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The Atmospheric electric field and condvctivity measuremfnts during the XVI Indian Antarctica expedition

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Abstract

Surface measurements of the atmospheric electric field and the conductivity of both polarities made at Maitri (70° 46'S, 11° 44' E,) Antarctica and along the cruise track are reported. The 20 fair -weather days average diurnal variation curve of the atmospheric electric field is single periodic with the maximum at 1300 GMT, and the minimum at 0100 GMT. It also shows a secondary but distinct maximum at 1900 GMT. The difference between the diurnal variation curve observed at Maitri and the universal varition curve observed at oceans and at the south pole is discussed with refrence to the validity of the classical global electric circuit. The electric conductivity does not show much change during a day either at Maitri or over open ocean. However, the conductivity has the minimum value at around 30°S the value of conductivity keeps increasing southward of 30°S upto 70°S and northward upto 10°S. The condutivity shows a decrease north of 10°S, The variation in conductivity with latitude on the onward and return cruises has been interpreted in terms of the shift in the inter tropical convergence zone and the presence of some synoptic systems around Antarctica in this period. The incidences of fog over ocean have been reported in which the electric conductivity decreases in the region of fog.

Introduction

In the classical picture of the global electric circuit, a potential difference of about 250 kv is maintained between the ionosphere and the Earth by the totality of all thunderstorms acting at the same time all over the globe. This classical theory proposed by Wilson (1920), finds strong support in the observation that the diurnal variation of electric field with universal time observd over the world oceans during Carnegie cruises dining 1910 -30 coincides with the diurnal valuation of global thunderstorm frequency with universal time (Whipple and Scarce,1936). The validity of classical theory has often been tested with observations of the atmospheric electric parameters made at clean places such as over the oceans, in polar regions, at high mountian peaks, and above exchange layer. These observatins are quite often contradictory and suggest the contributions of other than thunderstorm generator in maintaining the ionospheric potential. As a result, the validation of the classical concept of the global electric circuit still remains, as Dolezalek (1972)put it, "a fundamental problem of atmospheric electricity". We describe here, the measurements of the electrie field and conductivity of both polarities made during our stay at Maitri (70° 46,S, 11° 44,E), Antarctica and along the cruise track. Fig. 1 shows the onward and return cruise tracks. The arrows marked along the tracks show the wind speed and direction measured every 3-hours on the ship.

Instrumentation

The atmospheric electric field is measured with a vertical a. c. field-mill in which the sensor, a conducting plate , is alternately exposed and shielded from the atmospheric electric field. The sensor and rotor plates of 9 cm diameter and a cylinder of non-magnetic stainless steel are used for the fabrication of the field- mill to reduce the contact potentials (Bailey and Anderson, 1987). The rotor was driven with an a.c.motor(220v,50Hz and 1500rpm)whose shaft is grounded with a carbon brush. The signals received from the sensors of the field-mill are amplified with an operational amplifier IC 8007 and demodulated with IC 1596. the electronic circuit is fitted inside the field-mill. The electrical conductivity of both polarities is measured with a Gerdien's apparatus. It consists of two identical cylindrical condensers of stainless steel joined with a U-tue and has a common fan to suck the air through the two tubes. A potential difference applied between the inner and uter cylinders of each condenser drives the ions of one polarity to be colleted at the inner electrode. The critical mobility of each condenser is adjusted to be 3.60 x 10^{-4} m/V/s. The signal from each condenser is amplified separately with amplifier 31 IK of Analog Devices. The amplifiers are kept inside a shielded box near to the sensors. The air suction fan of the apparatus is shielded with a conical cap to avoid accumulation of snow or rain. The signals from both, field-mill and Gerdiens apparatus are recorded with a PC-based data acquisition system which has a capacity to sample 10 samples/ sec and can store and average the data at different time intervals. The data is stored in 1-min average and 30-mins average modes during the entire period. Maintenance of both instruments, especially cleaning of their insulators, is done atleast daily. The zero shift is checked and, if any,corrected every three hourly.

Installation of instruments

Fig. 2 shows the installation sites of the field-mill and conductivity apparatus at Maitri. Field mill is installed about 35m away from the hut, Tirumala on the Priyadarshini lake side. Field mill is placed in a pit with its sensors flush with the ground (Fig. 3). The Gerdiens apparatus is kept about 40 m away from the hut on the lake side such that its intake is 24 cm abve the ground surface (Fig.4) The main Maitri station building and its adjoining structures such as the generator huts, gas plant, incinerator etc. are 150-200 m away from the site of our measurements. Under dominant southeasterly or south-southwesterly wind direction, there is no or little chance of the measuring site getting any contamination from the bulding site.

