CCN Concentration in Troposphere over China

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ABSTRACT

CCN concentration in the middle–lower troposphere over northern China was observed using a cloud condensation nucleus counter, MEE–130, installed on an IL–14 aircraft in the summer of 1983 and 1984. More than 60 sets of data (each flight as one set) were collected.

The main results are: (1) in northern China, CCN concentration is 10^2–10^4 / cm^3 near ground, decreases with increasing height and follows exponential distribution; (2) the local CCN concentration and its distribution with altitude are influenced by some meteorological factors: such as inversion, cloud and precipitation, wind and land–sea breeze etc. The inversion makes CCN significantly accumulate just below the inversion level; CCN concentration is lower inside clouds than outside clouds at same level; wind plays an important role of transporting CCN horizontally; (3) the CCN concentration is higher above the land than above the sea at same level; CCN concentration is one order of magnitude lower over the coastal cities like Qingdao than over the continental cities like Zhengzhou; (4) all these suggest that CCN in northern China comes mainly from continental surface layer. Densely–populated areas and industrial areas may produce more CCN.

I. INTRODUCTION

Cloud condensation Nuclei (CCN) is important not only in cloud physics but also in weather modification, since cloud droplets first form on CCN in natural supersaturational condition. Therefore, observations and investigations on CCN have become one of the important aspects of cloud physics. The main investigations on CCN concentration include its geographical variation, vertical variation, variation associated with polluted air and meteorological factors, etc. The composition and sources of CCN have also been investigated broadly.

During 1983–1984, a cloud condensation nucleus counter, MEE–130, installed on an IL–14 aircraft was used for observing the concentration of CCN in the middle–lower troposphere (from ground to 6,000 M, ASL) in Shaanxi, Jilin, Inner Mongolia, Henan, Shandong and Beijing, etc. More than 60 sets of data (each flight as one set) were collected. In this paper we present the main results of analyses for the data.

II. INSTRUMENT AND OBSERVATION MODE

The principle of MEE–130 nucleus counter is similar with that described by Radke and Hobbs (1969, I). The sample air is drawn in a thermal diffusion cloud chamber. The supersaturation (0–4%) at the center in the chamber is controlled by temperature difference between the upper and lower plates. The concentration of CCN is determined by measuring automatically the intensity of light scattered from the cloud droplets formed on the CCN. The temperature difference between the two plates and the number of CCN are shown on the screen of the counter for watching in real time, also they are printed on paper for analyses thereafter. The sampling interval can be chosen to be 30 seconds, 1 minute or 5 minutes. The scope of measurements of CCN concentration is 0–19,999 cm^{-3}.

The air entrance tube of the counter is installed at 1 meter ahead of the aircraft wing and out of the aerodynamical surface layer of the aircraft. The inlet of the tube is toward forward in order to ensure the sampling air against the pollution of the aircraft.

Two sampling modes are used: one is in a local area, i.e. the aircraft flies up and down for measuring the local vertical variation of CCN concentration; the other is flight at some levels in the air over broad area for investigating the relation between the CCN concentration and other factors such as geographic location, time, meteorological factors, etc.

III. MAIN RESULTS OF OBSERVATIONS

1. *Vertical Profile of* CCN

It has been confirmed that the concentration of CCN declines with increasing height over continental area in the troposphere by observations in Europe, America and Japan, etc.(Hoppel et al., 1973; Fenn et al., 1965; Squires and Twomey, 1966). Similar results were observed in northern China.

Among the 30 measurements of CCN concentrations over a local area, 23 decline with height. Fig. 1 is an example. They well comply with exponential decreasing distribution:

$$N = N_0 \exp(-H / a).$$

Where N is the concentration of CCN at the altitude H in cm^{-3}: N_0 is the concentration of CCN near the earth's surface; a is some constant in m.

