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On the Dependence of Cirrus Parametrizations on the Cloud Origin

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EGU2020-6733
https://doi.org/10.5194/egusphere-egu2020-6733

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Abstract

Particle size distributions (PSDs) for cirrus clouds are required for both climate models as well as many remote sensing retrieval methods. This study presents parametrizations of Arctic cirrus PSDs. The dataset used for this purpose originates from balloon-borne measurements carried out during wintertime above Kiruna (Sweden), i.e. north of the Arctic circle. The observations are sorted into two types of cirrus cloud origin, either in-situ or liquid. The cloud origin describes the formation pathway of the ice particles. At temperatures below −38 °C, ice particles form in-situ from solution or ice nucleating-aerosol particles. Liquid origin ice particles have formed at temperatures warmer than or equal to −38 °C, either via ice-nucleating particles embedded in liquid drops or via homogeneous drop freezing, and are then further uplifted to the cirrus temperature regime.

In order to derive parametrizations for each cloud origin, the observed PSDs are represented by gamma functions. The gamma coefficients exhibit large differences with respect to cloud origin. Functions describing the relationships in between the gamma coefficients and with temperature are fitted. These functions for Arctic cirrus confirm established parametrizations for continental cirrus sorted by two particle size modes but differ from others depending only on temperature. We suppose that the agreement between the parametrizations of the geographically different cirrus is because in-situ and liquid origin cirrus also distinguish by particle size modes. We present a parametrization combining the established parametrizations for continental cirrus with our Arctic relationships for in-situ and liquid origin clouds. Since cloud sorting by their origin is based on physical processes that are independent of geographical region, we further hypothesize that these cloud-type-based parametrizations might be generally valid for use in global models and satellite retrievals, given the distribution of the cloud types is known.

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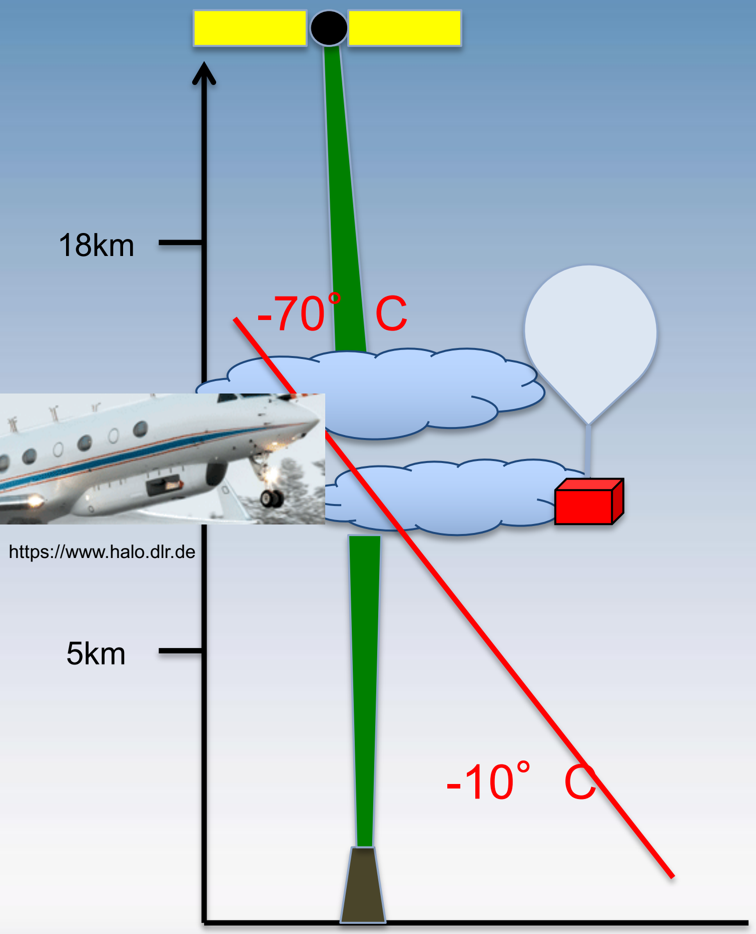
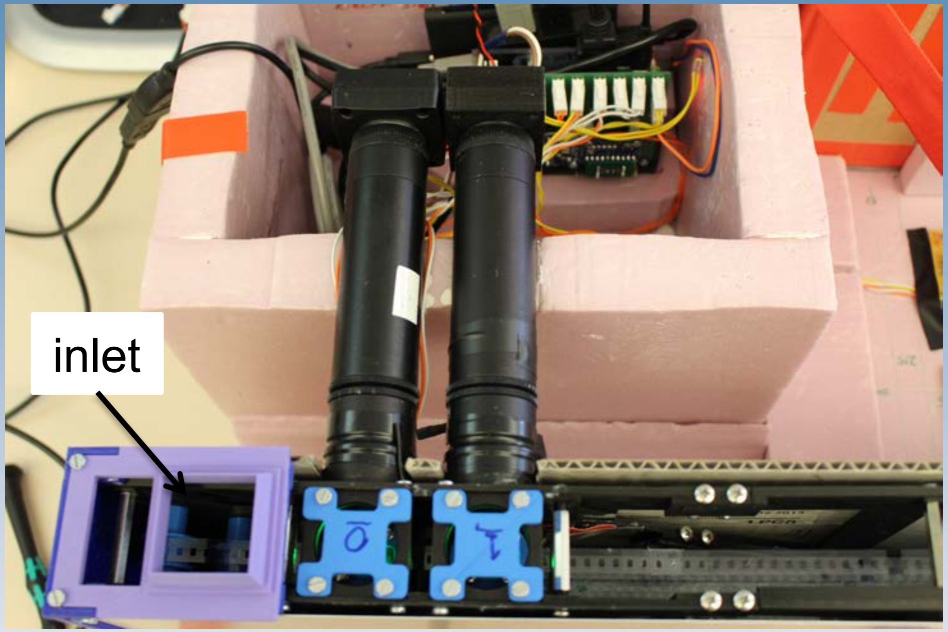


