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Long-term monitoring of condensation nuclei concentrations at Syowa Station, Antarctic

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Abstract: Concentrations of condensation nuclei (CN) with diameters larger than 10 nm and 7 nm have been measured using condensation particle counters at Syowa Station, Antarctica during the periods of May 1997 – January 2017 and January 2014 – December 2021, respectively. Herein, we present long-term CN records obtained at Syowa Stations. Data including local contamination and errors were screened for scientific usage. The daily mean and hourly mean CN data after the screening are provided.

1. Background and Summary

Antarctic regions are isolated from the human activities which occur in low and middle latitudes. In fact, they are the cleanest areas on Earth. However, atmospheric aerosols are present even in the Antarctic troposphere. Therefore, air quality of the Antarctic troposphere is monitored appropriately as representing "background conditions" or "pristine conditions". Atmospheric aerosols, which are related closely to atmospheric chemistry[1, 2] and climate change[3], are supplied and derive in the Antarctic troposphere through (1) secondary aerosol formation including new particle formation from aerosol precursors emitted from oceanic bioactivity and snowpack chemistry,[4–12] (2) primary emissions of sea-salt aerosols from sea-ice surface via snow erosion and ocean surface by bubble bursting[2, 13–16], and (3) long-range transport from desert, anthropogenic combustion, and biomass burning in the middle latitudes and low latitudes[17–20]. Condensation nuclei (CN) have been measured in the Antarctic to elucidate aerosol systems and their effects on climate and atmospheric chemical processes there.

Long-term and temporal CN measurements have been made at Syowa[4, 18, 21, 22], Neumayer[23-25], Mawson[26], Troll[6], and the South Pole[6, 25, 27]. Moreover, CN measurements started recently at other stations such as King Sejong[10, 11]. Using CN data, earlier works have elucidated new particle formation[21, 28], long-term trends[25], aerosol volatility[7, 29], and Antarctic haze phenomena[18, 30]. Additionally, CN data measured in the Antarctic were used as tracer and proxy data for local contamination from the station itself. Here, we present monitoring data of CN concentrations measured at Syowa Station, Antarctica since 1997.

2. Location and Measurement

The CN measurements were conducted at Syowa Station, Antarctica (69.005°S, 39.591°E, 20 m above sea level). Syowa Station has been located on East Ongul Island in Lützow-Holm Bay, Antarctica since January 1957 (Figure 1a). East Ongul Island, which is ca. 5 km distant from coastline of the Antarctic continent, is usually surrounded by multi-year sea-ice (i.e. fast ice). However, sea surface appears occasionally not only in summer by melting of sea-ice but also slightly in winter by breaking of sea-ice resulting from approaching cyclones. The distance between Syowa Station and the sea-ice margin is approximately 100 km in February–March and 1000 km in September–October. Although sea-ice is usually present around Syowa Station year-round, the island land surface appears after snows melt during summer (mainly January). The main area of Syowa Station is located in the northern area of the East Ongul Island. The atmospheric observatory and the clean air observatory are easterly ca. 150 m and ca. 400 m, respectively, from the main area, which has a diesel power station (Figure 1b). As is true also for other Antarctic stations[31], winds blow from the prevailing wind direction (NNE – ENE) at Syowa Station through the year because of the dominance of katabatic winds. Therefore, the air quality near surface at Syowa Station is affected strongly by katabatic winds (i.e. outflow from the continent). Characteristics and statistics related to the meteorology at Syowa Station were explained in earlier work by Sato and Hirasawa[32].

CN concentrations have been measured using a condensation particle counter (CPC) as part of aerosol monitoring at Syowa Station, Antarctica since April 1997. Aerosol measurements were conducted at the atmospheric observatory from May 1997 to January 2004. Because a new observatory, the clean air observatory, was built in January 2004, the in-situ aerosol measuring site changed from the atmospheric observatory to the clean air observatory in February 2004. CPC-3010

(TSI Inc.) and CPC-3783 (TSI Inc.) were used for CN measurements (Figure 2). CPC-3010 was operated from 00UT (Universal Time) on 1 May 1997 till 09UT on 22 January 2017. CPC-3783 has been operated since 05UT on 23 December 2013. Because maintenance and calibration of CPC-3010 by the manufacturer were halted, CPC-3010 was replaced by CPC-3783. CN concentration has been recorded every minute. For CN measurements in CPC-3010 and CPC-3783, 1-butanol and H_2O were used respectively as vapors for particle growth. Measurable size ranges are D_p >10 nm for CPC-3010 and D_p >7 nm for CPC-3783. Flow rates were 1.0 L min^{-1} in CPC-3010 and 0.6 L min^{-1} in CPC-3783.

