Measurements of the atmospheric electric field and conductivity made over Indian Ocean during December 1996 –January 1997

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Observations of the atmospheric electric field and conductivity are made over the Indian Ocean during the pre-Indian Ocean Experiment (pre-INDOEX) cruise of ORV *Sagar Kanya* in December '96–January '97. The average of the diurnal variations of electric field on 6 fair-weather days during the cruise shows a single periodic variation with a maximum at 1100 GMT and a minimum at 0300 GMT. Its possible implications with respect to the global electric circuit are discussed. Electric conductivity is generally less in the northern hemisphere and increases 2–3 times in the southern hemisphere. Background aerosol concentrations have been calculated from the observed values of the electrical conductivity and discussed with respect to the local meteorological conditions in the region. The results show aerosol concentration of 1300 to 1800 particles/cm^3 near the coastline in the northern hemisphere which slowly decrease as one goes away from the coast. Comparatively much lower aerosol concentrations of about 800 particles/cm^3 are observed at 12–14°S in the pristine air of the southern hemisphere. Observations indicate a change of 2 to 4 times in the background aerosol pollution since the Carnegie measurements in this area in the second decade of this century.

THE measurement of atmospheric electric parameters over the oceans help in better understanding of the global electric circuit and the extent of background aerosol pollution in the marine atmosphere. Over the oceans, the rate of ion production and the mobility of small ions can be considered as approximately invariable quantities[1]. So, any change in the value of conductivity is directly related to the change in the background aerosol concentration. Further, in the absence of any local or regional generator of charge, the electric field measurement over the oceans reflects the change in the potential of the global generator. Several measurements since the Carnegie cruises during the 1920s have been made over the oceans to verify the unitary diurnal variation of electric field[2–4]. Some of these investigations suggest the dominance of regional effects which modify the generally accepted classical picture of unitary diurnal variation of electric field[5,6]. In this paper, we report the results of the measurements of electric field and conductivity made over the Indian Ocean during the pre-Indian Ocean Experiment (pre-INDOEX) cruise of ORV *Sagar Kanya* during December 1996–January 1997. We discuss our observations with reference to the classical picture of unitary diurnal variation of electric field. We also estimate the secular change in the background aerosol pollution from our conductivity measurements.

Instrumentation

A U-shaped Gerdien's apparatus with two cylindrical condensers fitted along its two arms and a common fan to suck the air is used to measure the atmospheric electric conductivity of both polarities. The critical mobility of the apparatus is adjusted at 3.6×10^{-4} m^2 V^{-1} s^{-1} and is described in detail by Dhanorkar and Kamra[7]. An Am-242 radiaoactive probe with a strength of 6 μC stretched at 1 m height with Teflon wires on a balloon-launching platform of the ship, is used to measure the electric field. Measurements of both electric field and conductivity are made continuously and recorded on a strip chart recorder. The installation of the instruments and the precautions taken to exclude any contamination of the data by smoke from the chimney and by spraying of sea salt are explained in Kamra *et al.*[6].

Cruise and weather

The ship started on 27 December 1996 from Marmagao Port, Goa (15.25°N, 73.43°E) and sailed south up to 14°S where she made five north-south legs from 79°E to 71°E and returned to Marmagao on 31 January 1997. Figure 1 shows the values of the temperature, humidity, wind speed and wind direction taken at synoptic hours during the cruise period. During the period of the cruise, the temperature varied from 28.4°C to 25.2°C and the relative humidity from 58 to 95%. In this region, the winds are mostly north-north westerly in the southern hemisphere. NCEP analysis of 10 m winds clearly show that the north-north easterly flow is generally prevalent in the northern hemisphere during this period. There were periods of frequent precipation and cloudiness during the cruise.

