P1.3 An Analysis of Ice Crystal Number Concentration Versus Aerosol Number Concentration and Supersaturation During FIRE.ACE

I. Gultepe, G. A. Isaac, and S. G. Cober
Cloud Physics Research Division,
Meteorological Service of Canada,
Toronto, Ontario, Canada

1. INTRODUCTION

The purpose of this work is to analyze relationships between ice crystal number concentration (N_i), aerosol number concentration (N_a), cloud condensation nuclei number concentration (N_{CN}), and supersaturation (S_i) with respect to ice. Formulation of precipitation processes in numerical models would be improved by a better understanding of the relationships between these parameters.

Szyrmer and Zawadzki (1997) estimated that ice nuclei (IN) from anthropogenic sources could contribute to climatic change. However, at the present time, this connection has not been established, and the relationship between man-made pollution and the IN concentration remains unclear. Mossop (1985) showed that N_i were generally less than 100 l^{-1} at T>-30°C with many concentrations exceeding those of Fletcher (1962). Mossop and Ono (1969) stated that larger N_i values (10-100 l^{-1}) appeared to occur at warmer T~-5°C and that there could be 10^3 times as many N_i as expected on the basis of ice nucleus measurements. DeMott et al. (1982) suggest that in zones of rapid uplift, there may be higher S_i that causes ice nuclei to be activated. Mossop (1970) stated that nucleation processes are time dependent and many more ice nuclei would be activated in natural clouds that last tens of minutes compared to laboratory clouds which typically last 2-3 minutes.

These studies suggest that nucleation of ice crystals is not easily parameterized. Meyers et al (1992) parameterized ice crystal concentrations using S_i and T. Gultepe et al. (2001) showed that N_i in precipitation sizes (>1000 μm) could be parameterized as a function of T. However there was no apparent correlation for sizes less than 1000 μm. In the present work, the observations collected with a Convair-580 during the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment-Arctic Cloud Experiment (FIRE.ACE) will be analyzed to better understand relationships among N_i, N_a, and S_i. The ice nuclei concentration (N_{IN}) cannot be equal to N_i, but to first order it is assumed that N_{IN}~N_i (Rogers and Vali, 1987). N_i is compared to N_a (N_{CN}) to test the assumption that N_{IN} will increase with an increase in N_a (N_{CN}). It should be recognized that processes such as ice multiplication, along with temperature and supersaturation dependencies would confound any attempts to relate N_i with N_a. Because of a large particle's many nucleation sites, N_i can also be compared with aerosol surface area, but it will not be considered here.

Corresponding author address: Dr. Ismail Gultepe, Cloud Physics Research Division, Meteorological Service of Canada (MSC), 4905 Dufferin Street, Toronto, Ontario, M3H 5T4, Canada, Ismail.Gultepe@ec.gc.ca

2. OBSERVATIONS

The observations were gathered during FIRE.ACE which took place over the Arctic Ocean during April of 1998, and details on aircraft observations can be found in Gultepe et al. (2001, 2002). For this study, data collected during research flights over 12 days were analyzed.

The averages of N_i, N_a, and S_i over 5°C intervals were calculated from the measurements of the Particle Measuring Systems (PMS) 2-Dimensional Cloud (2DC) probe at sizes from 25 to 800 μm, 2-D Precipitation (2DP) probe at sizes from 200 μm to 6400 μm, Particle Cavity Aerosol Spectral Probe (PCASP) at sizes between 0.135 and 3 μm, and the Li-Cor infrared gas analyzer (Li-Cor 6262 CO2/H2O) frost point measurements, respectively. The Li-Cor measurements can be more accurate than EGG dew-point temperature (T_d) measurements at cold temperatures. Its accuracy for T_d is about ±0.2°C (Li-Cor Inc). The N_a measurements with the the PCASP at sizes>0.8 μm are affected by ice crystals where the uncertainty is about 10-50 particles per cm^{-3} (10-15%), and it is not considered in the calculations. The 2D-C probe measurements are not accurate at sizes less than 100 μm, and are discounted. Ice crystal number concentration from the Forward Spectral Scattering Probe (FSSP) (N_{if}) measurements at sizes <100 μm can sometimes be used to estimate N_i. The standard and extended size ranges for the PMS FSSP were 3-45 μm and 5-95 μm, respectively. Arnott et al. (2000) suggested that FSSP measurements in glaciated clouds can be used for N_i measurements. N_{if} was also used for a qualitative analysis of a relationship between N_i and N_a. The condensation nuclei (N_{CN}) for sizes>0.005 μm were measured with a TSI-3025 Particle counter.

3. METHOD

The Rosemount icing detector (RID) voltage signal, hot-wire probe and PMS measurements are used to identify glaciated regions (Cober et al. 2001). Liquid water content (LWC) and total water content (TWC) are obtained from the Nevzorov probe (Korolev et al. 1998).