Table 1 shows some examples of parameters and correlation coefficients better fitting for the exponential distribution. From these data, "a" is between 500–1,800, which is very close to the values of 678–1,335 observed in middle–Europe, and 890–985 in USSR(Glabofsky, 1956); N_0 is between 10^2– 10^4. It depends on geographical locations, air masses and meteorological factors, etc. discussed below.

The CCN concentration decreasing with altitude reflects that the main CCN comes from the surface. The exponential decreasing distribution results in the gravitational settling and turbulent diffusing upward.

2. *Influence of Meteorological Factors on* CCN *Concentration*

Those which display more differential to the exponential decreasing distribution or even increase with altitude are often associated with some meteorological factors such as inversion, wind direction, clouds and precipitation etc. For example, the main reason of the lower correlation coefficient (−0.85 in Table 1) in Beijing on 6 October 1983 is the influence of inversion. From the sounding data of 0800 Beijing Time (hereafter called BT) there was an inversion layer between 900–850 hPa, and this layer still maintained isothermal at 1400 BT.

Fig. 2 shows the CCN vertical profile observed on that day. It can be seen that the CCN concentration does not decrease with height and even a little increase in the morning. Because of the maintenance of the inversion, CCN is accumulated under the inversion and has the high value on the layer of 500–1,000m, ASL, in the afternoon. Scholz (Glabofsky, 1956) and Landsberg (Mason, 1971) show similar results.

Table 1. Parameters of CCN Concentration of Some Examples Fitting for the Law of Exponential Decreasing with Height

Time	Location	Observation Height (m)	Weather Situation	N_0 (cm^{-3})	a (m)	Correlation Coefficient
17 Aug. 1983	Zhungeer, Inner Mon.	2,000–4,000	high pressure clear, Ci fil. 1 / 0	16,229	713	−0.81
9, Sep. 1983	Zhungeer, Inner Mon.	1,000–4,000	prior to surface front, clear, Ci, 2 / 0	3,700	808	−0.95
14 Sep. 1983	Huolin, Inner Mon.	2,000–4,000	behind surface cold front, prior to 500 hPa trough, clear, Cu, Fc, 4 / 4	11,895	767	−0.95
16 Sep. 1983	Yimin, Inner Mon.	1,000–4,000	rear of high pressure, clear, Cs, 6 / 0	3,337	692	−0.93
22 Sep. 1983	Baotou, Inner Mon.	1,000–3,500	prior to surface cold front, Ci, Ac, 10 / 0	12,200	663	−0.95
22 Sep. 1983	Siziwangfu, Inner Mon.	1,500–3,500	prior to surface cold front, Ci, Ac, 10 / 0	3,370	1,295	−0.93
5 Oct. 1983, a.m.	Shahe, Beijing	100–2,000	high pressure, clear, Ci fil, 2 / 0	534	1,257	−0.99
5 Oct. 1983, p.m.	Shahe, Beijing	100–2,000	high pressure, clear, Cs, 8 / 0	12,240	459	−0.99
6, Oct. 1983, a.m.	Shahe, Beijing	100–2,000	rear of high pressure, clear, Ci dens, 2 / 0	1,914	1,220	−0.84
6, Oct. 1983, p.m.	Shahe, Beijing	100–2,000	rear of highpressure, clear, Ci dens, 10 / 0	5,632	766	−0.85
7, Oct. 1983, a.m.	Shahe, Beijing	500–4,000	forward trough, As, 10 / 0, light rain	7,453	1,087	−0.96
7, Oct. 1983, p.m	Shahe, Beijing	100–6,000	surface front closed to the station, Sc, 10 / 10, rain	2,781	1,423	−0.81
4, Aug. 1984	Liuting, Qingdao	100–1,800	prior to surface cold front and 850 hPa trough	1,014	1,815	−0.79
16, Aug. 1984	Liuting, Qingdao	100–1,800	high pressure, wind NE, 6 m / s	698	1,191	−0.82
17, Aug. 1984	Liuting, Qingdao	100–1,800	surface closed to a typhoon; at 850 hPa, prior to trough, wind SE, 4 m / s	630	1,066	−0.64
24, Aug. 1984	Liuting, Qingdao	100–1,500	prior to surface cold front, wind NW, 8 m / s	2,187	638	−0.85
27, Aug. 1984	Liuting, Qingdao	100–1,800	prior to surface cold front, wind NE, 6 m / s	1,205	1,808	−0.66
Middle Europe					678–1,335	
Summer, 1946	USSR				890	
Summer, 1947	USSR				985	

