ICE GENESIS Public Forum

Snow Microphysical Properties

WP5 Partners
Task 5.5

AIH, FR
CNRS, FR
EPFL, SUI

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824310.

Context / starting point for quantifying snow microphysical properties

Literature:

- Snowflake diameters mainly between 2 and 5 mm, ranging up to 15 mm. (Pruppacher 2010)
- Snowflake density varies, ranging from 0.005 to 0.2 g cm^{-3}, being inversely proportional to snowflake diameter, density almost four times larger for wet than for dry snowflakes.

Recent measurement campaigns:

- E.g. OLYMPEX or GCPEX: detailed µ-phys snow characterization is rare in terms of size dependent statistics of numerous microphysical & morphological snow particle properties.
- Accessible ground based and some limited airborne in situ snow measurements performed in the past often served to validate precipitation related remote sensing retrievals within GPM for example, without presenting extended microphysical/morphological snow particle analysis of the underlying data as is needed for trajectory, melting and accretion modelling (within and beyond ICE GENESIS)

Context / starting point for quantifying snow microphysical properties

- Therefore within ICE GENESIS, **proper ground and flight tests** have been conducted in snow conditions
- Overall objective has been the **most detailed characterization** of all relevant snow and precipitation related microphysical parameters
- to feed the **development of snow numerical tools** and for **comparison with artificial snow** generated in test facilities, bth within ICE GENESIS

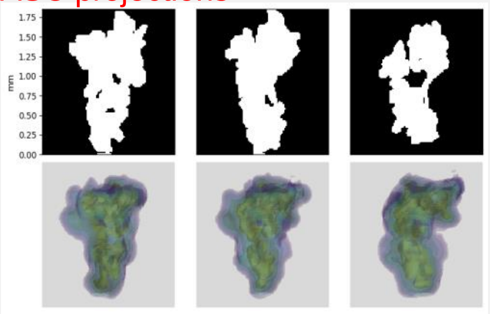
Considerable methodological effort within ICE GENESIS

Several Neural Networks implemented for snow properties' retrievals

1.

GAN (Generative adversarial network) deep learning method to generate 3D structures (and descriptors) from MASC 2D images: **Leinonen et al. (2021)**

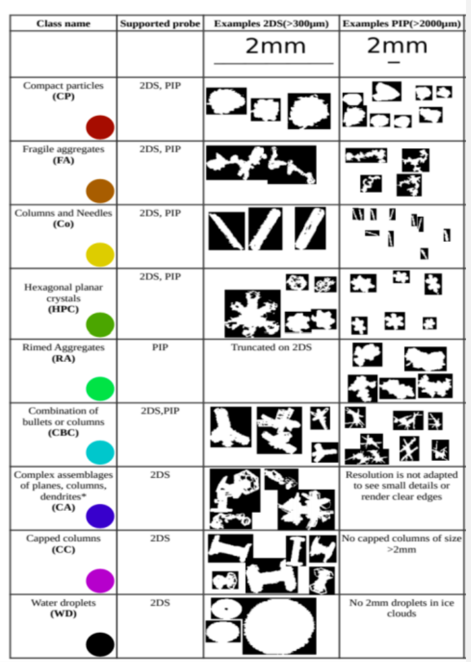
MASC projections



3D reconstructions with neural network

2.

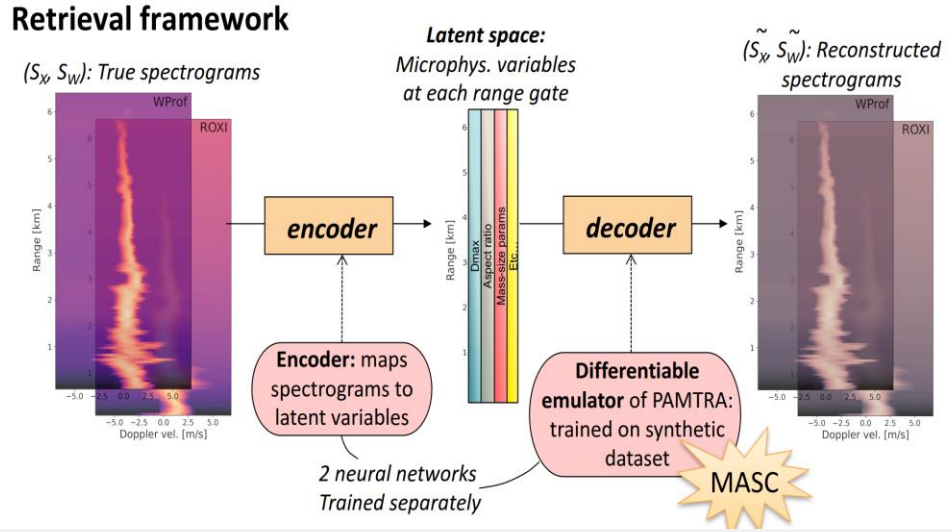
CNN (**Jaffeux 2022 AMT**) morphological retrieval (2DS & PIP OAP) and related crystal class statistics of snow descriptors.



Class name	Supported probe	Examples 2DS(>300µm)	Examples PIP(>2000µm)
		2mm	2mm
Compact particles **(CP)**	2DS, PIP		
Fragile aggregates **(FA)**	2DS, PIP		
Columns and Needles **(Co)**	2DS, PIP		
Hexagonal planar crystals **(HPC)**	2DS, PIP		
Rimed Aggregates **(RA)**	PIP	Truncated on 2DS	
Combination of bullets or columns **(CBC)**	2DS,PIP		
Complex assemblages of planes, columns, dendrites* **(CA)**	2DS		Resolution is not adapted to see small details or render clear edges
Capped columns **(CC)**	2DS		No capped columns of size >2mm
Water droplets **(WD)**	2DS		No 2mm droplets in ice clouds

3.

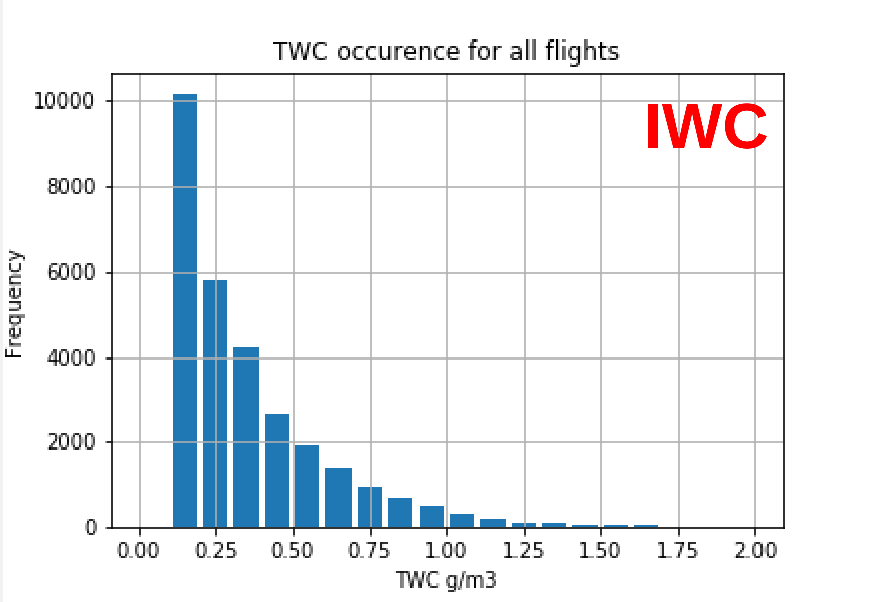
Dual-frequency retrieval (neural networks!) of snow properties: **Billault-Roux et al. (2022)**
Doppler spectrogram: vertical stack of Doppler spectra, the latter is the radar reflectivity as a function of Doppler velocity



