MEASUREMENT OF NATURAL ICE NUCLEI BY CONTINUOUS-FLOW THERMAL-DIFFUSION-CHAMBER TYPE ICE NUCLEUS COUNTER

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1. INTRODUCTION

Ice crystals play an important role in precipitation processes and affect precipitation forecast. Ice crystals also determine microphysical and radiative properties of clouds and affect the earth's climate system through modulations of coverage and life of clouds and precipitation distributions. Therefore, understanding of activation processes of natural ice nuclei and knowledge of spatial and temporal distributions of ice nuclei are very important from the viewpoint of both short range precipitation forecast and climate change prediction.

Studies on ice nuclei have been continued for more than 60 years, However many things remain unsolved.

The cloud physics group of MRI (Meteorological Research Institute) has been studying ice initiation processes through field observation, laboratory experiment and numerical modeling for many years. As a part of the study, we built a Continuous Flow Diffusion Chamber (CFDC) based on the design of Rogers et al. (1988, 2001) at Colorado State University, USA and have improved it to operate automatically.

This paper describes the performance of MRI-CFDC through examples of measurements on activation spectrum of ice nuclei in the atmosphere and test aerosol particles prepared during the International Workshop on Comparing Ice Nucleation Measurement Systems (ICIS-2007).

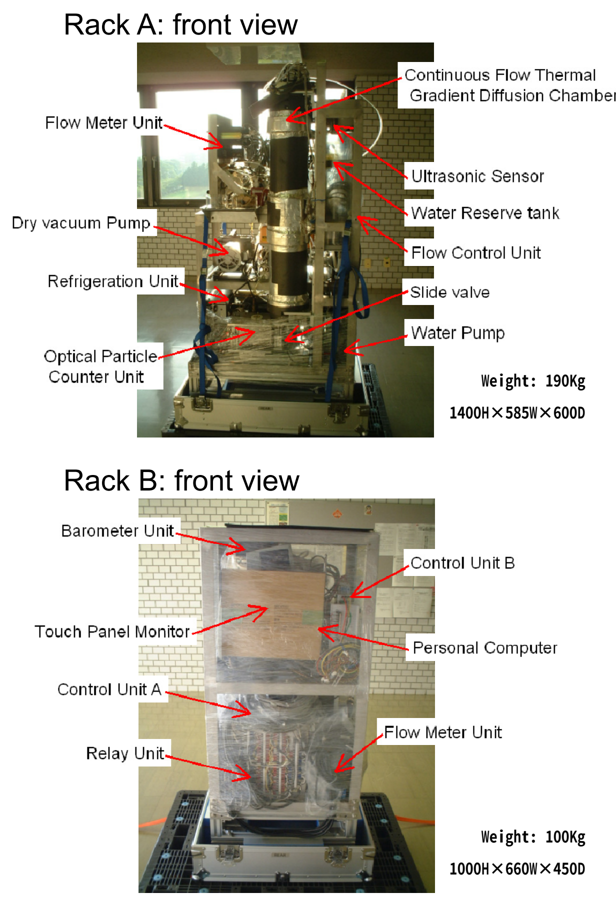

Figure 1.Rack mount arrangement for MRI-CFDC instrument.

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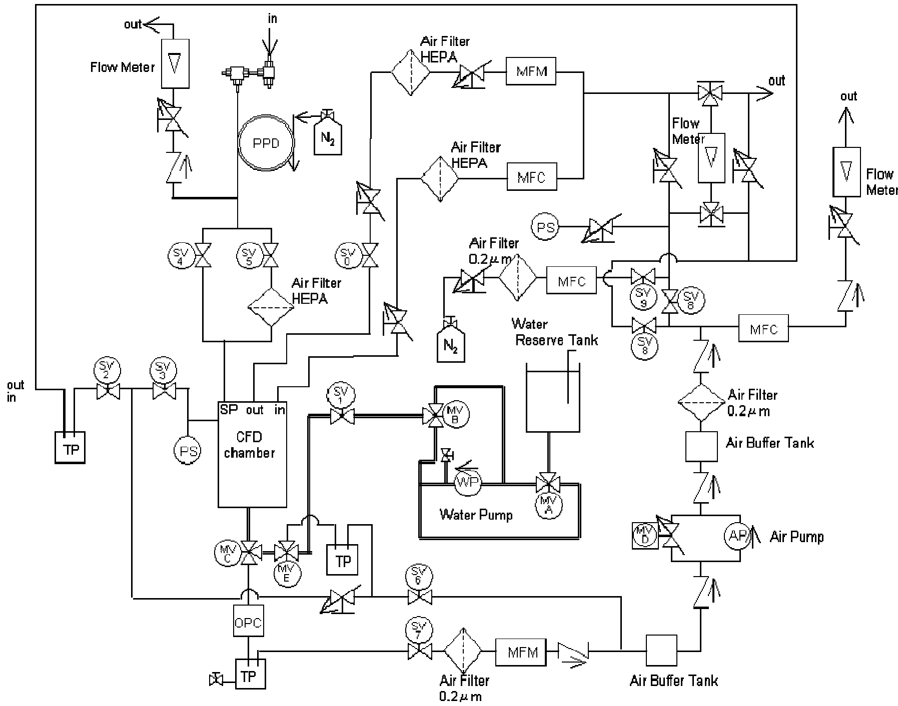

