Comparison of Two Acoustic Ice Nucleus Counters

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Abstract. Two acoustical ice nucleus counters (a.k.a. "NCAR counters") were compared at the Weather Modification, Inc. facilities in Fargo, ND, 17 – 19 September 2007. One counter was one of three built by NCAR in 1976 based on the design of the inventor (and one of the authors, Langer), and is traceable to the Colorado State University Cloud Simulation and Aerosol Laboratory. The other counter was built for WMI in 2006 by the first author. The purpose of the comparison was to document the reliability and reproducibility of the devices under controlled conditions. Both counters were brought to operating specifications, then comparisons were run using two types of AgI aerosols sampled through a common source: AgI-NH_4I-acetone and AgI-NH_4I-$C_6H_4Cl_2$-$NaClO_4$-acetone. The former was assumed to produce contact nuclei and the latter fast-acting condensation-freezing nuclei. The counters showed close agreement to within a factor of 1.04 to 1.66, depending on the type of AgI aerosol. Times to first indication of plume encounters were on the order of 20 to 30 s depending on the concentration of nuclei, and the instrument-induced smoothing of plume encounters were similar. The results indicate that these devices can provide similar quantitative measurements of different AgI ice nuclei, not merely yes/no indications of AgI presence.

1. INTRODUCTION

Adequate targeting of glaciogenic seeding material has been recognized to be a major problem in winter orographic cloud seeding (Rango 1986, Reynolds 1988, Super 1990, Warburton et al. 1995). Without the assurance that the proper cloud zones are treated with appropriate concentrations of effective AgI ice nuclei (IN), experimental and operational results are questionable. One device available to track AgI IN is the acoustic counter invented by one of the authors (Langer 1973). It is also known as the "NCAR counter" after the location where it was developed in the mid 1960s, the National Center for Atmospheric Research. This instrument continuously draws approximately 10 L min^{-1} through a humidifier to moisten the sampled air. The airflow is mixed with approximately 2 L min^{-1} from an atomizer, which produces abundant cloud condensation nuclei (CCN) from a saline solution. The combined air streams flow through a cloud chamber that chills the resulting supercooled liquid water cloud to approximately -20°C. In this environment AgI will produce ice embryos, which grow rapidly to the 20 µm minimum size needed for detection. The resulting crystals are detected by drawing the sample through a capillary tube that produces an audible signal sensed by a microphone. Formation of frost in the cloud chamber is prevented by wicking ethylene glycol through a felt lining. The counter requires about 1 min to detect most AgI, with some being detected within ~25 s. The reader is referred to Langer et al. (1967) for an early airborne application of the acoustical ice nucleus counter (hereafter AINC) and to Langer (1973) for further details of the counter's specifications and operation.

During the summer and fall of 2006, an AINC was built for Weather Modification, Inc. (WMI) by the first author. To the best knowledge of the authors, this is the first new AINC built since 1976 when Langer supervised the construction of three counters built to his specifications at NCAR. One of the 1976 AINCs, refurbished during late 2006 by Langer and McPartland, was compared with the WMI AINC during September 2007. The former AINC has the number "3-2" stamped on its frame and "Unit 3-2" is used to identify it in this paper.

The AINC is not a "turn-key" instrument and should be closely monitored by trained personnel during startup and operation. It has successfully been used in several winter orographic cloud seeding experiments, at fixed mountain top locations, in ground vehicles and in aircraft. Publications summarized by Super (1999) provide examples of each sampling mode. Careful monitoring of IN was not done in some projects which have reported poor results, wrongly tarnishing the reputation of this instrument. It was therefore prudent to do comparative tests with Unit 3-2 that has previously been successfully compared with the

isothermal chamber at the Colorado State University (CSU) Cloud Simulation and Aerosol Laboratory (DeMott et al. 1995). This paper documents the comparison of the two AINCs done at WMI's electronics laboratory, Fargo, North Dakota on 17-19 September 2007. Details not discussed in this article are given by Heimbach et al. (2007).

Table 1. Specifications for the WMI and "Unit 3-2" Acoustical Ice Nucleus Counters.