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Observations

The measurements of conductivity and electric field made on fair-weather days only are considered for discussion here. A fair-weather day is defined as the day during which the cloud coverage is less than 3 octa, no local precipitation occurs on the site, and the winds are less than 4 m/s. The dirunal variations of electric field and total conductivity averaged over a period of half an hour for 6 fair-weather days are plotted in Figure 2. The potential gradient shows a single periodic variation with a maximum at around 1100 UT and with a secondary peak at around 0100, 0800 and 1900 UT. This is in contrast to the maximum observed at 1900 UT during the Carnegie and some other expeditions[8]. Averaged values of conductivity show that the night-time values are approximately double the day time values.

Variation of conductivity with latitude is shown in Figure 3. The horizontal bars in the figure are the averaged values of conductivity for one fair-weather day covering the latitudinal distance travelled by the ship. However, in some regions where only part of the day could be classified as a fair-weather day due to excessive cloudiness or precipitation during rest of the day, the conductivity values are averaged for periods less than a day. The vertical bars show the standard deviation. As one goes away from the coast, the values of conductivity have only a small increase up to the equator. The conductivity values are only about 25% more over the equator than those near the coast of the Indian subcontinent. However, the conductivity values in the southern hemisphere are, on the average, more than twice those in the northern hemisphere.

Aerosol particle concentrations

Atmospheric ions either combine with each other or attach themselves to the aerosol particles. Through these processes of combination and recombination of ions, a state of electrical equilibrium can be assumed to have been attained over the marine atmosphere. Under the electrical equilibrium conditions, the concentration of aerosol particles can be calculated using the ion-balance equation. Assuming that the concentration of positive and negative small ions are equal and the unipolar large ion con-

