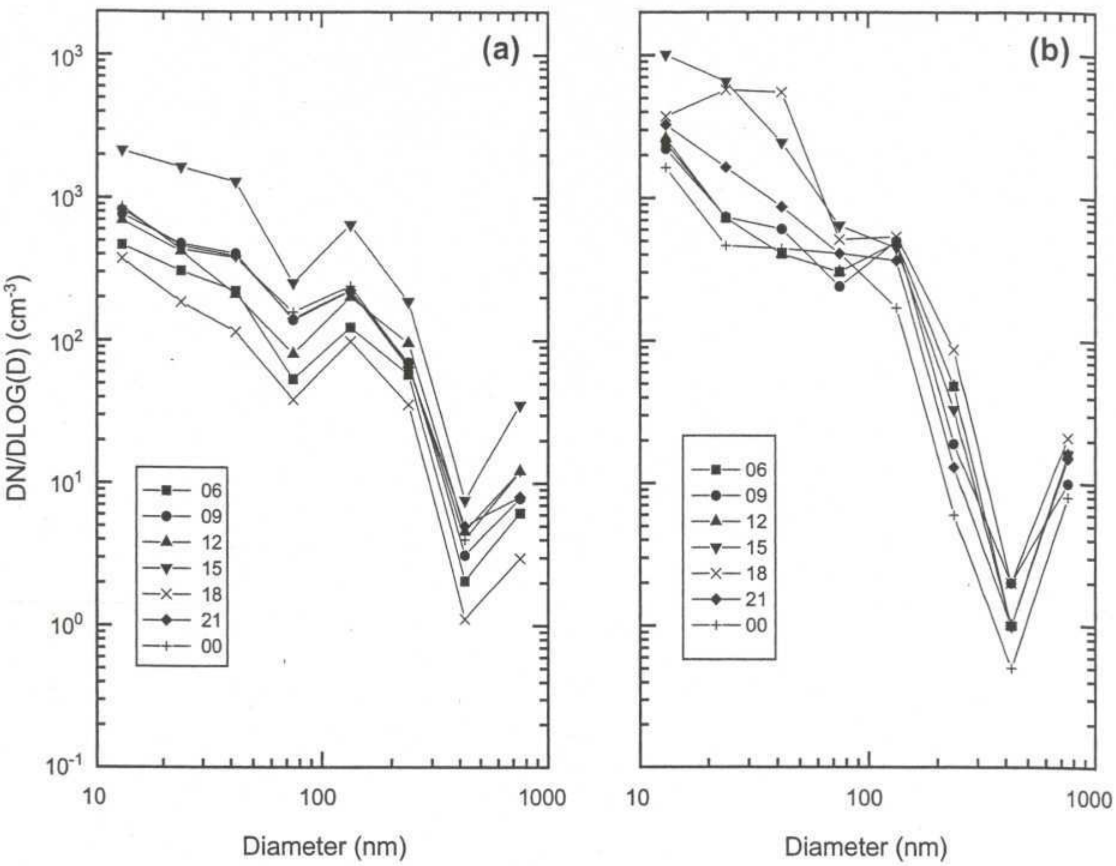

Fig. 4. The aerosol size distributions during and around the fog episodes on (a) December 25, 1996 and (b) January 5, 1997. Each point is an average of five observations taken at 3-h intervals with an Electrical Aerosol Analyzer system.

high for several hours afterwards. Moreover, the increase in concentration on this occasion is mostly confined to the nucleation mode particles.

6. Discussion

Electric conductivity over the ocean can change due to the change in (i) the local ionization, (ii) the size of aerosol particles, or (iii) the concentration of particles. In absence of any local source of ionization, cosmic rays are the only major source of ionization over the open ocean. However, in view of the small latitudinal width of fog zone, any change in the rate of ionization across it due to latitudinal change in the cosmic ray intensity can be ruled out.

Formation of water droplets or ice crystals during a fog episode substantially changes the size of some aerosol particles. Size of aerosol particles, especially of hygroscopic nuclei, sharply increases when the value of relative humidity exceeds 75%. The increase in relative humidity from 73% at 1200 UT to ~92% at 1500 UT on December 25, 1996 will cause such growth in the size of aerosol particles. Non-observation of a spectral shift to larger sizes in the aerosol size-distribution in Fig. 4a is most probably because of