Acoustic Ice Nucleus Counter Specification	WMI	Unit 3-2
Height of cylindrical portion of cloud chamber	28 inches	26 ¼ inches
Height of cone at bottom of chamber	6 inches	6 inches
Inside diameter of cloud chamber	8 inches [1]	7 inches [1]
Position of sample inlet on chamber lid	2 in inside chamber wall	Centered
Volume of cloud chamber including cone[2]	23.2 liters	16.5 liters
Chamber felting material	(3)	(3)
Chamber felted	Summer 2006	Fall 2006
Cloud chamber material	Brass	Aluminum
Ethylene glycol specific gravity	1.055 – 1.065	1.055 – 1.065
Glycol precooled	Yes	No
Approx. glycol flow rate during comparison runs	120-150 ml min^{-1}	150-200 ml min^{-1}
Acoustic sensor capillary inside diameter	1.5 mm	>1.5 mm[4]
Vacuum applied to sensor	120 mm Hg	120 mm Hg
Pressure applied to atomizer	3.3 psi	5 psi
Flow from atomizer[5]	2.0 L min^{-1}	2.0 L min^{-1}
Temp. near cloud chamber's bottom port	-19 to -21°C	-18°C
Humidifier temperature	23.5°C	20.0°C
Sample flow rate[6]	8.7 L min^{-1}	11.3 L min^{-1}

1 Listed diameter includes felt, which is 1/8 inch thick.
2 Volume excludes thickness of felt.
3 Stephenson & Lawyer, Inc., 5-800 CHARCOAL Z SIF FELT.
4 3-2's sensor was blown at NCAR and is quite old. It gave a larger flow than WMI's sensor under the same vacuum; therefore its inside diameter was larger by an unspecified amount.
5 Flow through atomizer measured by a precision flow meter at atomizer's output fitting.
6 Taken using a precision flow meter at the lead in to the humidifier with the atomizer functioning.

2. SPECIFICATIONS

The specifications of the two AINCs are summarized in Table 1. The WMI AINC had its ethylene glycol precooled prior to wetting the cloud chamber by having several coils of the copper glycol tubing soldered to the refrigeration lines near the top of the cloud chamber. Precooling shortens the cooling time of the cloud chamber, and it increases the volume of the chamber that is cold enough to activate AgI and grow crystals. Langer (1973) documented the effects of precooling. A comparison of vertical temperature profiles of the two AINCs is discussed below. Two nearly identical sets of electronics were available. These were built in 1976 and later modified for use in the Utah Wasatch Plateau experimentation (Super 1999). The electronics receive acoustic signals from the sensor, tests their legitimacy (see Sec. 3) and outputs a TTL signal to a data acquisition system (DAS) for each accepted count. A new electronics package was under development by WMI and a test version was on hand for the comparison.

3. BRINGING THE ACOUSTICAL COUNTERS UP TO STANDARDS

Below are particulars considered essential for proper operation of an AINC. These were applied to the two units compared in this paper.

Felt. The AINCs use porous polyurethane foam felt to line the cloud chamber and as wicking baffles in the humidifier. The felt deteriorates over the course of several years, especially when stored in warm humid conditions. Both AINCs had new felt within a year of the September 2007 comparisons from the same lot manufactured by Stephenson and Lawyer, Inc.[1] The type specified was 1/8 inch 5-800 Z SIF felt and charcoal color was selected to facilitate cloud and crystal viewing.

Glycol. *W*etting of the chamber felt with ethylene glycol can be problematic, especially if the felt is new or not used for a month or more. An even distribution of glycol from the weep holes at the top of the chamber is needed; otherwise there is risk of frost formation and subsequent false counts from pieces of frost being drawn through the sensor. Besides obvious dryness of portions of felt, poor wetting is also evidenced by rivulets of glycol flowing rapidly to the collector at the bottom of the chamber which can overflow causing spilling into the sensor. One or two ml of a wetting agent such as Synthropol added to the glycol reservoir and rubbing glycol into the felt eliminated this problem for the comparisons.

The specific gravity of the glycol should be between 1.055 and 1.065, measured at room temperature. This solution has a freezing point below the temperature maintained in the cloud chamber and minimizes cloud desiccation. Dryer values can partially deplete the cloud and wetter values risk freezing the glycol solution on chamber walls. During testing, glycol flow rates were 120 to occasionally as high as 200 ml min^{-1}, a high range. This was done to ensure that no frost formed. Normal flow is about 50 ml min^{-1}, depending on the thickness of the felt. Greater flow rates and turbulence during airborne use can cause spatters to reach the elbow at the base of the chamber. This is not a problem unless the spatters are large enough to flow into the sensor, which is easily diagnosed by a screeching sound in the raw audio and unrealistically high count rates.

