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1. Microphysics and Radiative Properties of Cirrus: Instrumentation and Analysis
2. Summary of Research
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Final Report FIRE 1995 - 1998: Research Summary.

I. Introduction

This section summarizes the scientific questions which originated with participation in FIRE II in Coffeyville KA, evolved through participation in several field projects related to FIRE and culminated in participation in FIRE III in the Arctic in March / May 1998. It is noted that many of the ideas generated in FIRE II 1992 - 1995 and published under the grant involving the role of CCN in cirrus formation have been followed through in this grant and have also been central in the ideas for work under the SUCCESS project and the laboratory work currently supported by NSF.

II. Scientific Questions

The basic question addressed is the origin and evolution of ice, primarily as cirrus, from the viewpoint of determining its role in the solar/thermal radiation budget of the earth. A theme running through the approach has been to assess any significant differences between cirrus formed under different conditions - tropical convection, mid latitude convection and frontal cirrus and arctic low level ice clouds which, although forming at typical cirrus temperatures, form at much lower levels, near surface pressure. A further consideration has been the role of anthropogenic aerosol, as in aircraft contrails at altitudes in the upper troposphere and industrial produced aerosol at low levels in the Arctic.

Specifically, instrumentation has been devised to characterize cirrus particles and the nuclei on which they form, to be carried by aircraft into sensitive regions where cirrus cloud formation is - or is not - taking place. The instruments have complemented more conventional instruments (PMS probes) providing information capable of being used in a predictive sense in a mesoscale or larger scale dynamical setting. Analysis has given rise to the following precepts, which are discussed in formal publications, past, current and pending.

III. Results

Below are general results that follow from the listed publications and are guiding the initial analyses of FIRE III data:

- Comparison between data obtained from probes mounted even in close proximity on the same aircraft must be interpreted in terms of the spatial variability along the flight track. This is particularly important in sampling cirrus and contrail modified cirrus in view of its high variability (see particularly Arnott et al 1998). This represents a major effort of this work; it will be submitted for formal publication shortly.
- The occurrence of giant (diameter > few m) hygroscopic nuclei in concentrations of cloud physics significance under some conditions (see particularly Meyers and Hallett 1998);
- The critical supersaturation for initiation of droplets in a lenticular cloud is small - 05% over water, comprising the tail of the CCN spectrum (see Jensen et al 1998);
- The occurrence of 'large' (100μm) and 'small' (5 μm) ice particles in close proximity (< 1 m) during sampling, (Meyers and Hallett 1998);
- The occurrence of multiple habit crystals in close proximity (10 μm equiaxed particles and extreme, 1:100, 1:1 habit 100 μm plates or columns), (Bailey and Hallet 1998);
- Aggregates are a rare but not completely absent phenomena; biaxial crystals occur; trigonal (3-fold symmetry) and 4 fold symmetry crystals sometimes occur (in preparation);
- Comparative rarity of regions with entirely 'pristine' crystals - that is having well formed low index plane crystal facets and single crystals, as plates or columns (in preparation).

IV. Projects from which aircraft data have been obtained:

FIRE II Coffeyville, KA, UND Citation, Nov/Dec 1991.

TOGA COARE From Townsville, over W. Pacific warm pool, January-February 1993, NASA DC-8.

ARM Mission from Ponca City, OK, UND Citation, October 1994.
ARM Mission from Ponca City, OK, UND Citation, September 1997.
ARM Mission from Ponca City, OK, UND Citation, April 1998.

Planning for FIRE III:
Canadian Convair: Over Beaufort Sea and to SHEBA from Inuvik, NT, April 1998.

NCAR C130: Over Beaufort Sea and to SHEBA from Fairbanks, AK, May 1998.

Other:
NASA DC-8: Cirrus from tropical storms Patrick AFB, FL, (CAMEX), September 1998.

V. Instrumentation Development.

Efforts have been made in two specific directions from the viewpoint of improving the characterization of ice.