During April 1997 – January 2004, the air intake was placed at the northeastern corner of the atmospheric observatory. The inlet was located approximately 5 m above the ground. Air was taken into the interior of the observatory using a ca. 3-m-long polymer tube (Uni-tube, Nippon Rikagaku Kikai Co. LTD.) with respective inner and outer diameters of 6 mm and 12 mm. The sampled air was distributed to CPC and other instruments using the same tube with length within 1 m. Since February 2004, the air inlet tower has been located at the northern side of the clean air observatory[33]. The air intake was located approximately 5 m above the ground. Air is taken into the observatory via a stainless tube with the respective inner and outer diameters of 96 mm and 100 mm; a sirocco fan maintained the current speed of 2–3 m s^{-1} in the stainless tube (ca. 870 L min^{-1} at flow speed of 2 m s^{-1}). Comparison with simultaneous CN measurements in the ambient air using tethered balloon measurements[28] indicated that particle loss by the inlet and tubes was estimated to less than 1–2 % for CN measurements in this study. In addition, simultaneous CN measurements at the atmospheric observatory and the clean air observatory showed insignificant difference (less than 2%). This difference was approximately same as inter-comparison of CPC measurements for simultaneous measurements as stated in the Section 5. Therefore, the particle loss by the inlet and tubes might be insignificant in CN measurements in our measurements. The sampled air was distributed into each instrument using conductive tubes with respective inner and outer diameters of 4.8 mm (0.19 inch) and 9.5 mm (0.375 inch) for CPC measurements. Instruments were operated inside the observatory at the room temperature (ca. 20 °C). Therefore, CN concentrations were measured under conditions of lower relative humidity than 10 % (i.e., dry condition).

3. Data analysis

At Syowa Station, prevailing winds were from the Antarctic continent because of katabatic winds. Aerosol data were clean under the prevailing wind conditions, with no mobile contamination source such as snow vehicles windward of the observatory. Strong local contamination, however, can occur in aerosol data in cases of (1) winds coming from main area of the station, (2) diffusion of contaminated air in calm or weak wind conditions, and (3) in the presence of mobile contamination sources in the windward of the observatory. The local contaminated data must be removed before data are used for scientific research.

The CN concentrations are very sensitive to local contamination. Therefore, variations of CN concentrations are useful as a proxy for local contamination. To identify local contamination events, 10-min mean CN concentrations, standard deviation, and relative standard deviation were calculated from raw CN data with 1 min resolution. When winds come from the direction of 180–330° (i.e. contaminable sector) and when wind speeds were less than 2 m s^{-1}, the 10-min mean CN data were removed as "local contaminated data" or "contaminable data". Wind data (speed and direction) provided by the Japan Meteorological Agency were used for data screening. Because operation of mobile and temporal contamination sources such as snow vehicles in the windward of the observatory can cause local contamination in aerosol data, the 10-min mean CN data were also screened in cases for which the relative standard deviation was larger than 10% under conditions with wind speed of less than 15 m s^{-1}. Operation of snow vehicles was not permitted during strong winds with blowing snow because of safety guidelines at Syowa. Additionally, stronger winds came from the prevailing wind direction (mainly 0–80°: clean air sector). In cases of wind speeds greater than 15 m s^{-1}, therefore, the CN data were retained as "non-locally contaminated", even if the relative standard deviation was greater than 10%.

4. Data Records

CN records each year were listed in the respective files. Data fields in daily mean and median are shown in as follows.

Date: Universal time (UT) was used in the CN records. Difference between UT and local time (LT) was 3 hours (LT = UT + 3 hours).
Amb_Median: CN concentrations (unit: cm^{-3}) in ambient air pressure
STD_Median: CN concentrations (unit: cm^{-3}) in standard condition (0 °C and 1 atm)
Amb_Mean: CN concentrations (unit: cm^{-3}) in ambient air pressure
STD_Mean: CN concentrations (unit: cm^{-3}) in standard condition (0 °C and 1 atm)

Data fields in hourly mean are shown in as follows.
Date time UT: Universal time (UT) was used in the CN records. Difference between UT and local time (LT) was 3 hours (LT = UT + 3 hours).
Amb_Mean: CN concentrations (unit: cm^{-3}) in ambient air pressure
STD_Mean: CN concentrations (unit: cm^{-3}) in standard condition (0 °C and 1 atm)

Term of "NA" in the data files indicates no CN data due to mechanical troubles and local contamination.

