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# A study on chloride aerosols in maritime and well-inland regions

S. K. PAUL, S. K. SHARMA AND R. K. KAPOOR
Indian Institute of Tropical Meteorology, Poona 411 005, India.

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## Abstract

Chloride aerosols at various levels, in the lower troposphere, were sampled over a long period at Rihand Catchment Area (well-inland) in northeast India during the summer monsoon season of 1973 and over a short period towards the end of the same season at Bombay (maritime) and its neighbourhood. Millipore filter assembly was used for this purpose.

Over the well-inland region, the chloride count showed a little increase with height while the particle mass was greater at lower levels. In the maritime region, the count indicated a decrease with height whereas the mass remained steady. The size spectra were broader at lower levels. The spectrum was narrower and the number more over the maritime than over the well-inland. The mass over the maritime (upwind) was higher than that over the urban (downwind) location. The variations noticed under different categories and situations are discussed.

Key words: Chloride aerosols, troposphere, well-inland, maritime, millipore filter, size spectrum, urban.

## 1. Introduction

A knowledge of chloride aerosol concentration at different levels and at meteorologically different locations is relevant to the studies in cloud physics and air chemistry. The presence of these aerosols in the giant size range may be a major factor in setting off coalescence process in some cumulus clouds for development of precipitation. Besides, such a study may enhance our understanding of the extent of nucleation necessary for rain enhancement by human intervention.

The major portion of the mass of chloride particles in the atmosphere is present in the size range of giant sea salt nuclei[1,2]. Twomey[3] studied the vertical distribution of sea salt particles during their transport well-inland and noticed that these particles were carried upward lowering their concentration near the surface. Byers *et al*[4], while studying sea salt particles over the Mississipi Valley at high levels, observed that the concentrations of the particles were comparable with those in maritime situations,

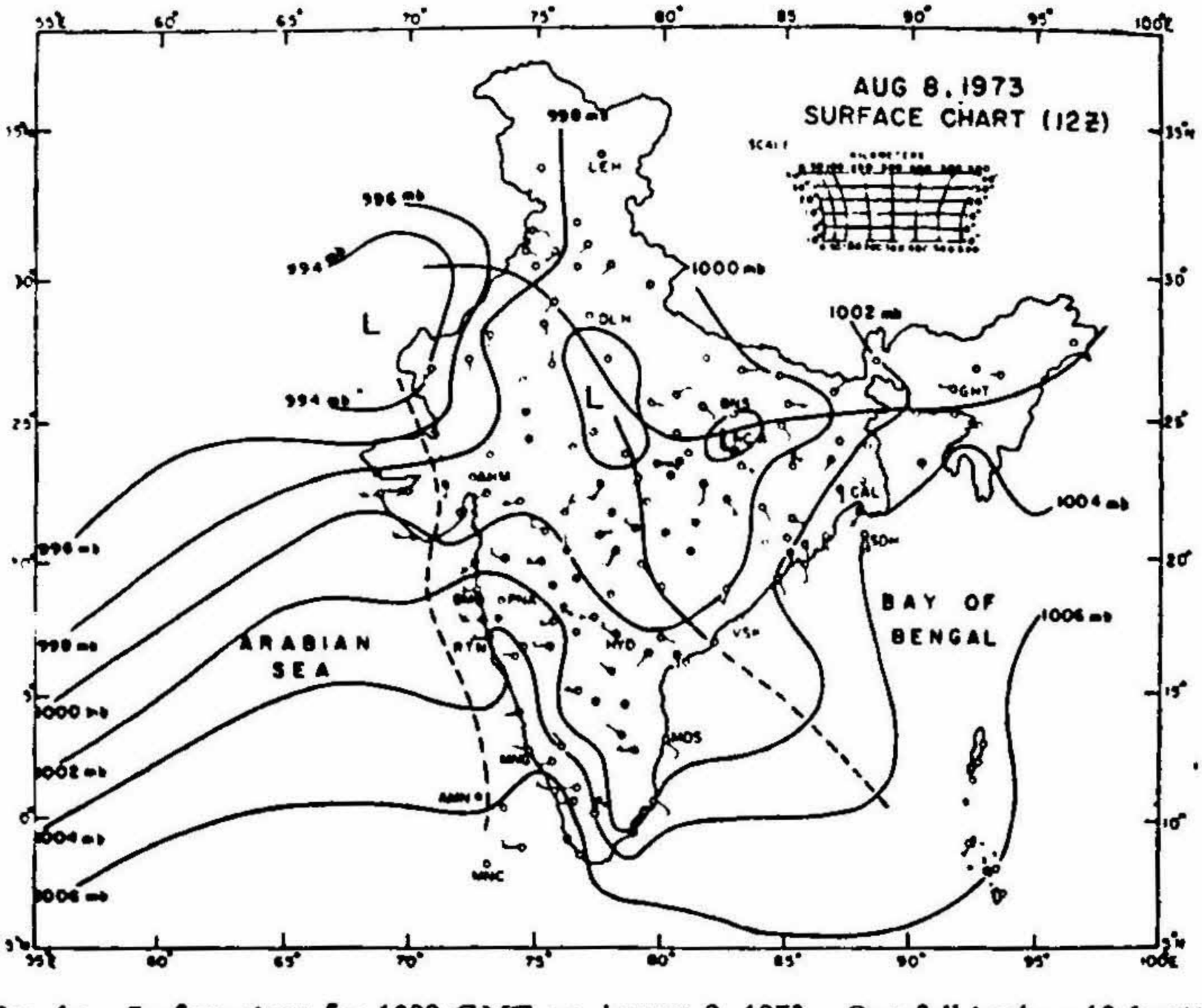


FIG. 1*a*. Surface chart for 1200 GMT on August 8, 1973. One full barb = 10 knots.

even at distances of 1,000 km from the coast. According to them, the giant sea-salt particle concentration over the continent is fairly constant with altitude, with a sharp reduction in the lowest several hundred feet (Fig. 6). The aerosol data for the polluted region of Srinagar, situated in the valley, showed higher counts for all the nuclei including chloride as compared to the values obtained at the high altitude station, Gulmarg in the Kashmir region[5].