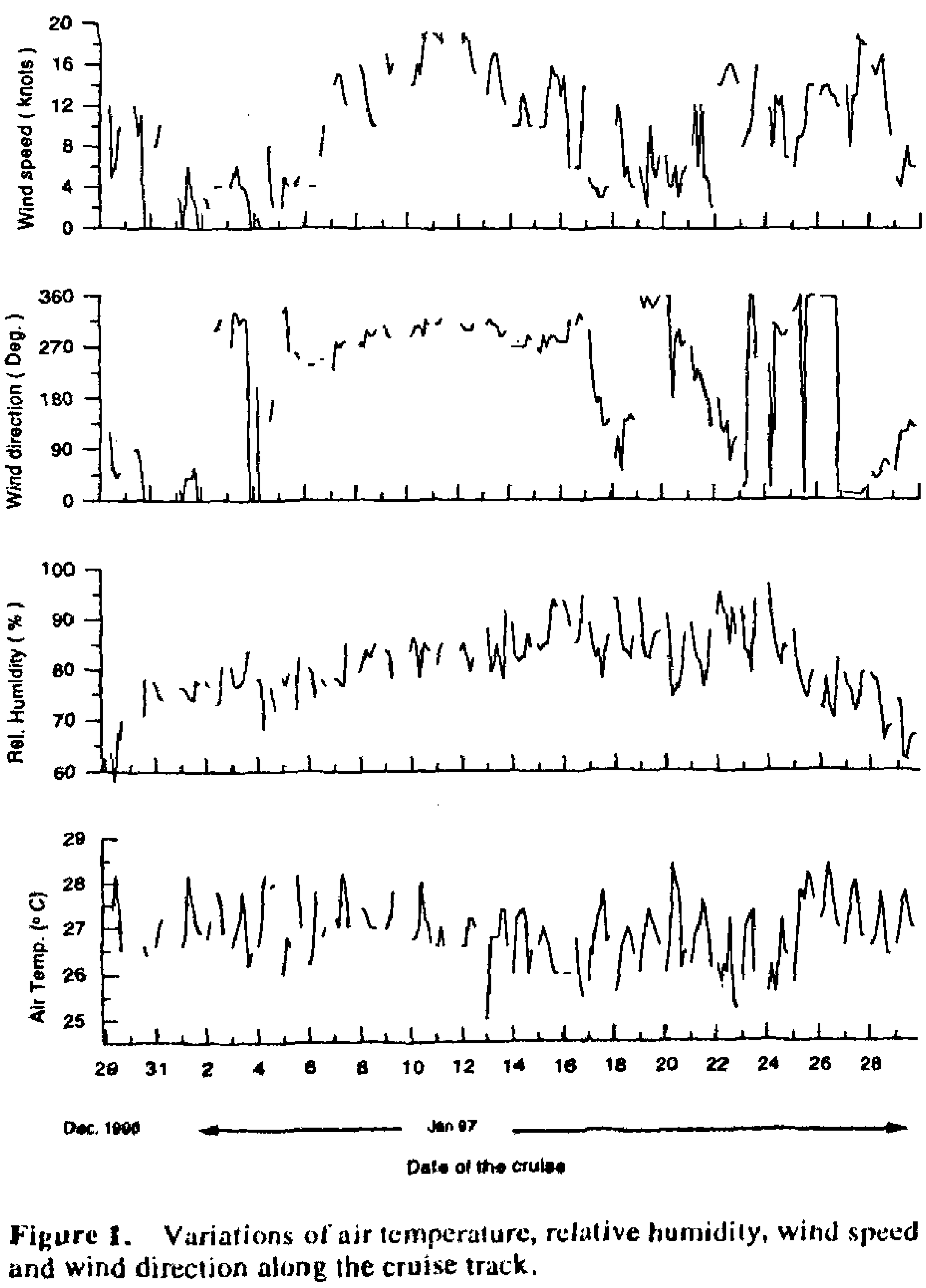

Figure 1. Variations of air temperature, relative humidity, wind speed and wind direction along the cruise track.

