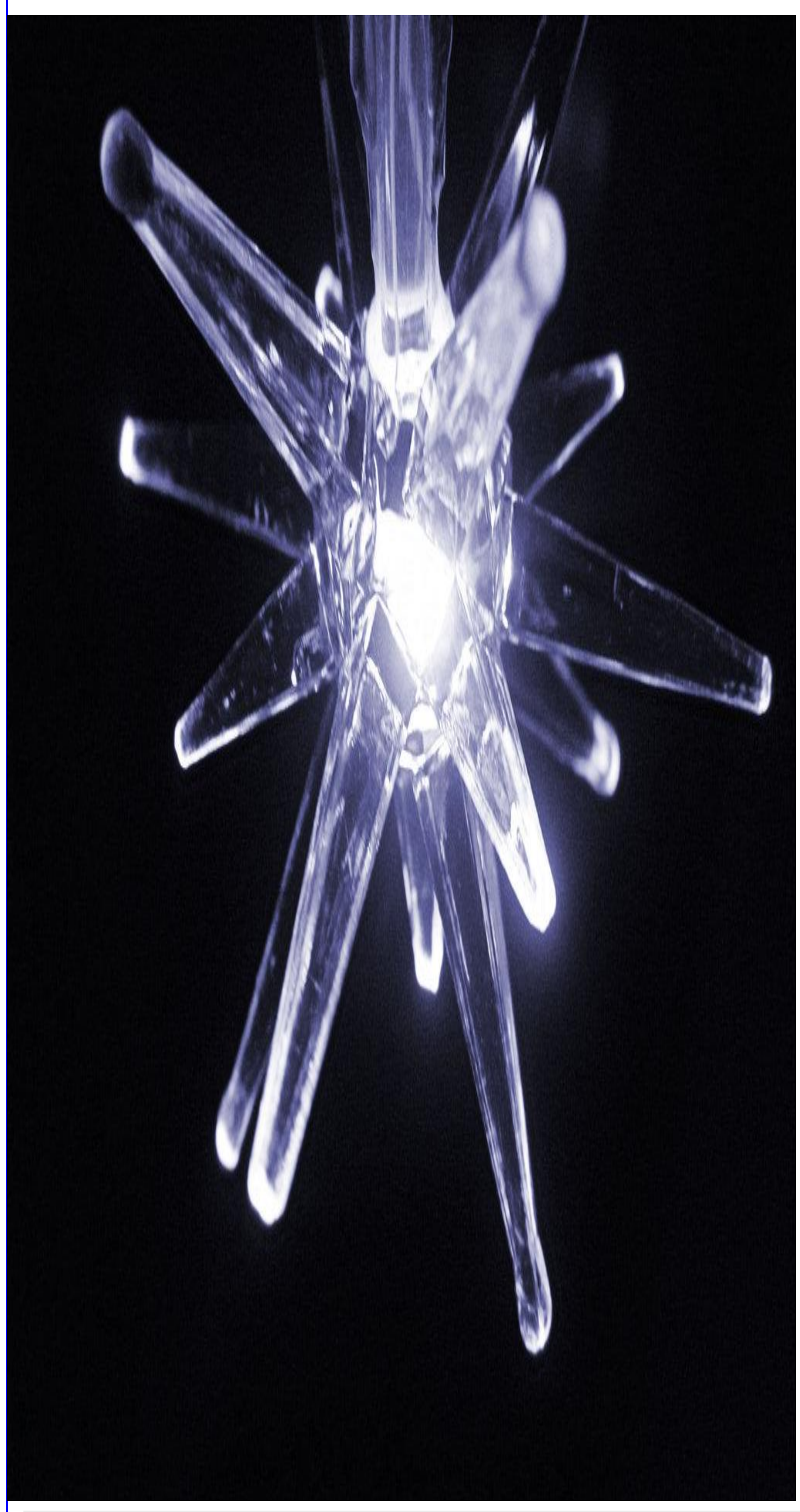

Aircraft Icing Potential and Ice- and Mixed-phase Cloud Microphysics

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Abstract

Cold cloud interactions with aircrafts that fly through them require knowledge of cloud microphysics. Aircrafts must be designed to fly into supercooled clouds, or they must avoid those clouds in order to prevent problems associated with airframe and engine icing. De-icing or anti-icing systems must be engineered to withstand reasonable extremes in terms of ice water content (IWC), supercooled liquid water content (LWC), ice particle size distributions (SDs), and temperature. The aircraft design or certification envelopes (FAR 25, Appendix C; Federal Aviation Administration, 1999) were developed before the advent of modern cloud physics instrumentation. In the case of ice and mixed-phase clouds, data from the aircraft measurements during recent field campaign suggest that cloud temperature is one of the main parameters governing cloud microstructure, the size distributions, and the current icing potential (CIP). This study may help improve airplane icing prediction through better understanding of the ice microphysical properties.

Introduction

Ice and mixed phase clouds have an important impact on aviation. In-flight icing is a significant threat to aircraft, resulting in loss of lift, reduced airspeed, and, in some cases, loss of control (Bernstein et al. 2005). This threat manifests through a significant number of accidents. Based on recent data, freezing precipitation often forms through nonclassical formation mechanisms, without requiring the formation of a melting layer. However these relationships are still not thoroughly studied.

The focus of this research is to help improve our understanding of winter aircraft icing occurrence through parameterizations of the ice microphysical cloud properties. The study explores possible relationships between different ice crystals size distributions, and airplane icing. The study utilizes data for different ice crystal size spectra in winter cold clouds, and data for the corresponding airplane icing occurrences.

Fig.1. Conceptual diagram. Precipitation types: snow (asterisks), rain (large open circles), and freezing drizzle (small gray circles), from Bernstein et al., 2005.