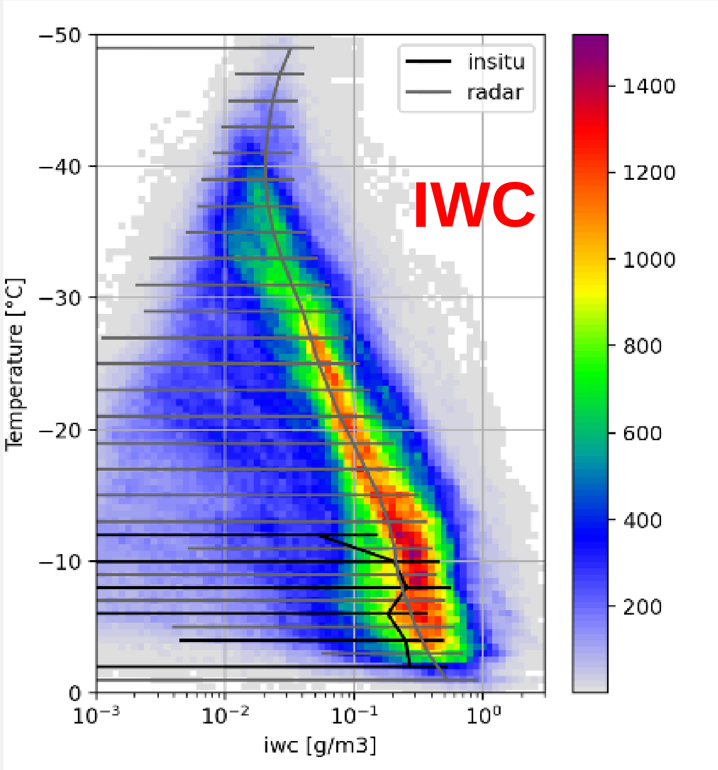
Snow microphysical properties

A. Bulk properties: IWC, proxy of typical snow particle size

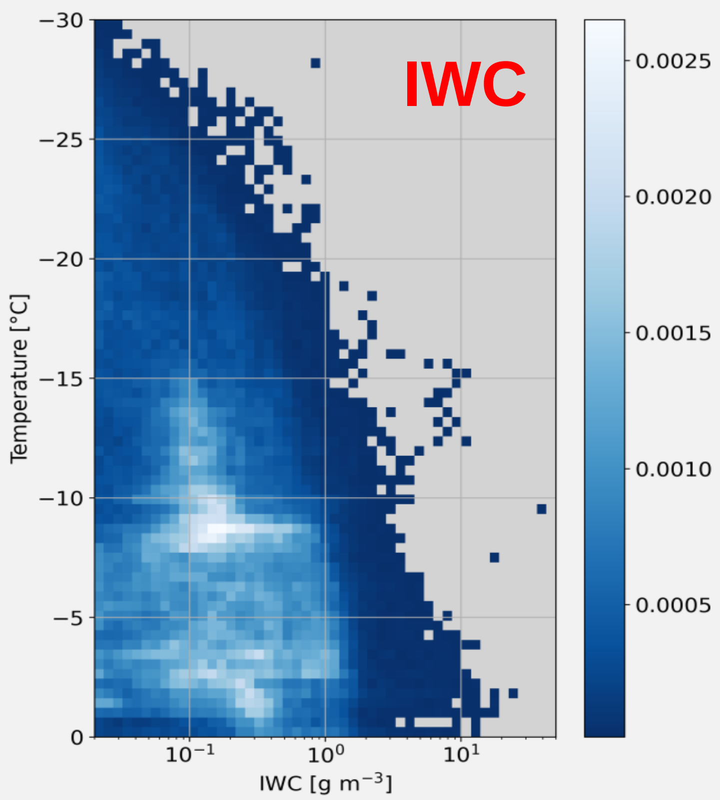
CVI bulk IWC on ATR



Multi-antenna W-band cloud radar
Retrievals of IWC in column

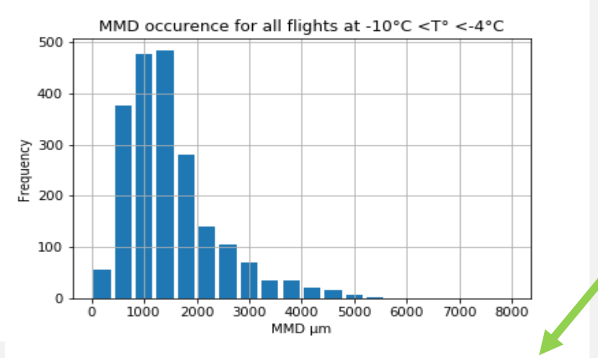


Dual frequency radar (X, W-band):
IWC retrievals in vertical column

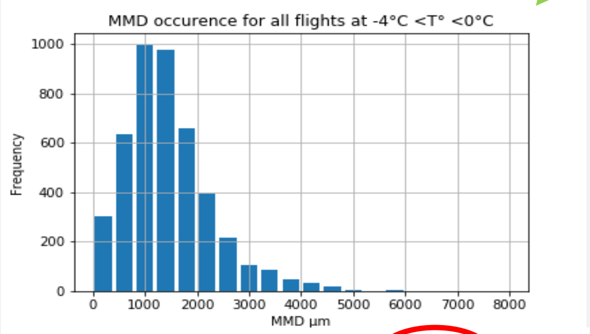


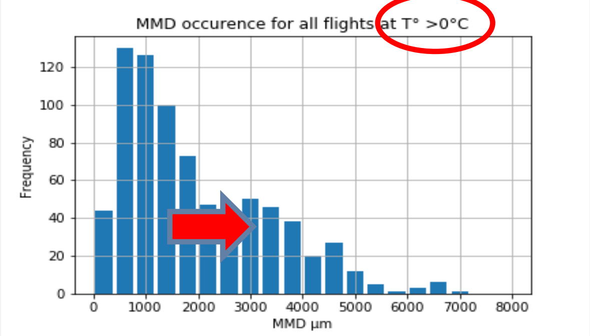
Snow microphysical properties

A. Bulk properties: IWC, proxy of typical snow particle size

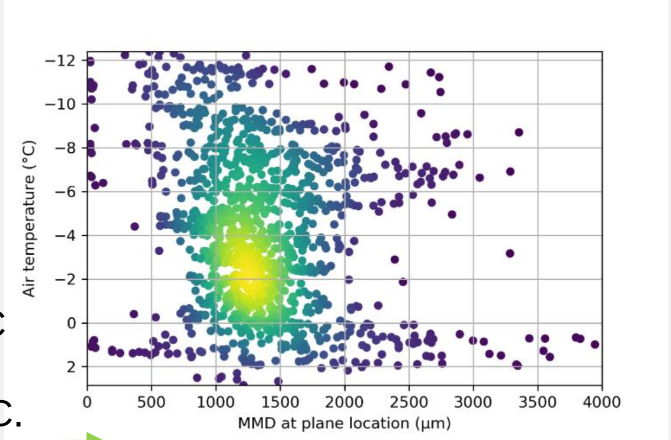


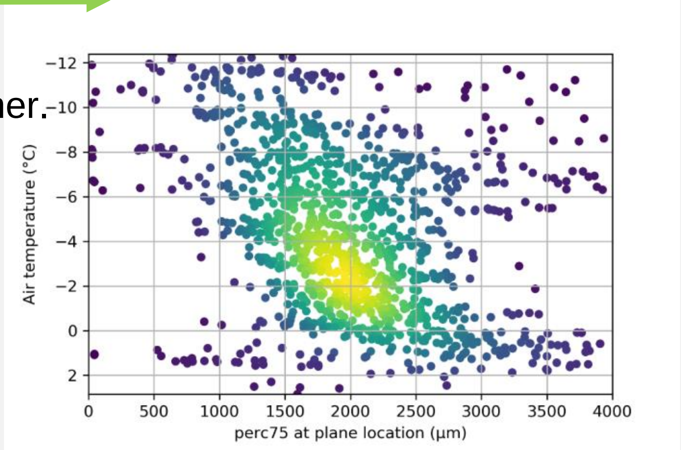
Frequency occurrence: In situ **MMD** from snow particle imagers on ATR



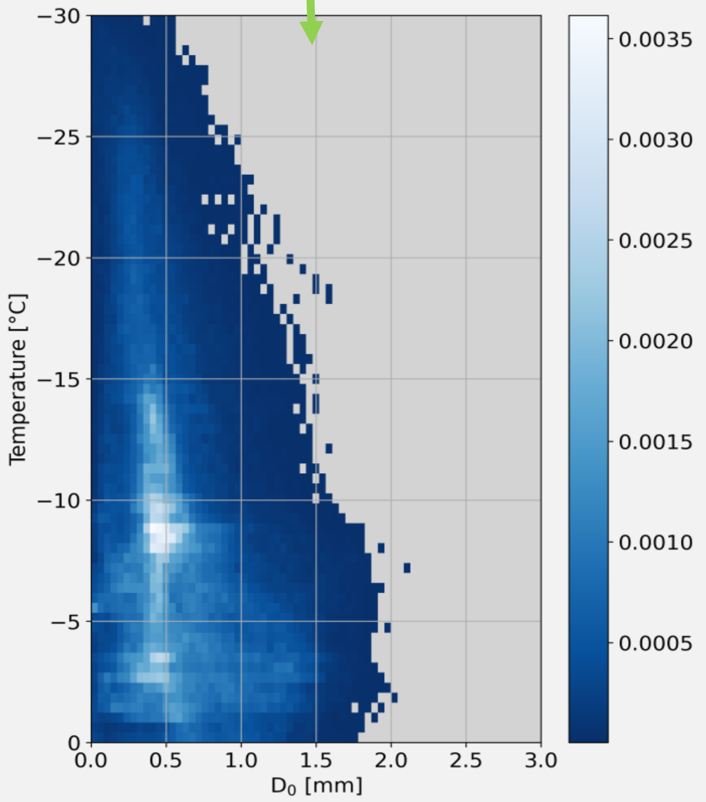


Mean **MMD and 75th percentiles** of the mass diameter for every 0.01°C temperature interval between -12 °C and +2 °C. The color of the points indicates the points overlapping with each other. In addition 25th and.