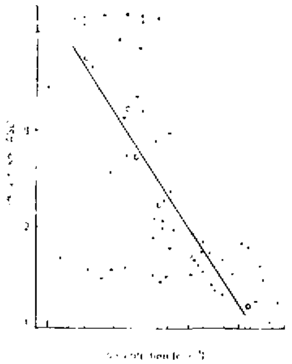

Fig. 1. Vertical variation of CCN concentration activated at 0.5% supersaturation on 9 September 1983 over Zhungeer, Inner Mongolia. The points represent observed values and circlets represent average values for each 500m layer. Straight line is the best fitting line using exponential decreasing law with $a = 808$m, $N_0 = 3{,}700$ cm^{-3}, correlation coefficient is −0.95.

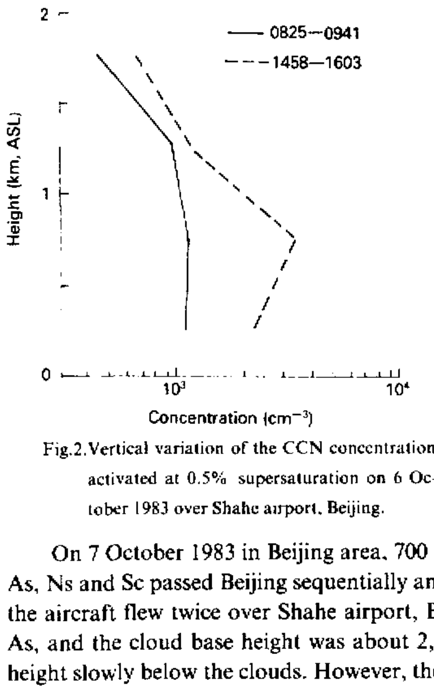

Fig.2.Vertical variation of the CCN concentration activated at 0.5% supersaturation on 6 October 1983 over Shahe airport, Beijing.

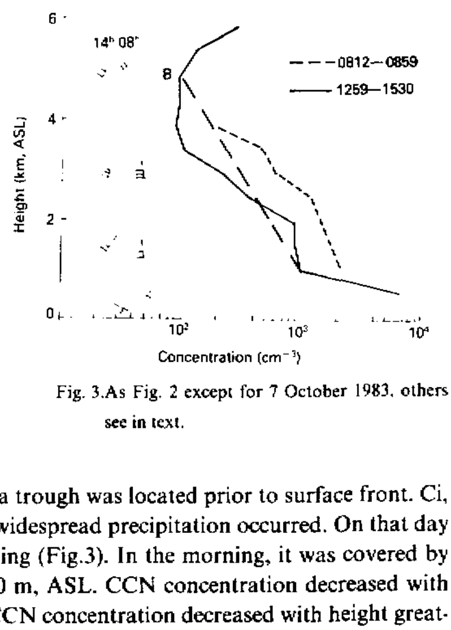

Fig. 3.As Fig. 2 except for 7 October 1983, others see in text.