Observations were averaged over 10-s intervals. N_i from the 2DC (2DP) probe are determined for sizes larger than 100 (1000) μm as N_{iDC} (N_{iDP}). N_{if} for sizes<100 μm are determined with the FSSP probes. Details on the rationale for using N_i from the FSSP probe can be found in Gultepe et al. (2001). N_{if} and CN number concentrations are also analyzed as a function of RHi using 1-s data.

Time series of the measurements are analyzed to better understand temporal variability in the microphysical parameters. Also, the parameters are averaged over 5°C intervals to show the relationships between N_i (or N_a) and T that are commonly used in large-scale models.

4. RESULTS

4.1 1-s Observations and profiles

Fig. 1 shows a time history of a flight in glaciated clouds on 22 April 1998. The panels from bottom to top show T, RID voltage, N_{ifs} (diameter<45 μm) and $N_{ife,}$ (<95 μm), N_a and N_{CN}, and IWC(TWC-LWC), respectively. The N_a is less than 100 cm^{-3} at about –2°C, but it increases to 1200 cm^{-3} at –20°C. When the aircraft reaches the –20°C level, the IWC has values of 0.05 g m^{-3}. The TWC (or IWC) is usually less than 0.05 g m^{-3}. Throughout the climb, IWC is about 0.03±0.01 g m^{-3}. In this case, N_{if} increased with increasing N_a and decreasing T where RHi was 100%. The RID values indicate that supercooled droplets were present for two short time periods. N_{if} reached values of more than 4000 l^{-1} and were generally correlated with N_a. The data points of N_i found at RH_i<100% are likely related to particles falling from higher levels.

N_a and N_{ife} versus T are shown in Figs. 2 and 3, respectively. The median, 5%, and 95% values did not show a clear trend with T. Fig. 4 shows 1-s data of N_a and N_{CN} for the entire project. Although, both parameters reached large values at about RHi=100%, there was no significant change in the mean and median N_a with changing of RH_i. Overall, the mean and median N_{CN} increased gradually with increasing RHi except at RHi>110%. Because of the size range of the probes, N_{cn} was higher than N_a. Fig. 5 indicates that N_{ife} also increased toward RHi=100% value, and it reached a maximum at about S_i=10%. Fig. 6a, which shows N_{iDC} versus RHi, indicates that the median N_i (also 90% values) increase with increasing RH_i. Fig. 6b shows N_{iDC} versus N_a and N_{CN}. Median and 90% values of N_{iDC} increased slowly with increasing N_{CN} from 200 cm^{-3} to 800 cm^{-3}, with most of the data points scattered below 5 l^{-1}.

4.2 Summary of Results

The N_{ife} versus S_i and N_a (or N_{CN}) showed some correlations, but these relationships were likely affected by the uncertainties related to N_{if}, S_i, and N_a. Overall, N_{if} was approximately 1 order of magnitude larger than N_{iDC}. Lawson et al. (2001) using a cloud particle imaging (CPI) probe measurements showed that high concentration of small ice crystals (sizes<100 μm) can exist in the ice clouds. Their results are consistent with those of the present work. Neither N_{ife} or N_a showed a trend with T (Figs. 3 and 2). N_{cn} measurements indicated the same lack of dependence (not shown). Both N_{ife} and N_a (N_{CN}) increase with increasing RHi.

N_{iDC} increased with increasing N_a and RHi but there are still large uncertainties related to ice particles with sizes larger than 100 μm. Also, it is expected that an uncertainty in RHi can be about 20%, causing further complications in the analysis. Ni values at low RHi levels are likely related to falling particles from high levels and the uncertainty in RHi.

5. DISCUSSION AND CONCLUSION

Gultepe et al. (2001) showed that N_{iDC}>100 μm did not have a relationship with T but they found that N_{iDP} (>1000 μm) has a relationship with T for data collected in several Canadian field projects. Although S_i is not included in their parameterizations, Figs. 5 and 6 suggest that N_i values at sizes >100 μm is correlated with S_i and consistent with earlier studies.

Overall, the variability and uncertainties related to N_i and N_a (N_{CN}) indicate that the results in the present work need to be verified using additional data sets. N_i may increase with increasing N_a, as shown in Figs. 6. This suggests that aerosols from either natural or anthropogenic sources can affect ice microphysical parameters. A better measurement of N_i at small size ranges is a necessity to better understand ice crystal nucleation processes.

Supersaturation with respect to ice is an important parameter affecting N_i formation (Fig. 5 and 6a), and it needs to be measured accurately in order to develop an appropriate parameterization. Dew-point measurements obtained from EGG hygrometers in the earlier studies were used to develop parameterized equations. Those equations need to be verified with new data sets.