Fluid Levels. Distilled water is needed to maintain the AINC's fluids. The humidifier should have enough water to ensure the felt baffles always have their bases covered, but not the holes above. The atomizer level should be almost to the top of the nozzle. The atomizer's solution is 0.1% NaCl or 0.5 gm NaCl per half liter, the amount needed for the atomizer. Use chemical grade NaCl; not table salt that is iodized. One of the authors (Langer) has found the use of iodized salt in the atomizer to be associated with contamination that produces IN. Too few CCN can result in large droplets of 20 to 30 µm that can trigger false counts (Langer 1973). The glycol level should be sufficient to maintain the flow rate without draining the reservoir but allow capacity for water vapor absorbed from the cloud chamber.

Atomizer Filter. Air forced through the atomizer first passes through a membrane filter to remove IN from the CCN source. This is typically a 47 mm filter of pore size 0.8 µm or less. These filters can last for years, but should be examined periodically.

Refrigeration. Laws regarding the protection of the ozone layer have stimulated the production of alternate refrigerants that cannot necessarily be used in older compressors. The Freon 12 (a.k.a. “R-12”) refrigerant was previously the standard and this was the case for Unit 3-2. The WMI AINC uses 404A refrigerant that has greater cooling capacity. Both of the AINCs have a refrigerant view port. After the cooling system stabilizes, refrigerant should be seen flowing through this port.

All AINCs have automatic expansion valves that control the temperature of the cloud chamber. Any adjustment should be done in small steps as the response is slow. The cloud chamber lid, thermometer, view port, and lightly insulated parts of the refrigeration system, will frost under normal conditions.

Pumps. Besides the refrigeration compressor, there are three other pumps on an AINC: vacuum, atomizer and glycol. The vacuum pump must maintain 120 mm Hg. These are typically carbon vane types that should be periodically cleaned by flushing with methanol through the intake. A source for the vacuum pump is GAST Mfg. Corp., 1531 Series. Rebuilding kits are available. The atomizer pump must maintain 3 psi or more through the

1 Naming this brand and others in this article does not constitute an endorsement

nozzle. The inside diameter of the atomizer nozzle is critical and experience has shown that its machining in Plexiglas is difficult due to heat generated by drilling. It should be 0.030 in (#69 drill) and a Delrin insert for the nozzle is recommended. If the nozzle is too large, 3 psi cannot be maintained, resulting in inadequate CCN production. There should not be any metal in the atomizer because the dilute saline solution can cause corrosion. The glycol pump must be able to maintain 200 ml min^{-1} with sufficient pressure to reach the top of the cloud chamber. These are typically small gear pumps, one source is Greylor Co., PQM-1.

Sensor. The inside diameter of the sensor's capillary tube is specified to be 1.5 mm. A 3.0 mm diameter was also documented by Langer et al. (1967). The Unit 3-2 sensor was slightly larger than 1.5 mm. Assuming a constant 120 mm Hg vacuum across the sensor, the flow rate through the 1.5 mm sensors is approximately 12 L min^{-1}. The sensor needs to be clean and dry as dust and droplets accumulated on the up flow side can create false acoustic signals. The sensor is the most vulnerable part of the AINC and is easily broken where the capillary tube joins the larger diameter glass tubing. It is difficult for a glass blower to repair a broken sensor without producing tiny flaws that preclude proper crystal detection. Use of silicon vacuum grease is recommended for sealing and lubricating joints.

Flow Calibration. Flow through the sensor at 120 mm Hg vacuum should approximate the flow into the humidifier plus that from the atomizer. The term “approximate” is used because indicated flow rates are a function of temperature and pressure. For the comparison, flow rates were measured with a high-resolution ball-in-tapered-glass-tube flow meter. At the sensor, this was done on the up-flow side of the capillary tube with the 120 mm Hg applied. For the humidifier, this was at the sample intake and the atomizer had its output flow measured just before teeing into the sample line from the exit side of the humidifier.