On 7 October 1983 in Beijing area, 700 hPa trough was located prior to surface front. Ci, As, Ns and Sc passed Beijing sequentially and widespread precipitation occurred. On that day the aircraft flew twice over Shahe airport, Beijing (Fig.3). In the morning, it was covered by As, and the cloud base height was about 2,200 m, ASL. CCN concentration decreased with height slowly below the clouds. However, the CCN concentration decreased with height greatly in cloud. The aircraft flew up to 4.200m, ASL, but it was still in the cloud. In the afternoon, the base of cloud (Sc) decreased to 1,700m, ASL, the aircraft flew up to 5,000m, ASL, and went out the cloud. The aircraft flew up continuously until 5,800m, ASL. The concentration of CCN in the air of each layer is shown in Table 2. It can clearly be seen that the CCN concentrations below cloud are higher than that in cloud. The CCN concentrations remain fairly constant between 1,000m and cloud base, but decrease with height rapidly in cloud. The CCN concentrations above cloud top are higher than that below cloud top again. In order to compare the difference of CCN concentrations in– and out–cloud, a dash line A–B is drawn in Fig. 3, which connects point A, where the CCN concentration has not increased from the evaporation of cloud droplets, and point B, the cloud top. Radke and Hobbs (1969, II) suggested that the CCN concentrations were lower in cloud resulted in that part of CCN was nucleated to cloud droplets.

Table 2. Relation between CCN Concentration and Cloud Layer Observed in the Afternoon 7 October, 1983 over Shahe, Beijing

Observation Height (m)	0–500	500–1000	1000–1500	1500–2000	2000–2500	2500–3000	3000–3500	3500–4000	4000–4500	4500–5000	5000–5500	5500–6000
CCN (cm^{-3})	1708	1074	980	978	421	267	123	109	119	116	154	355
Cloud Region	below	cloud					in	cloud			above	cloud
				cloud	base					cloud	top	
Gavolosky's Observation (cm^{-3})		6115			5135			2152			3240	

Another example was given for the influence of inversion and cloud on CCN concentration. It was observed in the air over Changchun on 6 August 1983.

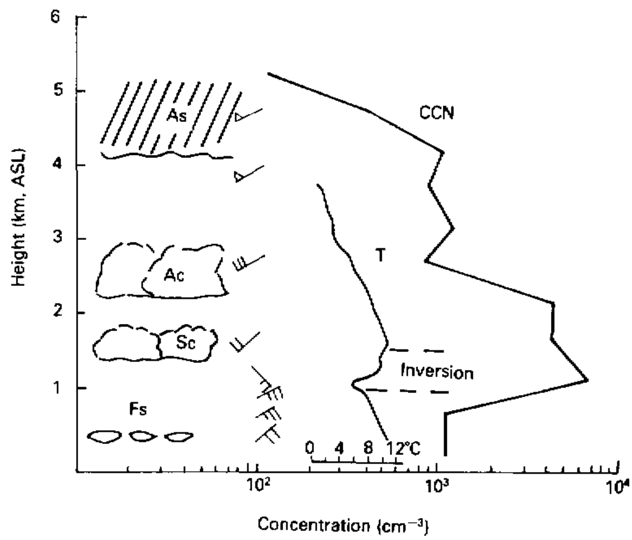

Fig.4. As Fig. 2 except for 6 August 1983 over Changchun. Temperature profile (marked by *T*) and clouds were observed by the aircraft, wind by rawinsonde at 0800 BT.

On that day Changchun was located north of the new developing low center on a stationary front. Cloud system composed of Ci, As and Ns associated with the front passed Changchun serially beginning from the evening on 5 August and moved north–eastward. In next morning from 0824–0948 BT, the aircraft measured CCN over Changchun airport up to

5,200m ASL. The aircraft passed through Fs, Sc, Ac and As on its way when it flew up. Fig. 4 schematically shows the levels of clouds. The temperature profile measured by the aircraft is also given in Fig. 4. It can be seen that there was an inversion between 1,100–1,600m, ASL. From the weather and veering wind in this layer of 0800 BT sounding data, the inversion was actually a warm frontal zone near the low pressure center. Above the frontal zone there was a thin layer of Sc (1,400–1,900m). Ac was formed by the convective instability ($\frac{\partial \theta_{se}}{\partial z} < 0$ at 0800 BT sounding data) in the layer of 2,200–3,000m, ASL. Above 4,100m there was a layer of As.