A. Formvar Replicator. This is an old technology (Hallett 1976) which is used for providing both "air truth" for electro-optical systems (FSSP, 2DC and 2DP), for collecting particles in the size range 5 -100 m which are not sampled by the other probes and also provide detail of ice particles by both optical microscopy and also scanning electron microscopy, if required. Major improvements have been made in recording frame location in the film in flight and in a laboratory system for automated frame advance to locate specific times for analysis. A frame grab system is in place to provide and classify images by habit; size, area and if required, volume from an empirical relationship. Plots of such data give distributions for these variables as required (Arnott et al 1998). Evidence is mounting that the sample volume estimates for the PMS system may be in error, resulting in an underestimate of particle concentration, (see Fig. 1).

B. A different replicator is used on the NASA DC-8 and the Canadian Convair which fits a PMS canister and faces into the airstream (as opposed to a cylinder at 90^{O} to the airstream), has a higher collection efficiency and collects particles down to 2 -3 m. This was modified to operate at slower and higher speed to be more effective both at lower and higher particle concentration.

C. The DRI cloudscope has been under development for the last 3 years (Arnott et al 1994) and was developed further for FIRE projects. This primarily involved improving illumination to enable data collection at high illumination in the bright environment of cloud top and over ice and snow below. A further development enabled the collecting window to be set to a given, higher, temperature (recorded) and evaporate particles more rapidly for the case of high liquid water content so that image overlap did not occur. Automated analysis initially gives size distribution and habit; more detailed analysis gives particle density, mass, and residue volume of evaporated particles. It is usually possible to obtain some estimate of the hygroscopicity of such particles (Arnott et al 1998).

D. A further development made the same improvements on a cloudscope with much larger format having a field of view nearly 2 cm as opposed to a field of view of 1/2 mm for the standard instrument. This enabled much better statistics to be obtained for larger particles and also better information on the spatial distribution of ice particles of different size collected at nearly the same time. The instrument has been used on the C130 in FIRE III and is anticipated to be used in the Florida CAMEX mission.