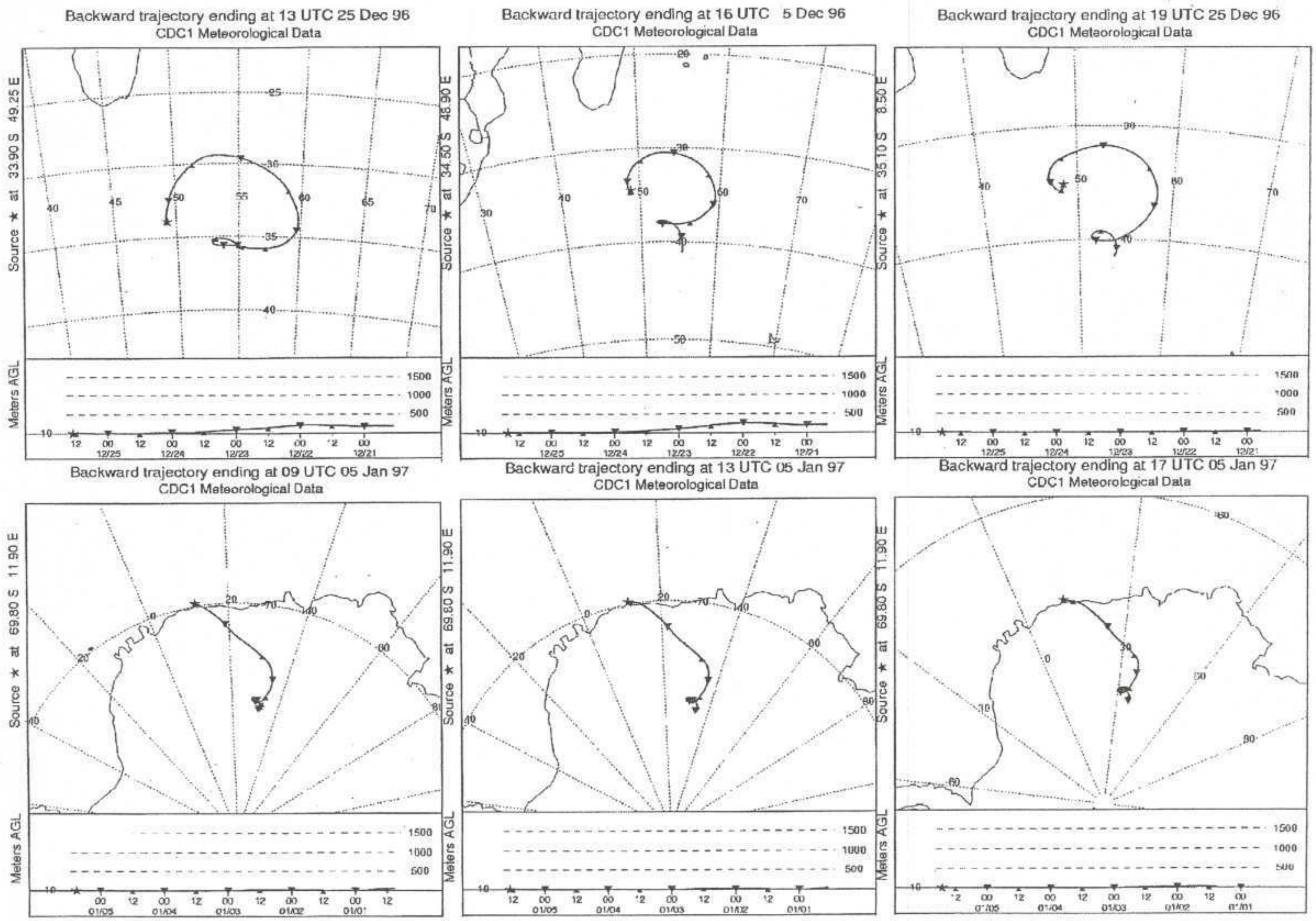

Fig. 5. The 5-day backward trajectories at 1300, 1600 and 1900 UT on December 25, 1996 and at, 0900, 1300 and 17oo UT on January 5, 1997.

coarse resolution of the EAA system. Larger particles in fog provide enhanced surface area for trapping of ions and make them immobile to cause a decrease in conductivity (Kamra et al., 1997). The higher aerosol concentration observed at 1500 UT on this day may be due to a change of air mass with higher aerosol concentration, which will further contribute to lower the conductivity value. The maximum in conductivity observed after the fog episode is associated with very low aerosol concentrations which might have resulted due to wash out of aerosols by fog droplets. Subsequent recovery of aerosol concentrations at 2100 and 2400 UT supports our observations of the return of conductivity to its ambient level.

Backward trajectories before, during and after the periods of fog for both sites of observation are shown in Fig. 5 (Draxler and Rolph, 2003; Rolph, 2003). Though the position of source remains almost the same, on January 5, 1997, it shifts southward from 36°S at 1400 UT to 41°S at 1600 UT on December, 25, 1996. Back trajectories for January 5, 1997 are consistent with the outflow drainage over the plateau associated with the polar high pressure system. On either day, however, there does not seem to be much of the vertical transport. Back trajectories obtained even at 0600 UT on January 5, 1997 are similar.

