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AEROSOL AND CLOUD CONDENSATION NUCLEI DISTRIBUTION DURING SUMMER SEASON OVER NORTHERN REGION OF THAILAND

การศึกษาการกระจายตัวของอนุภาคละอองลอยและแกนกลั่นตัวของเมฆในช่วงฤดูร้อนของพื้นที่ภาคเหนือ ประเทศไทย

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Abstract

Background aerosol and cloud condensation nuclei (CCN) measurements are crucial to comprehend the impacts of cloud processes and formations. During summer season from March to May 2012 using all 14 flights of research super king air aircraft, aerosol concentrations (CN) and CCN at super-saturation 0.50% were carried out over seven provinces in the rural background aerosol of northern Thailand. Aerosol size spectra between 20 nm and 50 μm were also measured with combining measurements from the differential mobility analyzer (DMA), passive cavity aerosol spectrometer (PCASP) and fast-forwarding scattering spectrometer probe (FSSP). CCN concentrations were measured with CCN Counter. In March the main source of aerosols is pollutants originated from the burning of vegetative trash in rural areas and wildfires [(1)]. The median aerosol spectra tend to have the strongest fine mode and also to have the widest spectrum broadening which dominated with a maximum at 0.12 μm. The aerosol number concentration gradually tends to lower in April and May, respectively, whereas in May, the size at maximum number concentration is 0.14 μm being a bigger size when comparing with the size at the beginning of summer season. We have also found that during summertime the fine mode of aerosol particles is dominated with a maximum value at altitude around 900-1200 m, approximately 0.10 to 0.20 μm.

For CCN number concentrations, which measured with CCN counter, at super-saturation 0.5% ($N_{CCN0.5\%}$) in March is exhibited the smallest concentration and become higher in mid-April to May, respectively. During March $N_{CCN0.5\%}$ was largely concentrated on the upper levels between 2500 to 3000 m, while $N_{CCN0.5\%}$ are mainly stronger concentration from near surface to 2500 m and decreasing with height between April and May. The activated fraction (N_{CCN}/N_A) has changed from mid-April and also maximum in May; therefore,

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it is apparent that the active aerosols in May are better than in March.

Keywords: Northern Thailand, aerosol size spectra, cloud condensation nuclei (CCN), activated fraction, number concentration

บทคัดย่อ

การตรวจวัดข้อมูลละอองลอยและแกนกลั่นตัวของเมฆ (CCN) นับว่ามีความสำคัญอย่างยิ่ง ทั้งนี้เพื่อนำไปสู่ความเข้าใจต่อผลกระทบในกระบวนการก่อตัวของเมฆและฝน การศึกษานี้ทำการตรวจวัดข้อมูลโดยใช้เครื่องบินวิจัยซุปเปอร์คิงแอร์ของสำนักฝนหลวงและการบินเกษตรในช่วงฤดูร้อน ตั้งแต่เดือนมีนาคมถึงพฤษภาคม 2555 จำนวนทั้งสิ้น 14 เที่ยวบิน ทำการตรวจวัดข้อมูลความเข้มข้นเชิงจำนวนของอนุภาคละอองลอย (CN) และแกนกลั่นตัวของเมฆ (CCN) ที่ระดับอิ่มตัวด้วยไอน้ำยิ่งยวด 0.50% ในพื้นที่ชนบทของ 7 จังหวัด บริเวณภาคเหนือของประเทศไทย โดยทำการตรวจวัดละอองลอยขนาดตั้งแต่ 20 นาโนเมตร จนถึง 50 ไมโครเมตร ด้วยเครื่องมือตรวจวัดขนาดอนุภาคจำนวน 3 แบบ ได้แก่ Differential mobility analyzer (DMA), Passive cavity aerosol spectrometer (PCASP) และ Fast-forwarding scattering spectrometer probe (FSSP) และเครื่องมือตรวจวัดแกนกลั่นตัวของเมฆ (CCN counter) จากผลการศึกษาพบว่า ในเดือนช่วงมีนาคม แหล่งกำเนิดที่สำคัญของละอองลอยเกิดจากฝุ่นละอองขนาดเล็กที่เกิดขึ้นจากมลพิษจากการเผาไหม้เศษวัสดุทางการเกษตรเพื่อเตรียมพื้นที่สำหรับการเพาะปลูก รวมทั้งไฟป่า[1] ค่ามัธยฐานของสเปกตรัมของขนาดละอองลอยที่ตรวจวัดได้มีแนวโน้มส่วนใหญ่อยู่ในโหมด Fine และมีความกว้างของสเปกตรัมมากที่สุด โดยขนาดอนุภาคที่พบมากที่สุดอยู่ที่ 0.12 ไมโครเมตร ขณะที่ปริมาณของมลพิษมีแนวโน้มลดลงในเดือนเมษายนและพฤษภาคมตามลำดับ ส่วนในช่วงปลายฤดูร้อน เดือนพฤษภาคมขนาดละอองลอยที่ระดับความเข้มข้นสูงสุด มีค่าเท่ากับ 0.14 ไมโครเมตร ซึ่งมีขนาดใหญ่กว่าเมื่อเทียบกับขนาดของอนุภาคในช่วงต้นฤดูร้อน อีกทั้งยังพบว่าตลอดช่วงฤดูร้อนอนุภาคในโหมด Fine จะมีค่าสูงสุดอยู่ที่ระดับความสูงประมาณ 900 ถึง 1200 เมตร โดยมีขนาดอนุภาคประมาณ 0.10-0.20 ไมโครเมตร