The authors have presented profiles and the size spectra of chloride aerosols obtained over the maritime and well-inland regions. They have also studied the variation of this aerosol in the well-inland and an urban location with respect to the maritime regions.

## 2. Measurement and analysis

Airborne measurements of atmospheric aerosols were undertaken over the catchment area of Rihand reservoir (24° 12′ N, 83° 03′ E, 310·5 m MSL) in northeast India during the summer monsoon of 1973. Similar measurements were made towards the end of the same season that year at Bombay (18° 51′ N, 72° 49′ E, 11 m MSL), at locations 25 km off the coast over the Arabian Sea and also over Kalyan which is 50 km inland of the coast.

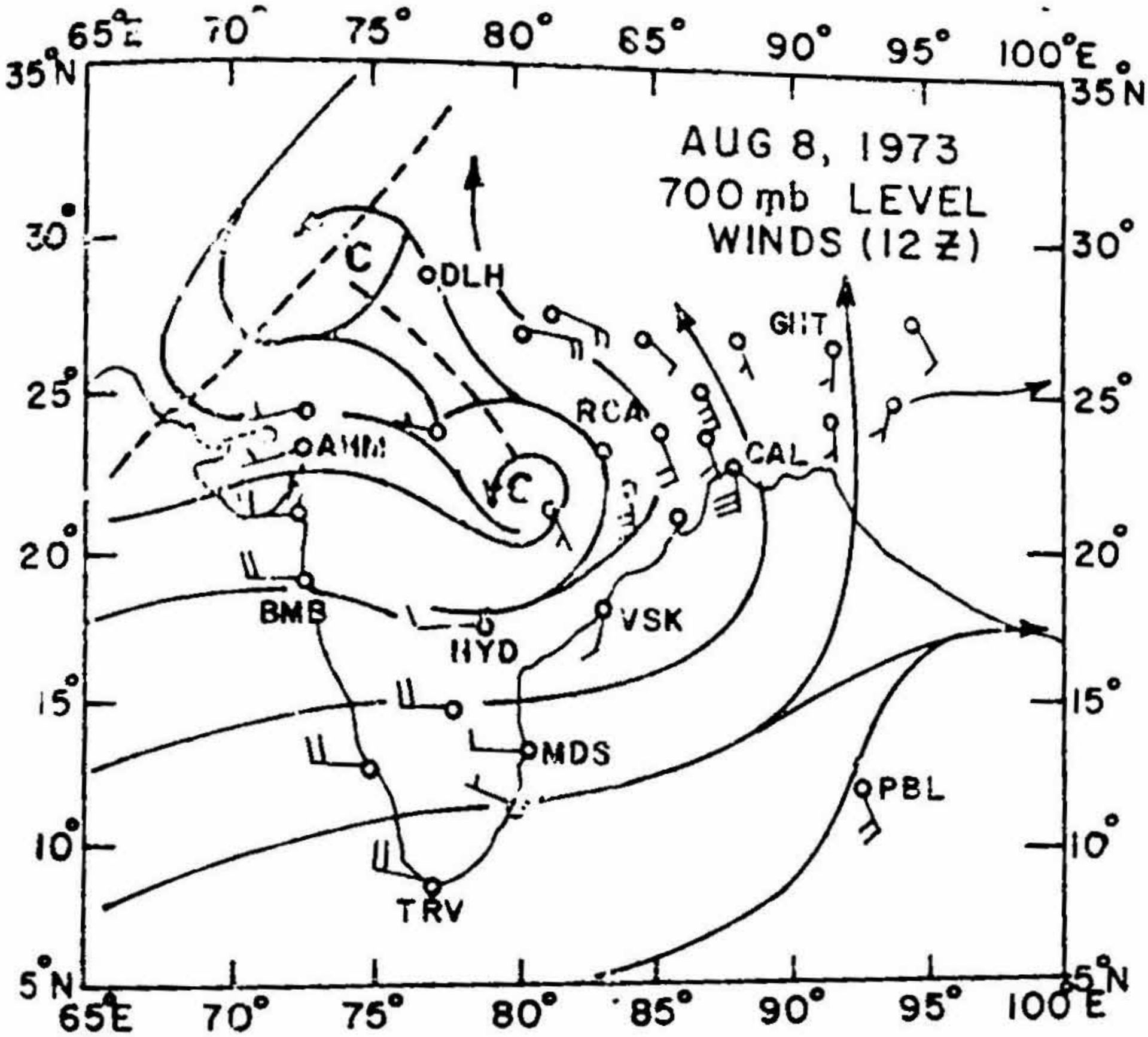


FIG. 1b. 700 mb chart for 1200 GMT on August 8, 1973. One full barb = 10 knots.

Rihand catchment area (hereafter referred to as RCA) is well-inland. It is 500 km to the northwest of the nearest coast (Bay of Bengal) and about 1,000 km northeast of the Arabian Sea. The winds over RCA, during the period of measurements, were variable. Bombay is a coast to the east of the Arabian Sea. The winds over Bombay, from surface to 3 km levels, were westerly. Hence, Bombay represents a maritime environment. Kalyan, where the major industrial complexes of Bombay are located, lies to the east of Bombay coast and is 50 km inland of the coast. Kalyan is representative of the downwind condition and urban environment while the observations over the Arabian Sea (maritme) represent upwind condition. The locations of the places is given in fig. 1. The typical synoptic features at surface and 700 mb levels on one of the days of measurements, namely, August 8, 1973, are also illustrated in the same figure. The axis of the monsoon trough, which demarcates the southeasterly Bay monsoon air flowing up the Gangetic Valley from the southwesterly Arabian Sea monsoon over Western and Central India, runs very close through RCA. RCA also lies directly in the path of the monsoon depressions (large majority of the depressions originates from the Bay of Bengal). Bombay and Kalyan areas lie southwest of and away from the seasonal position of the axis of monsoon trough. On August 8, 1973,

the surface chart shows that the axis of monsoon trough was passing through near RCA, with a surface low situated near that region. Winds at 700 mb, showed cyclonic circulation over the Rihand area.