Operating Temperatures. In general, the cloud chamber is run at -20°C, measured in the lower portion of the cloud chamber. This is cold enough to nucleate all AgI particles. Due to the high glycol flow rates employed during the comparisons, Unit 3-2 could only maintain -18°C. A humidifier too cool produces a weak cloud and too warm produces large droplets that can trigger acoustic signals. In the comparisons, the WMI AINC maintained 23.5^{o}C in its humidifier. This was the temperature the WMI AINC used in the previous winter field season and meets specifications by Langer (1972, 1973) who used a range of 22 – 24.5^{o}C in a larger AINC. Since then, improvements in the atomizer produce more CCN, decreasing the need for a higher water vapor input from the humidifier and allowing a faster cooling of the sample. Presently, a humidifier temperature of 20^{o}C is recommended and Unit 3-2 used this in the comparisons.

Threshold and Delay on Electronics. An electronics package is needed to process the acoustic signals from the microphone on the sensor. The threshold of detection should be set low enough to detect legitimate signals, which sound roughly like the snap of a finger, but not so low that background noises are falsely registered. Legitimate acoustic signals will propagate backwards into the cloud chamber, echo off the chamber top and return to the sensor, possibly causing double or potentially triple counts. For this reason, a delay is built in wherein echoes are suppressed. The time for the first echo depends on the length of the chamber and is approximately 7 ms. Adjusting the threshold and delay is best done with a triggered oscilloscope while sampling in conditions of elevated background IN.

Mechanical Noise. Background noise can produce false counts. This can be particularly troublesome with aircraft-mounted AINCs. In this situation careful adjustment of the electronics is essential. Loose items on the AINC can produce false counts, e.g., the WMI AINC had a glycol line that touched the glassware leading into the sensor producing false counts. This was easily remedied once known.

4. SETUP FOR COMPARISON

The two AINCs were connected to a common source using copper tubing connected to a “T”. The two copper lines were connected to the tygon tubing sample lines leading to the respective humidifiers. Both sets of electronics had their TTL outputs connected to a M300 DAS programmed specifically for this comparison test. The M300 recorded 1 s summations of counts for all the testing done on 18 and 19 September.

The comparison was done in several stages. On the 17th and morning of the 18th, an aerosol

of phloroglucinol dissolved in ethanol was used for initial testing and bringing the two AINCs into standard operating conditions. Beginning at mid-morning and continuing to 1700 of the 18th, IN samples were made by striking a book match dipped in a AgI-NH_4I-acetone solution. The match was struck outside and downwind of the laboratory, and dropped while burning into a plastic jug that was then sealed. Syringe samples of these IN, appropriately diluted with clean air, were input at the "T." Ice nuclei from AgI-NH_4I-acetone-doped matches have not been tested but for this paper it is assumed that contact nuclei are produced. This was suggested by the results of this comparison (Sec. 5). On 19 September, a WMI remote seeding generator located just north of the laboratory provided samples of IN from burning an acetone solution of 2% AgI by weight with NH_4I (1:1 molar ratio versus AgI) $C_6H_4Cl_2$ (0.1:1) and $NaClO_4 \cdot H_2O$ (1:1). This produces an aerosol characterized as $AgI_{0.8}Cl_{0.2}$-NaCl (Demott 1997), which is a fast-acting condensation-freezing nuclei (ibid., Finnegan 1999). There was a strong northerly wind on this date, causing the laboratory facilities to be thoroughly contaminated. For this reason it was not possible to make discrete inputs for this source of IN that are needed for plume edge calibrations.

5. TESTING THE AINCs

In this section the term "edge time" is used. This is the time from first AgI plume encounter (or sample input) to when there is an obvious increase in counts. This is used for estimating the position of a plume entry edge during cross-plume sampling by aircraft. The trailing end of an AINC response to a plume encounter is drawn out over several minutes due to the time needed to flush the cloud chamber. Encounters of broad plumes further complicate exit estimates. Heimbach et al. (1977) subtracted estimated counter-induced response variance from the total variance to estimate the character of plume encounter, but the exit edge remained too uncertain to be useful. Typical entry edge times are on the order of 0.5 min, and depend on cloud chamber size, sample flow rate, and number of IN encountered in a plume. Times to first detection of AgI (simulated plume edges) were estimated by noting time of AgI injection into the "T" and examining the 1 s data.