ค่าความเข้มข้น CCN ที่ระดับอิ่มตัวด้วยไอน้ำยิ่งยวด 0.50% ($N_{CCN0.5\%}$) ในเดือนมีนาคมพบว่า มีค่าความเข้มข้นน้อยที่สุด และมีค่าความเข้มข้นสูงขึ้นอย่างเห็นได้ชัดตั้งแต่ช่วงกลางเดือนเมษายนจนถึงเดือนพฤษภาคม จากการศึกษาความผันแปรของความเข้มข้น CCN เทียบกับความสูงพบว่าในช่วงเดือนมีนาคม พบว่า ค่า $N_{CCN0.5\%}$ จะมีค่าสูงสุดอยู่ที่ระดับความสูงประมาณ 2500 ถึง 3000 เมตร ขณะที่ในเดือนเมษายน และพฤษภาคม ค่า $N_{CCN0.5\%}$ ส่วนใหญ่จะพบตั้งแต่ระดับพื้นผิวจนถึงระดับความสูงประมาณ 2500 เมตรและจะมีค่าลดลงเมื่อความสูงเพิ่มมากขึ้น ส่วนค่าอัตราส่วนการกระตุ้น (N_{CCN} / N_A) จะมีค่าการเปลี่ยนแปลงอย่างมากตั้งแต่กลางเดือนเมษายนจนมีค่าสูงสุดในเดือนพฤษภาคมซึ่งแสดงให้เห็นว่าคุณสมบัติของละอองลอยในเดือนพฤษภาคมมีประสิทธิภาพในการเปลี่ยนเป็นแกนกลั่นตัวของเมฆได้ดีกว่าละอองลอยที่เกิดในเดือนมีนาคม

คำสำคัญ: ภาคเหนือของประเทศไทย, สเปกตรัมของขนาดละอองลอย, แกนกลั่นตัวของเมฆ, อัตราส่วนกระตุ้น, ความเข้มข้นเชิงจำนวน

Introduction

Various properties of atmospheric aerosol particle can affect climate directly by acting as CCN and also can influence clouds through microphysical processes during droplet nucleation. Previous studied have been that variation in cloud nuclei are primarily responsible for variations in cloud droplet concentrations and colloidal stability. Enhanced aerosol concentration can also suppress warm-rain processes by

reducing particle size and causing a narrow droplet spectrum that inhibits collision and coalescence process[2-5]. As the result, they in turn affect the processes that lead to the formation of many forms of precipitation[6-7].

Nowadays, continued advancement of aerosol and CCN instrumental technology has provided the improvement of research tool for studies of aerosol and CCN distribution. For instance, in ARREX project [8] using PCAS, FSSP and CCN counter mounted on board an Aerocommander 690A aircraft in order to study in aerosol-CCN relationship over southern Africa. CSRP project[9] used aerosol probes and CCN counter with two research aircraft to study aerosol and cloud microphysics over Southeast Queensland in Australia and in China, many observations of CCN in polluted areas also using CCN Counter were mounted on the research aircraft[10-11] as well.

Atmospheric aerosol particles produced by air pollution from metropolitan area and biomass burning are the common feature in Southeast Asian countries[12]. In Thailand, the northern region is one of the important parts of agriculture and economic development. This region is geographically characterized by multiple mountain ranges and composes the main river basin of the country. Nevertheless this region also faced to pollution problems during prior summer season from December to April every year, the main pollutants are originated from the burning of vegetative trash in rural areas and wildfires and dominated the maximum PM_{10} in March [1, 13].

For this reason the comprehension of background of natural aerosol and their microphysical characteristics and the factors that enable them to act as CCN in northern region, which is crucial for understanding an impact on the evolution of precipitation processes[10, 14-16]. These results also provide the comprehension for further study on impacts of cloud formations for using in precipitation enhancement studies in Thailand[17].

In this study, we present the study of significant features of aerosols[9, 18], and vertical distribution of aerosol and CCN [11] and CCN activation ratio [19-20] during summertime variation using data from airborne measurements. The aerosol number, CCN number and size distribution are analyzed[21], and the characteristic of which aerosol serve as CCN is discussed. Aerosols and CCN data were obtained with the advent of the cloud physics aircraft from Bureau of Royal Rainmaking and Agricultural Aviation (BRRAA). These instruments can provide 3 modes of aerosol spectra including nucleation, accumulation and coarse mode[22] and CCN spectra, which are an efficient way

to study and observe atmospheric aerosol characteristics and its behaviors derived from all 14 flights in summer season from March to May 2012. There were carried out over seven provinces in the northern region of Thailand.