It can be seen from Fig. 4 that the CCN concentration increased below 1,200m because of the cumulation under the inversion; the CCN concentration decreased rapidly with height in the cloud layers of 1,200–1,700, 2,200–2,800 and above 4,200m, ASL. In the gaps of clouds, 1,800–2,200, 2,800–4,200m, the CCN concentration was basically constant or increased with height. It was consistent with that discussed above.

3. *Relation between* CCN *Concentrations and Upwind Geography*

It was found that CCN concentration is closely related to upwind geographical background. CCN concentration is higher if industrial urban area is located upwind, lower if rural or mountain area is there. The measurements over Shahe airport, Beijing on 5 October 1983 was an example (Fig. 5). CCN concentration is one order of magnitude higher in the afternoon than in the morning near the surface. In addition to the factor that turbulence was stronger so might transmit more CCN from ground to the air in the afternoon, another important reason might be the wind direction. The wind direction at the level of 380m above ground was NE in the morning and SSE in the afternoon. Shahe airport is located northwest of Beijing city. At northeast of Shahe airport there are mountains and reservoirs.

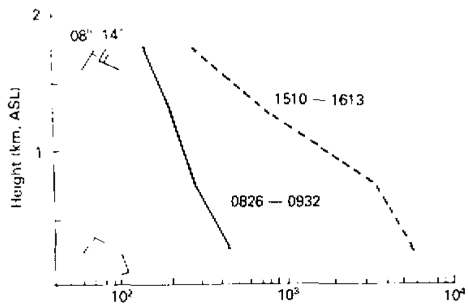

Fig.5. As Fig. 2 except for 5 October 1983.

So the wind blew from the urban area in the afternoon and from the rural area in the morning, respectively. Above 1,500m, ASL, although wind direction was NE and NW in the morning and afternoon, respectively, CCN concentrations observed were close because both these two directions are mountains and reservoirs.

By contrast, CCN concentrations from 1,000–4,000m, ASL over Shahe airport on 7 October 1987 was higher in the morning than in the afternoon (Fig. 3). Wind direction measured by rawinsonde changed from SSE in the morning to SW in the afternoon, i.e. Shahe airport was located downwind of Beijing city in the morning and rural area in the afternoon.

The aircraft flew and observed CCN from south to north part in Shaanxi Province on 8 June 1983. The aircraft took off at 0829 BT from Xi'an (industrial city), flew up to the altitude of 2,500m at Sanyuan, then flew straight up to north at this level, passed Baishui and out of the middle area of Shaanxi, went in the Yellow Soil Plateau of northern Shaanxi, passed Yan'an, then landed at Yulin (a small town). In the afternoon the aircraft took off at 1322 BT from Yulin and flew back to Xi'an at 1452 BT.

On that day Shaanxi Province was in high pressure and located ahead the ridge at 500 hPa. It was clear only with a little Ci. Atmospheric stratification was stable according to 0800 BT sounding data. Wind direction was SW below 3,000 m, ASL.

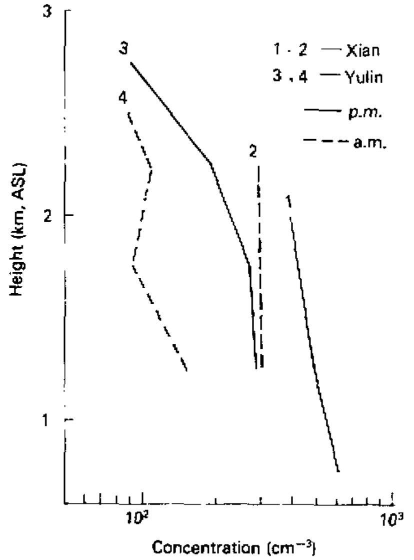

Fig. 6. As Fig.2 except for 8 June 1983 over Xi'an and Yulin, respectively.