Cirrus
Balloon-borne
In-situ measurements

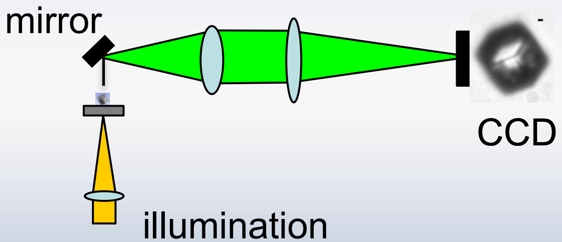
Esrange Space Center

Cirrus / ice clouds
- high altitude
- very often
- consist of ice crystals
- thin, translucent

In-situ imager B-ICI



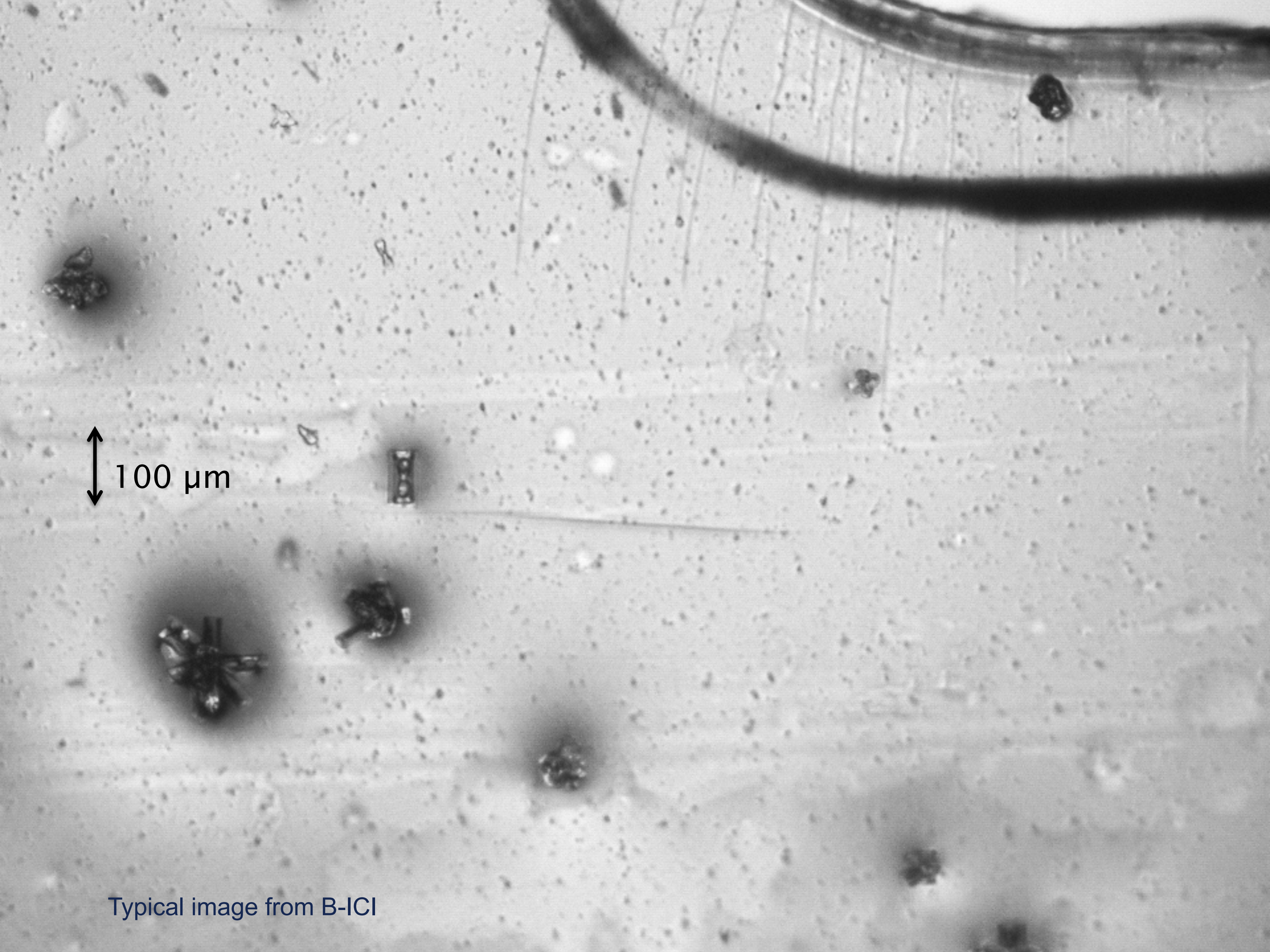
B-ICI, cover removed



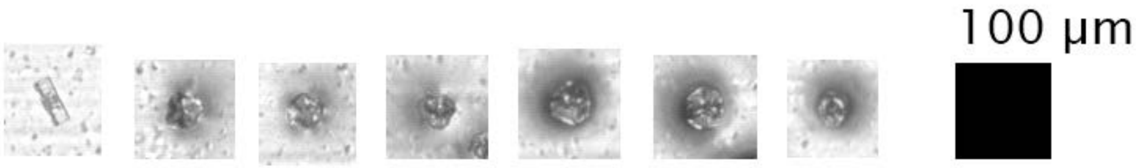
B-ICI, imaging/illumination setup

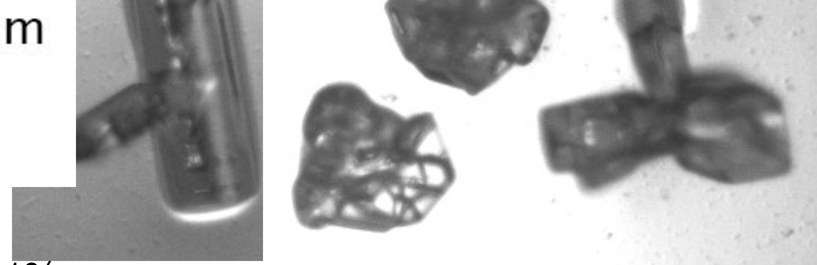
- 30 mm long inlet
- 4 m long film tape