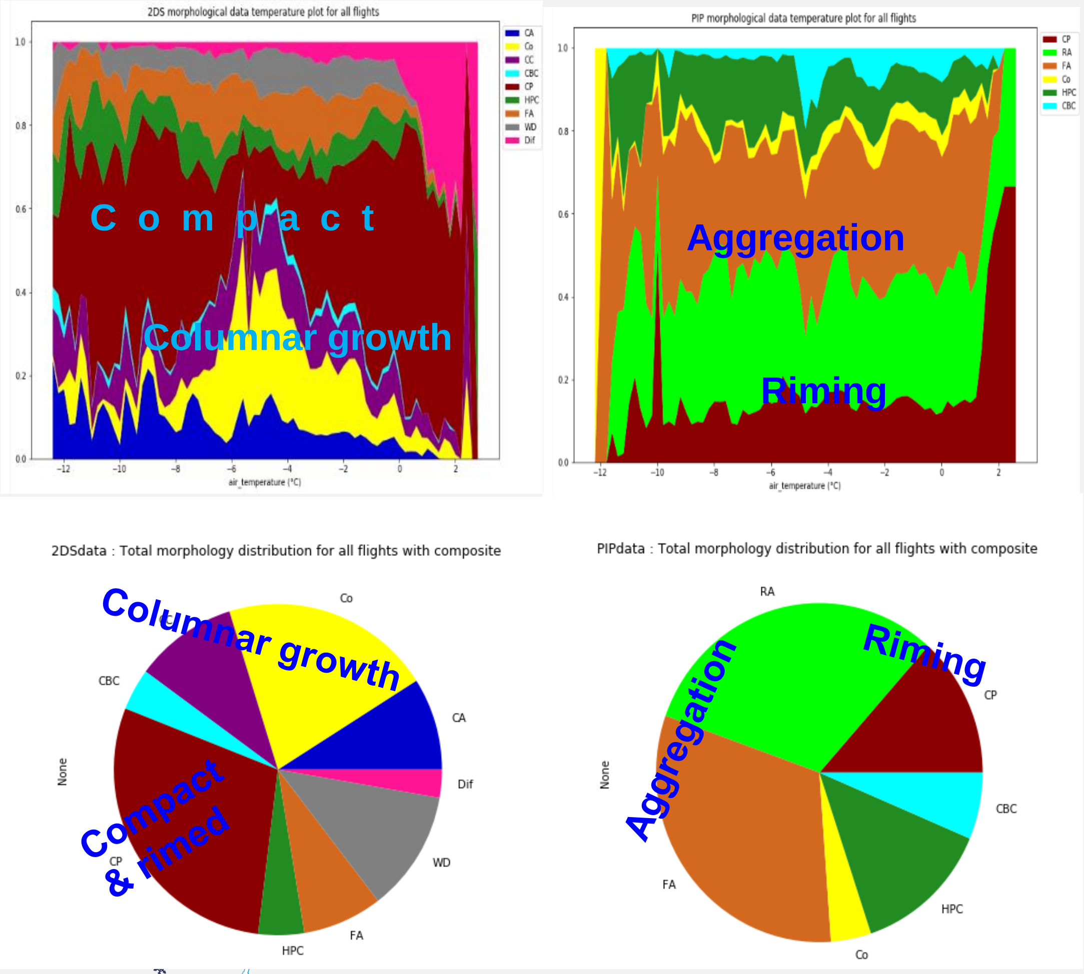


Dual frequency radar (X, W-band): **D_0** retrievals in vertical column



Snow microphysical properties

B. Ice particle morphological classification / riming degree / dry & wet snow



CNN retrieved **morphological classes** of the 2D-S and PIP snow particles: relative number fractions as a function of T and total number pie charts

Morphological classes (2DS & PIP images)

- Compact Particles (**CP**),
- Fragile Aggregates (**FA**),
- Columns and Needles (**Co**),
- Hexagonal Planar Crystals (**HPC**), and
- Combination of Bullets or Column (**CBC**).

3 further classes for the 2D-S images

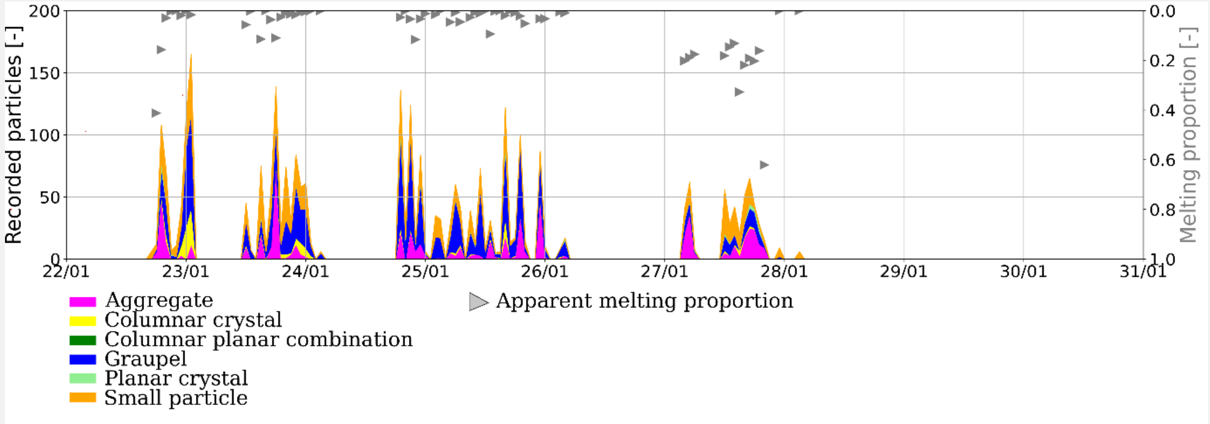
- Complex Assemblages of Planes, Columns, and Dendrites (**CA**),
- Capped Columns (**CC**),
- Water Droplets (**WD**).

1 further class for PIP images of

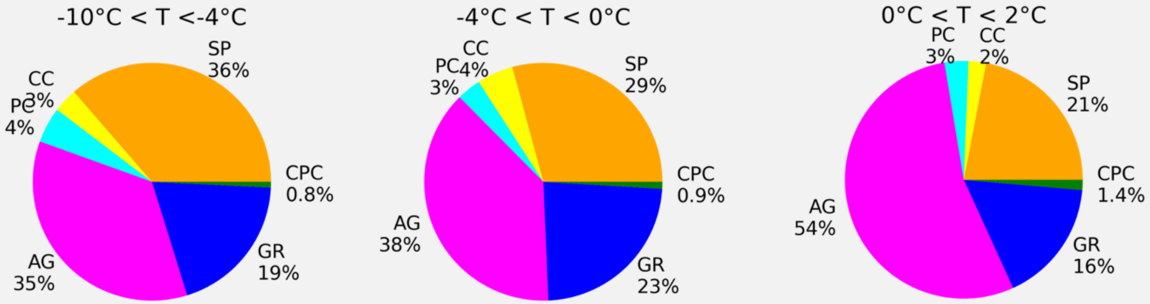
- Rimed Aggregates (**RA**).