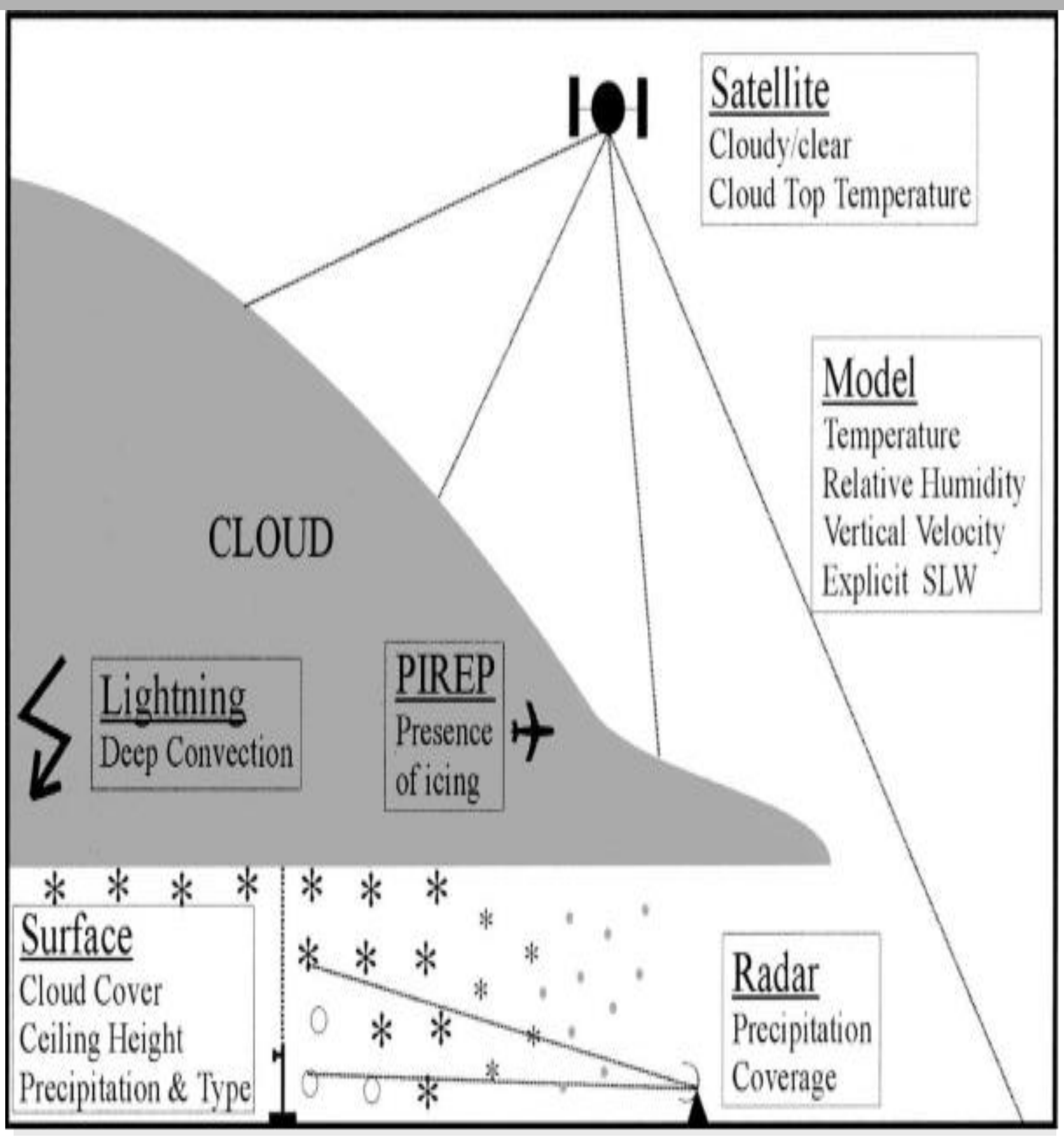


Fig.2 . Icing accumulates while in cloud. Photo credit: NASA Glenn Research Center .