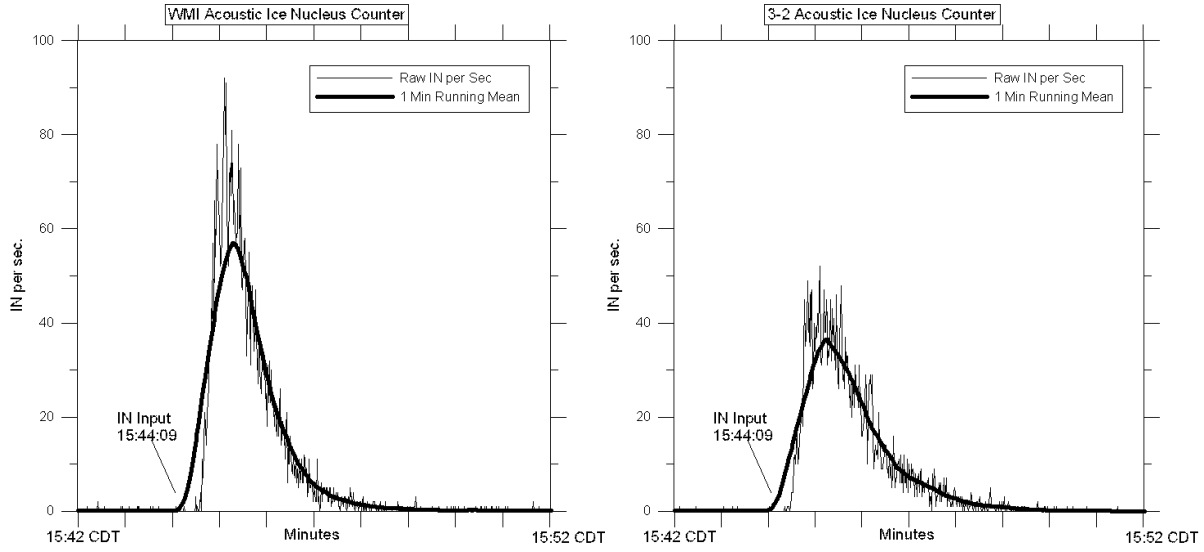

Fig. 1. Plots of detected IN from combustion of AgI-NH_4I-acetone solution on a match. Both 1 s accumulations of IN and 1 min running means are shown. The left graph is for the WMI AINC and the right for Unit 3-2. The period corresponds to the middle plume in Fig. 2.

5.1. AgI-NH_4I-acetone Solution Testing on 18 September

Several AgI samples, produced using a AgI-NH_4I-acetone-doped match as described above, were diluted and input at the "T." The input durations were usually 6 s or less. Figure 1 shows the responses of both AINCs to one such IN input. One-second accumulations are plotted as well as running averages of 61 s (effectively 1 min). The plots demonstrate the expected short-term variability of the AINCs' data, showing a characteristically rapid rise at the "edge time" and illustrate that cloud chamber flushing requires several minutes.

Table 2 summarizes the test inputs for this solution as well as the WMI perchlorate solution used on 19 September. Total counts were taken from the displays on the respective electronics, and both were simultaneously reset after recording the sum.

Part A of Table 2 shows that the WMI AINChas a somewhat greater efficiency detecting the IN from AgI-NH_4I-acetone, averaging 20% greater. Consideration of the sample flow rate difference between the two AINCs enhances this difference. The ratio of sample flow rates (L min^{-1}) was (Unit 3-2)/(WMI) = 11.3/8.7 = 1.30. The WMI/Unit 3-2 ratios of detected IN of Part A in Table 2 adjusted for the difference in sample rates range from to 1.44 to 1.66. One would expect a greater efficiency in the WMI AINC due to the greater supercooled residence time in the larger chamber and the smaller flow rate. Figure 2 is a 1 min running mean plot of the three plumes in Table 2A. For this figure the WMI AINC data have been multiplied by the flow rate ratio, 1.30. Combustion of the AgI-NH_4I-acetone solution produces pure AgI particles which are relatively slow-acting contact nuclei; however it is uncertain what effects the match combustion products have on these IN. The greater efficiency of the WMI AINC with its larger cloud chamber residence time support the notion that these IN acted as contact nuclei.