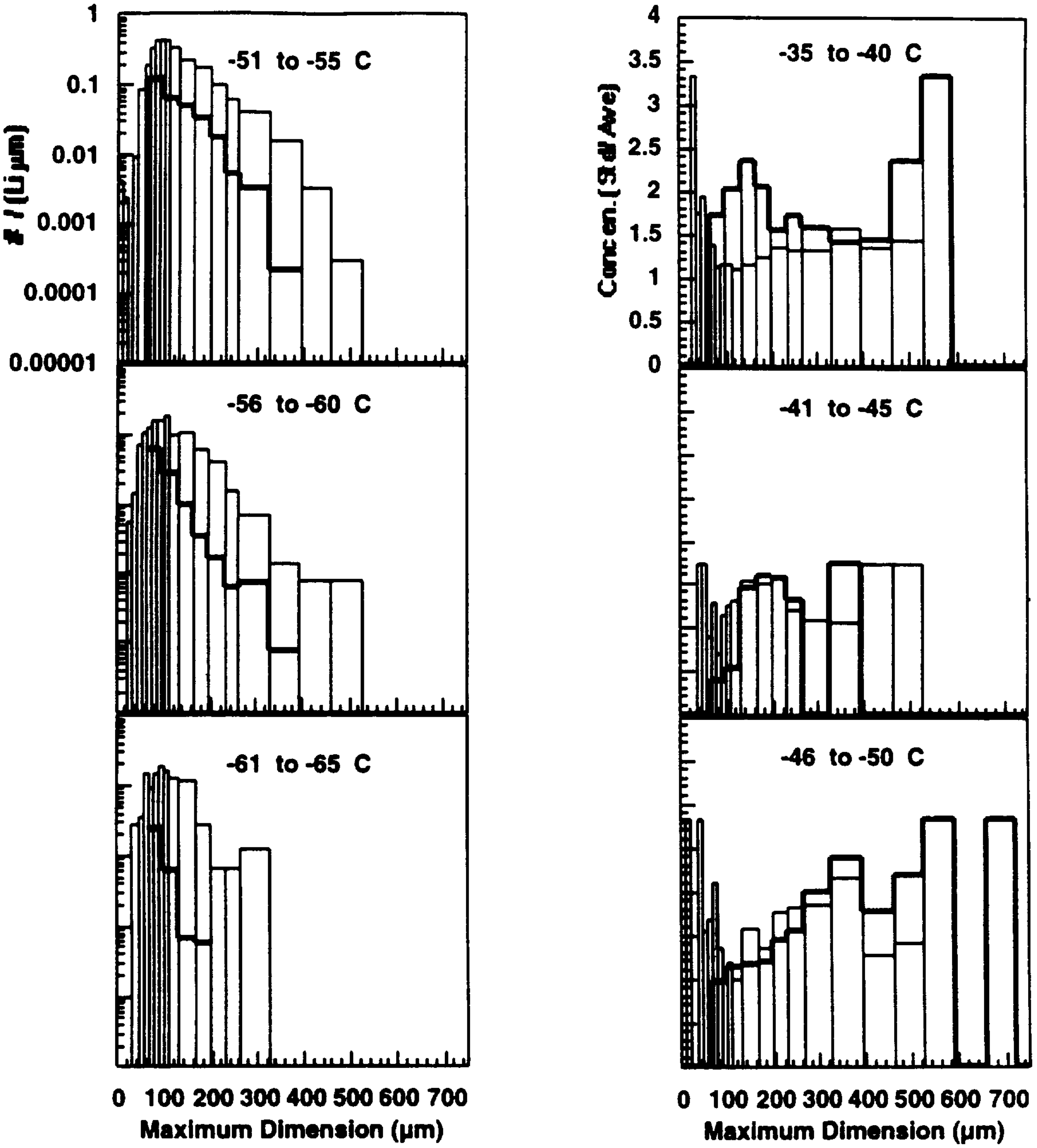

Figure 1. Size distribution standard deviation normalized by the average distributions for replicator and 2DC (thick lines), for the indicated temperature ranges.

Problems resulting from relating data from two probes located on the same aircraft - even if nearly collocated - are non trivial and are addressed in various publications listed below (Arnott et al 1998; Kinne et al 1998). Distant probes, as on opposite wing tips or fuselage and wing tip, obviously sample regions separated by some 50m and direct comparison at the same time (1 second) may be an exercise in futility when variability in the aircraft flight direction varies on this scale. This indeed may be the case in cirrus as even a casual inspection of high-resolution data - and indeed a view from the ground - suggests. Thus an averaging of the data needs to be undertaken, and the detail of such averaging needs careful attention as the statistics of the occurrence of larger, rarer, particles may require a time well in excess of the scale of the cloud element being considered. Such considerations point to instruments with much larger sample volumes for the large particles with data combined with instruments with much smaller sample volumes for the smaller particles - and herein lies the problem. Even if the two instruments are in the same pod cluster, the problem is far from solved as different airflow at the different sampling sites often occur, depending on the flight characteristics of the aircraft. The conclusion is that measurements to be combined need to be made with truly collocated instruments - and probably by different measurements of the *same air* volume. These themes run through the data as it is analyzed.

VI. Field Preparation:

Major efforts were undertaken in this project in preparation, installation and operation of instruments in aircraft for FIRE III from Inuvik (Canadian Convair replicator and small format cloudscope) and Fairbanks (NCAR C130 – small and large format cloudscope). We participated in both field programs and data was obtained in most flights of the above aircraft. Initial analysis of the data is currently underway in collaboration with the Canadian group.

VII. Related Project:

In parallel with this FIRE study, a NSF funded laboratory study has been underway of the habit of ice crystals growing from the vapor under cirrus conditions. Specifically, a water vapor diffusion chamber has been constructed which enables temperature, air pressure and ice supersaturation to be varied independently over -30C to -70C, supersaturation from a few % to over 200% over ice, and air pressure from 700 to below 50 mb. Thus the observed cirrus habits can be related to environmental conditions through a map as in Fig. 2, with the effective supersaturation being corrected for fall velocity through a ventilation coefficient, (Bailey & Hallett, 1998).