The measurements at RCA were made on 16 days between August 5 and September 23 while those at and around Bombay were made on six days between September 29 and October 16. The sampling levels at RCA varied from 600 to 3600 m and at Bombay from surface to 1,000 m above mean sea level. The number of samples at RCA, Bombay, Kalyan and over the sea were 30, 18, 4 and 5 respectively.

The equipment used for sampling aerosols was the millipore filter assembly[6]. Millipore filters of diameter 47 mm, pore size 0·8 $\mu$m and type AA were used for this purpose. The sampler was operated in cloud-free air through an opening provided in the body of a DC-3 aircraft flying at 54 m sec$^{-1}$. The inlet of the millipore holder faced the airstream, and the outlet connected through an airflow meter to a suction pump using a small rubber tubing having no bends. During sampling, the aircraft movement was kept across the prevailing wind. The sampling of air through the millipore was made along a transverse section of the aircraft body. Since the direction of aerosol sampling was not along the aircraft direction nor against the wind, the aircraft velocity or wind velocity did not alter the filter sampling velocity. However, the wind speed was fairly uniform for different samples. The average sampling rate was 12 l min$^{-1}$ giving an air speed of 7 m sec$^{-1}$ through the millipore. The average volume of air sampled was 60 litres. An exposed millipore filter was developed in the usual process, *i.e.*, treating it with acidified silver nitrate solution (1%) followed by repeated washings in distilled water, drying in a dessicator and then exposing it to bright sunlight. The chloride particles were detected as brown spots. The spot sizes were measured under an oil immersion optical microscope. A uniform factor of 6, as determined in the laboratory, was used for obtaining the true particle size from the corresponding spot size. A density of 2·16 (applicable to pure sodium chloride) has been used for the conversion of particle diameter to particle weight.

## 3. Results

### 3.1. *Vertical profile*

The mean profiles showing the concentration (no. m$^{-3}$) of the particles against particle weights ($\mu\mu$g) over RCA and Bombay, are shown in figs. 2 and 3. The standard deviations are also given in the figures. The altitudes mentioned in the paper are all above mean sea level.

#### 3.1.1. *Variation at RCA*

The number concentrations at 600, 1,100, 1,500, 2,100, 2,700 and 3,600 m levels were $4{\cdot}5 \times 10^4$, $4{\cdot}8 \times 10^4$, $4{\cdot}9 \times 10^4$, $4{\cdot}9 \times 10^4$, $5{\cdot}4 \times 10^4$ and $6{\cdot}5 \times 10^4$ m$^{-3}$ respectively