5. Technical Validation

CPC-3010 was operated at Syowa Station from May 1997 through January 2017. CPC-3783 has been used since January 2014 (Figure 3). For comparison between CPC-3010 and CPC-3783, simultaneous measurements were conducted from January 2014 through January 2017 (Figure 4). Because of differences in cut-off sizes (i.e. minimum measurable sizes) in the CPCs, CN concentrations measured using CPC-3783 were varied occasionally at higher concentrations than those by CPC-3010, although the CN concentrations mutually matched well. Indeed, high correlation between CN concentrations measured by CPC-3010 and those by CPC-3783 was found in daily mean and daily median CN concentrations (Figure 4), as follows.

$$\text{Daily mean: } [CN]_{3783} = 0.9643[CN]_{3010} + 19.06 \quad R^2 = 0.8907$$

$$\text{Daily median: } [CN]_{3783} = 0.9819[CN]_{3010} + 7.57 \quad R^2 = 0.9217$$

$[CN]_{3783}$ and $[CN]_{3010}$ mean respectively CN concentrations measured by CPC-3783 and CPC-3010.

To verify the CPC conditions, flow rates and zero counts were measured once–twice a month. For CPC maintenance, CPC was changed every summer in cases without mechanical troubles. Before replacing CPC, simultaneous measurements were made for one to two weeks to confirm measurement error within ±2% in most cases. For inter-comparison, CN concentrations were measured using each CPC under almost identical conditions such as tube length and bend. The CPC returned to Japan was maintained and calibrated by the manufacturer.

6. Competing interests

The authors declare that they have no conflict of interest.

7. Figures

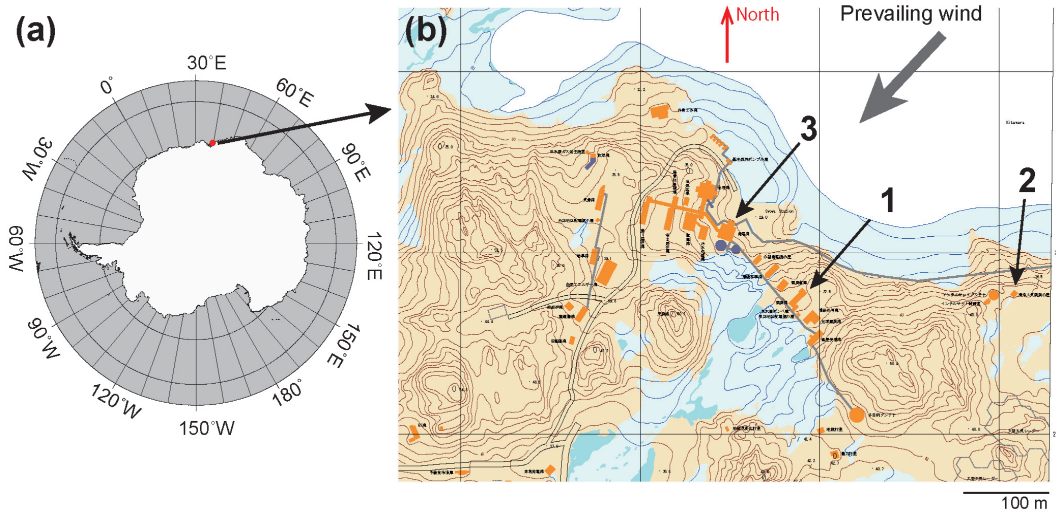

Figure 1. (a) Location of Syowa Station, Antarctica and (b) locations of the atmospheric observatory, clean air observatory, and diesel power station at Syowa Station. The red circle in (a) shows the location of Syowa Station. Buildings marked as 1, 2, and 3 in (b) are the respective locations of atmospheric observatory, clean air observatory, and diesel power station. Red and gray arrows respectively directions of the north and prevailing wind shown by Sato and Hirasawa[32]. The map in (b) was provided by Geospatial Information Authority of Japan (GSI: https://www.gsi.go.jp/antarctic/index-e.html)

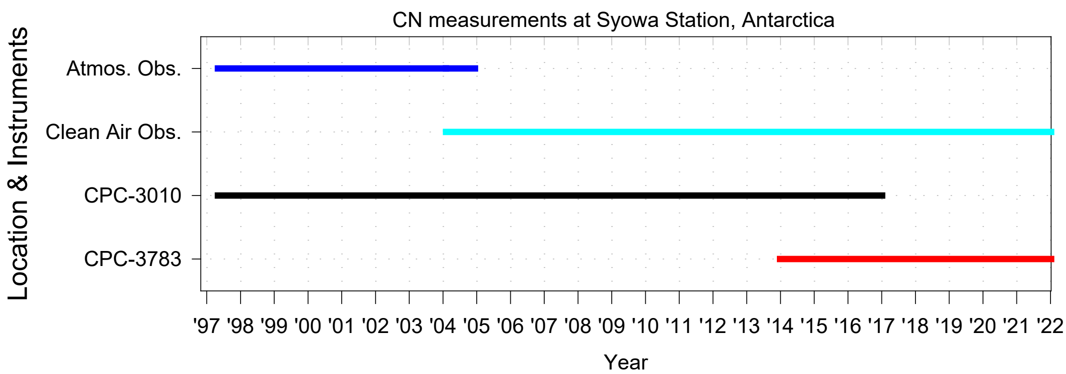

Figure 2. Periods of measuring locations and CPCs used for CN measurements at Syowa Station from April 1997.