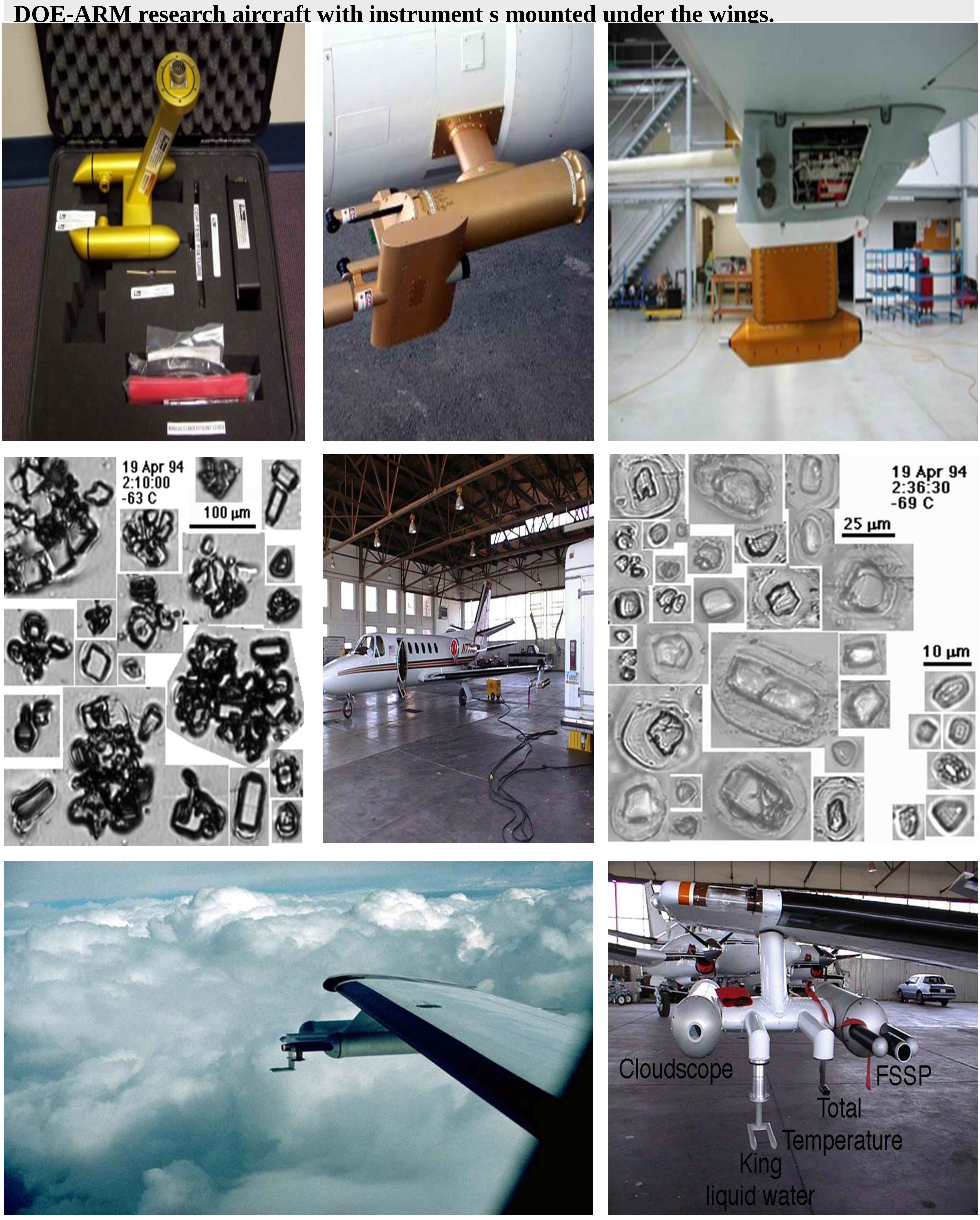
Fig.3. After ascending above cloud. Photo credit: NASA Glenn Research Center