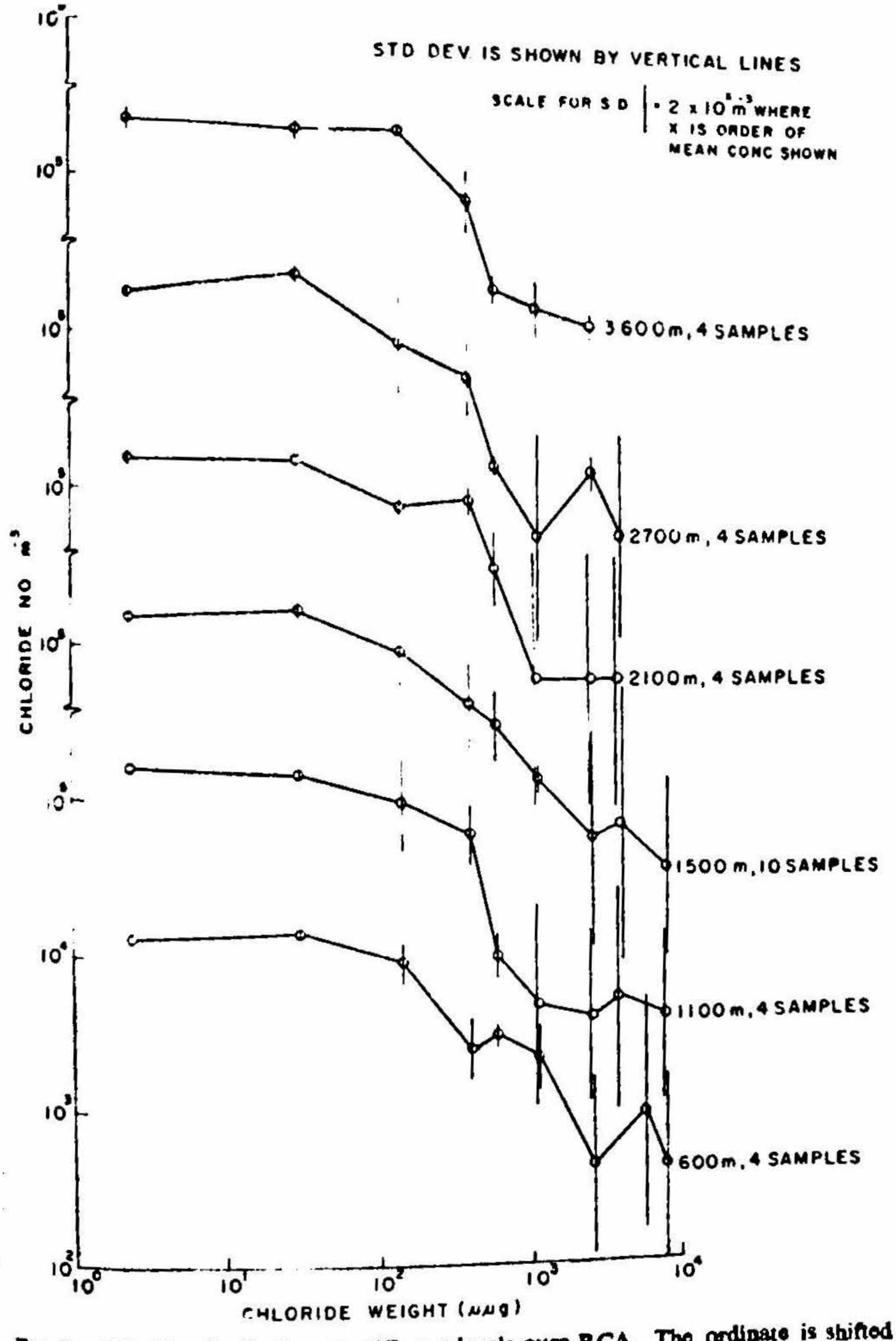


FIG. 2. Chloride distributions at different levels over RCA. The ordinate is shifted by one scale each for the successive heights.

It gradually increased a little with height. This trend is comparable to the observations of chloride particles over Illinois[4] which showed maximum concentration at

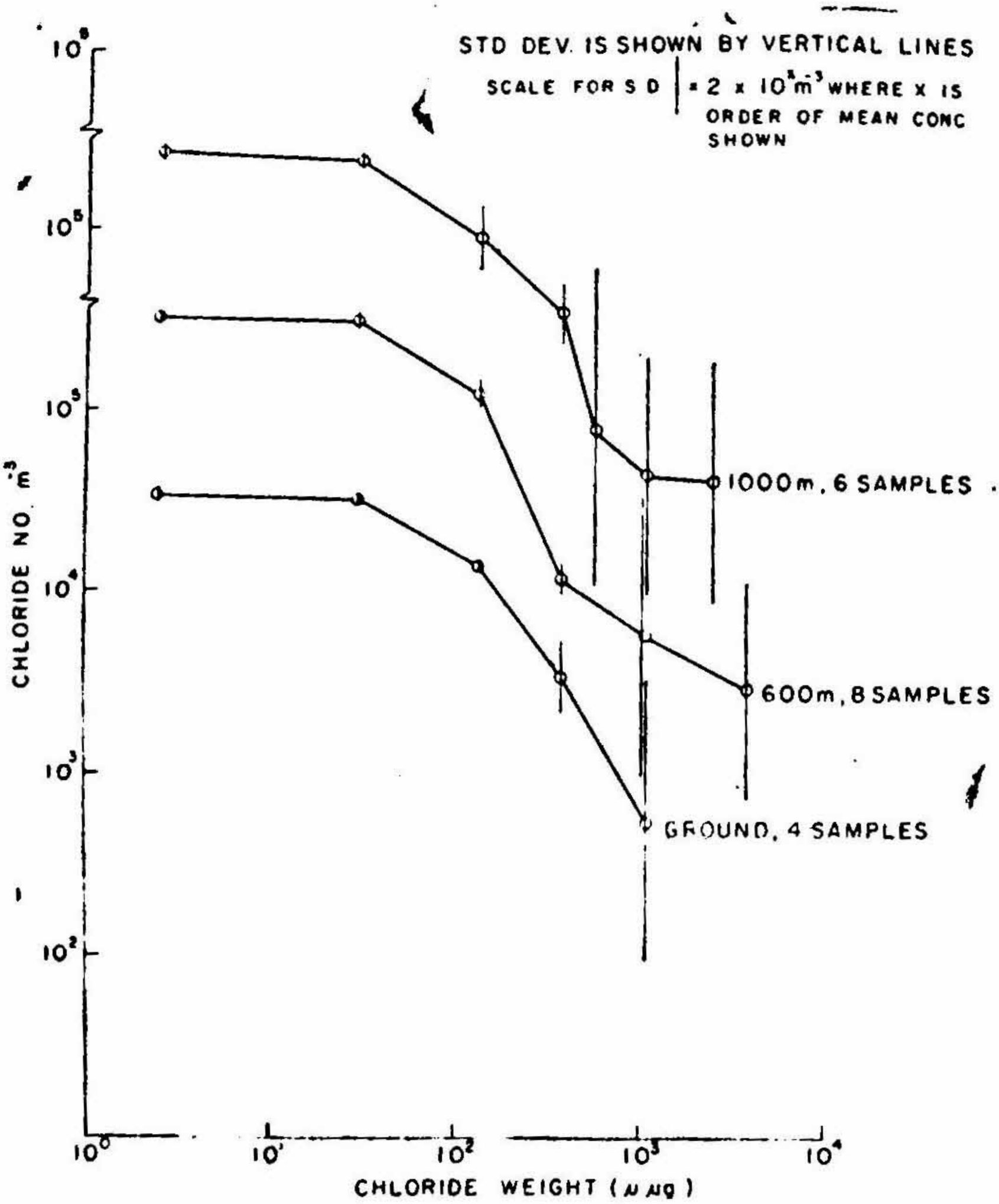


FIG. 3. Chloride distributions over Bombay at the indicated levels. The ordinate is shifted by one scale each for the successive heights.

higher altitude (Fig. 6). Durbin and White[8] noticed lower chloride concentrations at higher altitudes, over land (Fig. 6). The mass concentrations at the respective levels were 16·6, 11·3, 13·1, 10·5, 9·7 and 10·3 $\mu g\ m^{-3}$ respectively. The mass at lower levels (600 to 1500 m) was greater than that at higher levels (2100 to 3600 m). However, this difference was not statistically significant. The width of the chloride spectrum was broader at lower altitudes (600–1500 m). The weights for the largest particle were 7800 $\mu\mu g$ at 600–1500 m, 3800 $\mu\mu g$ at 2100 m and 2700 m and 2500 $\mu\mu g$ at 3600 m levels (the corresponding particle diameters were 19, 15 and 13 $\mu m$ respectively). The smallest particle mass for all the observations was 2·5 $\mu\mu g$ (1·3 $\mu m$ dia). The

distributions at different levels were usually unimodal with peak concentrations at 2·5–31 $\mu\mu$g. The secondary modes at some levels are due to averaging of samples.