Figure 2. Airflow and waterflow diagram of MRI-CFDC

2. APPARATUS DESCRIPTION

We built a Continuous Flow Diffusion Chamber (CFDC) based on the design of Rogers et al. (1988, 2001) at Colorado State University, USA and have improved it to operate automatically. Main improvements are

1) decreasing heat inertia of inner cylinder so as to control wall temperatures more quickly.
2) automatic measurement of temperature and supersaturation spectrum of ice nuclei activation for a fully-automated operation and efficient measurement of activation spectrum.
3) automatic procedure to ice cylinder walls for a fully-automated operation.

Figure 1 shows the rack mount arrangement for MRI-CFDC instrument.

Airflow and waterflow diagram of MRI-CFDC is shown in Figure 2. Specifications of MRI-CFDC are as follows.

- Sample flow rate is 1.0L/min.
- Temperature range is -10℃ ~ -35℃.
- Humidity range is from RHi = 100% to RHw = 110%.
- Particle detector is OPC (0.5~8 μm).
- Inlet impactors remove particles > 1 μm or > 2 μm.
- Nucleated ice particles are determined by size > 2.5 μm or > 3 μm, respectively.

It is possible to control temperature and humidity of the sample air by controlling ice-coated wall temperatures of inner and outer cylinders. Figure 3 shows the time series of temperatures of warm and cold wall and temperature, SSi and SSw of sample air

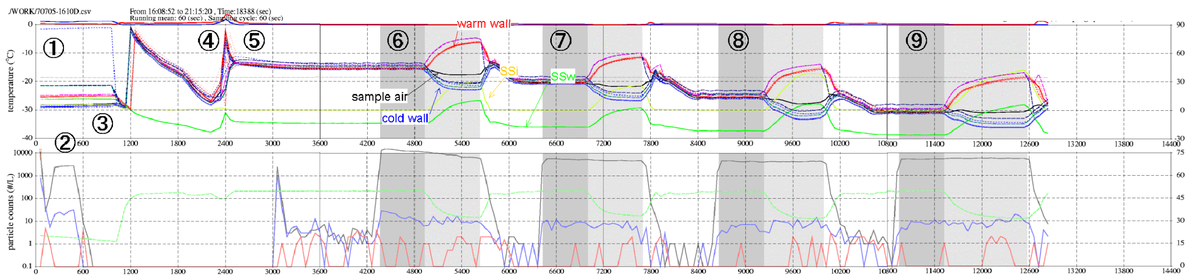

Figure 3. Time series of temperatures of warm wall, cold wall and sample air, SSi, SSw (upper panel), number concentrations of particles with d < 3 μ m, 3 μ m < d < 8 μ m, d > 8 μ m, and fractional distance of sample air from cold wall (lower panel).

(upper panel), number concentrations of particles with d < 3 μ m, 3 μ m < d < 8 μ m, d > 8 μ m, and fractional distance of sample air from cold wall (lower panel). Measurements of ice nuclei activation spectrum at 4-5 different temperatures and in the humidity range of RHi=100% to RHw=110% were automatically made within 2-3 hours.