On the ship, the field-mill was installed on the deck in front of the navigational bridge. A reduction factor for this position of the field-mill is found by simultaneiously running another similar field-mill on the ice Shelf for a few hours while the ship was stationary before her return journey. The Gerdiens apparatus was installed on the portside deck of the ship such that its intake is about 24 cm above the platform. The height of this desk is about 10m above the sea level. The position of Gerdien's apparatus is so selected that the exhaust of the chimney of the ship does not pollute the air around the site of measurement.

Diuranal variations of atmospheric electrical parameters

Fig. 5 shows the average diurnal variations of potential gradient and conductivity of both polarities for 20 fair-weather days at Maitri. It also shows the diurnal variation of the calculated value of the air-earth conduction current. The upper and lower dashes show the standard deviation of the parameters from the mean value. We define a fair-weather day when there is no precipitation/snowfall at the site, high clouds are less than 3 octas throughout the day and wind speed is less than 10 m/s. The potential gradient shows a single periodic diurnal variation with a maximum at about 1300 GMT and another secondary maximum at about 1900 GMT and a minimum at 0100 GMT. The mean value of the potential gradient for 20 fair weather days is 83 V/m. The maximum and minimum value of petential gradient are 1.55 and 0.73 times, respectively, of the mean value of potential gradient measured by us is comparable with 71 V/m as observed by Cobb (1977). However, the variation of potential gradient from the mean value is much larger in our measurements than that of Cobb.

Kasemir (1972) reports that the average curve of potential gradient for 105 fair-weather days at Amundsen-Scott station at South Pole during 1964 shows a maximum at 1900 GMT and a minimum at 0230 GMT. However, his average curves for the months of January and February show a maximum at 1300-1400 GMT and a minimum at 0200-0400 GMT and are in better agreeement with our potential gradient curves at Maitri.

The electrical conductivity of both polarities do not show much diurnal variation. The mean values of polar conductivity observed at Maitri are +1.2 and -0.9 S/m. Thus the total conductivity at Maitri is 2.2 S/m and is approximately double of that observed in the Indian ocean (Gopalakrishnan et al., 1994).

The air-earth current, calculated from the potential gradient and conductivity shows variation almost parallel to that of potential gradient. The mean value of air-earth current at Maitri is 1.74 pA/m, which is about 70% of that observed by Cobb (1977) at Amundesen Scott station, South Pole, The maximum and minimum values are 1.54 and 0.6 times, respectively of the mean value of air-earth current and is almost double of that observed by Kamara et al. (1994) over the Indian oceans.

Electircal conductivity over the Indian ocean

Electrical conductivity is measured on both the onward and return cruises to the Antarctica. However, due to several reasons such as the rough weather conditions, trubulent sea conditions in the roaring forties, being close to coastline, or the malfunctioning or maintenance of the equipments, only eight fair-weather clays observations on open ocean are used in our analysis. Fig. 6 shows values of the diurnal variation of the average polar conductivity of both polarities for eight fair-weather days during the total period of the onward and return cruises. On these clays the distance of the ship from the coastline is always more than 200 kms.

The value of polar conductivity during the cruise as in our earlier observations over the Indian ocean (Kamra et al., 1994) does not show any diurnal variation.However, the conductivity values during nighttime are comparatively higher than those during the daytime. The average value of total conductivity for eight fair-weather days along the cruise is 1.74 S/m. This value is comparatively higher than that observed by Gopalakrishna et al. (1994) in the equatorial Indian ocean, the Arabian Sea or the Bay of Bengal since most of the fair weather days during the crusie happen to be in the southern hemisphere where the prestine air has much lower concentrations of aerosol particles compared to that in the northern hemisphere.

Latitudinal variation in the electrical conductivity

The daily averaged values of total conductivity for eight fair-weather days are plotted agianst the mid-day latitude in Fig. 7a. The vertical bars show the standard deviation of the total conductivity form the average values. The minimum value of conductivity occurs at around 30 deg S which is most likely due to the aerosols carried form the South African continent, especially on the return cruise. The conductivity keeps increasing southward of this point and becomes almost three fold at 70 deg S. It also keeps increasing northward of 30 deg S upto about 10 deg S from where it shows a slight decrease towards the Indian cost line Takagi and Kanada (1972) obesrved a decrease in electric field with latitude and explianed it on the basis of the increase in conductivity with latitude. Morita(1971), however did not observe any latitudianal dependence of electric field and discussed the effect of the local influence as the possible cause of any change in field.

In Fig.7b, the daily average of total conductivity for all cruise days except for the days with rain on or neary the ship or with high winds causing wave-breaking at the sea surface, is plotted against the mid-day latitude for the onward and return cruises, separately, Again, the minimum in conductivity appears to be around 30 deg S. The conductivity values on the on ward and return cruises, however, show some opposite trends between 10 deg N and 20 deg S, and between 60 deg S and 70 deg S. This is probably linked with the change in the positions of the Inter Tropical Convergence Zone or due to the presence of some synoptic systems around Antarctica during the periods of onward and return cruises.