### 3.1.2. *Variation at Bombay*

The counts were $8{\cdot}0 \times 10^4$, $7{\cdot}4 \times 10^4$ and $6{\cdot}0 \times 10^4\ m^{-3}$ at surface, 600 m and 1000 m altitudes. The counts reduced with height. This trend is similar to the observation of Woodcock[1] according to whom the vertical distribution of airborne sea salt particles over the ocean was an exponential decrease (Fig. 6). The mass was constant at about $4{\cdot}8\ \mu g\ m^{-3}$ at the three levels measured. The spectrum was broadest at 600 m. The weights for the largest chlorides at the surface, 600 and 1000 m were 1100, 3800 and 2500 $\mu\mu$g (the respective diameters were 10, 15 and 13 $\mu$m) respectively. The smallest particle mass was 2·5 $\mu\mu$g (1·3 $\mu$m dia). The distributions were all unimodal with peak concentrations at 2·5–31 $\mu\mu$g. The narrower spectrum at the surface suggests that the larger particles are probably removed by trees and other obstructions near the ground.

## 3.2. *Variation—Maritime vs well-inland*

At RCA (well-inland), the total number and mass concentrations, at an average level of 1900 m, were $5{\cdot}1 \times 10^4\ m^{-3}$ and $12{\cdot}2\ \mu g\ m^{-3}$. Over Bombay (maritime), these were $7{\cdot}1 \times 10^4\ m^{-3}$ and $4{\cdot}8\ \mu g\ m^{-3}$ at 600 m (average level). The average 24 hr rainfall for the two regions, on the days of observations were 11·6 and 5·0 mm respectively. The corresponding spectra are presented in fig. 4. The standard deviations are given in the figure. Over Bombay, the count was more and the mass less as compared to the values over RCA. The spectrum was broader over RCA than over Bombay, maximum particle weight being 3800 and 1800 $\mu\mu$g (19 and 15 $\mu$m) respectively. Application of Mann–Whitney's Test shows that the differences in the number and mass concentrations over the two regions were statistically significant (at ·001 and ·01% levels respectively). The distributions were unimodal at RCA with peak concentrations at 2·5–31 $\mu\mu$g (1·3–3 $\mu$m) and bimodal at Bombay with primary and secondary peaks at 2·5 and 1100 $\mu\mu$g (1·3 and 10 $\mu$m) respectively. The sea-spray distribution is generally believed to have a maximum around 0·5 $\mu$m radius[7]. The concentration over Bombay was higher for chlorides 170 $\mu\mu$g and below, while those over RCA was higher for particles greater than 170 $\mu\mu$g.

## 3.3. *Variation—Maritime vs urban*

The size spectra of chlorides over sea (upwind and maritime) and Kalyan (downwind and urban) are indicated in fig. 5. The standard deviations are given in the figure. Over the sea, the total number and mass concentrations, at 900 m level (average) were $6{\cdot}9 \times 10^4\ m^{-3}$ and $7{\cdot}1\ \mu g\ m^{-3}$. Over Kalyan, the values were $6{\cdot}6 \times 10^4\ m^{-3}$ and $3{\cdot}9\ \mu g\ m^{-3}$ at 600 m.