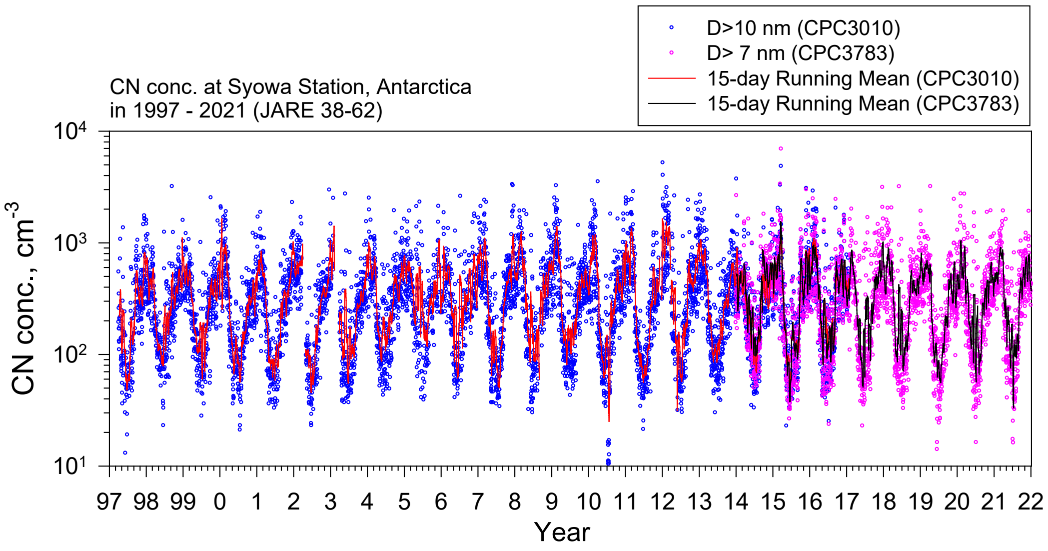

Figure 3. Long-term variations of daily mean CN concentrations at Syowa Station, Antarctica since April 1997.

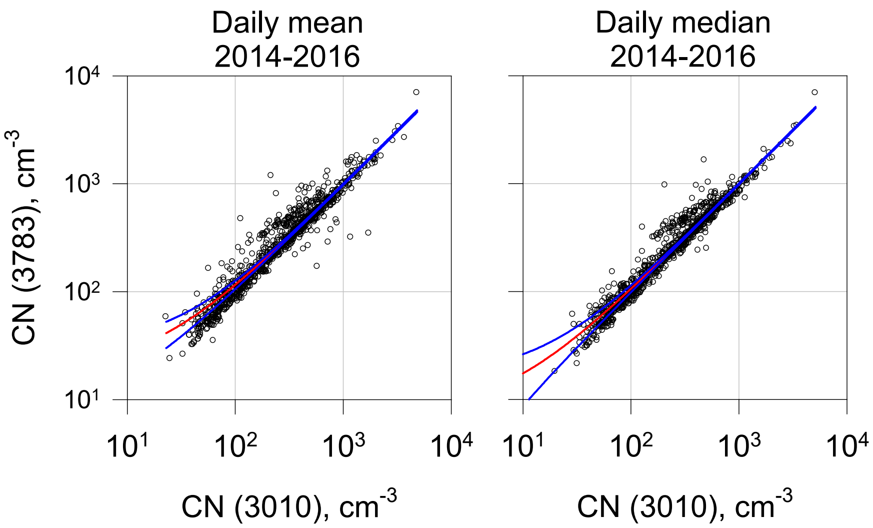

Figure 4. Relation between CN concentrations measured by CPC-3010 and those by CPC-3783 during 2014–2016. Red and blue respectively represent regression lines and 95% confidence band.

Author contributions

KH did Conceptualization, Data, Curation, Formal analysis, Investigation, Writing - Original Draft, and Visualization. KO did Conceptualization, Data, Curation, Formal analysis, and Investigation. MY did Data Curation and Investigation. MH did Conceptualization and Investigation. MS did Project administration and Funding acquisition. NH did Data Curation and Funding acquisition. TY did Conceptualization, Project administration and Funding acquisition.

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