Effect of fog on conductivity

The onset and dissipation of fog is knwon to have considerable effect on the value of conductivity of the air (e.g.Serbu and Trent, 1958). There were two occasions when the ship passed through the fog during the onward cruise. On December 25,1996, the ship entered into the fog region at 1430 GMT and came out of it at 1630 GMT. The electrical conductivity of both polarities, which shows increasing trend upto 1230 GMT starts decreasing about 2 hours before the ship enters into the fog zone (Fig.8) The conductivity of both polarities, shows a minimum value at about 1600 GMT and starts increasing thereafter. The other incidence of fog on January 5, 1997 also produced almost similar results.

Discussion

Even though the soil at Maitri station is not snow-covered in the southern summer, the atmospheric electric measurements made there are expected to be representative of the Antarctic enviornment. Firstly, because the ground radioactivity at this station is very small and is comparale to its values generally observed over open ocean. Measuements of Ramachandran and Balani (1995) show that the levels of Rn^{222} and its daughter products at Maitri stations varies Fom O.02 to 0.03 Bq/m^3 and are not much different form those observed over oceans. Secondly, there is hardly any dust raised form the earth's surface by winds when these are less than l0m/s. Even for winds stronger than l0m/s, the amount of dust raised bby erosion of rocks is very small and is mostly confined close to the ground.

The averaging of the atmospheric electricity data over atleast a week is one way to avoid the contributions of the local generators or due to the local conductivity variations. The average diurnal variation of potential gradient for 20 fair-weather days in January and February 1997 at Maitri, is remarkably different from the variation of oceanic potential gradient observed during the Carnegie expeditions and in the south polar regions. Although, the annually averaged diurnal variation curve of potential gradient in earlier observations in the south polar regions shows a maximum at 1800-1900 GMT which is in agreement with the Carnegie curve, the monthly patterns of the potential gradient curves, especially for the months from January to July, differ from the annually-averaged universal curve. Now, the global thunderstorm activity is the main generator for the global electric circuit in the Wilson's hypothesis (1920). As pointed out by Dolezalek (1972), the peak global thunderstorm activity over different continents differ with the time of the day. At times, a whole continent may be without any thunderstorm. The satellite data of global lightning activity also confirms that the lightning activity has a definite isolated latitudianal dependence and it is also season dependent (Williams and Heckman, 1993). Longitudinally, Maitri is just below the African and European continents. The maximum in potential gradient at 1300-1400 GMT at Maitri coincides with the peak in the thunderstorm activity for the African and European continents (Whipple and Scare, 1936). Aslo, from the satellite data analysis presented by Williams and Heckman (1993), the maximum global thunderstorm activity occurs in the months of January February in the African continent. Moreover, the Optical Sensor data of NASA for the 9 fair weather days available during our period of observations at Maitri also show the maximum thunderstorm activity in the south African region. Therefore, the maximum in the potential gradient at 13.00 GMT observed at Maitri may be associated with the maximum in lightning activity in South Africa at 1200 GMT. The secondary peak at 1800 GMT may be because of the less intense lightning activity in the far-distant South American continent with the maximum at 1700-1800 GMT.

Since the ionisalion due to radon and other radioactive products is almost negligible and cosmic rays are the major source of ionisation over the ocean and at Maitri, the rate of ion production at these places does not have any significant diurnal variation. The value of conductivity at these places is, therefore, mainly determined by the aerosol concentrations. Thus, the higher values of the conductivity observed by us along the crusie track which is mostly in the southern hemisphere, as compared to those observed by Kamra and Deshpande (1995) in the Equatorial Indian ocean indicate lower aerosol concentrations in the southern hemisphere. Similarly, still higher values of conductivity observed at Maitri show even lower values of aerosol concentrations at Maitri as compared to those over ocean. The total average conductivity value observed over the southern Indian ocean by us is less than half of the one observed by Cobb and Wells (1970) in a controlled area in the southern Pacific ocean. Comaparison of conductivity values for such different locations of measurements in the southern hemisphere gains some strength from the fact that the conductivity values of Cobbs and Wells (1970) obtained in 1967 in the southern Pacific ocean are not much different from those of Carnegie measurements made during 1907-30 either in the same area in the southern Pacific ocean or in the equatorial Indian ocean. The comparison of our conductivity measurements made in 1997 with the Cobb and Wells data obtained in 1967, suggests a secular decrease in conductivity in the southern hemisphere during the last 30 years. Such a result is of considerable imporatnce since the southern hemisphere is considered to be less influenced by the continental Pollution. The observation suggests an exchange of aerosol pollutants between the two hemispheres, possibly associated with the coross-equatorial flow in the Indian ocean.