Snow microphysical properties

B. Ice particle morphological classification / riming degree / dry & wet snow



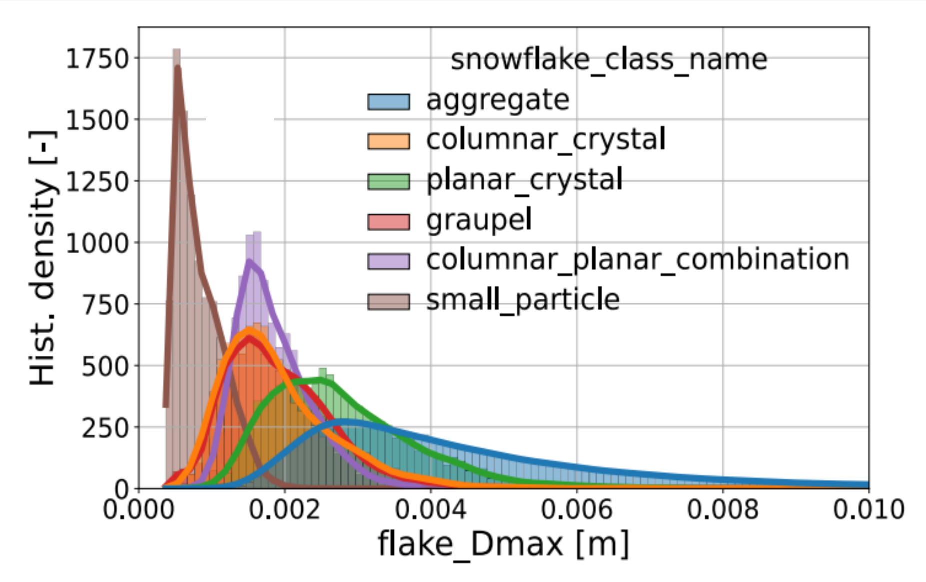
Time evolution of **hydrometeor types recorded by the MASC** near ground level and average proportion of particles showing **melting morphology** (MASC data averaged over 1 h consecutive intervals). Only MASC data collected at temperatures lower than 2°C are shown and hourly time intervals with at least 5 particles recorded.



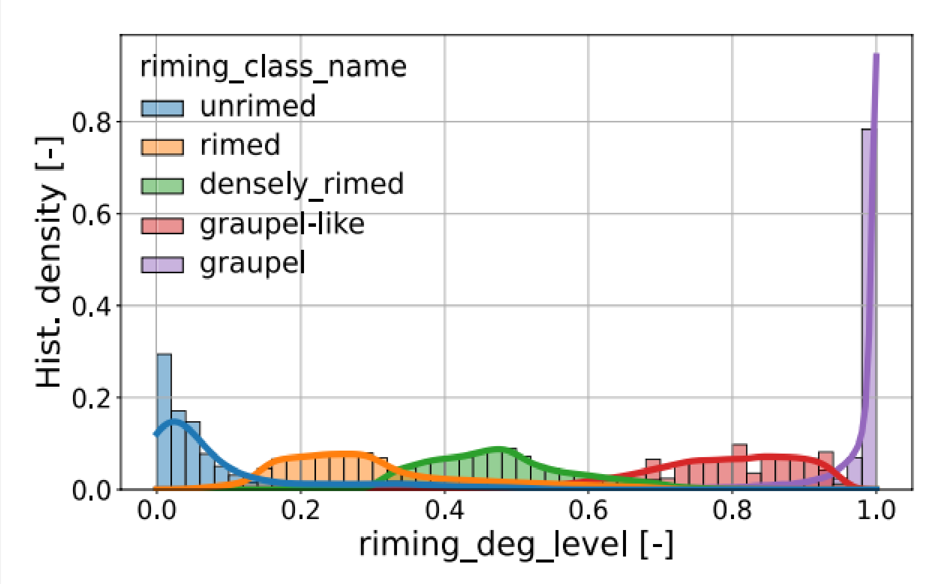
Entire **MASCDB dataset**, separated according to temperature range: number proportions

Snow microphysical properties

B. Ice particle morphological classification / riming degree / dry & wet snow



MASC data: Normalized histogram bin density according to the estimated hydrometeor type. Maximum dimension Dmax