Data set and Methods

Airborne measurement and data sets comprising both aerosol and CCN instrument which were mounted on the Super King Air aircraft. All instrument including DMA[23], Passive Cavity Aerosol Spectrometer Probe (PCASP-100X) and FSSP[24] which measured aerosol number concentration and aerosol diameter at the size range from 0.02 to 50 μm, and Cloud Condensation Nuclei (CCN-100) counter [25] for measuring CCN number concentration. Further information on these instrumentations is presented in Table 1.

Table 1 List of instrumentation on the research aircraft (KASET 2013) of BRRAA

Instrument	Purpose	Range
DMA-MCPC (Differential Mobility Analyzer)	Nucleation mode and Aiken aerosol spectra	0.02-0.8 μm
PCASP-100X (Passive Cavity Aerosol Spectrometer)	Accumulation mode aerosol spectra	0.1-3.0 μm
Fast-FSSP (Fast Forwarding Scattering Spectrometer Probe)	Coarse mode aerosol spectra	1 to 50 μm
CCN Counter (Cloud Condensation Nuclei)	Cloud Condensation Nuclei	0.75-10.0 μm

The aerosol flight mission of this research is to characterize the size distribution and the CCN activity obtaining the horizontal transects and vertical profile of aerosol content from minimum allowable altitude through the top of the mixed (boundary) layer the descending profile should be in a different region to characterize spatial homogeneity. CCN measurements were set continuously to the 0.5% supersaturation (SS) throughout all flight operations[6], except under certain conditions when it would be cycled through additional supersaturations of 0.2%, 0.5% and 0.8%. The aircraft had to be flying at constant altitude, out of cloud and usually below cloud base, for at least 10 minutes (the duration of the CCN supersaturation cycle)[14].

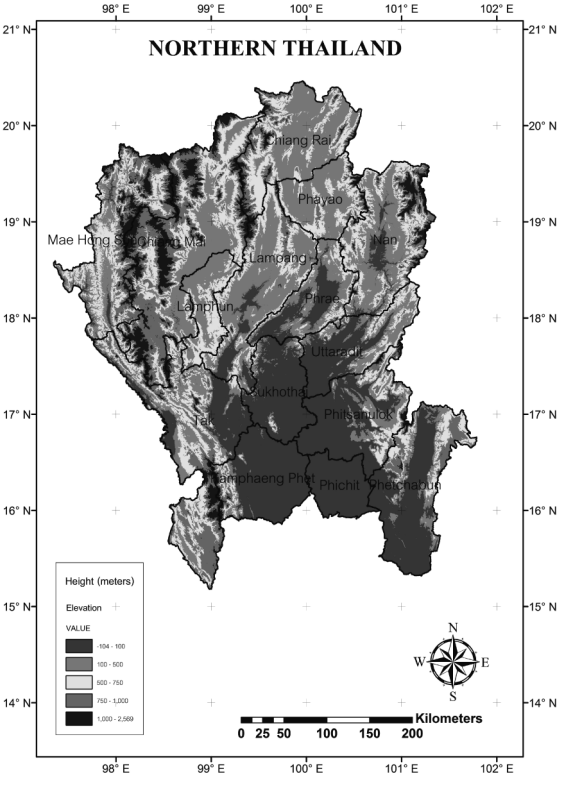

Figure 1 The study area over northern region of Thailand (18 00 N 100 00 E)

The observation were conducted over northern Thailand (Figure 1) in seven provinces including (i)Tak (TK), (ii)Lampang (LP), (iii)Phayao (PY), (iv)Chiang Mai (CM), (v)Maehongson (MH), (vi)Pichit (PC) and (vii) Uttaradit (UT), respectively in summertime period during March to May 2012 from totally 14-flights data in four constant levels; 900-1200 m, 1200-1800 m, 1800-2800 m and 2800-3900 m. There were 6 flights in March, 5 flights in April and 3 flights in May. The additional meteorological parameters for this study were observed by (1) two atmospheric observational stations of BRRAA and one station from TMD (Thai Meteorological Department) using radiosonde over the northern region, (2) three air monitoring quality stations including CM, LP and MH from Pollution Control Department (PCD) and (3) the surface wind flow were revealed by HYSPLIT back trajectory modeling.

During the observation period in summer (March–May 2012), the variation of cloud condensation level (CCL), average PM_{10}, and average surface wind flow over northern Thailand as presented in Figure 2. Also, we can describe as followed.

1. The average highest CCL was shown in March 2012 at around 3,000 m and become gradually lower in April at around 2,400 m and May at around 1,600 m, respectively (Figure 2(a)).