Measurements of conductivity in foggy conditions mostly indicate a decrease in its value during fog. This attachment of small ions to fog particles reduces their mobility and thus the electical conductivity of the atmosphere. The oceanic fogs are mostly localised. Moreover, the concentration of small ions over open oceans can be assumed as almost constant. Therefore, when the ship enters into a zone of fog, sharp decrease in conductivity before entering it, and the reverse effect of the increase in conductivity before exiting the fog zone is expected. Our observations of conductivity in the regions of fog over ocean confirm such changes in the conductivity values.

Acknowledgements

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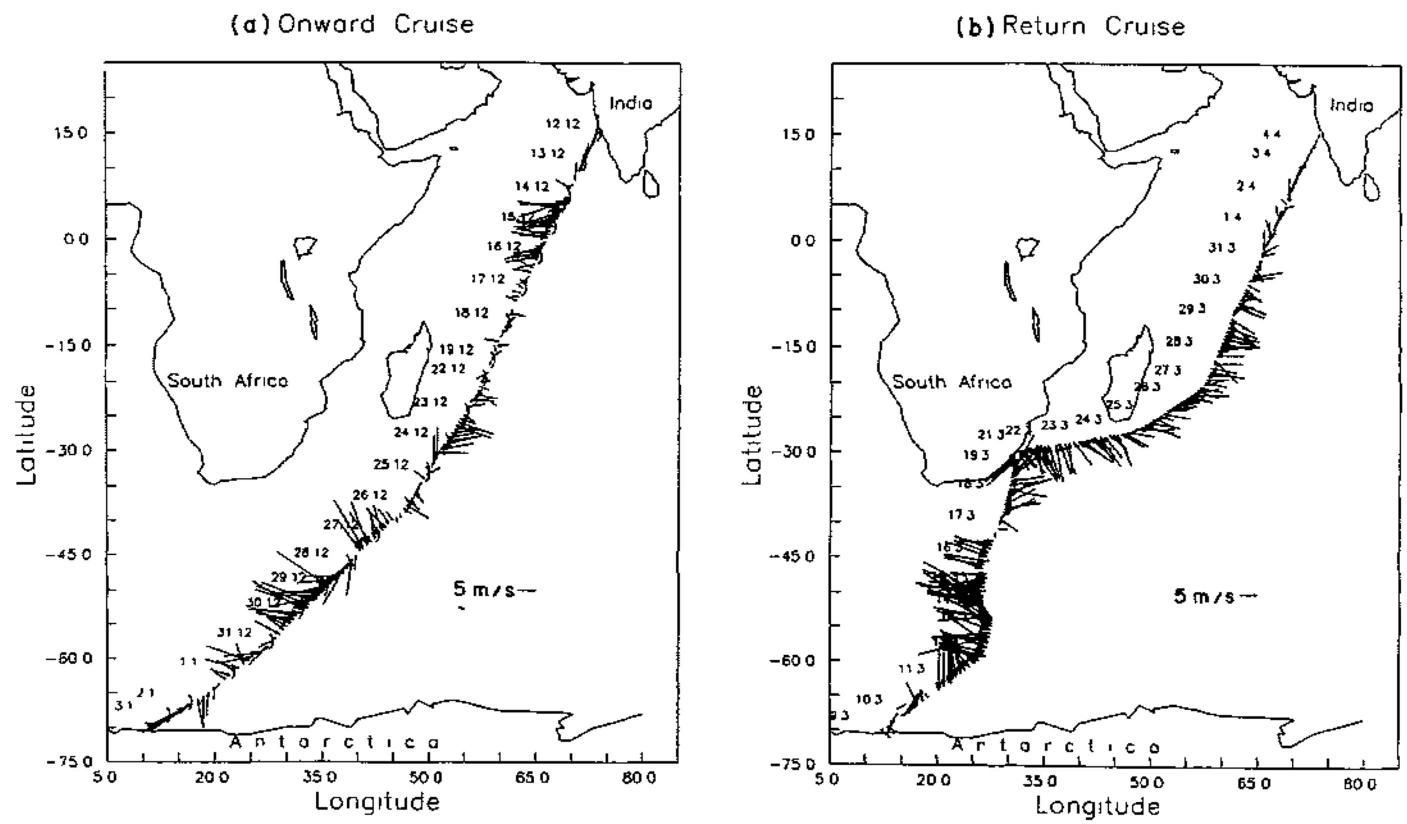

Fig.1. The onward and return cruise tracks of the XVI Indian Expedition to Antarctica. Arrows plotted along the tracks show the three-hourly values of the wind speed and wind diection.