The numbers in Figure 3 indicate the automated procedures for the measurements of ice nucleus activation spectrum:

① Initialization of airflow rate and valve setting
② Introduction of the sample (1L/min) and sheath air (9L/min)
③ Measurement of the background noise
④ Icing walls
⑤ Preparation for the measurement
⑥ Target temperature: -15℃
⑦ Target temperature: -20℃
⑧ Target temperature: -25℃
⑨ Target temperature: -30℃

3. MEASUREMENTS

Example of ground-based measurements of aerosol particles and ice nuclei in the summer of 2007 in Japan is shown in Figures

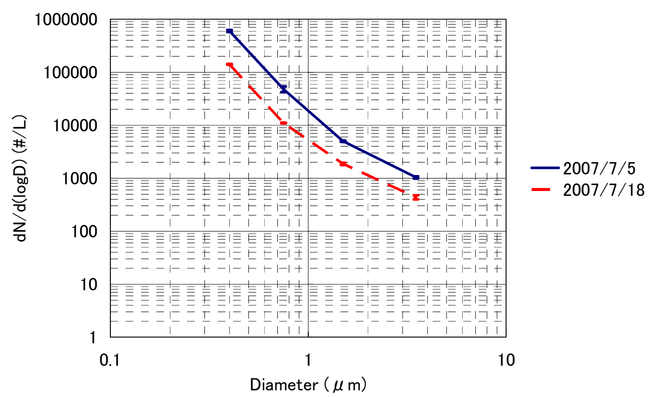

Figure 4. Aerosol size distributions on July 5th and July 18th.

4 and 5. Figure 4 shows size distributions of aerosol particles ranging from 0.3 to 5 μ m on 5th and 18th July 2007. Figure 5 shows the number concentrations of activated ice nuclei as a function of temperature and supersaturation with respect to water. Although ice nuclei tend to increase with decreasing temperature and increasing relative humidity in general, the temperature dependency of ice nuclei on 18th July is stronger than that on 5th July. Figure 6 shows that the relationship between the concentrations of ice nuclei activated at water saturation and the total number concentrations of aerosol particles in July 2007. The difference in the temperature dependency of activated ice nuclei concentra-

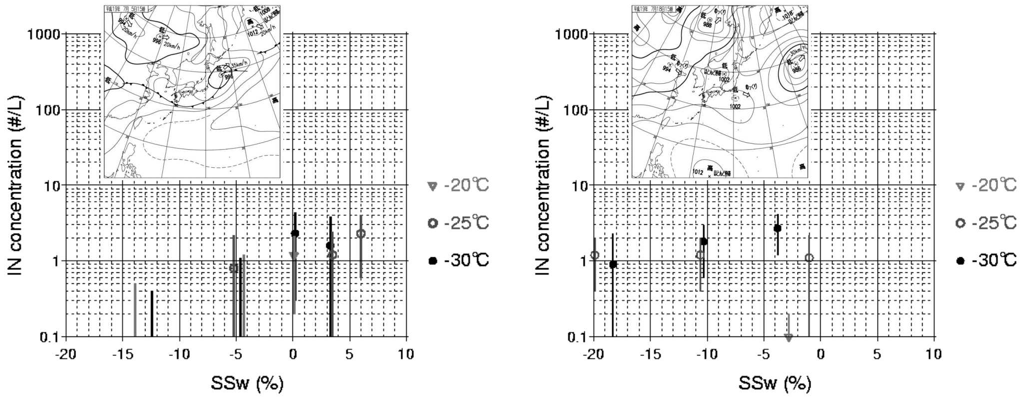

Figure 5. Ice nuclei activation spectrum and weather chart (left: July 5th, right: July 18th).

tions on 5th and 18th July is clearly shown in Figure 6. The remarkable changes in aerosol concentrations and ice nuclei activation spectrum occurred on July 15th. Before July 15th, the observation site was located on the north side of the seasonal rain front, and a tropical cyclone passed through the observation area on July 15th and brought maritime air mass to the area (Figure 5).

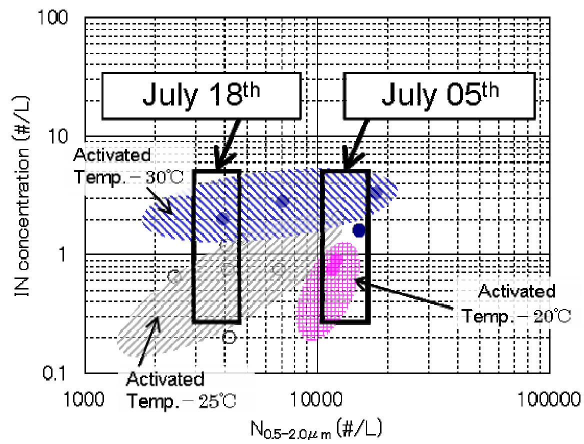

Figure 6. The relationship between the concentration of ice nuclei with water saturation and the total number of aerosol particles in July 2007.