The presence of high humidity and solar radiation in a clean environment with low aerosol surface area causes the formation of new particles by photo-oxidation processes (Covert et al., 1996; Ito, 1985). Higher emissions of dimethyl sulphide (DMS) in the ice-melt regions around the continent of Antarctica certainly add to the new particle formation process (Davison et al., 1996; O'Dowd et al., 1997). For example, O'Dowd et al. (1997) has observed events of new particle formation in the Weddell Sea (Antarctica) region under conditions of high DMS flux and low aerosol surface area. Growth of these ultra-fine particles to ~ 10-nm size, which can be recorded by our EAA system, requires at least a few hours in free troposphere (Raes, 1995; Clarke, 1992). However, their growth in the high-humidity, clean conditions of the atmospheric boundary layer is still not well understood. On January 5, 1997, sky continues to be overcast and the surface temperature does not appreciably increase showing almost no change in the solar radiation up to 0900 UT (Fig. 1). Consequently, not much of the new particle formation ahead of the fog is expected. Increase in solar radiation from 0900 UT onwards will cause formation of new particles. However, these nucleation mode particles will cause a decrease in conductivity, as evidenced in our observations, but will take at least a few hours to grow in size to be detected by our EAA system. Observations of the maximum aerosol concentration at 1500 UT when the solar radiation is expected to be maximum, and its subsequent decrease from 1500 to 1400 UT, support such a hypothesis. However, the present data are not sufficient to clearly associate the origin/advection of these particles with the fog episode.

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References

Anderson, R.V., 1974. Atmospheric electricity in the real world. In: Dolezalek, H., Reiter, R. (Eds.), Proc. 5th Int. Conf. On Atmospheric Electricity, Electrical Processes in Atmospheres. Steinkopff, Darmstadt, pp. 87–99.

Anderson, R.V., Trent, E.M., 1962. Atmospheric electricity measurements in the North Atlantic during fallex-60, U.S. Naval Research Laboratory, NRL Report 5833.

Anisimov, S.V., Mareev, E.A., Shikhova, N.M., Sorokin, A.E., Dimitriev, E.M., 2003. Electrodynamics of the fog. Proc. 12th Intl. Conf. on Atmospheric Electricity. Versailles, France, pp. 279–282.

Clarke, A.D., 1992. Equatorialconvection as a source of tropospheric nuclei over the remote Pacific. In: Restelli, G., Angeletti, G. (Eds.), Dimethylsulphide: Oceans, Atmospheres, and Climate. Kluwer Academic Publishing, Norwell, MA, pp. 323–330.

Covert, D.S., Kapustin, V.N., Bates, T.S., Quinn, P.K., 1996. Physical properties of marine boundary layer aerosols particles of the mid-Pacific in relation to sources and meteorological transport. J. Geophys. Res. 101, 6919–6930.

Davison, B., O'Dowd, C., Hewitt, C.N., Smith, M.H., Harrison, R.M., Peel, D.A., Wolf, E., Mulvaney, R., Schwikowski, M., Baltensperger, U., 1996. Dimethyl sulfide and its oxidation products in the atmosphere of the Atlantic and Southern Oceans. Atmos. Environ. 30, 1895–1906.

Deshpande, C.G., Kamra, A.K., 2001. Diurnal variation of the atmospheric electric field and conductivity at Maitri, Antarctica. J. Geophys. Res. 106, 14207–14218.

Dolezalek, H., 1962. Atmospheric electric parameter study: Survey on an effect relating atmospheric electric variations with formation and dissipation of fog, Contract Nonr 3388 (00) Final Rept., 123 pp.

Dolezalek, H., 1963. The Atmospheric electric fog effect. Rev. Geophys. 1, 231–282.

Draxler, R.R., Rolph, G.D., 2003. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Israel, H., Kasemir, H.W., 1952. Studien iiber das atmospharische Potentialgofalle VI: beispiele fur das Verhalten Luftelektrischer Elemente bei Nebel. Arch. Meteorol. Geophys. Bioklimatol., A Meteorol. Geophys. 5, 71–85.

Israelsson, S., 1999. On electric properties of radiation fog. Proc. 11th Intl. Conf. on Atmospheric Electricity, Guntersville, AL, pp. 587–590.

Ito, T., 1985. Study of background aerosols in the Antarctic troposphere. J. Atmos. Chem. 3, 69–91.

Kamra, A.K., Deshpande, C.G., Gopalakrishnan, V., 1997. Effect of relative humidity on the electrical conductivity of marine air. Q. J. Royal Meteorol. Soc. 123, 1295–1305.

O'Dowd, C.D., Lowe, J.A., Smith, M.H., 1997. Biogenic sulphur emissions and inferred non-sea-salt-sulphate cloud condensation nuclei in and around Antarctica. J. Geophys. Res. 102, 12,839–12,854.

Raes, F., 1995. Entrainment of free tropospheric aerosols as a regulating mechanism for cloud condensation nuclei in the remote marine boundary layer. J. Geophys. Res. 100, 2893–2903.

Reiter, R., 1992. Phenomena in Atmospheric and Environmental Electricity Elsevier, Amsterdam, Netherlands.

Rolph, G.D., 2003. Real-time Environmental Applications and Display sYstem (READY) Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Ruhnke, L.H., 1966. Visibility and small-ion density. J. Geophys. Res. 71, 4235–4241.

Serbu, G.P., 1958. Atmospheric electricity and advection fog forecasting. In: Smith, L.G. (Ed.), Recent Advances in Atmospheric Electricity, pp. 239–240.

Serbu, G.P., Trent, E.M., 1958. A study of the use of atmospheric electric measurements in fog forecasting. Trans. Am. Geophys. Union 39, 1034–1042.