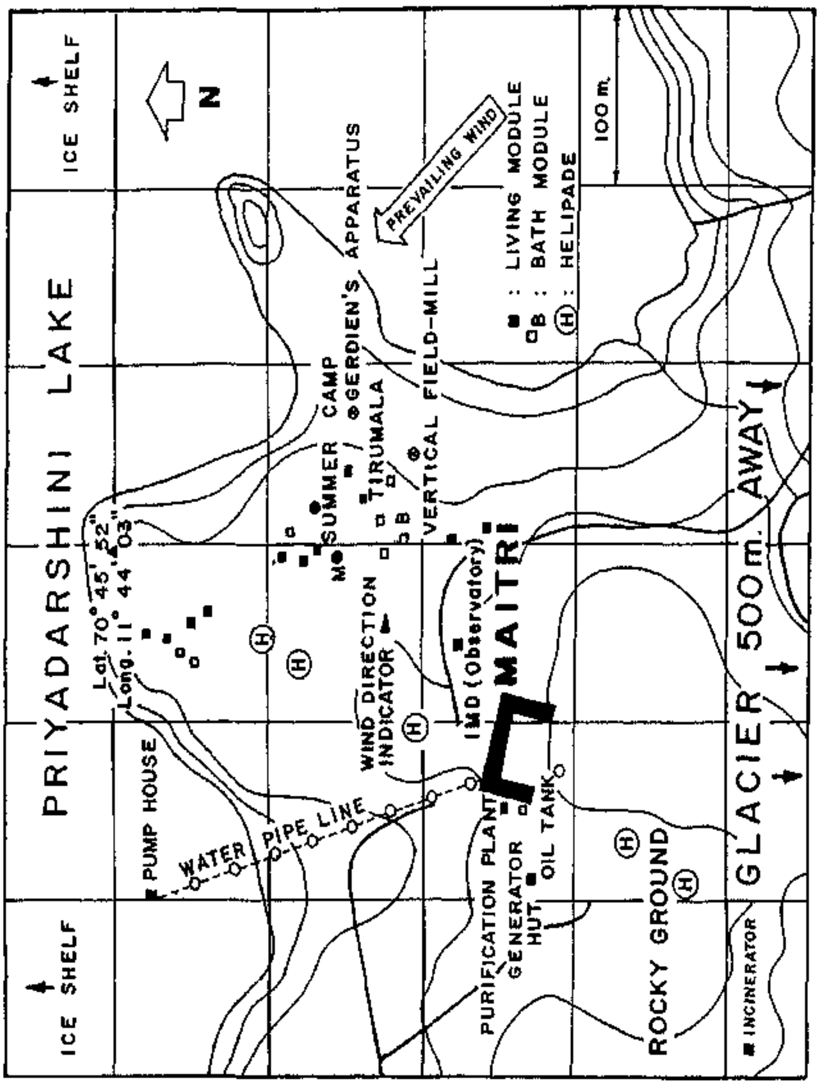

Fig. 2: The map of Maitri station and surroundings showing the installation sites of field-mill and Gerdien's apparatus.