2. The average PM_{10} obviously exhibited the largest in March and become gradually lower in April and May, respectively (Figure 2(b)).

3. The average surface wind flow directions from radiosonde data (averaging from surface level to around 1,500 m above ground) continuously shifted from West (inland area) to Southwest (Andaman sea) during summertime accord with the result from the HYSPLIT back trajectory modeling (24 hrs back trajectory at 1,000 m above ground) as illustrated in Figure 2(c), (d).

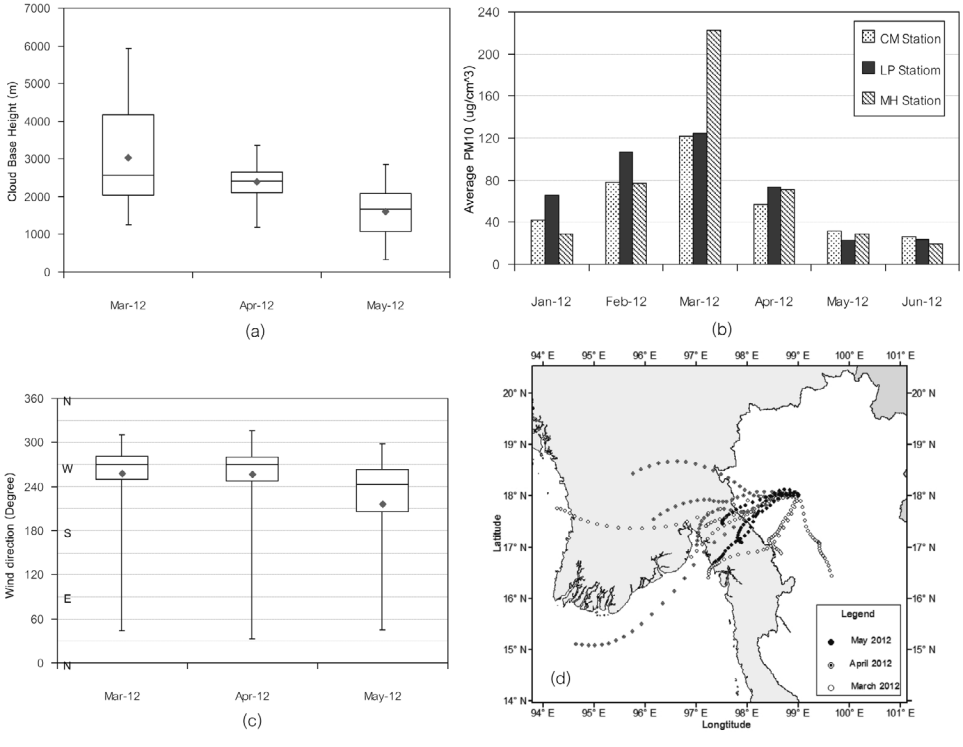

Figure 2 Show the additional meteorological parameters over northern region of Thailand (a) the Box and Whiskers plot of average CCL from three atmospheric observational stations of BRRAA (Omkoi and Phisanulok station) and TMD (CM station) (b) the average PM_{10} measurement from PCD (3 stations including CM, LP and MH) during January to June 2012. (c) The Box and Whiskers plot of average surface wind direction from atmospheric observational stations of BRRAA (Omkoi station) and (d) the surface wind flow for all 14 flights by HYSPLIT model using 24 hrs back trajectory at 1,000 m above ground.

Results and Discussion

Distribution of aerosol size

1. Aerosol size spectra in boundary layer

The full aerosol size spectra[9,26] created by combining measurements from the DMA, PCASP and FSSP (Figure 3) from minimum allowable altitude through the boundary layer which in this paper is at the altitude lower than 2800 m MSL. From the distribution of aerosol number concentration and size spectra for different months during summertime period from March to May 2012, the median spectra emphasize the tendency in March to have the strongest fine mode of aerosol particles and to have the widest spectrum broadening as well. As both of the number concentration and aerosol size spectra tend to become lower in April and May, respectively. The coarse modes, which unfortunately are merely available in March because the Fast-FSSP was malfunction, are quite low concentrations of large particles and notably only exhibit the size between 3.8 and 17.2 μm.

The main source of aerosols in March over the northern region is pollutants originated from the burning of vegetative trash in rural areas and wildfires[1], and the aerosol number size distributions are dominated with a maximum at 0.12 μm. The pollutants gradually tend to lower in April and May, respectively. On the other side, the strong Southwest wind from monsoon onset at the beginning in May have an effect on the source of aerosols. They are originated from clean air from Andaman Sea in the west of Thailand, and the size at maximum number concentration is 0.14 μm which is bigger size when comparing with the size at beginning of summer season.

The aerosol size spectra in summer season exhibits significantly in a normal distribution to the fine mode of aerosol particles, in that like individual months it has a strong accumulation mode and slightly stronger nucleation mode. Furthermore, the number concentration rapidly decreases to extremely low concentration when the particle sizes are closely 1.0 μm, and also the size ranges of particle from 2.0 to 3.0 μm are absent in summertime.