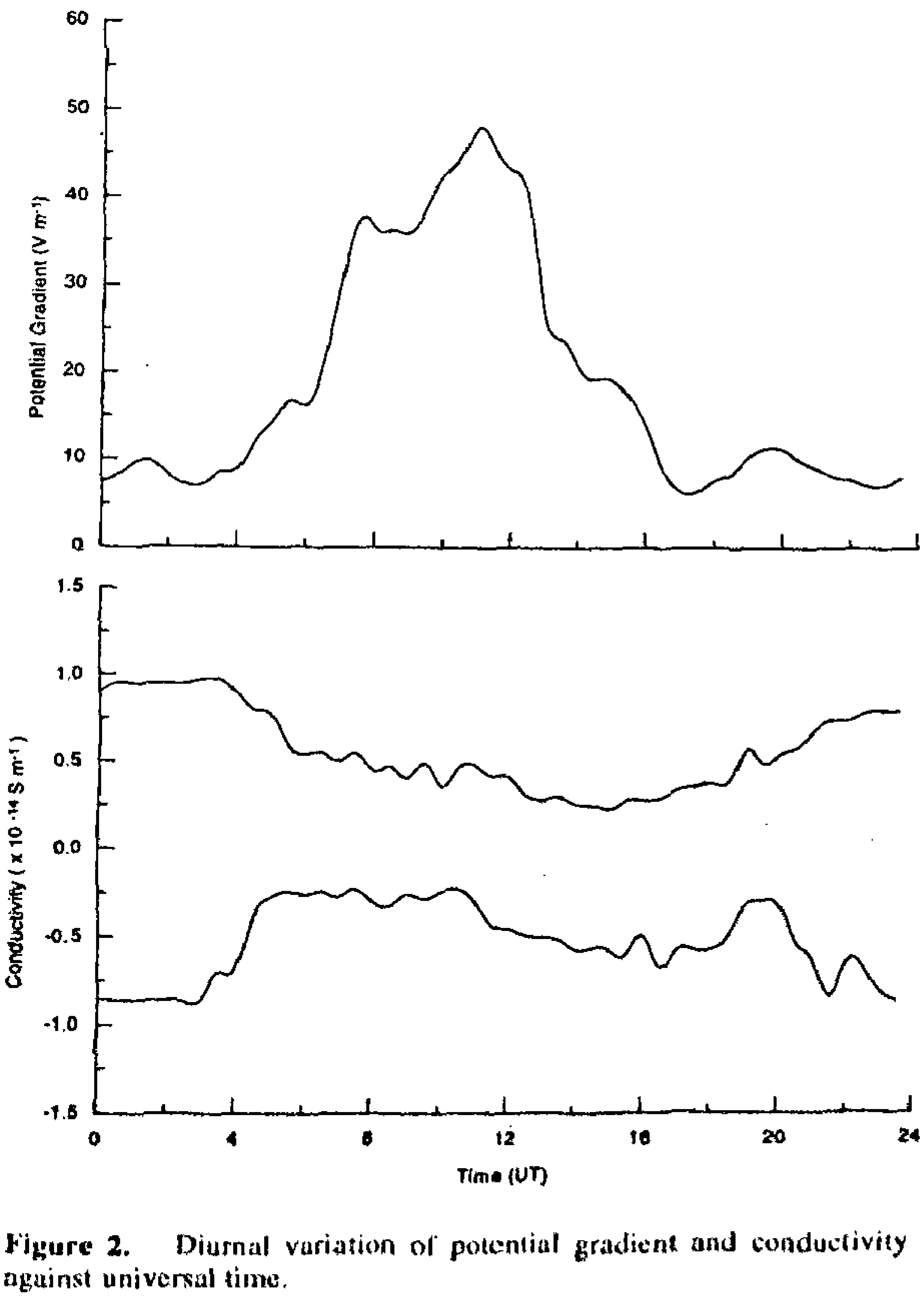

Figure 2. Diurnal variation of potential gradient and conductivity against universal time.