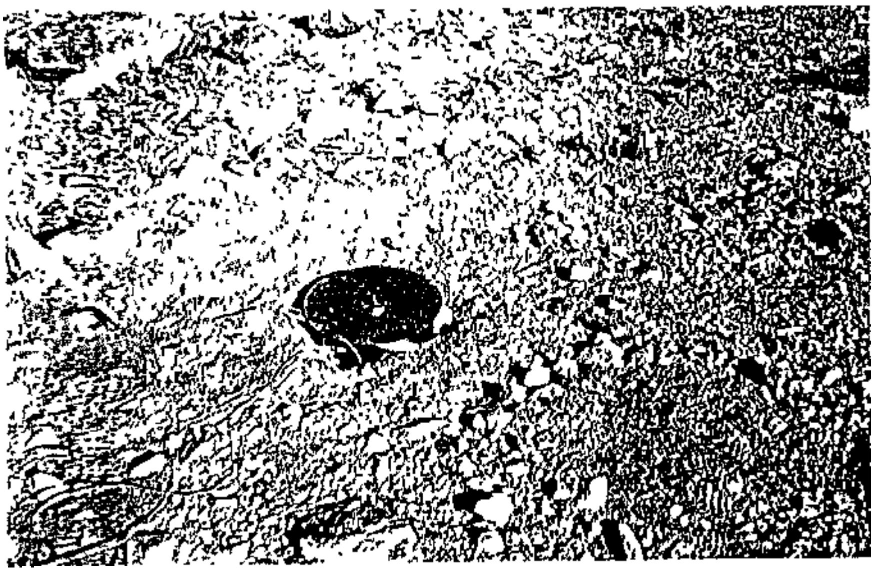

Fig 3 : The field-mill placed in a pit

Fig. 4. The Gerdien's apparatus

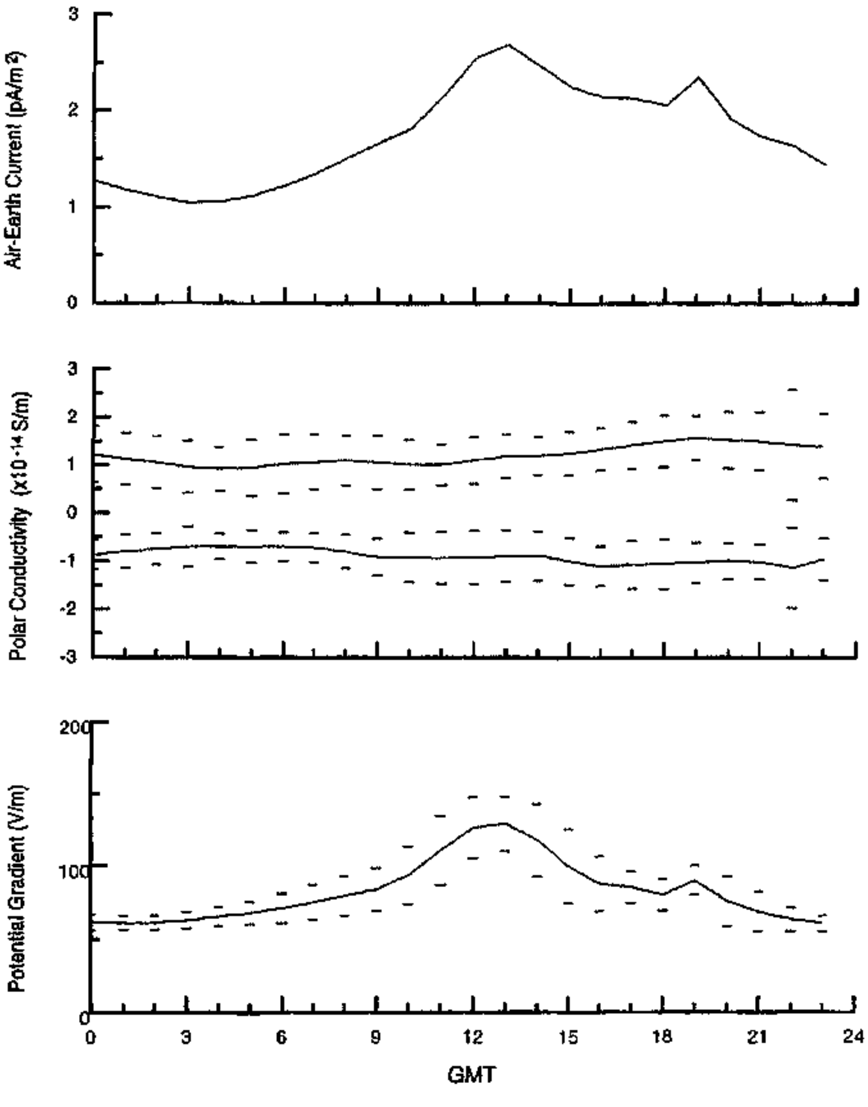

Fig. 5 : Diurnal variations of the potential gradient, the conductivity of both polarities and the air-earth current averaged for 20 fair-weather days at Maitri.