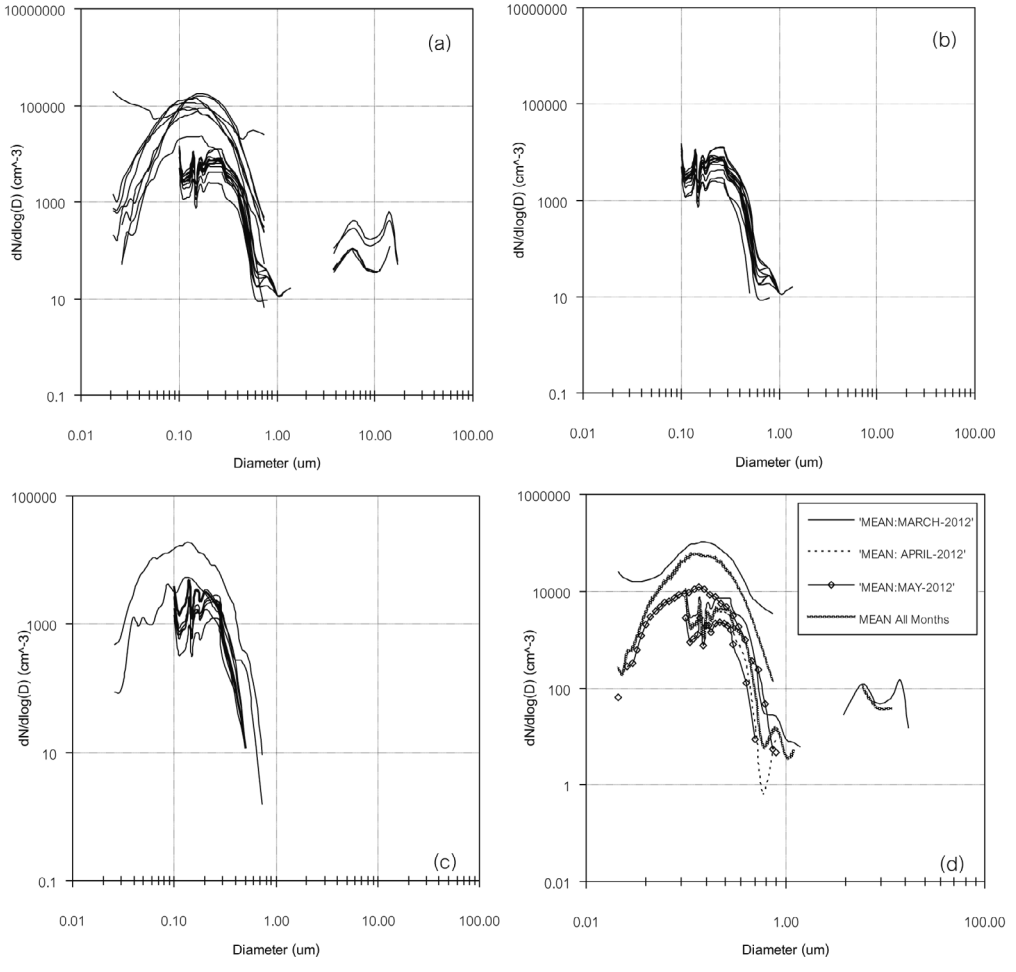

Figure 3 Aerosol size spectra for all aerosol flights in boundary layer during summer season over northern Thailand; March (a), April (b) and May (c), and the mean spectra for each month and all months (d).

2. Aerosol size spectra with altitude

In summertime over the northern Thailand, the aerosol size spectra is quite different with height from minimum allowable altitude through the top of the mixed layer that are determined in four levels; 900-1200 m, 1200-1800 m, 1800-2800 m and 2800-3900 m (Figure 4). In this study we have found that the fine mode of aerosol particles is dominated with a maximum value at the minimum altitude about 900-1200 m and almost the aerosol size at maximum number concentration is around 0.10 to 0.20 μm. Additionally, we found that the

nucleation mode of aerosols is shown the maximum number concentration near the cloud base height around 1800-2800 m, whereas the accumulation mode is shown the tendency similar to fine mode.

During the time that the coarse mode of aerosols are exhibited greatly low concentrations of large particles, the maximum value is found near the cloud base height at 1800-2800 m and their size is around 14.0 to 15.0 μm.