Canadian Research on Aircraft In-Flight Icing and Russian Research on Ground Icing:

- **Supercooled large drops (SLD) often coexist with ice crystals in mixed-phase environments. Approximately 80% of SLD observed during the Canadian Freezing Drizzle Experiment (CFDE) were formed without requiring the classical formation mechanism – ice particles falling through a melting layer (Isaac G. A. et al., 2001).**
- **Bezrukova N. A. et al., (2000, 2004, and 2006) published atlas of the frequency of the ground icing events observed over the territory of the former USSR during three decades (1971-2001) for a network of over 80 stations.**

Instrumentation

Fig. 4. a) – h) presents instruments and ice crystal data from several Department of Energy (DoE) – Atmospheric Radiation Measurements (ARM) campaigns . Fig. 4a) , b), and c) show a Cloud Droplet Probe (CDP) , Cloud Aerosol Precipitation Spectrometer (CAPS), and Cloud Particle Imager (CPI) . CDP measures particles from 2 to 50 µm in diameter, CAPS measures particles from 0.35 to 1550 µm in diameter, and CPI provides high-resolution images of ice crystals as particles pass through a sample volume. Fig. 4d) and f) depict various ice crystal distributions. The images were taken using the DRI Automated Replicator System from data collected on April 19th 1994, an Intensive Observation Period (IOP) of the DoE - ARM project . Fig. 4e), g) and h) are pictures of the Citation – ASCII DOE-ARM research aircraft with instrument s mounted under the wings.