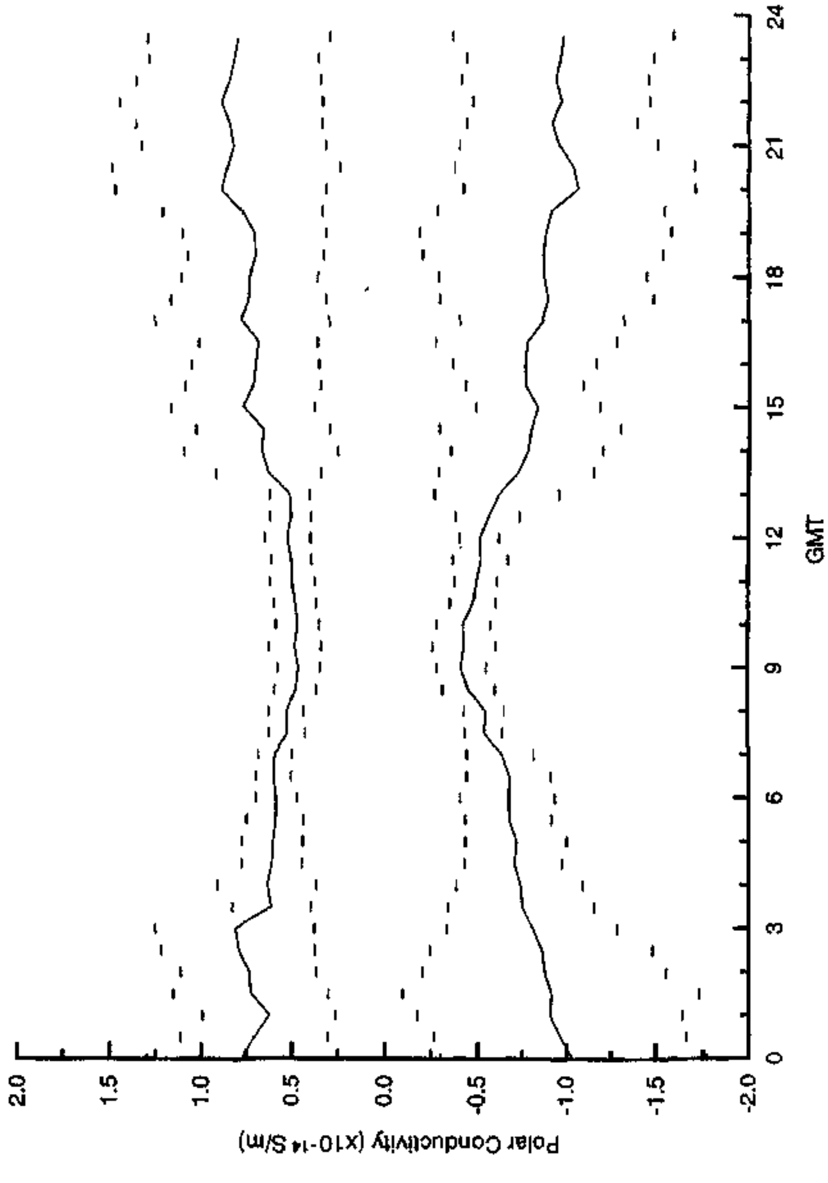

Fig. 6 : Diurnal variation of the electrical conductivity of both polarities averaged for 8 fair weather days during the cruise