Other data sets from the Canadian field projects can also be used for a further understanding of the N_i versus N_a and S_i relationships. The uncertainties in the data from most of the instruments used in this study pose very difficult problems. Hopefully, with further analysis, these can be overcome. Some new instrumentation can also be tested in the future. For example, a new Small Ice Detector (SID) as described by Field et al. (2000) can be used in future field projects to help estimate N_i at small sizes.

Acknowledgements:

The authors are thankful to R. Leaitch, W. Strapp, and other MSC Staff for collection of the data and helpful discussions during course of this work. The Panel on Energy Research and Development provided financial support for FIRE.ACE. Additional support was given from NASA for the collection of the FIRE.ACE data.

6. REFERENCES

Arnott, W. P., D. Mitchell, C. Schmitt, D. Kingsmill, and D. Ivanova, 2000: Analysis of the FSSP performance for measurement of small crystal spectra in cirrus. 13th international Conf. On Clouds and Precipitation, 14-18 Aug. 2000, Reno, Nevada, 191-193.

Cober, S.G., G.A. Isaac, A.V. Korolev, and J.W. Strapp, 2001: Assessing cloud-phase conditions. *J. Appl. Meteor,* 40,1967-1983.

DeMott, P. J., W. G. Finnegan, and L. O. Grant, 1982: A study of ice crystal formation in a stable stratified orographic cloud. Preprints, Cloud Phy. Conf., Chicago, IL, 488-490.

Field, P. R., R. J. Cotton, and D. Johnson, 2000: Ice nucleation in orographic wave clouds 13th international Conf. On Clouds and Precipitation, 14-18 Aug. 2000, Reno, Neveda, 33-35.

Fletcher, N. H., 1962: *Physics of Rain Clouds*. Cambridge University Press, 386 pp.

Gultepe, I., G. A. Isaac, and S. G. Cober, 2001: Ice crystal number concentration versus T in mid-latitude and Arctic clouds. Inter. J. Climate, 21, 1281-1302.

Gultepe, I., and G. Isaac, 2002: Airmass origin effect on cloud microphysical characteristics during FIRE.ACE. J. Geophy. Res., in Press.

Korolev, A.V., J.W. Strapp, G.A. Isaac, and A. Nevzorov, 1998: The Nevzorov airborne hot wire LWC/TWC probe: Principles of operation and performance characteristics*. J. Atmos. Ocean. Tech*., **15**, 1496-1511.

Meyers, P. M., P. J. DeMott, and W. R. Cotton, 1992: New primary ice-nucleation parameterizations in a explicit cloud model. J. Appl. Meteor., 31, 708-721.

Lawson P.R., Baker B.A., , and Schmitt C.G., 2001: An overview of microphysical properties of Arctic clouds observed in May and July 1998 during FIRE.ACE. J. Geophy. Res., 106, 14989-15014.

Mossop, S. C., 1985: The origin and concentration of ice crystals in clouds. Bull. Amer. Meteor. Soc., 66, 264-273.

Mossop, S. C., and A. Ono, 1969: Measurements of ice crystal concentration in clouds. J. Atmos. Sci., 26, 130-137.

Mossop, S. C., 1970: Concentration of ice crystals. Bull. Amer. Meteor. Soc., 51, 474-479.

Rogers, D. C., and G. Vali, 1987: Ice crystal production by mountain surfaces. J. Clim. And Appl. Meteor., 26, 1152-1168.

Szyrmer, W., and I. Zawadzki, 1997: Biogenic and athropogenic sources of ice forming nuclei: A review. Bull. Amer. Meteor. Soc., 78, 209-228.

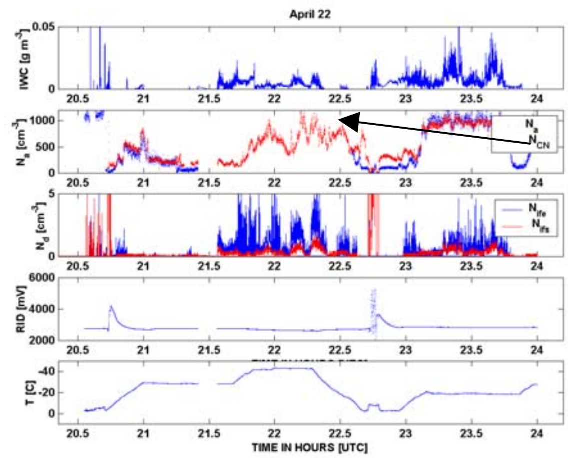


Fig. 1: Time series for April 22 case

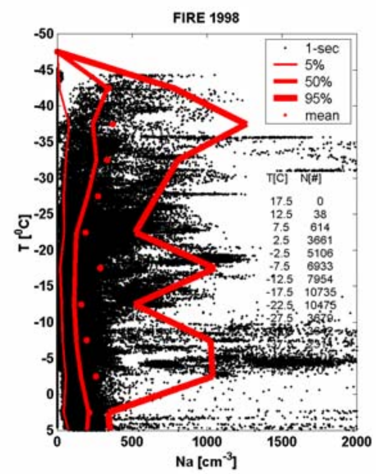


Fig. 2: PCASP N_a profile versus T for entire project data.