  - coated with oil
  - move ~ 1mm/s
- Ice particles fall through the inlet
- Particles are collected on a tape
- Imaging < 1 min after collection
- Good image resolution
- Well defined sampling volume
- Data retrieved from images:
  - Size
  - Area
  - Shape
  - Concentration
  - Size distribution

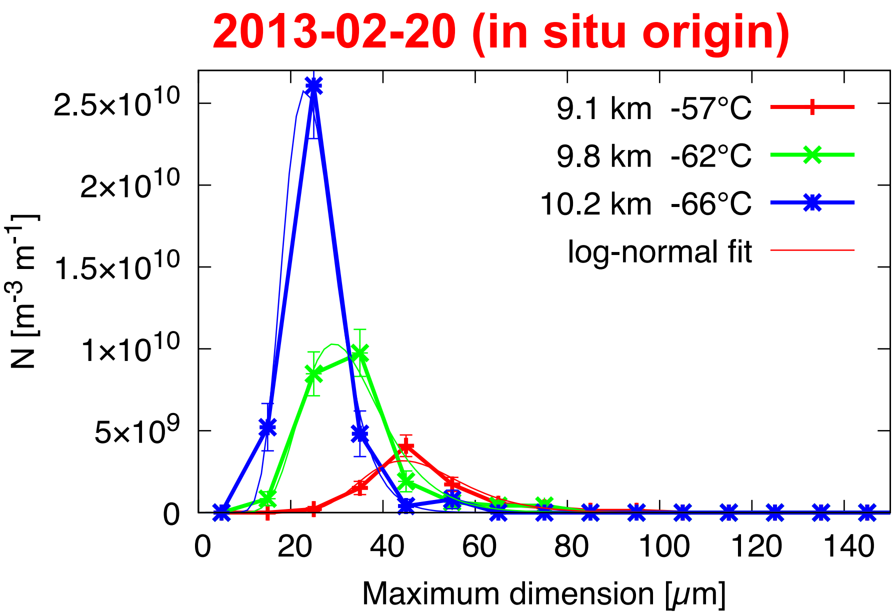
B-ICI
Kuhn, T., and A. J. Heymsfield (2016), Pure Appl. Geophys., 173 (9), doi: 10.1007/s00024-016-1324-x.