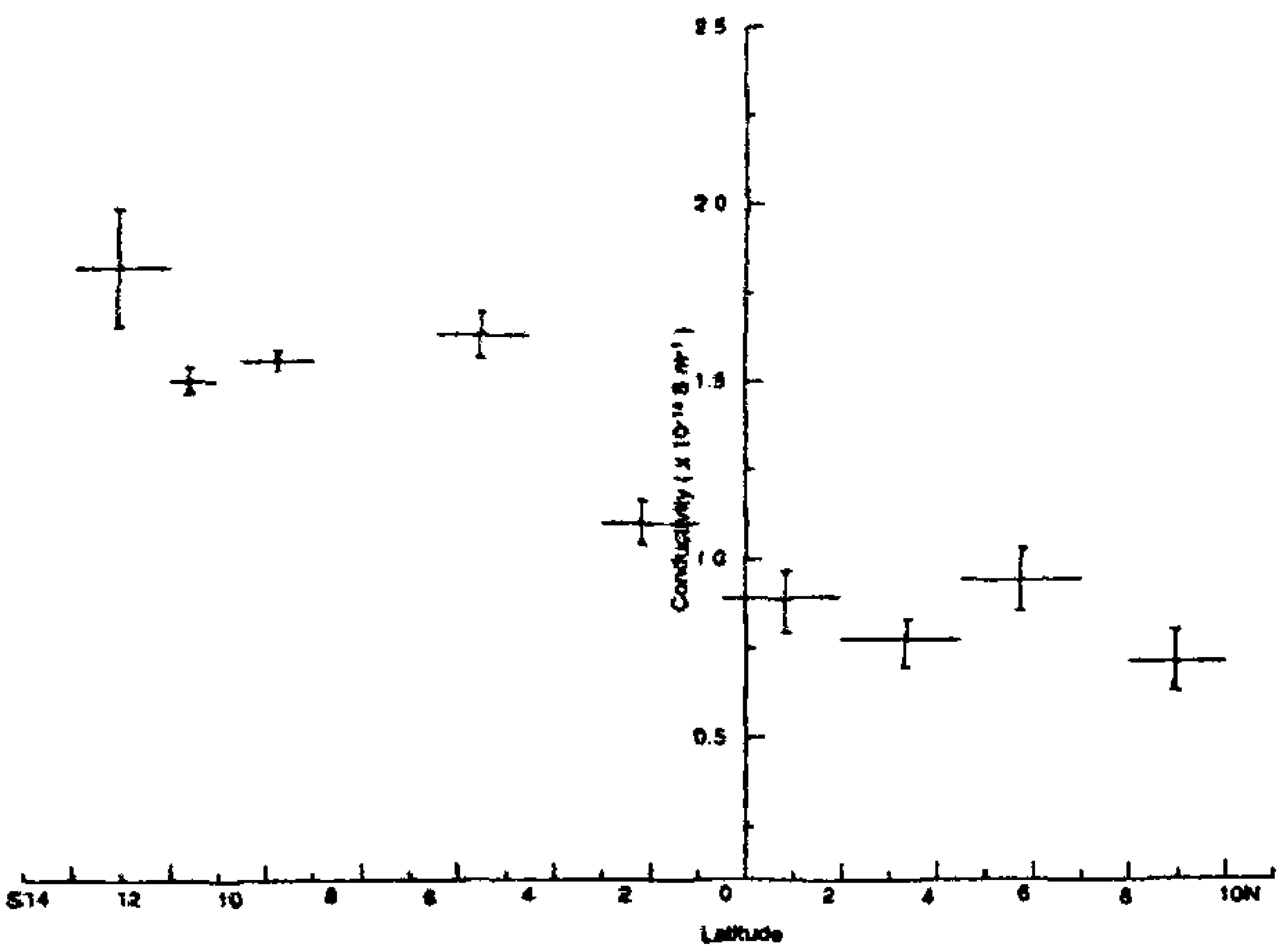

Figure 3. Variation of conductivity with latitude. Vertical bars are the standard deviation.