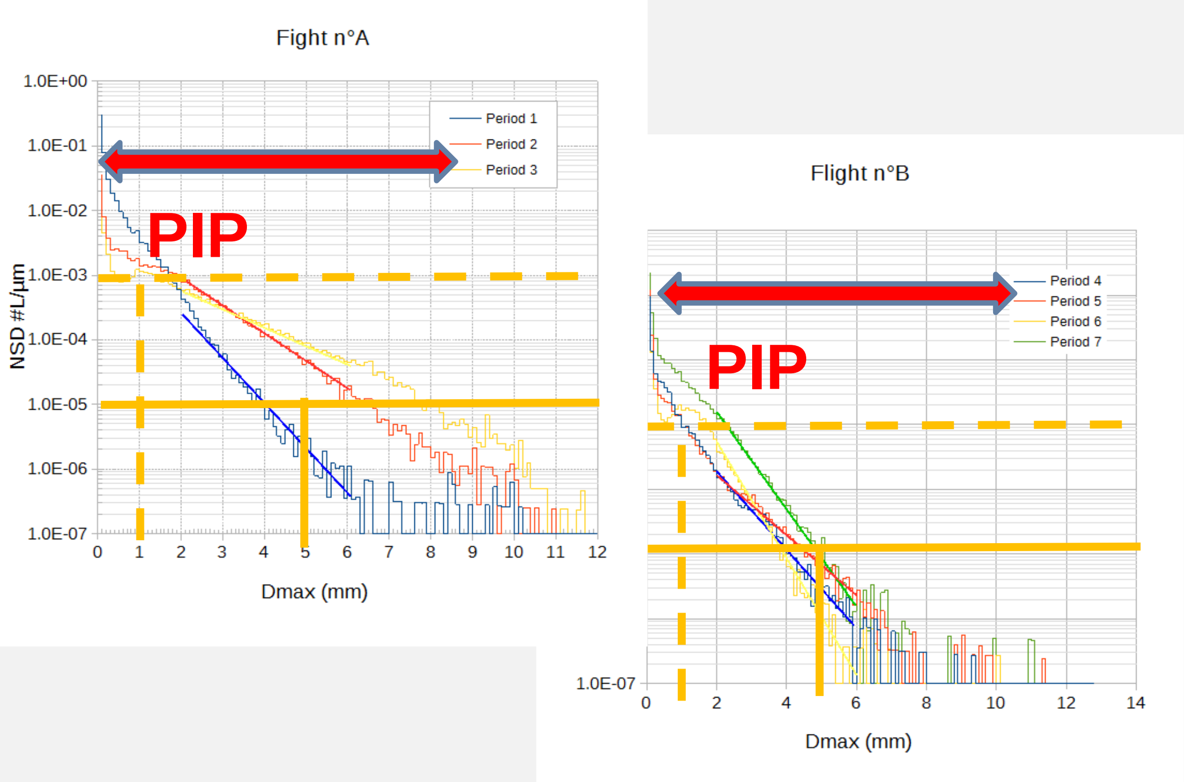


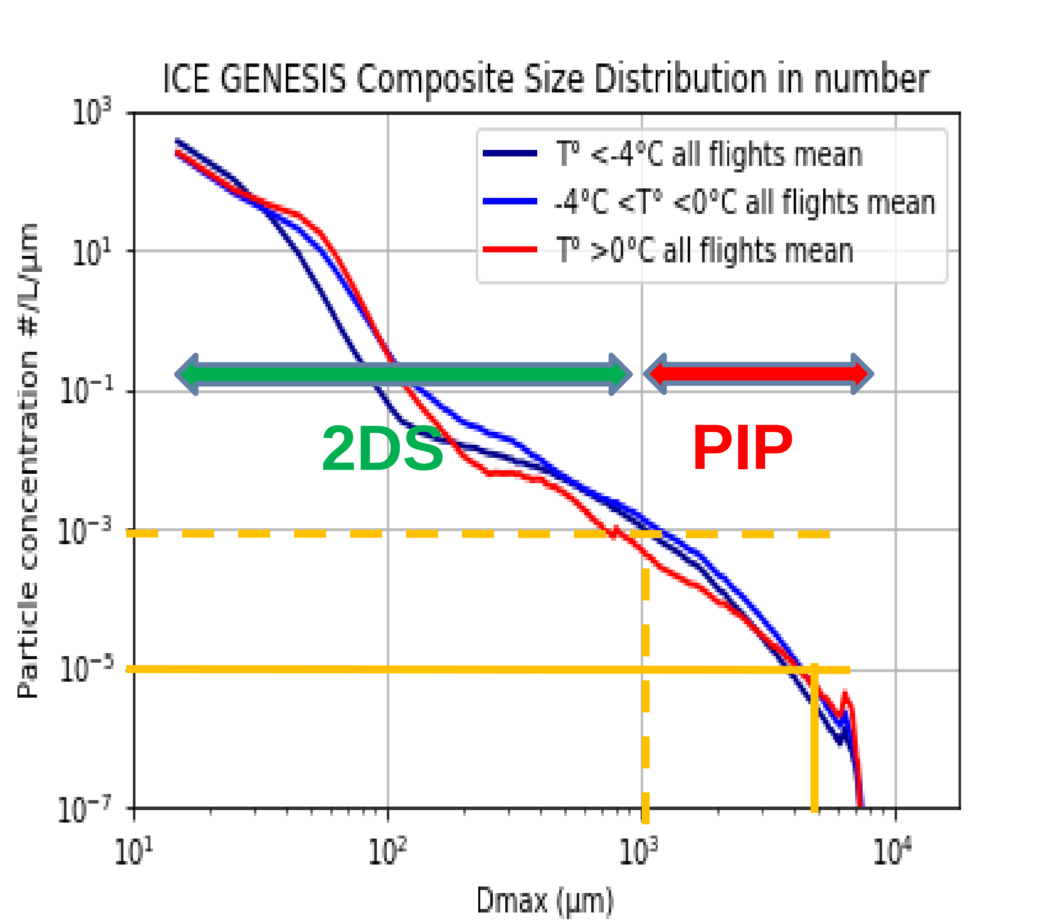
MASC data: Normalized histogram riming degree level.

Snow microphysical properties

C. Size dependent characterization of relevant snow particle microphysical properties

Variability of snow number size distributions (NSD) during two H160 (left) and averaged NSD for all ATR-42 flights (right)



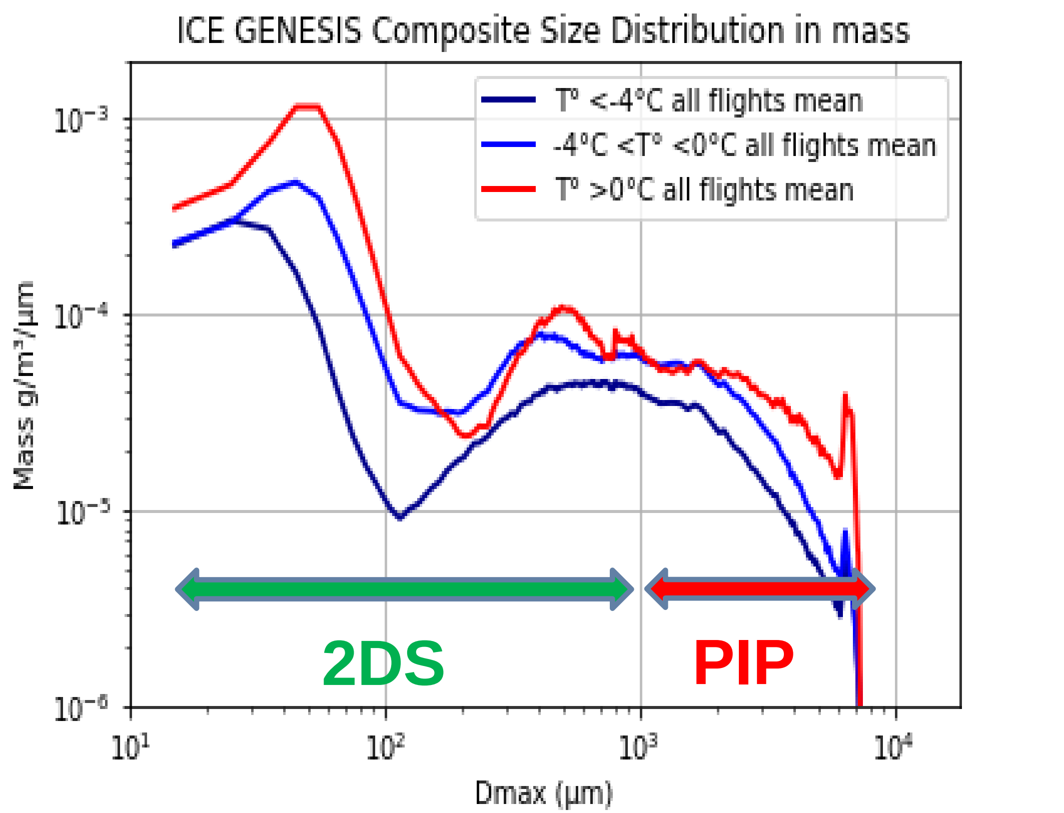


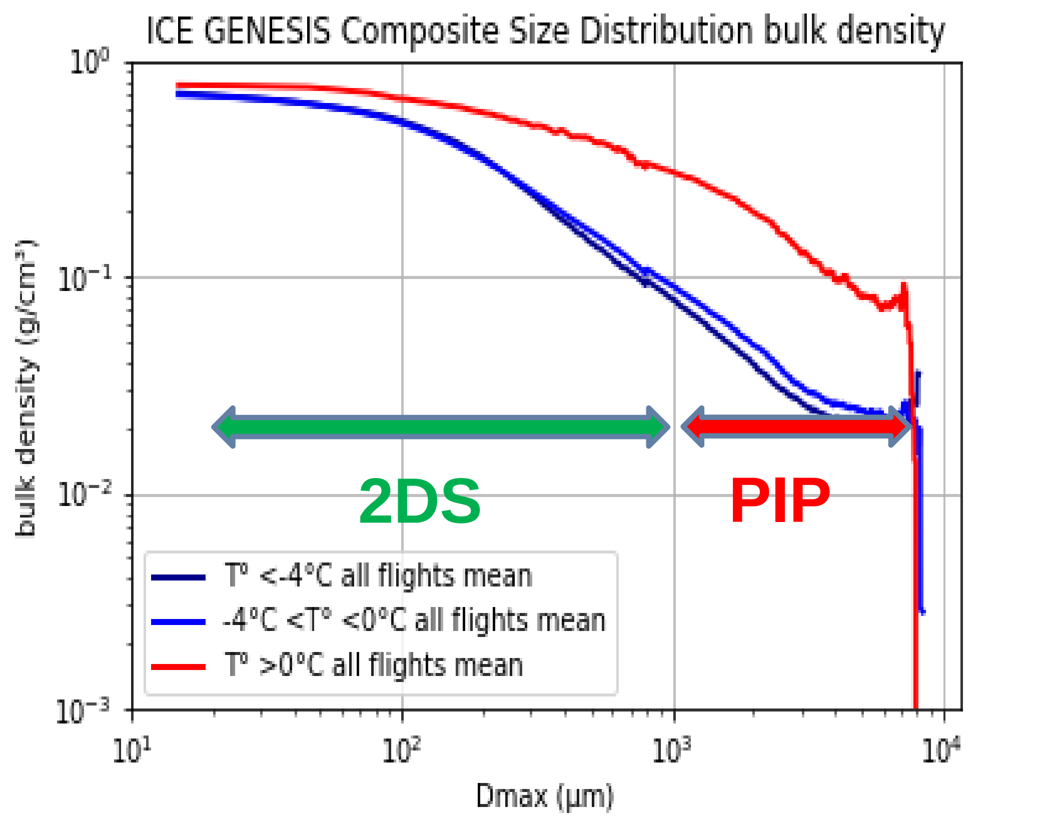
Exponential fit intercomparison $N = N_o . e^{-\lambda D}$, within 2-6mm size range