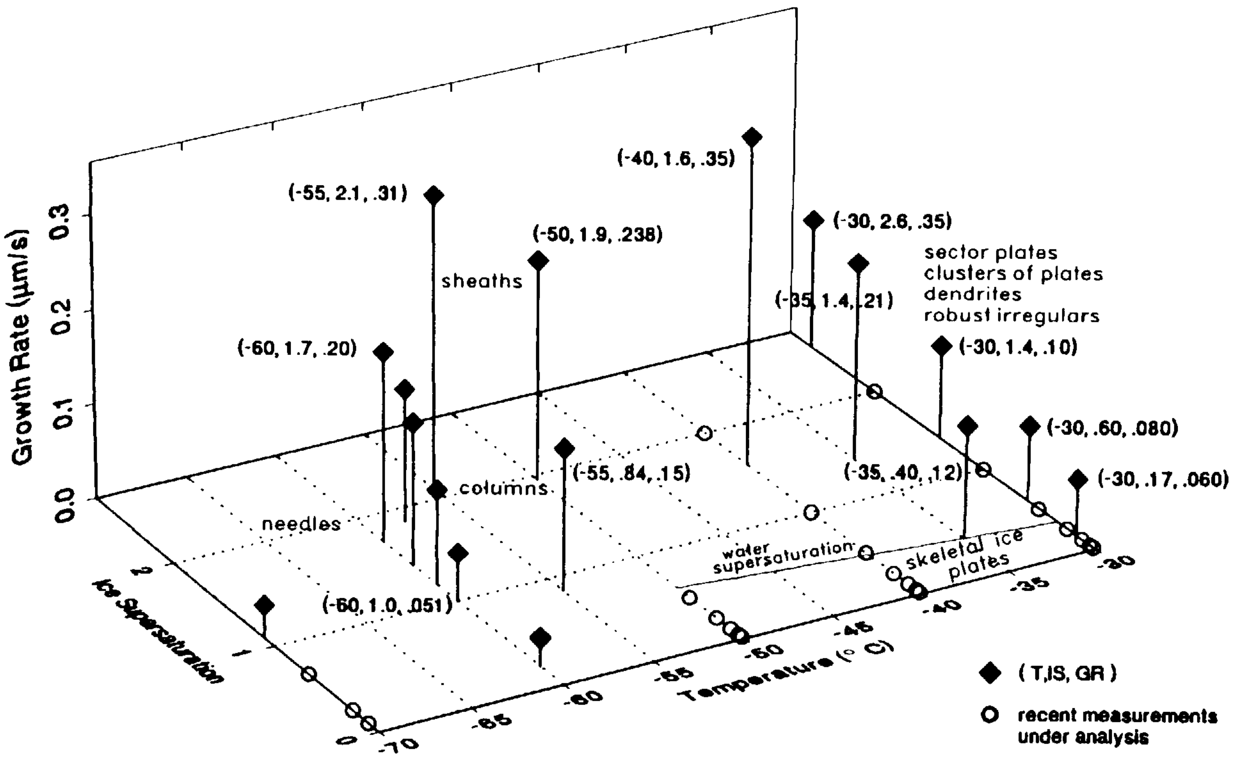

Figure 2. Summary of the ice crystal habits and growth rates for -30°C to -70°C and a pressure of 100 mb.

References:

Arnott, W.A., Y.Y.Dong, J.Hallett, 1994, Observations and importance of small ice crystals in a cirrus cloud from FIRE II. JGR 99 1371 – 1381.

Hallett, J. 1976 Measurement Size Concentration and Structure of Atmospheric Particulates by the Airborne Continuous Replicator, Final Report. AFGL-TR-76-1149.

Publications resulting directly* from or related† to this grant:

*Hallett, J. J.G. Hudson and R. Pueschel 1996 Aerosol in Tropical Cirrus, In 14th Conference on Nucleation and Atmospheric Aerosols, Ed. Kulmala and Wagner, Helsinki. 880 - 883.