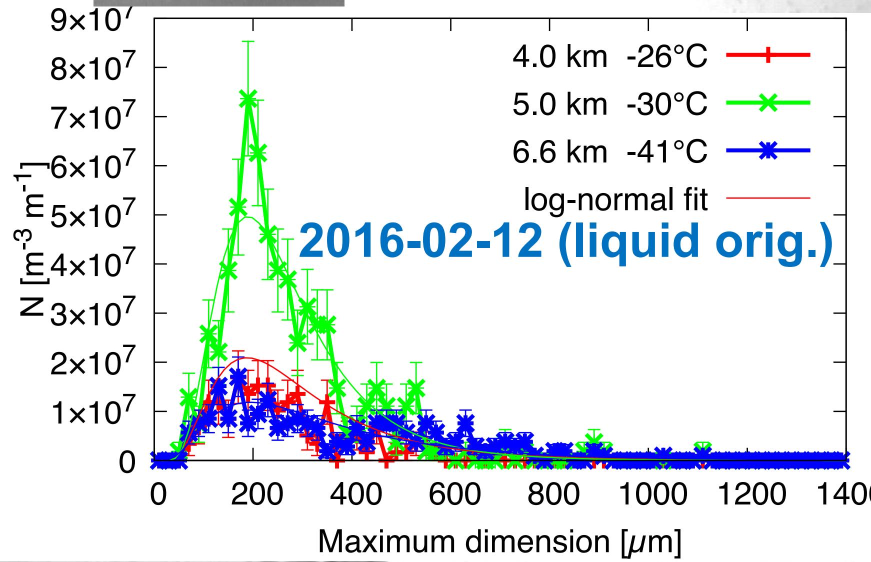


Typical image from B-ICI

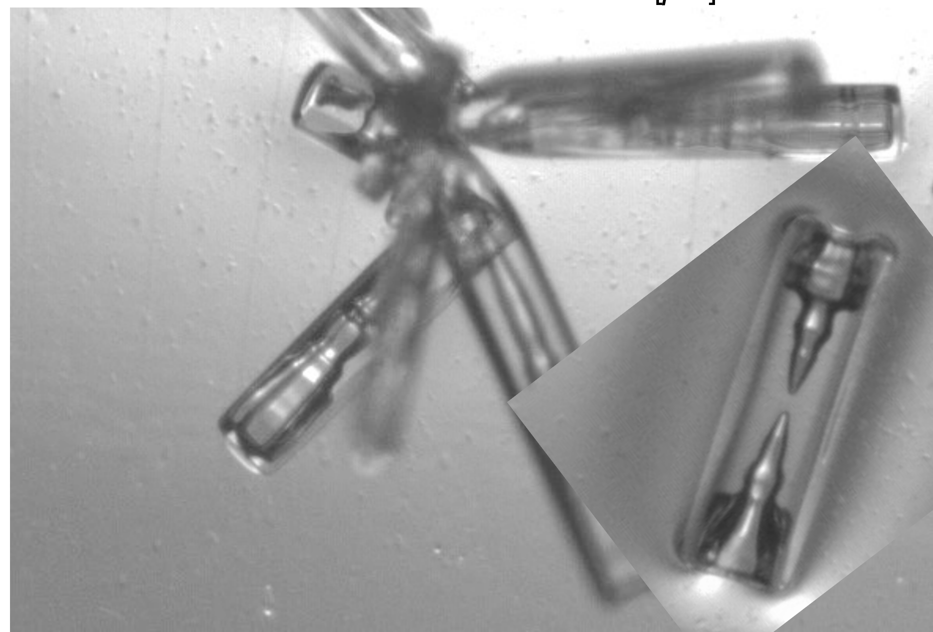








- Local temperature can be misleading:
  - look at conditions along back trajectory (history)
  - classify clouds according to origin
- Cloud origin:
  - formation at warmer (liquid origin) or colder temperatures (in situ origin) lead to different properties