Snow microphysical properties

C. Size dependent characterization of relevant snow particle microphysical properties

Variability of snow mass size distributions (MSD) and bulk density distributions

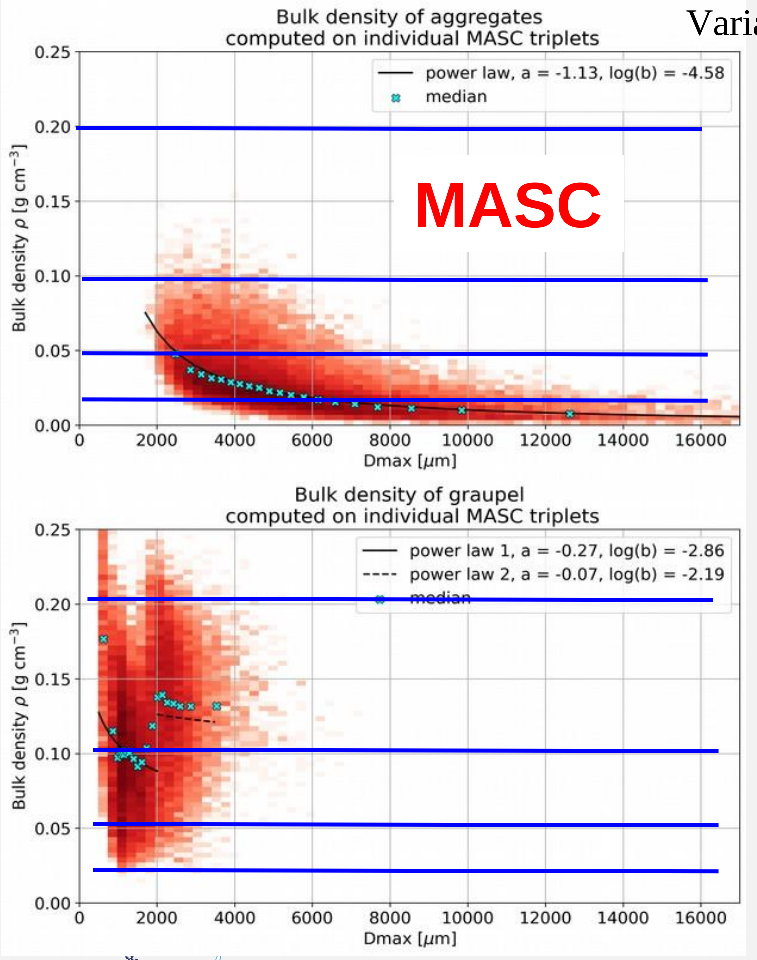


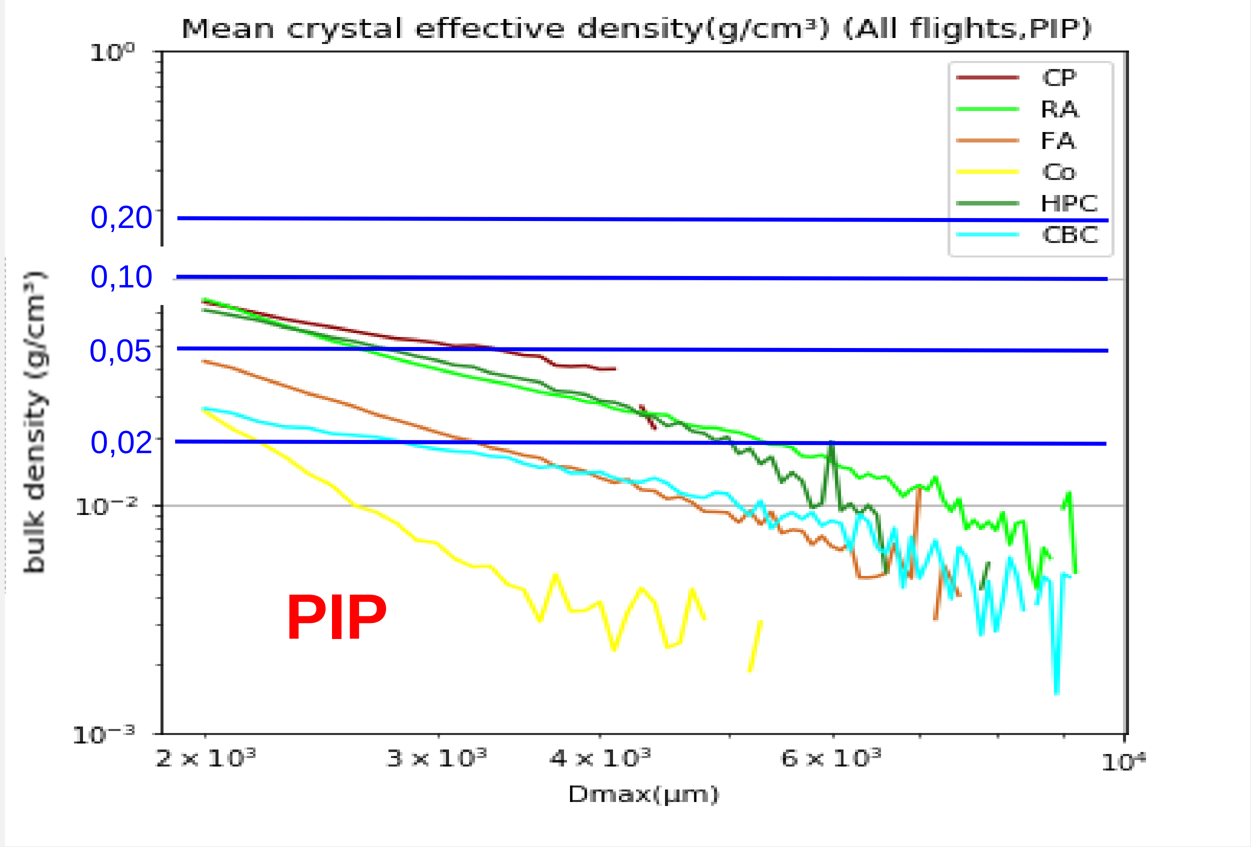


Snow microphysical properties

C. Size dependent characterization of relevant snow particle microphysical properties

Variability of snow bulk density size distributions (NSD) for various morphological classes: MASC & OAP data

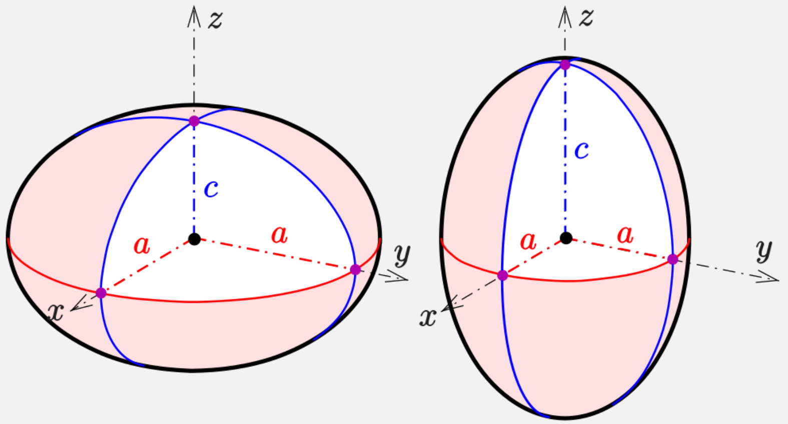




Snow microphysical properties

C. Size dependent characterization of relevant snow particle microphysical properties

Further **3D descriptors** for WP 10 modelling effort



2D ONERA/AIH Model

- Approximation of the snowflake as an oblate or prolate spheroid
- Major diameter of the spheroid is the maximum Feret diameter D_{max}
- Minor diameter of the spheroid is the Feret diameter orthogonal to the maximum Feret diameter $D_{\mathrm{max},\perp}$
- The volume of the spheroid is given by

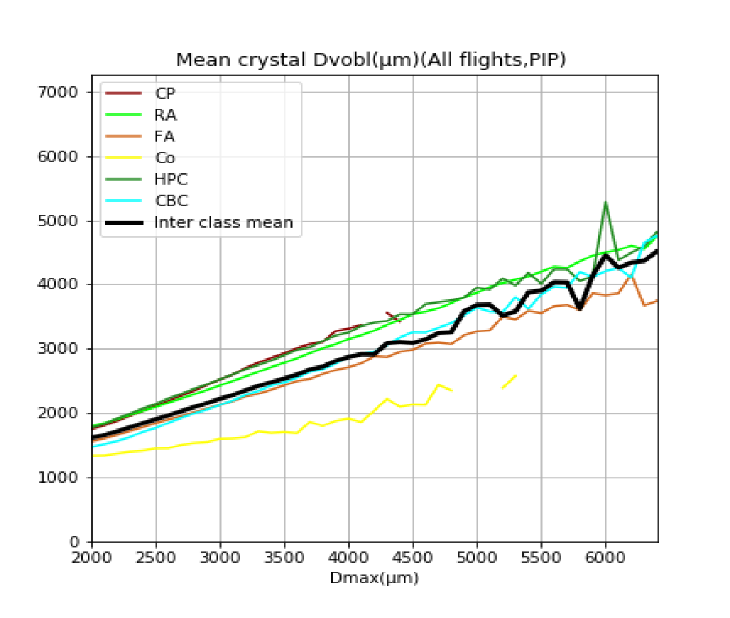
$$V = \begin{cases} \frac{1}{6}\pi D_{\mathrm{max}}^2 D_{\mathrm{max},\perp}, & \text{if oblate} \\ \frac{1}{6}\pi D_{\mathrm{max}} D_{\mathrm{max},\perp}^2, & \text{if prolate} \end{cases}$$