*Hallett, J., J.G. Hudson, F. Rogers, E. Teets, S.S. Yum and Y. Xie, 1997, The Influence of Natural and Aircraft Exhaust on Aerosol and Cirrus Formation. Third Conference on Atmospheric Chemistry, AMS, February 1997, Long Beach CA 45 - 53.

*Pueschel, R.F., J.Hallett, A.W. Strawa, S.D. Howard, G.F.Ferry, T.Foster and W.P. Arnott. 1997, Aerosol and Cloud Particles in Tropical Cirrus Anvil: Importance to Radiation Balance. 1997: J. Aerosol Science, 28 1123 - 1136.

†Hallett, J., W.P. Arnott, R. Purcell and C.S Schmidt: 1998, A Technique for Characterizing Aerosol and Cloud Particles by Real time Processing. In Proceedings, $PM_{2.5}$ Conference, Long Beach CA, February 1998, 318 - 339.

†Poellot, M.R., W.P. Arnott and J. Hallett, 1998, In Situ Observations of Contrail Microphysics and Implications for their Radiative Budget. J.G.R., In Press.

†Jensen, E.J., O.B. Toon, A. Tabazadeh,G.W. Sachse, B.E.Anderson K.R.Chan, C.W.Twohy, B.Gandrud, S.M.Aulenbach, A.Heymsfield, J. Hallett and B.Gary, 1998; Ice nucleation processes in upper tropospheric waveclouds observed during SUCCESS. G.R.L.25 1363 -1366.

*Pueschel R.F., J.Hallett, A.W. Strawa, S.D. Howard, G.F.Ferry, T.Foster and W.P.Arnott, 1997; Aerosol and Cloud Particles in Tropical Cirrus Anvil: Importance to Radiation Balance. 1997; J. Aerosol Science, 28 1123 - 1136.

*Sassen, K., G.G. Mace J. Hallett and M. Poellot: 1998; Corona - producing ice clouds: a case study of a cold mid-latitude cirrus layer. Appl. Optics, 37 1477 - 1485.

Papers to be presented at the AMS Cloud Physics Conference, Everett WA August 1998:

*Arnott, W.P., T.J. Ulrich, R.Cole and J.Hallett: 1998; Summary of in-situ observations of Cirrus Microphysics During FIRE II: Instrumental Response. Conference on Cloud Physics, Everett, WA, August 1998.

†Bailey, M. and J. Hallett, 1998; Laboratory investigation ice growth from the vapor under cirrus conditions between -30C and -70C, Conference on Cloud Physics, Everett, WA, August 1998.

†Meyers, M. and J. Hallett 1998 Ice crystal Morphology in Aircraft contrails and Cirrus, Conference on Cloud Physics, Everett, WA, August 1998.

†Schmitt,C., W.P. Arnott and J. Hallett,1998; Infrared Extinction and Emission by Laboratory Ice Clouds: Simulation of Cold Cirrus and Contrail Radiative Properties. Conference on Cloud Physics, Everett, WA, August 1998.

*Presentation to be made at AMS Dallas Meeting, Polar Symposium, (Jan 1999): Meyers, M. and J. Hallett Aircraft Observations of Giant Nuclei in Arctic Regions.

Presentations to be made at the CIRRUS Conference in Baltimore, October 1998:

*Shape and Fall of Cirrus Particles.
(Invited paper) John Hallett and Pat Arnott (DRI).

*New Insight for in situ quantification of cirrus
W. Patrick Arnott and John Hallett (DRI) and Michael R. Poellot (UND)

Papers in Preparation:

†Laboratory study of cirrus growth habit related to environmental parameters.
Matthew Bailey and John Hallett

†Kinne, S., J. Hallett, et al
Intercomparison of aircraft measurements by instruments mounted at different locations.

*Hallett,J., J.G.Hudson, F.Rogers, E.Teets, S.S. Yum and Y. Xie, 1997, The Influence of Natural and Aircraft Exhaust on Aerosol and Cirrus Formation.