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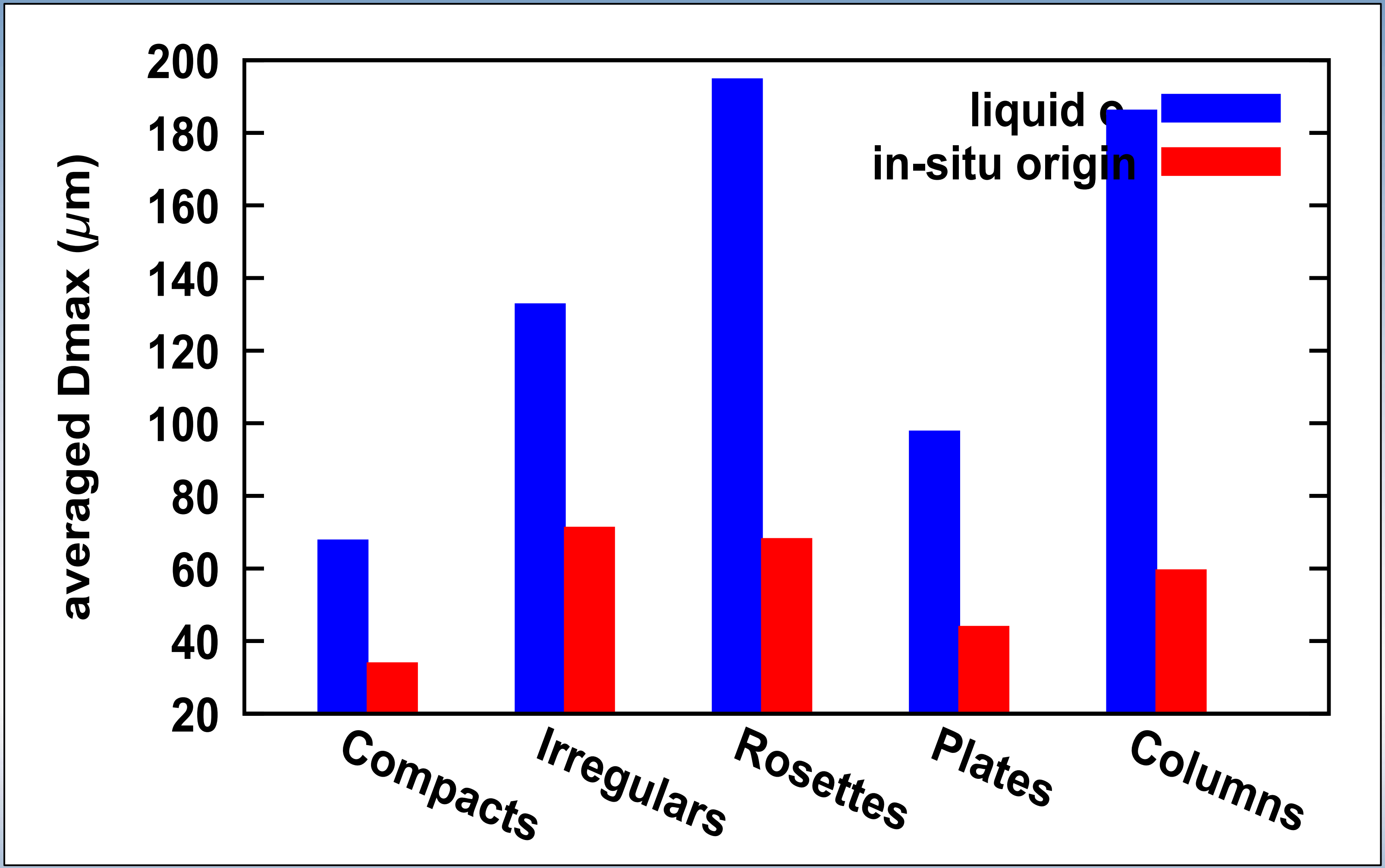
Average size



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Wolf, V., T. Kuhn, M. Milz, P. Voelger, M. Krämer, and C. Rolf (2018), Atmos. Chem. Phys., 18(23), doi: 10.5194/acp-18-17371-2018.