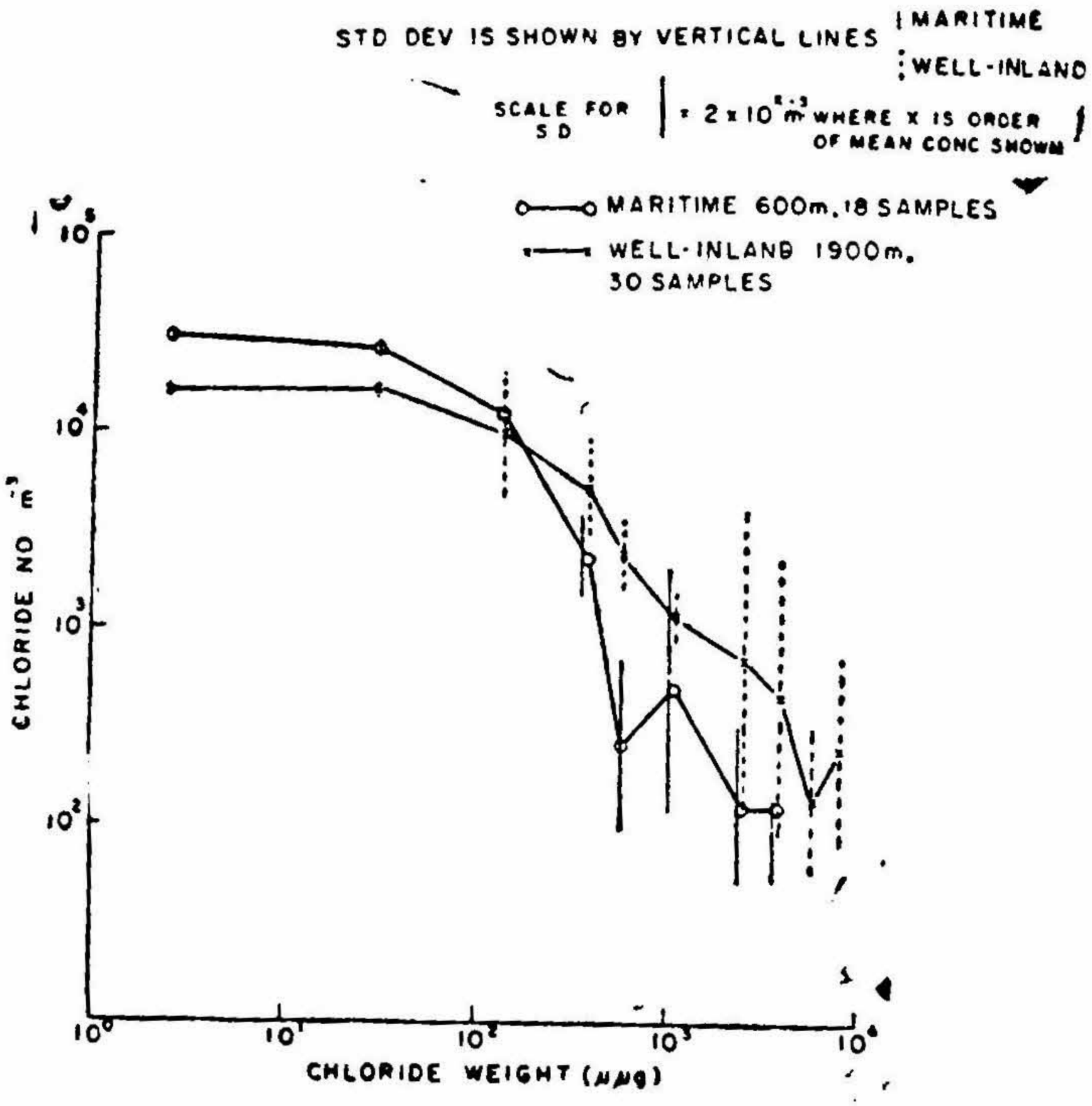


FIG. 4. Variation of chloride—Maritime *vs* well-inland.

The number concentration at both the locations was nearly the same while the mass concentration over the sea was almost double the value over the other location. The spectrum was broader over sea than over Kalyan, maximum weight being 3800 and 1100 $\mu\mu$g (15 and 10 $\mu$m dia) respectively. While the difference in number over the two locations is not significant, the difference in the mass is nearly significant (at 9·5% level, Mann–Whitney). The distribution over Kalyan was unimodal while that over the sea was bimodal. However, the number of samples at the two locations were not sufficient. The secondary peak, over the sea, noticed here and in the earlier section is due to averaging of samples.

## 4. Discussion

The order of the number concentrations obtained in the present context, in the well-inland region, is nearly in agreement with those found over the land[8] and is higher

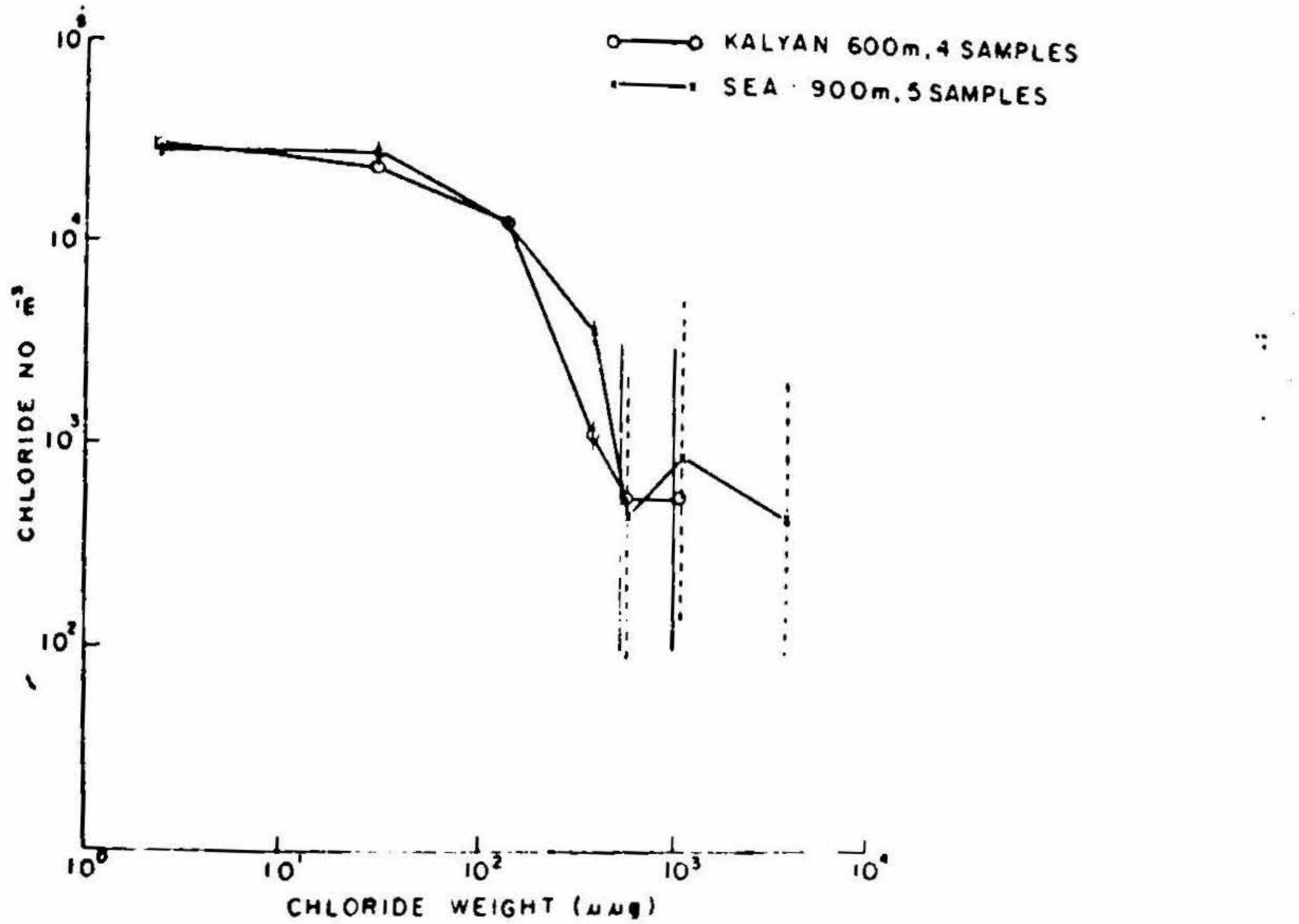


Fig. 5. Variation of chloride—Maritime (upwind) *vs* urban (downwind).

than that observed over Illinois[4] (Fig. 6). The number concentrations over the maritime region are nearly consistent with those measured by Woodcock in maritime air. The difference lies mainly in the weight (or size) of smallest particle sampled by the different observers (Fig. 6). The mass concentrations referred to in the paper are of the order of those reported by others[1,8].