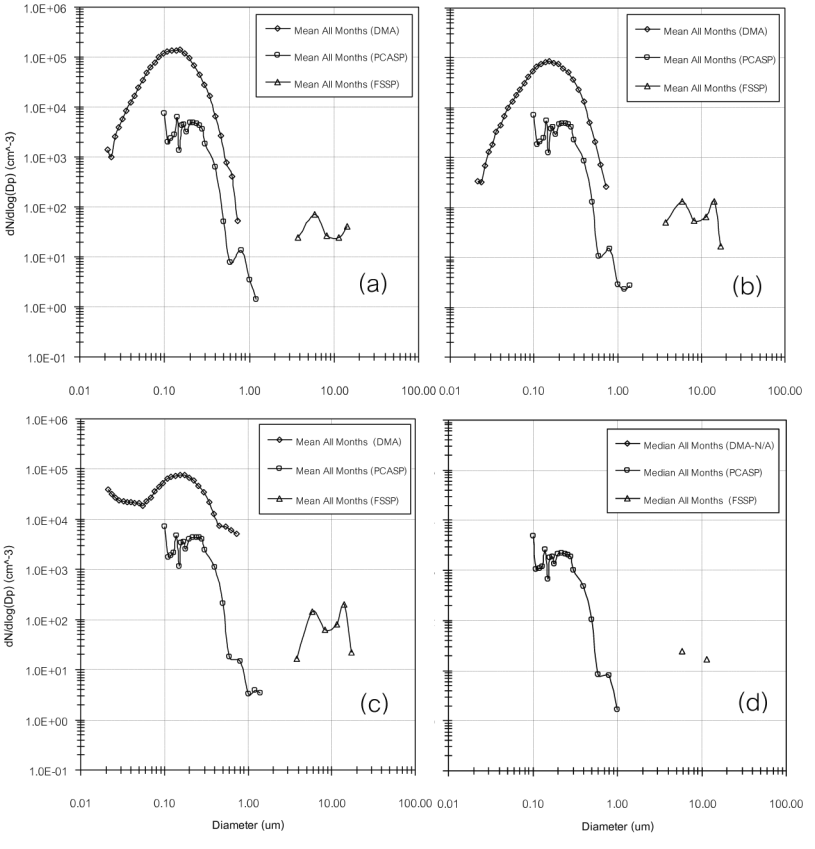

Figure 4 Aerosol size spectra during summer with four altitudes; (a) 900-1200 m, (b) 1200-1800 m, (c) 1800-2800 m and (d) 2800-3900 m

Distribution of aerosol and CCN concentrations

1. The temporal variation of average aerosol and CCN

The distribution of average number concentration of aerosol particles from PCASP (N_A) and CCN at constant SS=0.5% ($N_{CCN0.5\%}$) for different days during summer

season and provinces over northern Thailand are shown in Figure 5. Obviously, N_A is the largest in March and become gradually lower in April and May, respectively. The diameter range of observed N_A is smaller than 1.0 μm mainly in accumulation mode of aerosol particles. In March, these particles considerably come from pollutants causes a significant amount of anthropogenic aerosol and wildfires to be added to this concoction. As in May the monsoon onset established a strong wind from Southwest, the considerably aerosol is from the Andaman sea and the west of Thai peninsula.

Additionally, for $N_{CCN0.5\%}$ in March is exhibited the smallest number concentration and become higher in mid-April to May. The active aerosols in May are clearly better than in March. These imply from discussed above that there are the distinct physics and chemical characteristic at the beginning and the end of summer causes the notably variation of $N_{CCN0.5\%}$ and N_A, which are other sources in the $N_{CCN0.5\%}$ except observation aerosol were nucleation, and there are the aerosol particles less than 0.1 μm in a large proportional of aerosol size spectrum.

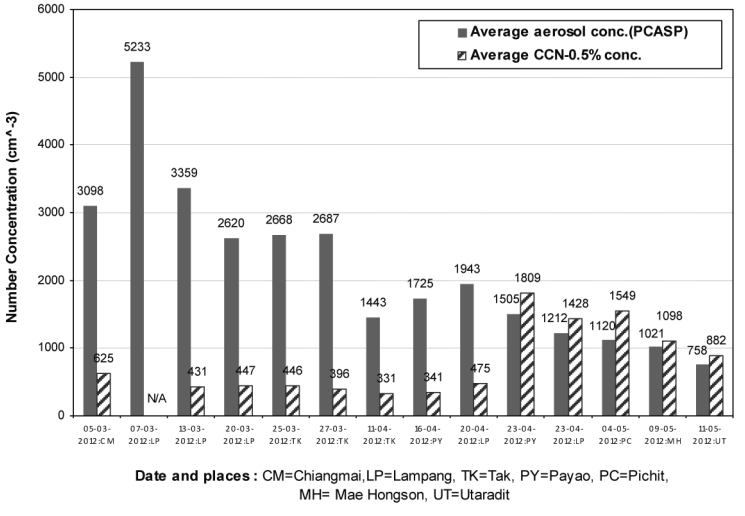

Figure 5 The temporal variation of average N_A and $N_{CCN0.5\%}$ during summer season over northern Thailand

2. The vertical distribution of aerosol and CCN

Figure 6 exhibits temporal variation of the vertical distribution of N_A and $N_{CCN0.5\%}$ (SS=0.5%) over northern region of Thailand in summer season (March – May 2012). In March, N_A was mainly concentrated on the levels from near surface to 2500 m;

however, $N_{CCN0.5\%}$ was largely concentrated on the upper levels between 2500 to 3000 m. During April and May, the N_A and $N_{CCN0.5\%}$ are mainly stronger concentration from near surface to 2500 m and decreasing with height. Interestingly in April from the observations we have found the variations of $N_{CCN0.5\%}$ are shifting from lower to higher concentration since around mid-April. From above result suggests that the aerosol count at higher altitudes in summer season over north region is usually very low concentrations [27] and the main source of CCN is near the altitude of cloud bases according to the average cloud base altitude (CCL) in each month as Figure 2(a).