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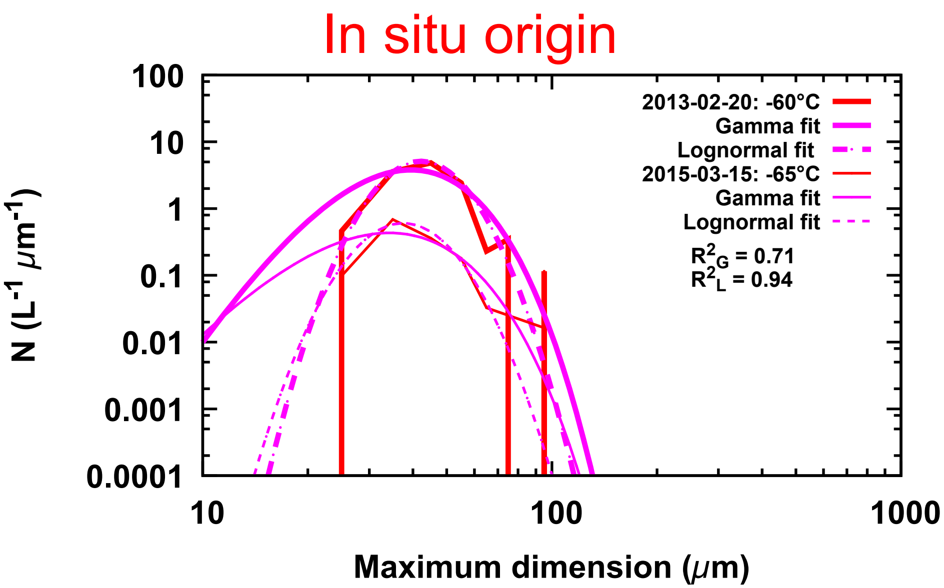
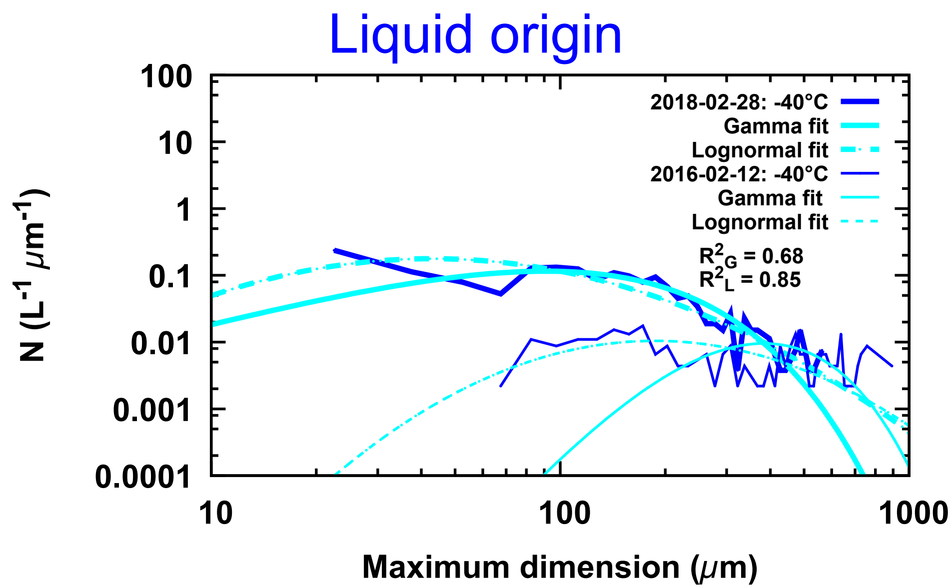
Particle size distribution (PSD)
(two days)





10 measurement days:
4x in situ origin (21 PSDs)
6x liquid origin (24 PSDs)
Particle size: 10 µm - 1000 µm
Number concentration: 1 L^{-1} - 500 L^{-1}

Wolf, V., T. Kuhn, and M. Krämer (2019), Geophys. Res. Lett., 46(21), doi: 10.1029/2019GL083841.