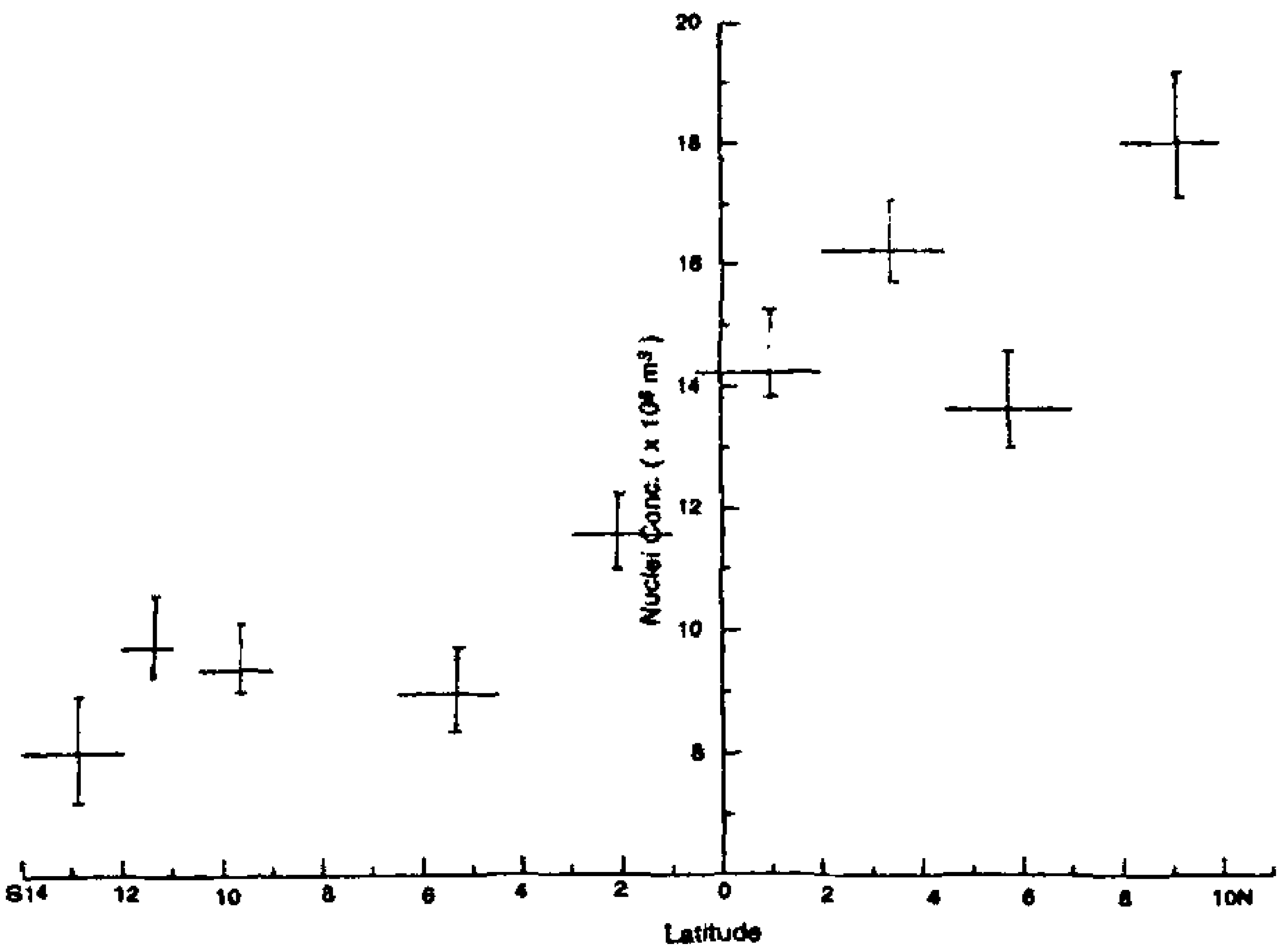

Figure 4. Variation of nuclei concentration against latitude. Vertical bars are the standard deviation.

Table 1. Average values of the total conductivity and nuclei concentration 5° latitudinal belts

Period	Area	Total cond. ($\times 10^{-14}$ S m^{-1})	Nuclei conc. ($\times 10^{8}$ m^{3})
Dec. 1996–Jan. 1997	10–5°N	0.81	15.80
	5–0°N	0.83	15.24
	0–5°S	1.4	10.47
	5–10°S	1.6	9.12
	10–15°S	1.68	8.68

centration N is 20% of the total nuclei concentration Z, we get[9],

$$Z = 5\left[\left(\frac{ekq}{\beta}\right)\frac{1}{\lambda} - \left(\frac{\alpha}{ek}\right)\lambda\right], \tag{1}$$

where α, the coefficient of recombination of oppositely charged small ion is equal to 1.6×10^{-12}; β, the effective attachment coefficient is equal to 10^{-11} m^3 s^{-1}; q, the ion production rate is equal to 1.6×10^{6} ion pairs m^{-3} s^{-1} over the ocean; k, the mobility of small ions is equal to 1.14×10^{-4} m s^{-1} V^{-1} and e is the electronic charge.

Under equilibrium conditions, the conductivity is inversely proportional to the aerosol concentration. The aerosol concentration is evaluated using eq. (1) and is plotted against latitude in Figure 4. The concentration is the highest near the Indian coast and gradually decreases with distance from the coast. The aerosol concentration in general, is lower in the southern hemisphere than in the northern hemisphere. For example, the concentration of aerosol particles at 13–14°S, 79°E is less than half of that near the Indian coast. Our observations indicate that the north-north easterly wind loaded with aerosol pollutants from the Indian subcontinent gradually loses its aerosol content as it blows away from the coast. In the Inter-Tropical Convergence Zone (ITCZ) region, relatively polluted air from the nothern hemisphere mixes with the cleaner air from the southern hemisphere. So, the aerosol concentration continues to decrease southward and may reach the pristine level beyond the ITCZ.