To convert from IN per time to IN per sample volume one must consider the proportion of the IN counted by the sensor and the sample flow rate. Langer (1973) reported that for AgI IN, the correction factor used to compensate for crystals falling out on the cone at the bottom of the chamber instead of being drawn through the sensor is 10. For the WMI AINC, ice nuclei per liter can be estimated by,

$$IN_{WMI}\ (L^{-1}) = IN(s^{-1})60\ s\ min^{-1})(10)/(8.7\ L\ min^{-1})$$
$$= IN(s^{-1})*69.0,$$
$$= IN(min^{-1})*1.15.$$

Similarly for Unit 3-2;

$$IN_{3\text{-}2}\ (L^{-1}) = IN(min^{-1})*0.89.$$

Table 2. Summary of AINC responses to IN from two sources. Total raw counts are unadjusted for flow rates.

	WMI		3-2		
Date/Time (dd/hhmmss CDT)	Total	Edge (s)	Total	Edge (s)	Count Ratio WMI/3-2
A. AgI-NH_4I-Acetone on match (likely primarily contact-freezing nuclei)					
18/153144	48197	22	43539	18	1.11
18/154409	5025	25	3935	22	1.28
18/155256	1489	28	1208	24	1.23
B. AgI NH_4I-$C_6H_4Cl_2$-$NaClO_4$-Acetone from generator (condensation-freezing nuclei)					
19/104325	2692	NA	3380	NA	0.80
19/1047--	5348	NA	6480	NA	0.83
19/105810	21400	NA	21758	NA	0.98
19/1110--	28218	NA	28900	NA	0.98
19/115620	20850	NA	20930	NA	1.00

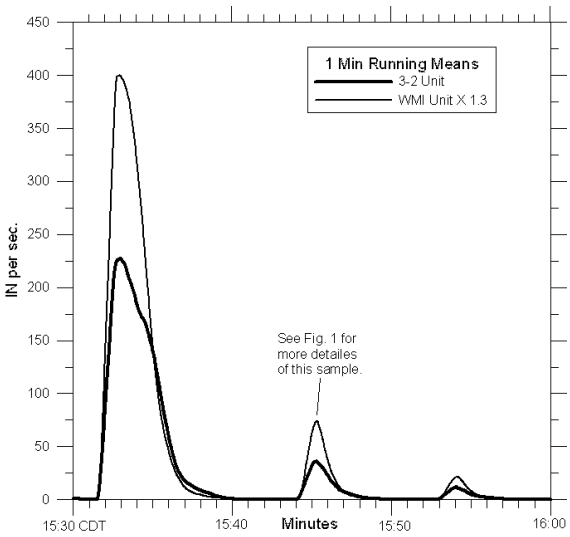

Fig. 2. Plots of the three comparison tests of 18 September. One minute running means of IN s^{-1} are shown.

5.2. AgI-NH_4I-$C_6H_4Cl_2$-$NaClO_4$-acetone Burned in the WMI Remote Generator

The two AINCs were operated on 19 September while the lab was deliberately contaminated (by opening doors into the facility) with AgI from the generator just upwind of the laboratory on this date, burning a perchlorate solution prior to 10:33 CDT. At 10:33 the WMI generator was turned off. The increasing contamination of the lab facilities is shown in Fig. 3, which is a plot of 1 min running means, with the WMI counts being multiplied by the 1.30 sample flow rate factor. At about noon, downwind doors to the lab were opened, allowing uncontaminated air to flush the lab at a greater rate.

Figure 3 shows that the WMI AINC had a total filter placed in line at 11:11 CDT, followed by Unit 3-2 AINC sampling filtered air beginning at 11:32 CDT. Both AINCs showed decreased count rates going nearly to 0 s^{-1} as expected. The count rates approaching zero in a heavily contaminated room indicates neither AINC had significant leaks.