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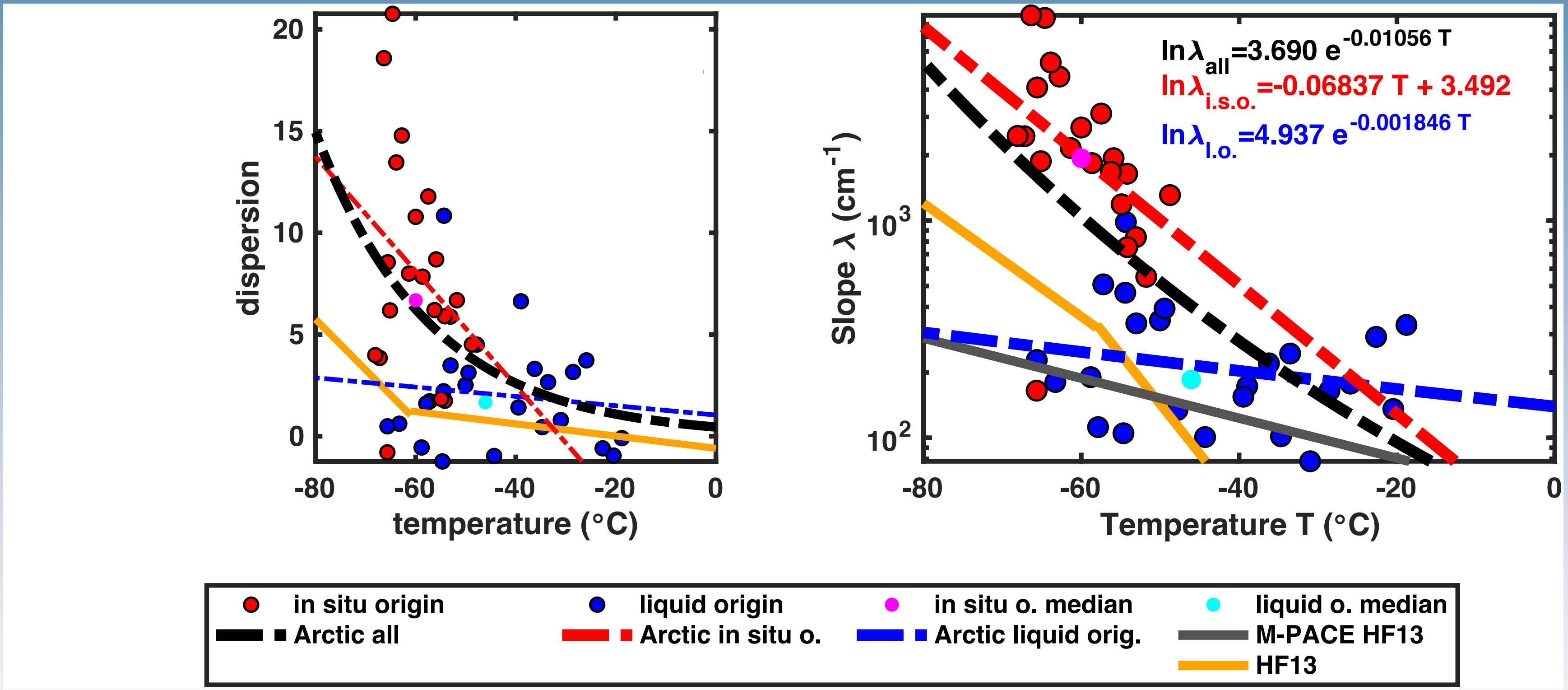
Particle size distribution



Gamma function: $N = N_0 \times D^{\mu} \times e^{-\lambda D}$

N_0 = intercept

μ = dispersion

λ = slope

D = maximum dimension

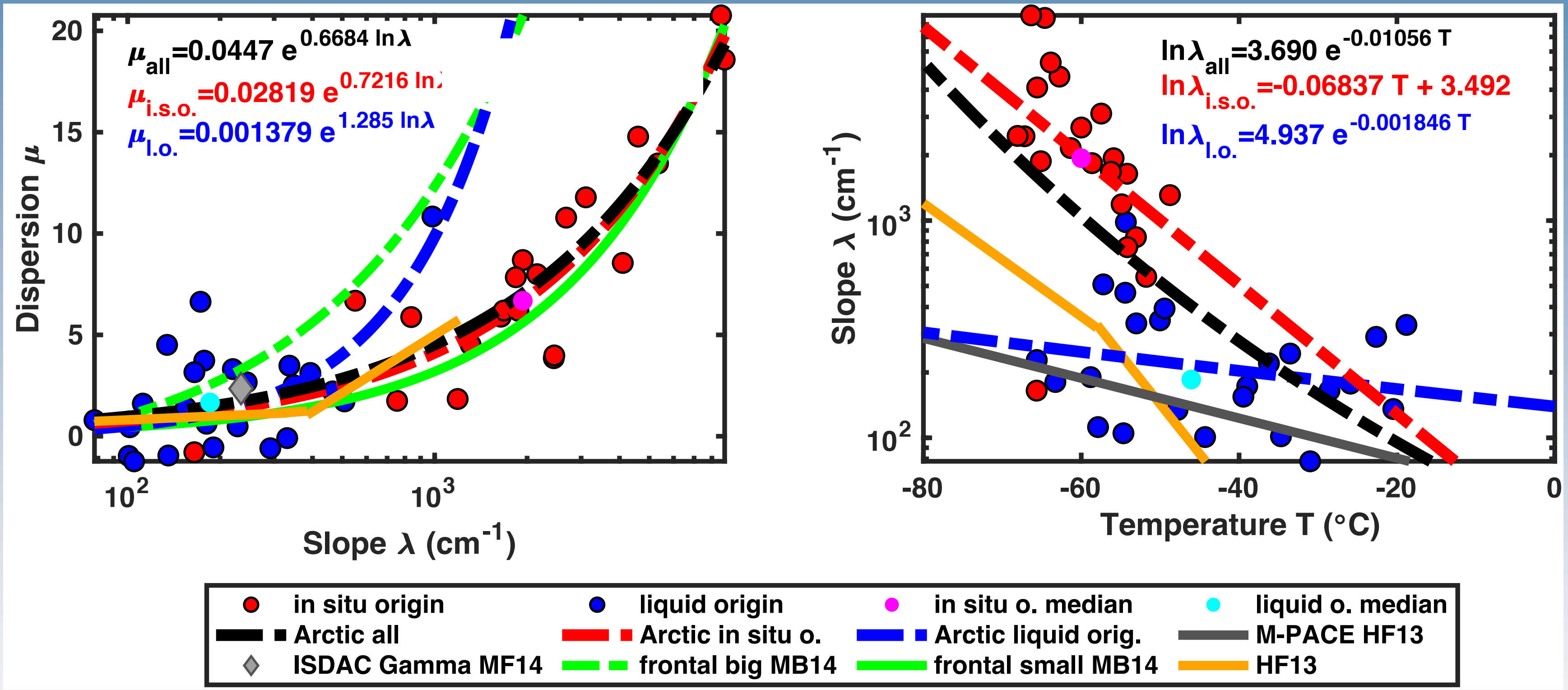
each fitted PSD:

one set of dispersion μ and slope λ

(one point in above plots)

Wolf, V., T. Kuhn, and M. Krämer (2019), Geophys. Res. Lett., 46(21), doi: 10.1029/2019GL083841.

Particle size distribution



Gamma function: $N = N_0 \times D^{\mu} \times e^{-\lambda D}$

N_0 = intercept

μ = dispersion

λ = slope

D = maximum dimension

Dispersion μ versus slope λ:

Agreement with MB14 (they use large, >100µm, and small, <100µm, instead of liquid and in situ origin)

For new parametrization, combine
μ(λ) from MB14 and
λ(T) from this study

Wolf, V., T. Kuhn, and M. Krämer (2019), Geophys. Res. Lett., 46(21), doi: 10.1029/2019GL083841.

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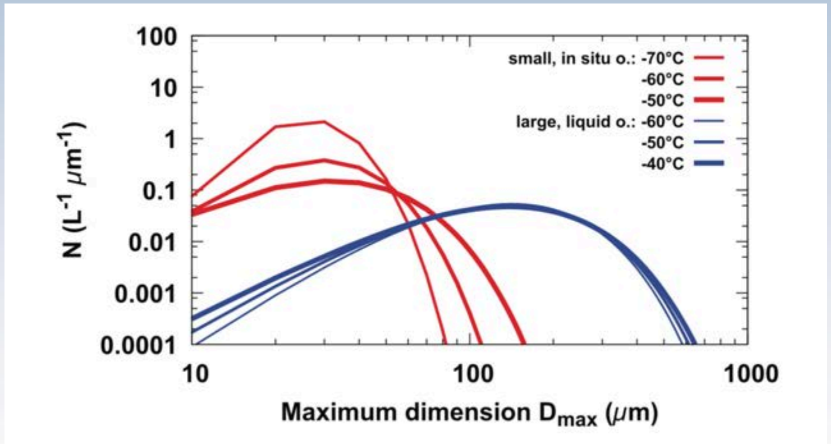
Summary

- In situ measurements of cirrus ice particles and PSDs with balloon-borne B-ICI
- Classify measurements by origin: liquid and in situ origin
- Fit gamma functions to measured PSDs
  - Coefficients dispersion μ and slope λ from fits larger for in situ origin than for liquid origin
  - Better agreement of liquid-origin coefficients with literature data and parametrizations
  - Continental cirrus parametrizations by MB14 for large and small particle modes agree with liquid and in situ origin

=>

- Combine μ(λ) from MB14 and λ(T) from this study: new parametrization by origin
- For cirrus, more relevant to classify by origin than by geographical region

Particle size distribution



New parametrization combining μ(λ) from MB14 and λ(T) from this study

Wolf, V., T. Kuhn, and M. Krämer (2019), Geophys. Res. Lett., 46(21), doi: 10.1029/2019GL083841.

Acknowledgements:
We thank the Swedish National Space Agency for funding the balloon campaigns and research (Grants 85/10, 86/11, 143/12, 273/12, 168/13, and 124/14) and the Graduate School of Space Technology at Luleå University of Technology for additional financial support.

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