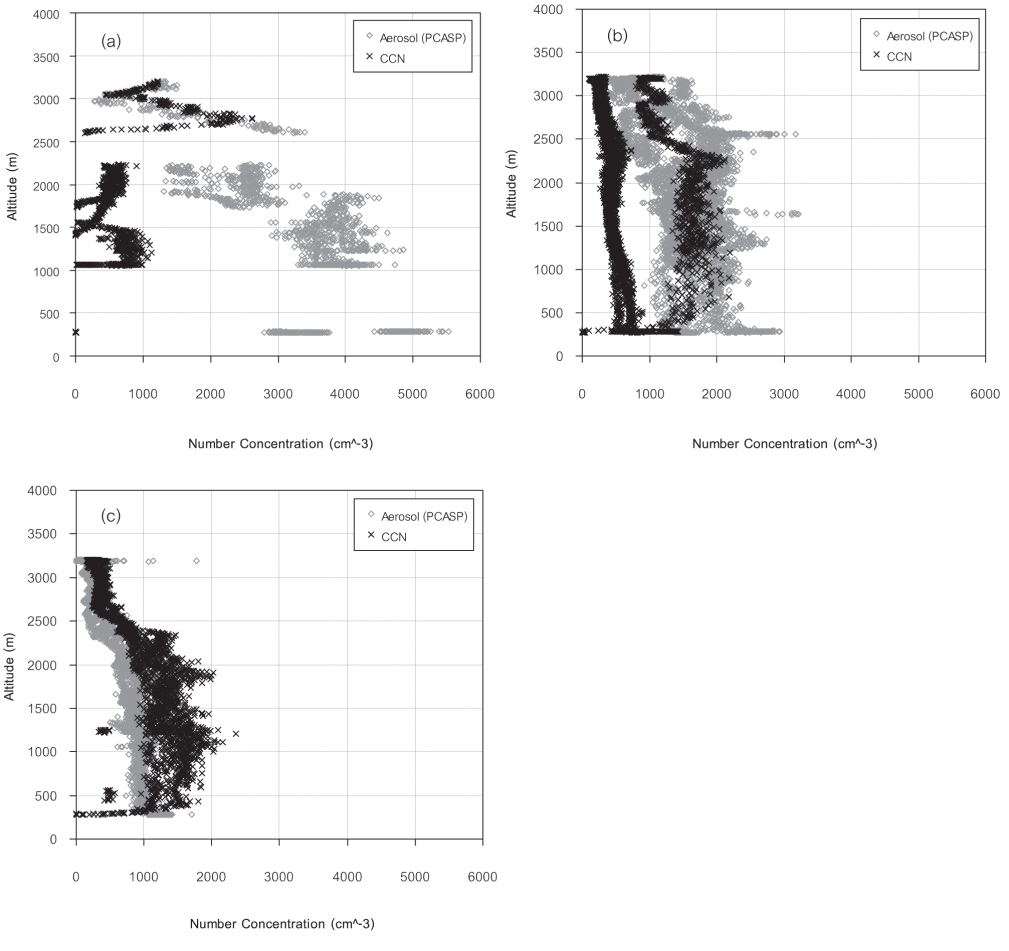

Figure 6 The vertical distributions of aerosol and CCN concentration for each month in summer season; (a) March, (b) April and (c) May 2012.

3. CCN activation ratios and their relationships

To investigate possible monthly trends in summer season over northern Thailand, time series of aerosol particles from PCASP (N_A) and CCN concentrations at supersaturation 0.5% ($N_{CCN0.5\%}$), and the activated fraction ($N_{CCN0.5\%}/N_A$)[6] were evaluated statically and each flight median and mean value were calculated. The activated ratio in daily flights are listed in Table 2 for SS=0.5%, representing an average case in the range of measured super-saturations. The observations exhibit a monthly pattern with minimum CCN concentration in March and maximum concentrations in May during summertime. It is apparent that the activated fraction has changed from mid-April and also maximum in May (Figure 7). The changes in proportional of CCN are related to changes in aerosol properties. Hence, from the mid-April to May particles are more hygroscopic and CCN active than in March[28].