The chloride particles are lifted up from the sea surface by strong winds and the air mass carrying them is slowly transported away into the well-inland regions. However, the probability of wash-out of chlorides by rain and that of size increases and number decreases due to cloud droplet scavenging followed by evaporation of droplets exist in the path of transport of the particles to RCA from the coasts. Also, advection from storm areas play an important role in the distribution of larger size particles at higher levels. Eriksson[9] showed that chloride rich air can be transported at high levels into continental from maritime regions, without washout of them. The relatively higher

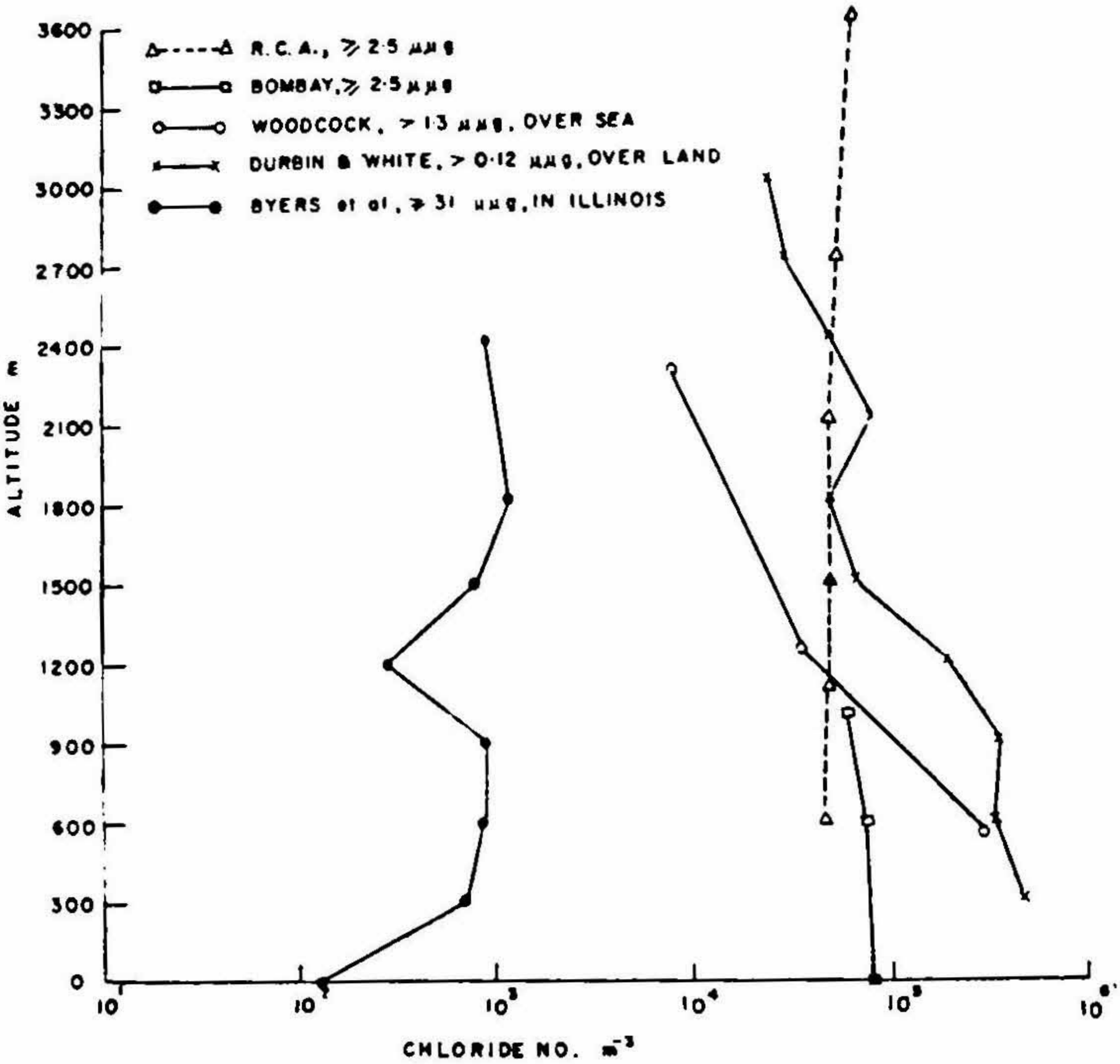


FIG. 6. Curves comparing chloride distributions at different places by various observers.

concentration of chloride particles at higher levels and the presence of large size particles at lower altitudes, in RCA, may be explained on the basis of the average thermal structure at various levels on the days of measurements. This is indicated in fig. 7 which indicates a discontinuity in the temperature lapse (suggesting the presence of a thermally stable layer) at about 3,700 m level at all the places, namely, RCA, Bombay and in between Calcutta (22° 39′ N, 88° 27′ E, 6 m MSL) and Vishakhapatnam (17° 43′ N, 83° 14′ E, 3 m MSL). The latter two are the coasts on the Bay of Bengal nearest to RCA (for which radiosonde observations are available). The discontinuity in the thermal structure (or the presence of the thermally stable layer) checked the transport of aerosols in the atmosphere. Further, fig. 7 suggests that at the three coasts over the Bay and the Arabian Sea, the depth of atmospheric mixing by convection (of chloride particles originating from the sea surfaces) is quite good.