Table 1 shows the average values of conductivity for each 5° latitudinal belt. In the northern hemisphere, these values show only marginal increase in conductivity and decrease in nuclei concentration. However, comparatively larger differences between the northern and southern hemispheric values can be clearly noted.

Secular change in the background aerosol pollution

The value of total conductivity found during the Carnegie cruises in the region 0–14°N, 60–94°E in the second decade of the twentieth century ranged between 2.9 and 4.2×10^{-14} S m^{-1} which corresponds to 3.48–5.03×10^{8} particles m^{-3}. Our observations made in 1996–97 show that now the values of the total conductivity from 0 to 14°N along the cruise route between 79 and 71°E have reduced and range between 0.52 and 1.26×10^{-14} S m^{-1} which corresponds to $9.99–24.32 \times 10^{8}$ particles m^{-3}. Thus these observations indicate that the background air pollution in this area has changed by 2 to 4 times since the second decade of this century. This increase in the background air pollution is most probably due to the increased industrialization, automobiles and urbanization during this period.

On the universal diurnal variation of the electric field

The diurnal variation cruve of the electric field observed during the oceanic measurements of the Carnegie and Maud expeditions[8] closely follows the global thunderstorm frequency curve of Whipple and Scarce[10]. Both potential gradient and the world-wide thunderstorm frequency attain maxima at 1900 h UT. The diurnal variation curve of the potential gradient which is averaged for 6 days in our observational period shows a maximum at 1100 UT (Figure 2). Similar diurnal variation in the electric field with a maximum at 1000 UT from the observations made in the equatorial Indian Ocean and the Bay of Bengal has been reported earlier[6]. This contradicts the generally accepted classical picture of the global electric circuit based on the thunderstorm generator hypothesis. It is to be noted that the curve of Whipple and Scarce[10] has been obtained from up to 81 years averaged values of thunderstorm frequencies over the 4 major regions of New Zealand, Asia and Australia, Africa and Europe and America with maxima at 0130, 0800, 1400, and 2000 UT respectively. The timings of the secondary peaks observed in our diurnal variation curve of the electric field roughly coincide with these timings. A higher frequency of thunderstorms occurring in these regions on the fair-weather days of our observational period may explain these peaks in the electric field diurnal variation curve. Thunderstorm frequency over continents is highly variable and validity of this curve for short periods of few days is to be tested. Further, Whipple and Scarce's curves are averages over a long period of time and when shorter time-averages are used the correlations show great departures from these curves[11]. Hence the electric field data must be averaged for a longer duration to get the clear picture of the universal diurnal variation.

In addition to the frequency of thunderstorms, the distance from the thunderstorm may also influence the electric field measured over the oceans. Kamra *et al.*[6] have averaged their data obtained over the Bay of Bengal, Arabian Sea and equatorial Indian Ocean for 40 days and explained their observation of maxima at 1000 UT as a 'tendency to accentuate the effect of storm activity over Asia–Australia and Africa–Europe and to attenuate the effects of far distant storms over America' as mentioned by Anderson[5]. Similar observations have been made by Anderson[5] also who flew above the exchange layer over Tasmanian Sea and Mediterranean Sea and measured air–earth current density. He attributes his observation to the imperfect propagation of regional effects to all the regions of the ionosphere. The observation of secondary peaks at 0130, 0800 and 1900 UT when the thunderstorm frequency attains a maximum in the regions of New Zeland, Asia and Australia, and America, respectively, indicates that the global thunderstorms are driving the global electric circuit. These observations also indicate that even in measurements of electric field made hundreds of kilometers away from continents, regional generators may play a major role.

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