Table 2 Daily flight averages of CCN concentration and activated fraction ($N_{CCN0.5\%}/N_A$) measured from PCASP-100X and CCN counter, over northern Thailand in summer season (March 2012- May 2012). The data are for constant super-saturation at 0.5%.

Date	Provinces	N_A [cm^-3]	N_{CCN} [cm^-3]	Activated fraction
05-Mar 2012	CM	3098	625	0.20
07-Mar 2012	LP	5233	N/A	-
13-Mar 2012	LP	3359	431	0.13
20-Mar 2012	LP	2620	447	0.17
25-Mar 2012	TK	2668	446	0.17
27-Mar 2012	TK	2687	396	0.15
11-Apr 2012	TK	1443	331	0.23
16-Apr 2012	PY	1725	341	0.20
20-Apr 2012	LP	1943	475	0.24
23-Apr 2012	PY	1505	1809	1.20
23-Apr 2012	LP	1212	1428	1.18
04-May 2012	PC	1120	1549	1.38
09-May 2012	MH	1021	1098	1.08
11-May 2012	UT	758	882	1.16

All values are at super-saturation SS=0.5% ; N/A= Not available data

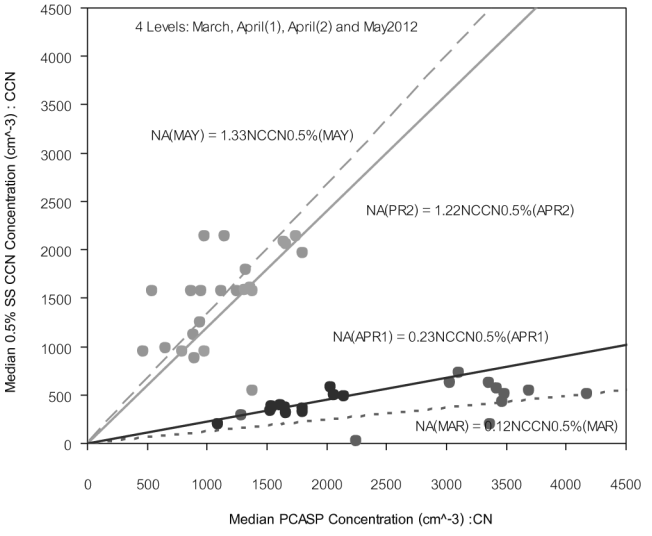

Figure 7 Median of measured N_A vs. $N_{CCN0.5\%}$ and their monthly relationships; Mar (Dotted), Apr (1; 1-20 Apr 2012)-Apr (2; 21-31 Apr 2012) (Solid) and May (Dash)

Conclusions

In this study we have presented the physical aerosol and CCN characteristics from 14 flights of research Super King Air aircraft during summer season in 2012 over Northern Thailand. The full aerosol size spectra have been measured with the DMA, PCASP and FSSP as they have been presented by combining all measurements, as well as aerosols and CCN number size distribution and their relationship have been measured with PCASP and CCN counter using SS=0.5% as they have been presented in temporal variation, vertical distribution and activated fraction.

The result show that the median aerosol size spectra in boundary layer emphasize the tendency to have the strongest fine mode of aerosol particles (Diameter < 1.0 um) and to have the widest spectrum broadening in March as well. The coarse modes are quite low concentrations of large particles and notably only exhibit the size between 3.8 and 17.2 μm. As both of the number concentration and aerosol size spectra tend to become lower in April and May, respectively.

According to the observation of aerosol size spectra changes with altitude, the fine mode of aerosol particles is dominated with a maximum value at the minimum altitude about 900-1200 m and almost the aerosol size at maximum concentration is around 0.10 to 0.20 μm. The nucleation mode of aerosols is shown the maximum concentration near the cloud base height

around 1800-2800 m, whereas the accumulation mode is shown the tendency similar to fine mode. Finally, the coarse modes are exhibited extremely low concentrations of large particles, the maximum value is found near the cloud base height around 1200-1800 m and their size is around 14.0 to 15.0 μm.

It is clear that in March, an important observation is that pollution events are characterized by an increased contribution in fine aerosol, which is mainly in accumulation mode and become gradually lower in April and May. Conversely, $N_{CCN0.5\%}$ is exhibited the smallest concentration in March and become higher from mid-April to May. The availability of $N_{CCN0.5\%}$ is more than N_A because there are other sources in the $N_{CCN0.5\%}$ except observation aerosols were nucleation which is in a large proportional of aerosol size spectrum. It is consistency to activated fraction (N_{CCN}/N_A) variation in daily flights during summertime that the active aerosols in May are clearly better than in March. It is exhibited that there are the different physics and chemical characteristic of aerosol between the beginning and the end of summer owing to the sources of aerosol particles. At the beginning of summer in March, the sources of aerosol are pollutants from agricultural trash burning and wildfires, whereas at the end of summer a strong southwesterly wind is established; thus, the sources of aerosol are cleaner air from the Andaman Sea and the west of Thai peninsula.

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