We attended ICIS-2007, which was held at the AIDA facility of the Institute for Meteorology and Climate Research (IMK-AAF) at Forschungszentrum Karlsruhe, Germany in September 2007, for the purpose of comparison among our automated CFDC ice nucleus counter and other group's ice nucleus counters. During the ICIS-2007 workshop, we measured high concentrations of aerosol particles from aerosol chamber (NAUA) and aerosol particles with much less concentrations from cloud simulation chamber (AIDA). Their physical and chemical properties were well characterized. Figure 7 shows the activated fraction of sub-micron Arizona Test Dust (ATD) particles. ATD particles began to be activated at -25 ℃ through condensation-freezing nucleation mode. At -35℃ they began to be activated at 93% of relative humidity with respect to water through deposition nucleation mode, and showed a rapid increase in concentrations of activated ice nuclei beyond water saturation, which is probably due to the transition from deposition to condensation-freezing mode. Figure 8 shows the conditions (temperatures and RHi) for which 0.01% (0.0001 fractions) of aerosol particles was activated for ATD and bacteria

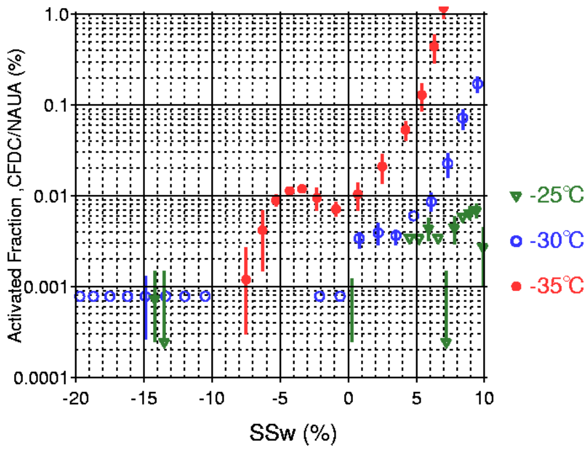

Figure 7. Activated fractions of ATD as a function of temperature and supersaturation with respect to water.

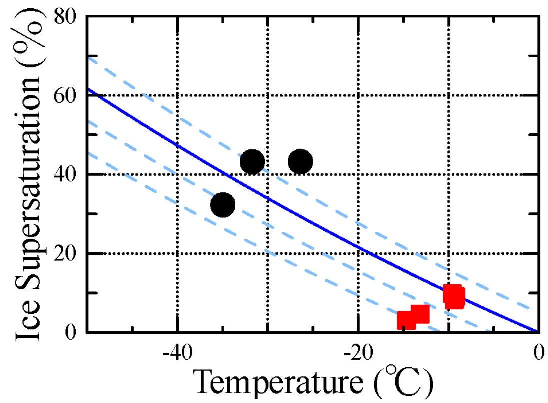

Figure 8. Conditions (temperature and ice supersaturation) for which 0.01% activation of particles was activated for ATD (black dots) and Snomax® (red squares).

(Snomax®). Snomax® particles were easily activated through condensation-freezing mode at temperatures as warm as -9℃ and started to be activated through deposition mode at temperatures colder than -12℃.

4. CONCLUSIONS

Ground-based measurements in summer time in Japan showed that the concentration of natural ice nuclei activated under the condition of water saturation was about one particle per liter at -20℃, and ten particles per liter at -30℃. The concentrations of activated ice nuclei increase with decreasing temperature and with increasing relative humidity.

On the other hand, laboratory measurements during ICIS-2007 workshop showed aerosol type dependency of activation spectrum and a rapid increase in concentrations of activated ice nuclei beyond water saturation, which is probably due to the transition from deposition to condensation-freezing mode.

Thus it appears that MRI-CFDC can measure ice nuclei for identifying and quantifying the mechanism of the ice initiation. And our future plan includes the followings.

1) Calibrating the relative humidity that MRI-CFDC produced in sampling air flow.
2) Discriminating ice particles from water droplets.
3) Enhancing refrigeration ability.
4) Using it for continuous ground-based measurements and aircraft measurement and for simultaneous measurements with MRI dynamic cloud chamber.

ACKNOWLEGEMENTS

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