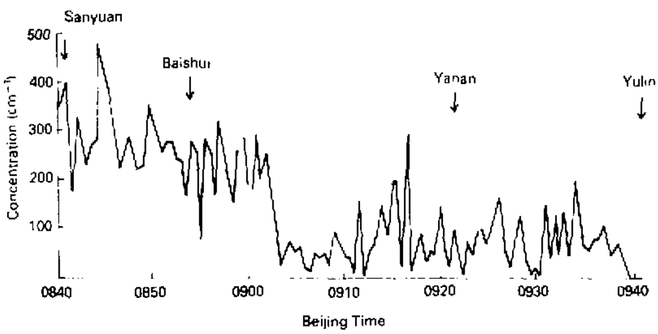

Fig. 7. CCN concentration activated at 0.5% supersaturation measured in the level of 2,400–2,500m, ASL, on 8 June 1983 from Sanyuan–Yulin in Shaanxi Province.

Fig. 6 shows the CCN concentration measured when the aircraft was taking off and landing at Xi'an and Yulin. It can be seen that CCN concentrations are 2–3 times higher over Xi'an than Yulin, and in both areas CCN concentration is higher in the afternoon than in the morning.

Fig.7 shows CCN concentration is 2–3 times higher in the middle area of Shaanxi (from Sanyuan to Baishui, downwind of urban area) than in the Yellow Soil Plateau (from Yan'an to Yulin, rural area).

The influence of upwind geographical condition on CCN concentration discussed above is consistent with that observed by Fitzgerald et al. at St. Louis (1973) and by Zhang Bojin at Tianjing (1982).

4. CCN *Concentration Observed over Coastal Area and Comparison with Continental Area*

During the period of time from 4 to 27 August 1984, CCN concentrations were observed over Shandong Peninsula. 9 sets of data were obtained. In this section, we will give some new characteristics of the CCN concentration over the coastal and sea area, and compare with that of continental area.

(1) *Distribution of* CCN *concentration with height over coastal area*

The distribution of CCN concentration with height over coastal area is similar with that over the continental area discussed in the first section. The CCN concentration in the surface layer is the order of 10^2– 10^3 cm^{-3}, and mostly decreases with height except the days when some meteorological factors such as inversion, cloud, precipitation and wind direction have important influences, which are similar with that discussed in the second and third sections.

The distribution of CCN concentration with height over coastal areas complies somewhat with exponential law but not as well as over continental areas. From Table 1 we can see that most correlation coefficients over Qingdao are lower than that over continental areas such as Beijing.

(2) *Comparison of* CCN *concentration between coastal and sea area*

The aircraft flew along the line of Liuting–Che island–Hui island–Shi island–Moyie island on two levels: 1,500 and 1,800m, ASL for five times (Fig.8). On its way the aircraft passed over both coast and sea on same level.

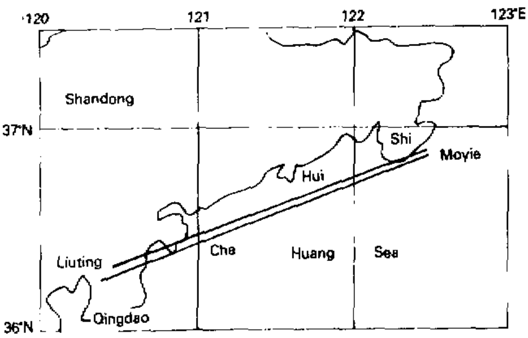

Fig. 8. Aircraft route for observing CCN concentration during August 1984 over Qingdao coastal area.

Fig. 9 shows the results, where the solid line is one example, which was observed on 9 August 1984, and the dashed line gives the average value of 5 flights. It can be seen that the CCN concentration is higher over coast (from Liuting to Che island and from Shi island to Moyie island) than that over sea (from Hui island to Shi island). The average value over coast and sea is 390 and 250 cm^{-3} at 1,500m, ASL, 364 and 209 cm^{-3} at 1,800m, ASL, respectively.