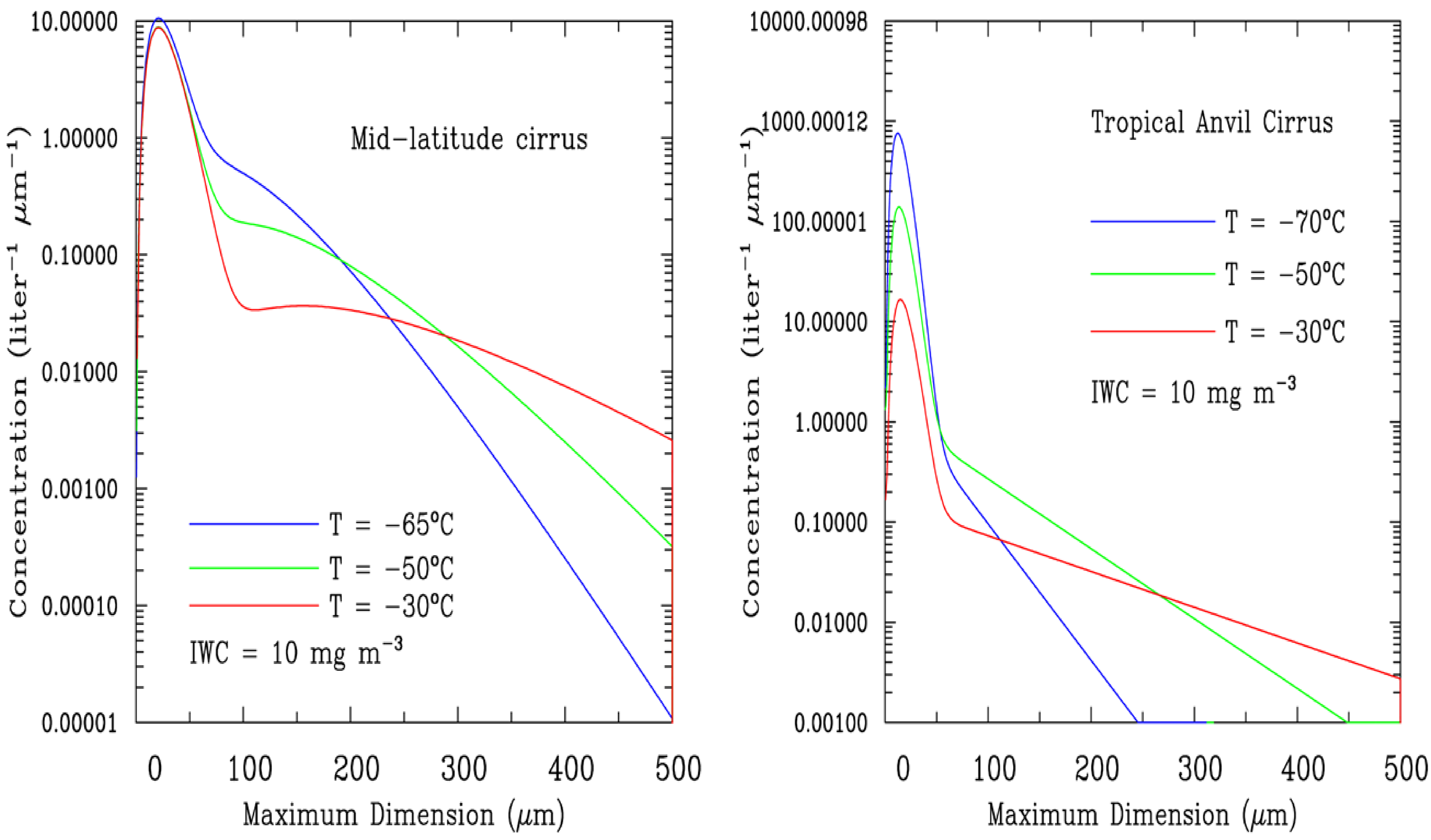


Fig. 5. Difference between microphysics and size distributions of Mid-latitude and Tropical ice- and mixed-phase cloud as a result of our analysis. Small ice crystals (diameter < 100 micrometers) enhancement with decreasing temperature T for tropical anvil cirrus; Opposite for mid-latitude cirrus. Both ice crystals size distributions schemes are based on 2DC and FSSP instruments in-flight measurements.