Snow microphysical properties

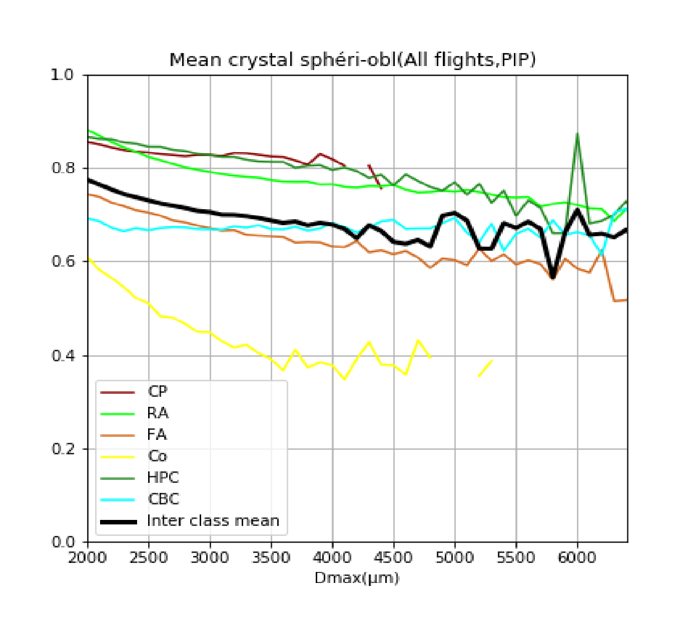
C. Size dependent characterization of relevant snow particle microphysical properties

Further **3D descriptors** for WP 10 modelling effort: Illustrations just for PIP snow particles: **morphology dependent 3D descriptors** for the **oblate spheroid** assumption

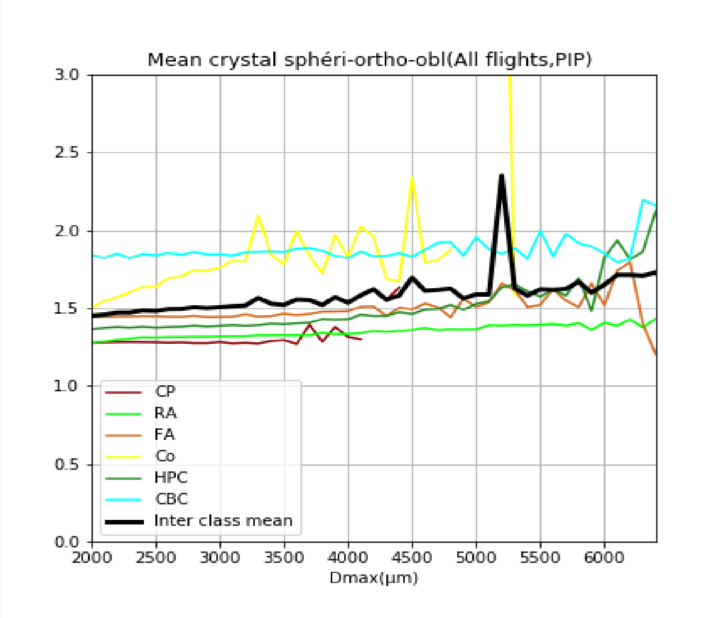
Diameter (D_v) of the sphere equivalent to the volume of the ellipsoid



Sphericity (= surface ratio S_D_v / $S_{ellipsoid}$)



Orthogonal sphericity (inverse area ratio)



3D descriptor dependency on size and morphological shape, likewise for prolate assumption (next slide)!!

Conclusion & Way Forward

- Valuable **falling snow data** gathered during winter 2020/21 for ICE GENESIS: **ATR-42**, **ground site 'Les Eplatures'** in situ & remote sensing measurements

- Considerable methodological effort for snow properties' retrievals (in situ MASC & OAP, dual frequency radar) within ICE GENESIS

- Snow characterization beyond H160 snow data possibilities and limited literature information of size dependent & snow particle morphology dependent microphysical properties

- Still, ICE GENESIS snow data set remains one snow « sample » within all imaginable snow situations….

- Quantification of snow properties certification and modelling purposes in table form: (mass fractions, density, sphericity, etc… in distinct diameter ranges, for three T domains, as fct of morphological classes).

- Dissemination of science results

THANK YOU

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824310. This text reflects only the author’s views and the Commission is not liable for any use that may be made of the information contained therein.

Context / starting point for quantifying snow microphysical properties

- **Unfortunately, rare effort of more detailed snow particle statistics:**
- e.g. Jeck (1998): Snow & Ice Particle Sizes & Mass Concentrations

Report number: DOT-FAA-AR-9766

- Data are from 50 research flights by six agencies in eight flight research projects in wintertime clouds, snowstorms, cirrus, and other high-altitude clouds using Particle Measuring Systems' one-dimensional (1-D) and two-dimensional (2-D) particle sizing probes.

- Primary estimated/recorded variables of IWC (=total ice particle mass), crystal total numbers, and maximum particle dimension (MPD) determined from the highest PMS probe channel to contain at least one particle per cubic meter in a given data record.