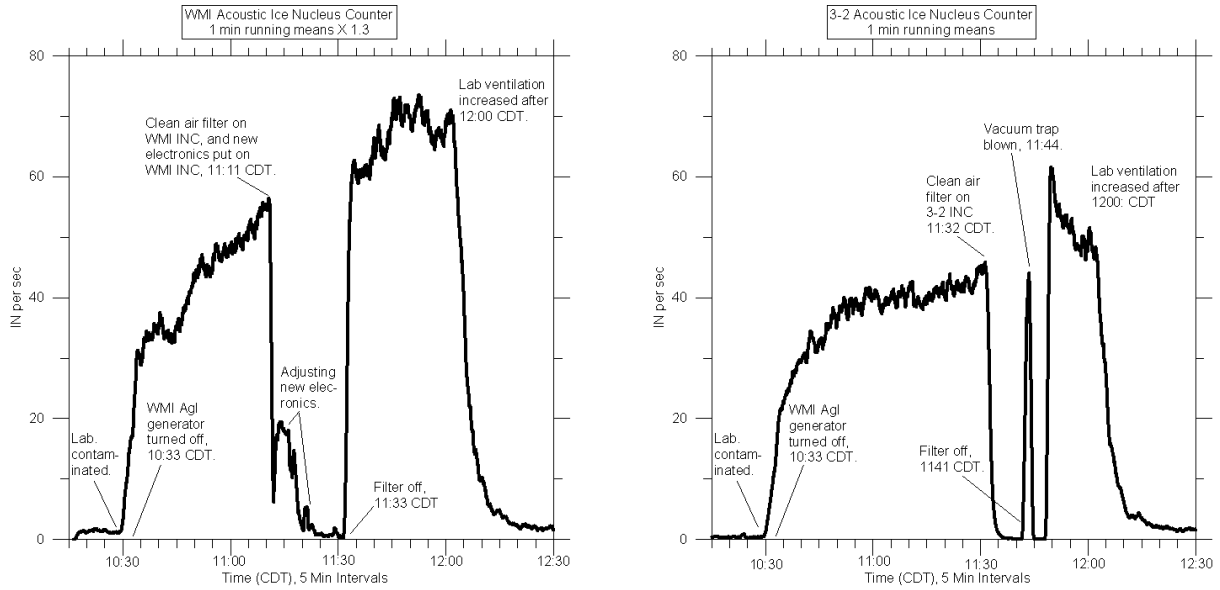

Fig. 3. One minute running means from the 19 September period of lab contamination, sampling with total filters, and clearing the lab. AgI source from burning a solution of AgI-NH_4I-$C_6H_4Cl_2$-$NaClO_4$-acetone. The 1.3 factor for the WMI AINC plot accounts for differences in sample flow rates.

At the same time the clean air filter was put on the WMI AINC, the electronics were replaced by the set under development. There were some false counts from this set of electronics (see Fig. 3) shown at the start of the filtered period. Some adjustments were made to the threshold, then the new electronics were removed. The decrease in contamination level starting at approximately noon, when ventilation was increased by opening upwind and downwind doors, is clearly shown in Fig. 3.

The AgI-NH_4I-$C_6H_4Cl_2$-$NaClO_4$-acetone solution used on 19 September produces fast-acting condensation-freezing nuclei. These are less sensitive to cloud droplet concentration and residence time in the cloud chamber. Therefore, the Unit 3-2 AINC compared better to the WMI AINC when sampling the aerosol from the combustion of this solution. The raw count WMI/(3-2) ratios ranged from 0.8 to 1.0 (see Table 2B). Taking the sample flow rates into account gives the WMI AINC a somewhat greater efficiency, with the ratios ranging from 1.04 to 1.30; whereas the ratio for the IN from the AgI-NH_4I-acetone-doped match ranged from 1.44 to 1.60.

6. CLOUD CHAMBER TEMPERATURE PROFILES

On the afternoon of the 19th, a Fluke 52 K/J thermometer was inserted through available ports in each counter's chamber lid to take vertical temperature profiles approximately 1 inch from the felted wall. The intent was to document the influence of precooling the glycol. Figure 4 shows the resulting temperature profiles. It is clear that precooling the glycol lifts the level where the cloud becomes supercooled. The WMI AINC reached 0°C within 5 inches below the chamber top, and the Unit 3-2 AINC at about 13 inches. Langer (1973) documented similar differences in profiles measured at the wall and at the center of a cloud chamber for precooling vs. none.

The threshold for AgI to nucleate is generally accepted to be about -6°C, depending on the type. Fig. 4 suggests that this temperature is not reached until 7 inches below the top of the chamber for the WMI AINC, and 14 inches for Unit 3-2. Subtracting the volumes greater than this temperature from the totals gives volumes where effective nucleation and growth can occur of 17.8 L and 8.3 L respectively for the WMI and Unit 3-2 AINCs. This is equivalent to 77% and 50% of the total volumes of the two cloud chambers. These values are approximate because the temperature profile was assumed constant across the chambers. Nevertheless, this exercise highlights the importance of glycol precooling, which likely contributed to the greater AgI concentrations indicated by the WMI unit.