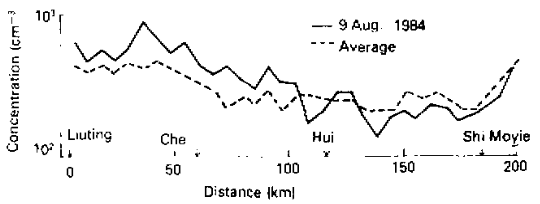

Fig. 9. Distribution of CCN concentration over Shandong Peninsula in the layer of 1,500–1,800m, ASL. Dashed line represents the average of CCN concentrations measured in 5 times; solid line for 1458–1531 9 August 1984.

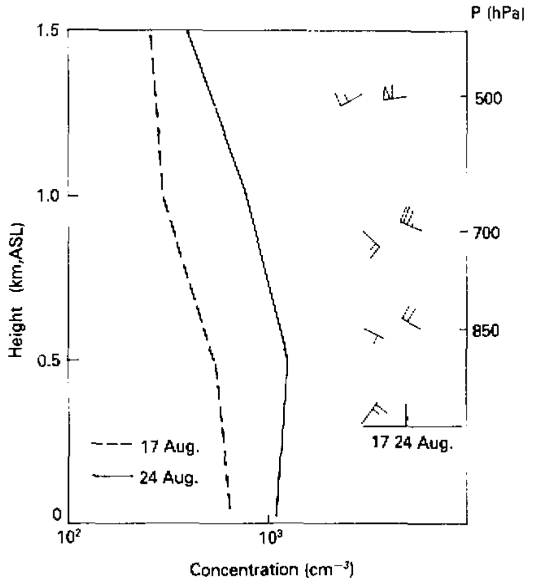

Fig.10. As Fig.2 except for 17 August 1984 (dashed line) and 24 August 1984 (solid line) over Liuting airport, Qingdao.

(3) *Comparison of CCN concentration observed over Qingdao and Zhengzhou*

Table 3. Comparison of CCN Concentration Observed over Qingdao and Zhengzhou

Observation Location	CCN Concentration in layers (cm^{-3})				Weather Situation
	No.	0–500	500–1000	1000–1500m	
Zhengzhou	11059	11186	8117	3458	High Pressure, Clear.
Qingdao	792	747	586	360	High Pressure, Clear.
Zhengzhou / Qingdao	14.0	15.0	14.0	10.0	

In order to consider the source of CCN we now compare the data observed over Qingdao which is located at the coast of Pacific Ocean and Zhengzhou which is located at the inner–continent in Henan Province. These two cities nearly have same latitude. The data chosen for comparison are in a same season and under similar weather situation.

Table 3 gives the comparison between the two cities. It can be seen that the CCN concentration is one order of magnitude higher over the continental city Zhengzhou than that over the coastal city Qingdao. This shows that continental area supplies more CCN than ocean.

(4) *Comparison of* CCN *concentrations between continental and marine air mass*

Using the data observed over the coastal city Qingdao it is possible to compare the CCN concentrations in continental and marine air mass. Fig. 10 is an example. On 17 August 1984, Qingdao was located prior to 850 hPa trough, the wind was from southeast. So Qingdao was under the control of marine air mass. By contrast, on 24 August 1984, Qingdao was located behind 850 hPa trough, the wind was from northwest, so Qingdao was under the control of continental air mass. The CCN concentration on 24 August was estimated to be about 2–3 times of that on 17 August.

IV. CONCLUSIONS

1. Generally, in northern China CCN concentration activated at 0.5% supersaturation near surface ranges from the average values on the order of 10^2 cm^{-3} over the sea to 10^3 cm^{-3} rural areas to 10^4 cm^{-3} or even higher in polluted air over cities. It decreases with increasing height and complies with exponential distribution law.

2. The local CCN concentration and its distribution with height are influenced by some meteorological factors: inversion makes CCN be accumulated below it; CCN concentration is lower inside cloud than outside cloud; wind transmits CCN to downwind areas.

3. Therefore in northern China the land may act as an important source of CCN. Densely–populated areas and industrial park may produce more CCN.

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