Context / starting point for quantifying snow microphysical properties

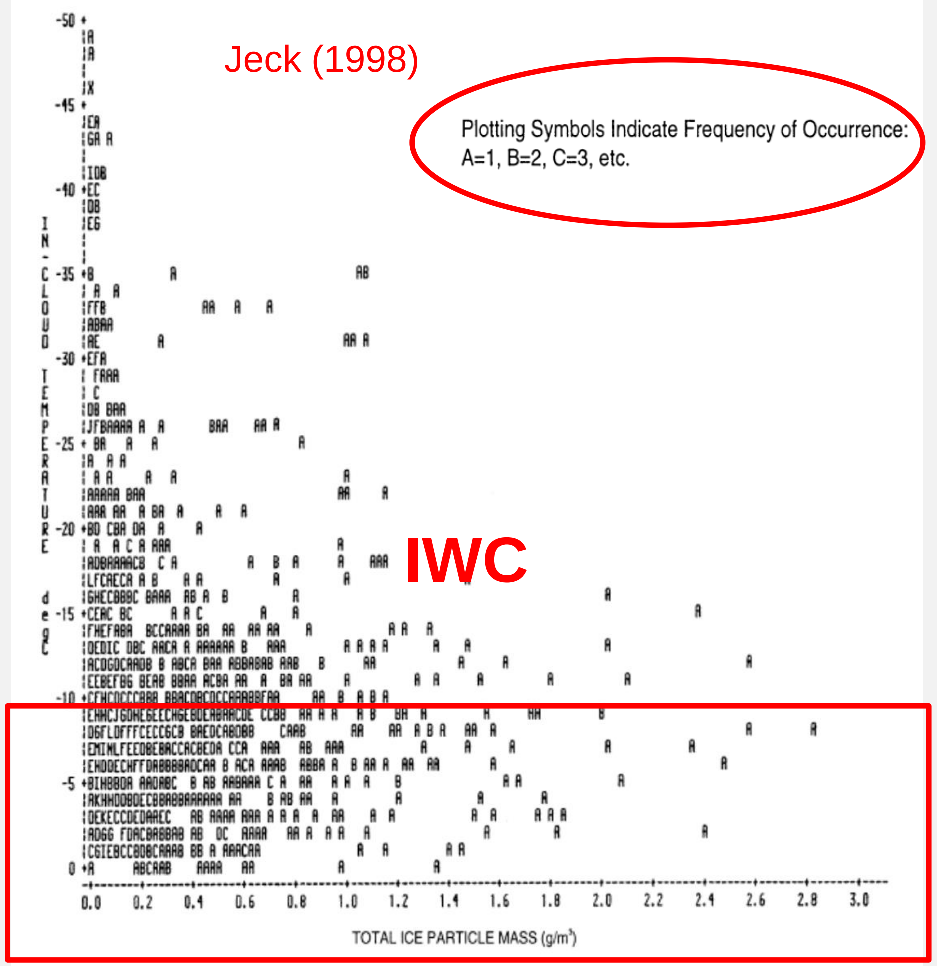


FIGURE 5c. COMPUTED, EVENT-AVERAGED, TOTAL ICE PARTICLE MASS VERSUS TEMPERTURE FOR ALL TYPES OF ICE PARTICLE CLOUDS

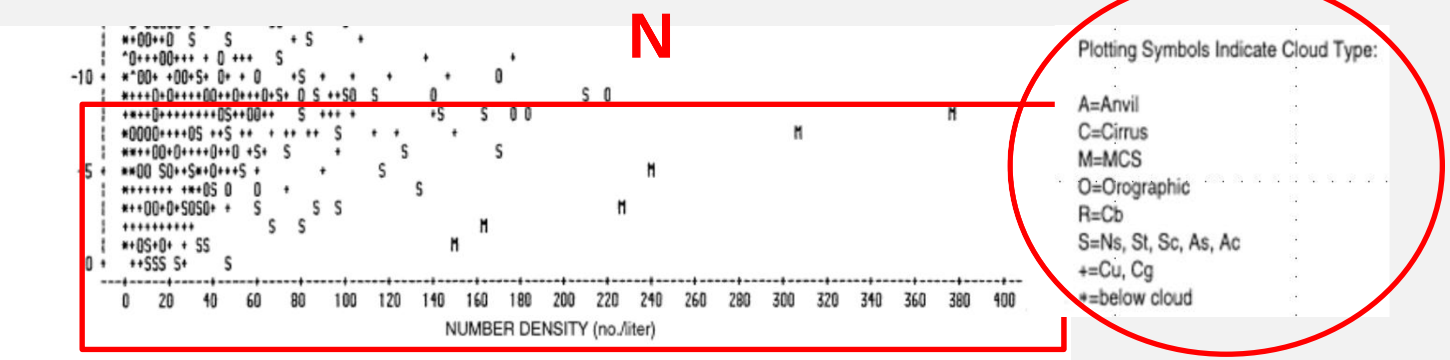


FIGURE 7a. EVENT-AVERAGED ICE PARTICLE CONCENTRATIONS (LINEAR SCALE) VERSUS TEMPERATURE FOR PARTICLES LARGER THAN 0.1 mm AND FOR ALL TYPES OF ICE PARTICLE CLOUDS

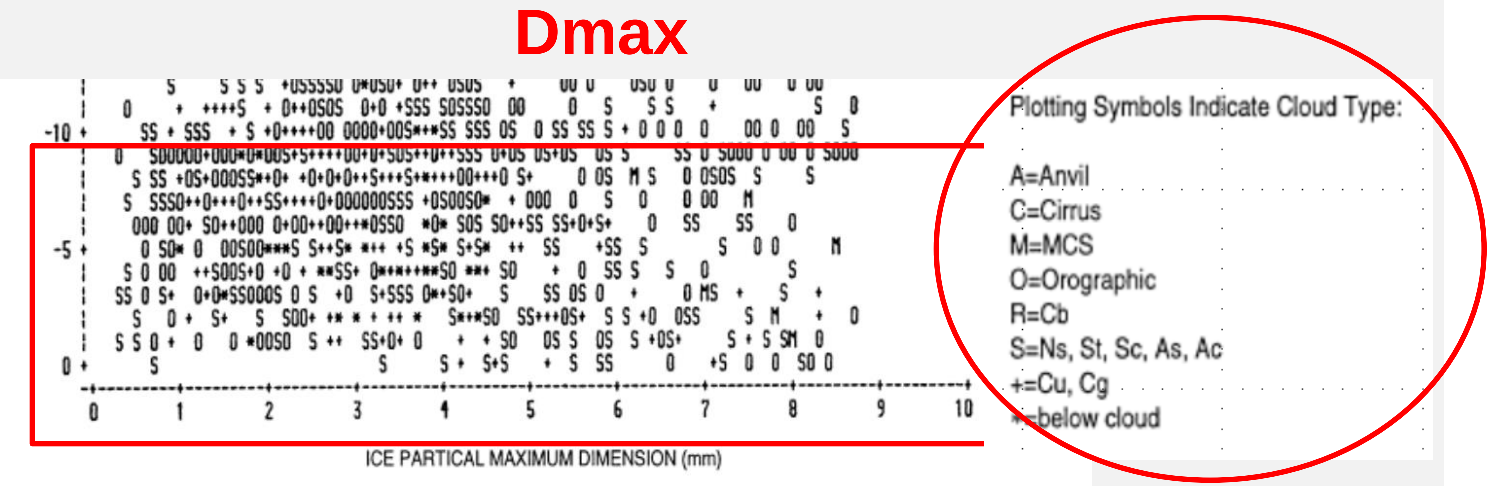


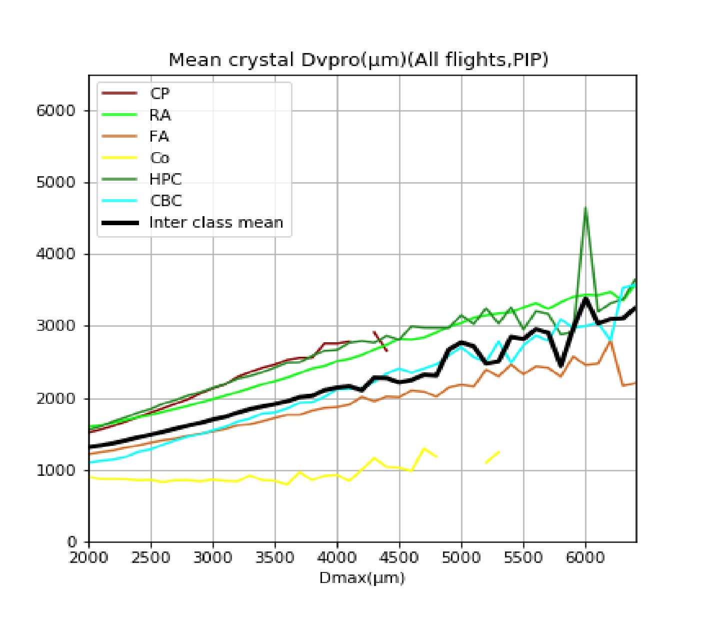
FIGURE 9a. EVENT-AVERAGED ICE PARTICLE MAXIMUM DIMENSION VERSUS TEMPERATURE FOR PARTICLES LARGER THAN 0.1 mm AND FOR ALL TYPES OF ICE PARTICLE CLOUDS

Snow microphysical properties

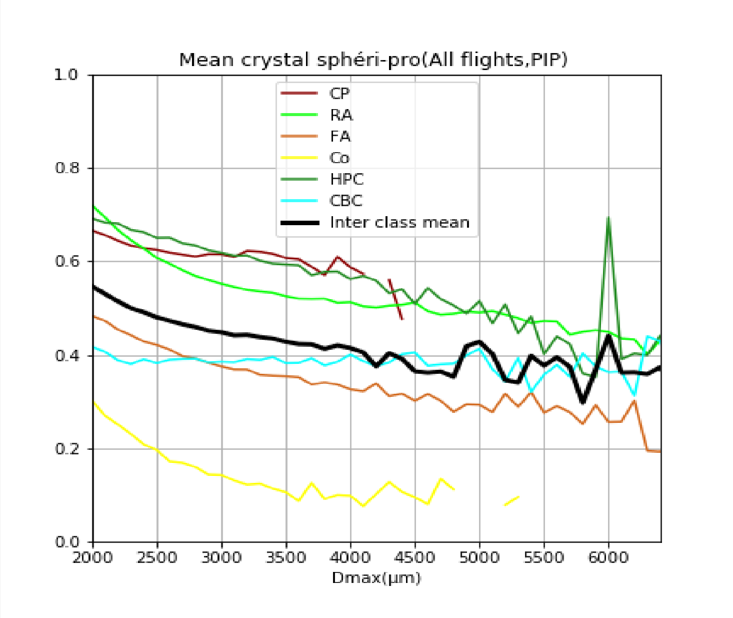
C. Size dependent characterization of relevant snow particle microphysical properties

Further **3D descriptors** for WP 10 modelling effort: Illustrations just for PIP snow particles: **morphology dependent 3D descriptors** for the **prolate spheroid** assumption

Diameter (D_v) of the sphere equivalent to the volume of the ellipsoid



Sphericity



Orthogonal sphericity