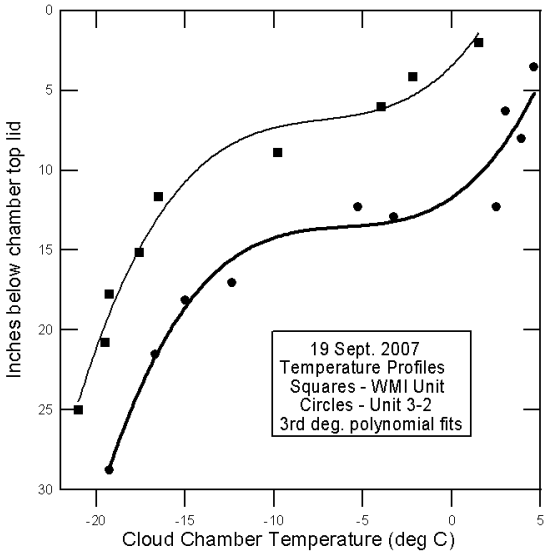

Fig. 4. Vertical temperature profiles of the two AINCs taken approximately 1 inch from the cloud chamber wall. The curves are cubic fits to the data.

The smaller supercooled volume of Unit 3-2's cloud chamber would limit the time available for diffusional crystal growth. This would make the counter less sensitive, especially for contact nuclei, the type tested on 18 September. The fast-acting condensation-freezing nuclei used on 19 September would require less time to nucleate and would be less sensitive to cloud droplet density. Therefore, the Unit 3-2 AINC fared relatively better in the tests of the 19th.

7. CONCLUDING REMARKS

The recently constructed WMI AINC was compared to an older AINC, "Unit 3-2," made in 1976 and traceable to the CSU Cloud Simulation and Aerosol Laboratory. The two AINCs compared very favorably for

the two types of AgI reported herein; within an overall factor of 1.3 for raw counts, and within a factor of 1.7 for counts L^{-1}. This demonstrates that reliable and reproducible measurements of AgI IN are possible if the devices are properly maintained and operated. Furthermore, these results give confidence to plume tracing experiments that apply this instrument to examine the difficult transport and dispersion link in the weather modification chain of events. Some summarizing points specific to the two compared AINCs are made below.

- The WMI AINC had a more robust refrigeration system. It used a modern refrigerant, 404A. Unit 3-2 AINC used the older Freon-12 refrigerant with a smaller compressor; 1/5 versus WMI's 1/3 HP. The WMI AINC was able to cool to operating temperature, -20°C, within 15 min whereas Unit 3-2 required 45 minutes and had difficulty getting colder than -18°C with the relatively high glycol flows used to prevent frost.

- The WMI sample rate was smaller than that for Unit 3-2: 8.7 compared to 11.3 L min^{-1}. The WMI AINC had count rates that were consistently greater than Unit 3-2's on 18 September when AgI-NH_4I was burned on a match. The resulting aerosol likely acted mostly as contact nuclei, a slow process highly dependent upon cloud droplet concentration. One would expect the larger volume and slower sample flow intake rate of the WMI AINC to be more efficient on this day. The WMI/Unit 3-2 ratios adjusted for sample rate averaged 1.6, supporting this premise.

- Agreement was markedly better with the condensation-freezing AgI IN from the WMI generator. Cloud droplet concentration and chamber residence times should have had less impact on the test results of 19 September. For these tests, the WMO/Unit 3-2 ratios adjusted for sample rate averaged 1.2.

- Conversion of counts from s^{-1} to L^{-1} showed the WMI AINC to be somewhat more efficient than Unit 3-2 regardless of IN type.

- The glycol feed system at the top of the WMI AINC is more apt to spatter drops into the sensor in turbulent situations because the weep holes are more exposed to the chamber. Unit 3-2 does not have this problem. Alternate lid designs are available and if turbulent flight poses a problem for the WMI AINC, then a new top should be designed.

- Vertical temperature profiles taken near the edges of the cloud chambers showed that glycol precooling lowered the WMI chamber temperature to below 0°C significantly faster. For Unit 3-2, lack of precooling limited the cloud chamber volume having a temperature of -6°C or less to approximately 50% of the total. For the WMI AINC, 77% of the chamber's volume had this temperature range.

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