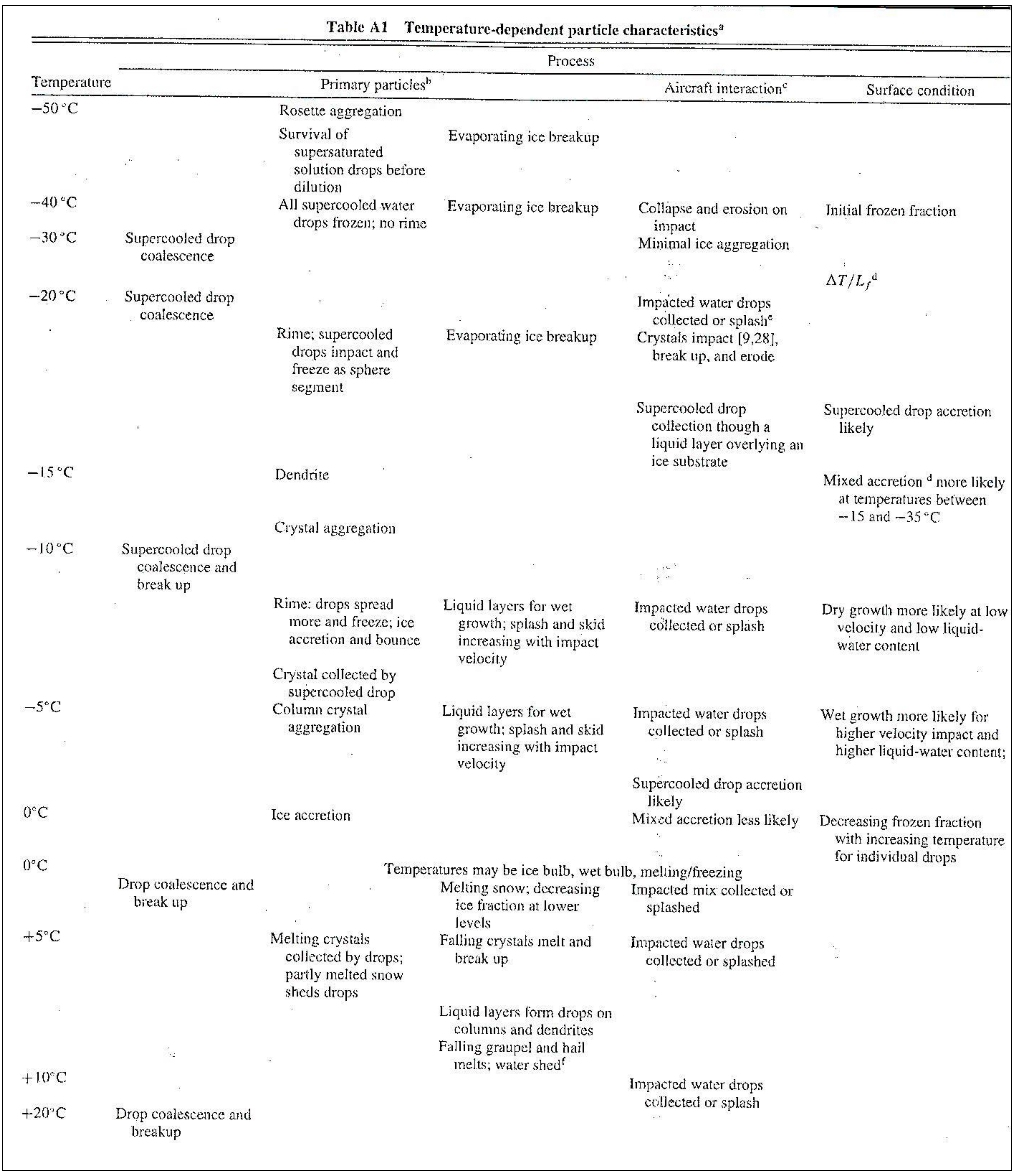


Table A1 Temperature-dependent particle characteristics[a]