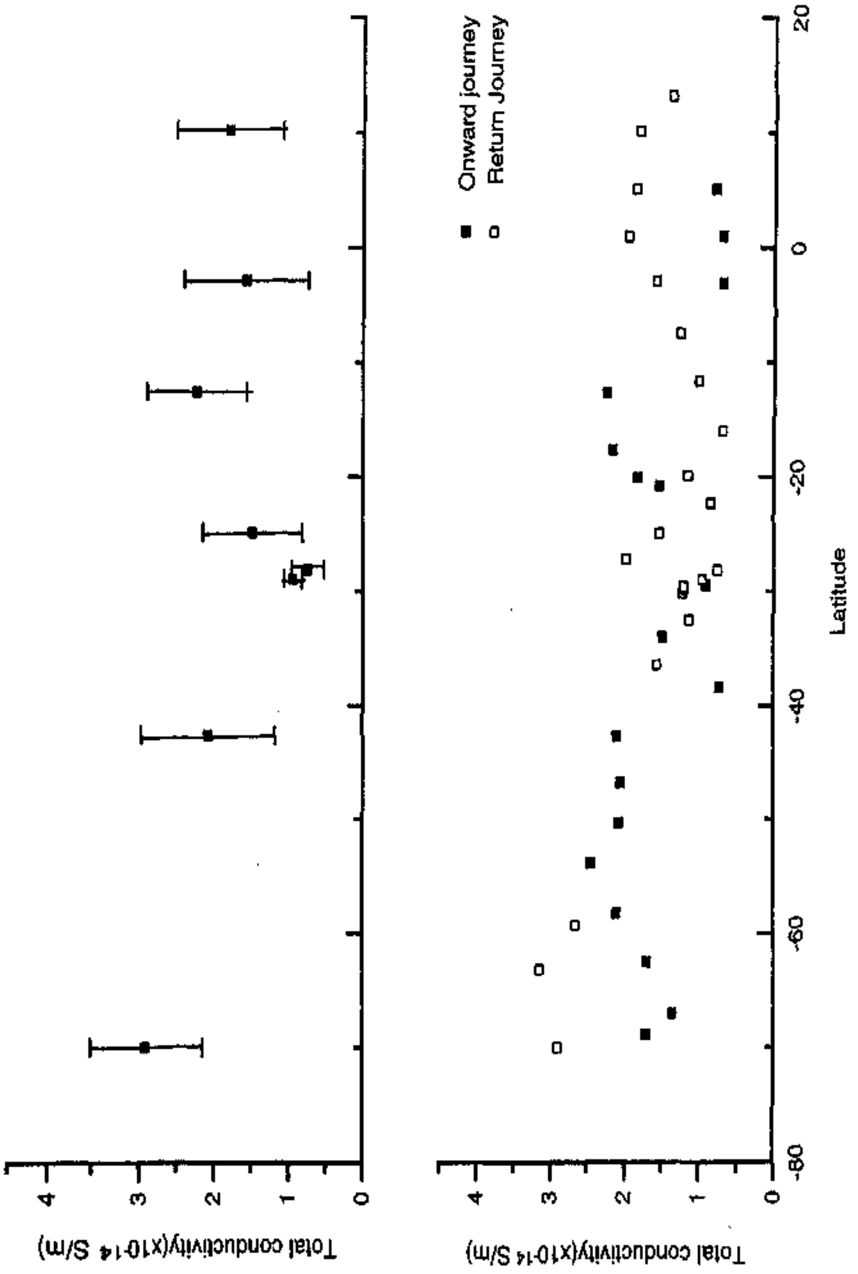

Fig. 7 : Latitudinal variation of the electrial conductivity for (a) 8 fair-weather days, and (b) all cruise days

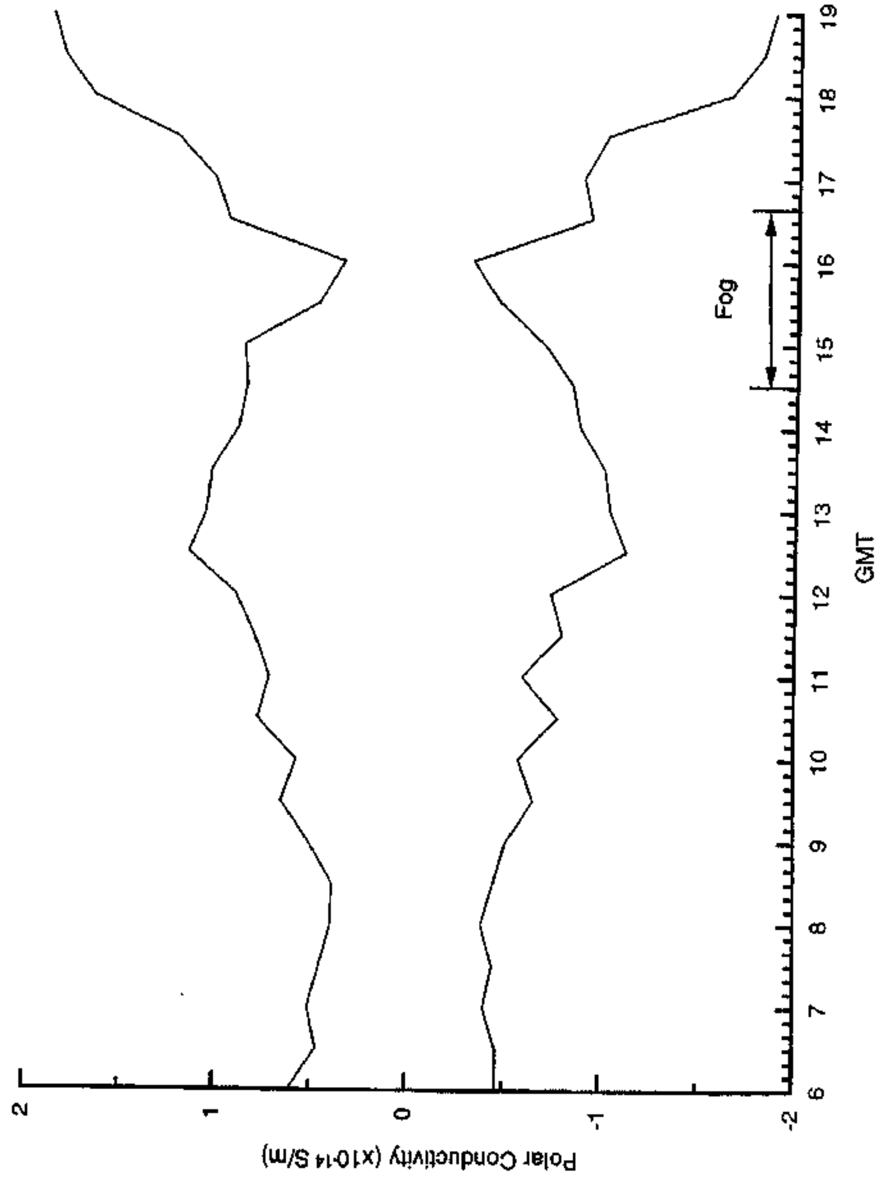

Fig. *8 : The electrical conductivity in the zone of fog over ocean on December 25, 1996*