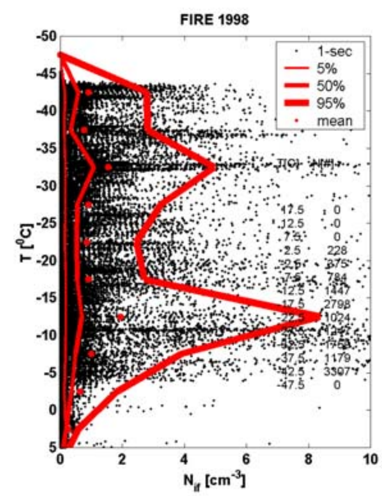


Fig. 3: FSSP N_{ife} profile versus T for entire project data.

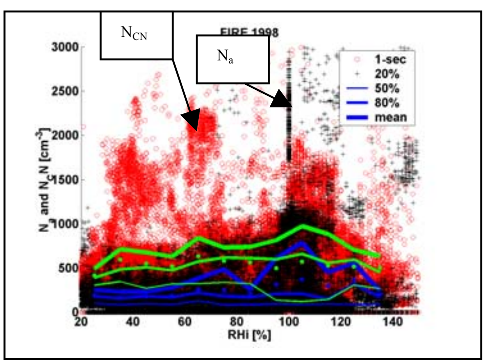


Fig. 4: N_a and N_{CN} versus RHi for entire FIRE.ACE data set. The green lines (blue lines) are for N_{CN} (N_a) values.

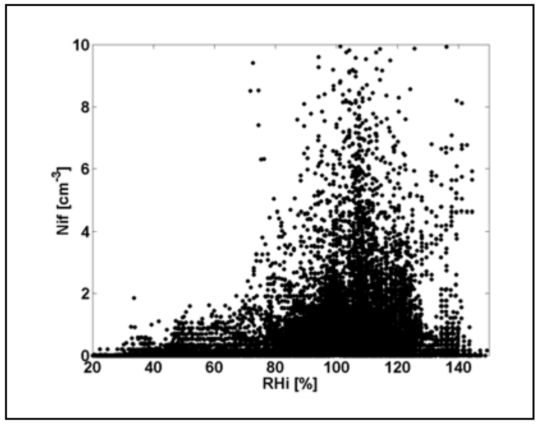
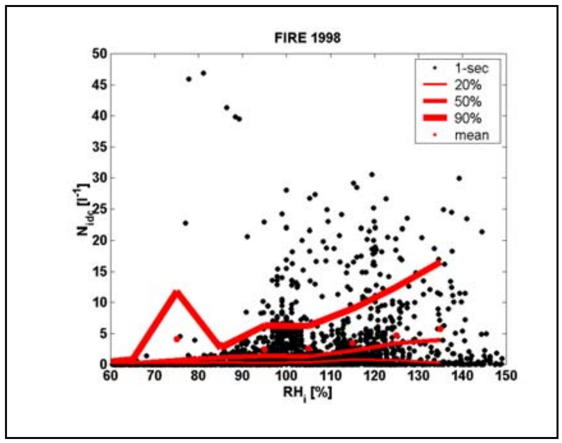


Fig. 5: N_{ife} versus RHi for all cases.



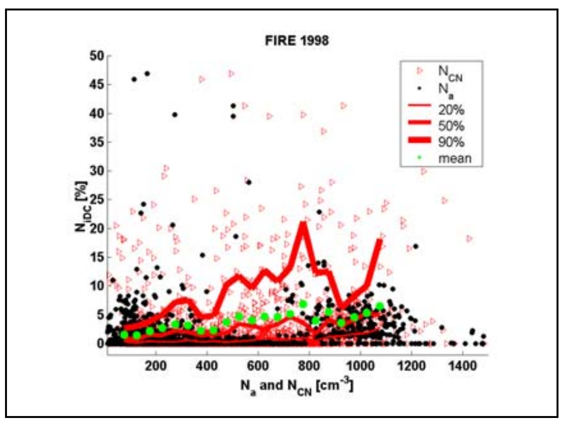


Fig. 6: N_{iDC} versus RHi (a), and versus N_a overlaid on N_{CN} (b).