			Process		
Temperature		Primary particles[b]		Aircraft interaction[c]	Surface condition
−50 °C		Rosette aggregation			
		Survival of supersaturated solution drops before dilution	Evaporating ice breakup		
−40 °C		All supercooled water drops frozen; no rime	Evaporating ice breakup	Collapse and erosion on impact	Initial frozen fraction
−30 °C	Supercooled drop coalescence			Minimal ice aggregation	
					$\Delta T/L_f$[d]
−20 °C	Supercooled drop coalescence			Impacted water drops collected or splash[e]	
		Rime; supercooled drops impact and freeze as sphere segment	Evaporating ice breakup	Crystals impact [9,28], break up, and erode	
				Supercooled drop collection though a liquid layer overlying an ice substrate	Supercooled drop accretion likely
−15 °C		Dendrite			Mixed accretion [d] more likely at temperatures between −15 and −35 °C
		Crystal aggregation			
−10 °C	Supercooled drop coalescence and break up				
		Rime: drops spread more and freeze; ice accretion and bounce	Liquid layers for wet growth; splash and skid increasing with impact velocity	Impacted water drops collected or splash	Dry growth more likely at low velocity and low liquid-water content
		Crystal collected by supercooled drop			
−5°C		Column crystal aggregation	Liquid layers for wet growth; splash and skid increasing with impact velocity	Impacted water drops collected or splash	Wet growth more likely for higher velocity impact and higher liquid-water content;
				Supercooled drop accretion likely	
0°C		Ice accretion		Mixed accretion less likely	Decreasing frozen fraction with increasing temperature for individual drops
0°C		Temperatures may be ice bulb, wet bulb, melting/freezing			
	Drop coalescence and break up		Melting snow; decreasing ice fraction at lower levels	Impacted mix collected or splashed	
+5°C		Melting crystals collected by drops; partly melted snow sheds drops	Falling crystals melt and break up	Impacted water drops collected or splashed	
			Liquid layers form drops on columns and dendrites Falling graupel and hail melts; water shed[f]		
+10°C				Impacted water drops collected or splash	
+20°C	Drop coalescence and breakup				

Table A1. Relevant temperature – dependent particle characteristics data from Hallett and Isaac (2008). Particle characteristics and microphysics in ice- and mixed-phase clouds should be considered in aircraft icing processes. Ice crystal size distributions, shape, and concentration provide insight for possible aircraft structural or engine performance degradation during aircraft icing events.

Recommendations for Future Research

- **Since 80% of the SLD observed in-flight during CFDE were formed through the non-classical mechanism, further research is crucial for understanding the relation between cloud microphysics, size distributions, temperature, and ice water content (IWC) in ice- and mixed-phase clouds.**
- **Supercooled water can often co-exist with ice crystals in mixed-phase clouds, therefore supercooled drop coalescence is important and needs further studies together with ice crystal aggregation and accretion.**
- **Aircraft – particle interactions such as collapse, erosion, and structural breakup upon impact should be investigated during ice aggregation, SLD accretion and mixed accretion events.**

References

Bernstein, B. C., F. McDonough, M. K. Politovich, B. G. Brown, T. P. Ratvasky, D. R. Miller, C. A. Wolff, and G. Cunning, 2005: Current Icing Potential (CIP): Algorithm description and comparison with aircraft observations. *J. Appl. Meteor*., 44, 969–986.

Berzukova, N. A., R. K. Jeck, M. F. Khalili, L. S. Minina, A. Y. Naumov, and E. A. Stulov, 2006: Some statistics of freezing precipitation and rime for the territory of the former USSR from ground-based weather observations. *Atmos. Res.*, 82, 203–221.

Hallett, J., and G. A. Isaac, 2008: Aircraft icing in glaciated and mixed phase clouds. *J. Aircr*., 45, 2120–2130

Isaac, G. A., S. G. Cober, J. W. Strapp, A. V. Korolev, A. Tremblay, and D. L. Marcotte. 2001. Recent Canadian research on aircraft in-flight icing. *Can. Aeronaut. Space J*, 47:213–221.

Ivanova, D., D. L. Mitchell, W. P. Arnott, and M. Poellot, 2001: A GCM parameterization for bimodal size spectra and ice mass removal rates in mid-latitude cirrus clouds. *J. Atmos. Res*., 59-60, 89–113