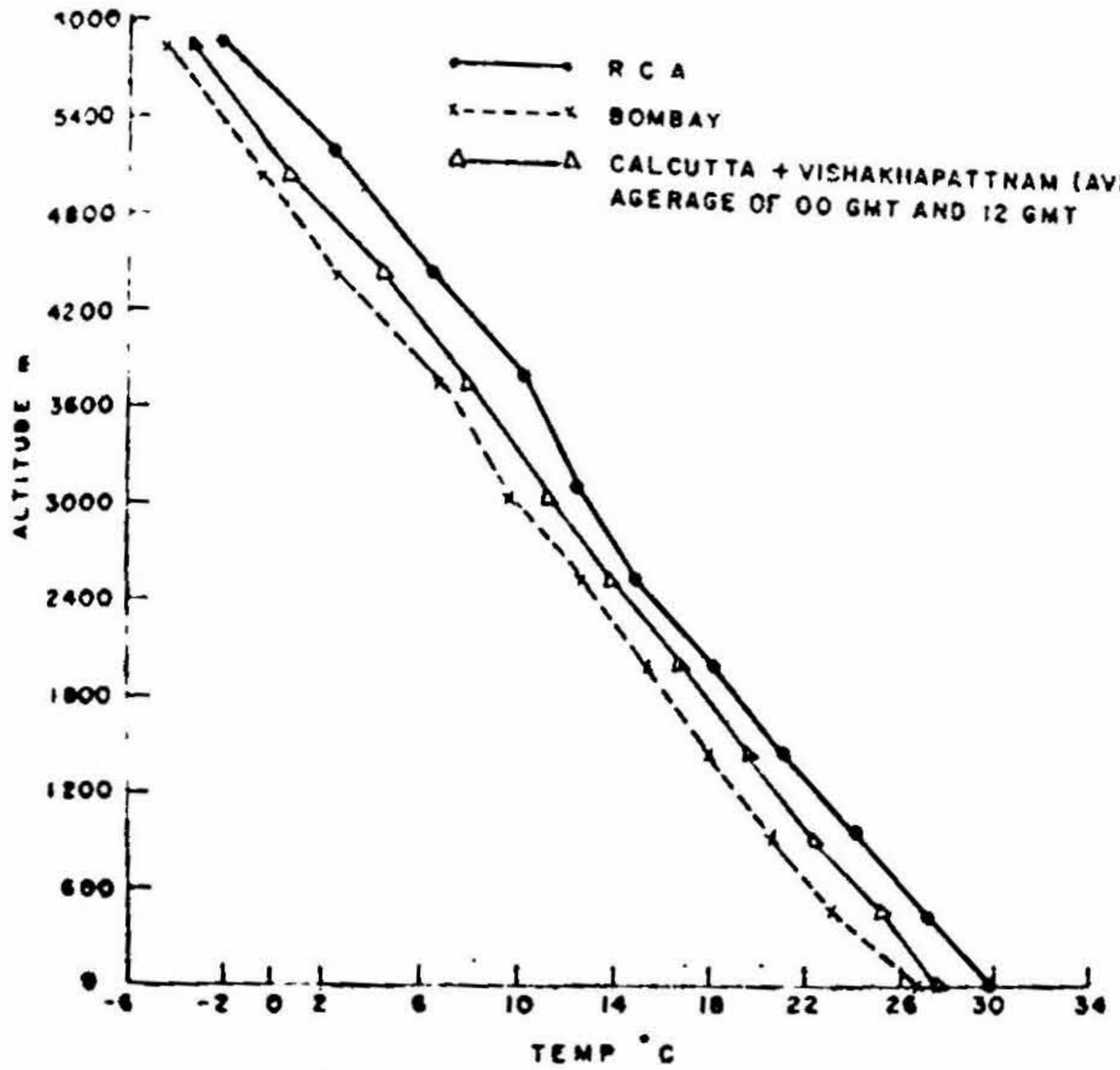


FIG. 7. Curves showing average thermal structures, on the days of measurements, at different levels and places.

The higher mass concentration and presence of bigger chlorides over RCA (than Bombay) may be attributed to the facts given below :

1. RCA is far nearer to the Bay than the Arabian Sea, and it lies directly in the path of the monsoon depressions orginating from the Bay (vide section 2 para 3 and fig. 1 *a*, *b*). Hence the origin of RCA chlorides is predominantly the Bay of Bengal. The origin of Bombay chlorides is the Arabian Sea. As the sea surface in the Bay is warmer than that over the Arabian Sea and number of monsoon depressions and cyclonic storms forming in the Bay is many more than in the latter, the mechanism for the uplift of bigger chlorides from the Bay surface by the process of advection is relatively stronger.

2. Measurements at RCA were made during the period of strong monsoon activity with heavy influx of chloride rich air from the seas while those at Bombay were made in the end of the monsoon.

3. Wash-out of bigger chlorides (in rain), was, perhaps, greater in maritime air (the frequency of rainfall prior to sampling was higher).

Lastly, the relative deficiency of larger size chloride particles at higher levels suggest that a warm non-precipitating cloud that is defficient in microstructure (wherein bigger size droplets is very less) could be modified by warm cloud seeding, *i.e.*, by introducing giant sodium chloride particles into the cloud. The giant hygroscopic particles become big solution droplets under the high relative humidity condition and grow by condensation and coalescence (with smaller cloud droplets), and help in the the precipitation of the cloud.

## 5. Conclusion

The study of chloride aerosols over the regions under consideration brought out the following characteristic features:

The number concentration increased a little with height over RCA (well-inland) whereas it reduced with height over Bombay (maritime). Over RCA, chloride mass was greater and the size spectra broader at lower levels. Over Bombay, the mass was approximatey the same at the measured levels. The count was more and the mass less in the maritime than those in the well-inland region. The mass over the maritime (upwind) was higher with respect to the urban (downwind) location while the number was nearly constant at the two locations. The chloride spectrum was narrower over the maritime than over the well-inland and broader over the maritime than over the urban regions. The distributions at different levels and locations were unimodal.

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