Study of the mass properties of ice particles observed at temperature from -50°C to -30°C in tropical MCS

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MOTIVATION

The ***density of ice particles*** is a key parameter in many applications in atmospheric sciences such as models (ice particle fall speed, precipitation rate, cloud lifetime) and active/passive remote sensing retrievals (backscattering cross section, attenuation factor). The estimation of the density of natural ice particles from in-situ observations has been an active field of research over the last decades. Most of the published mass-size relationships assume that this relation conforms to a power law. A ***new method based on an inverse problem approach*** has been recently proposed to retrieve ***bin-resolved mass*** from in situ measurements (PSD, IWC) **[1]**. In this study, we apply this new method to ice crystals sampled at different atmospheric conditions typical of tropical MCSs (***HAIC-HIWC Darwin-2014 campaign***). The study focuses on the size dependent effective density retrieved for some selected subsets of ice particles sampled between -50°C and -30°C and reports on the observed variability.

METHODOLOGY

Inverse problem approach **[1]**:

The ***bin-resolved masses*** (***m***) of ice particles are derived from Particle Size Distribution (PSD) and Ice Water Content (IWC) by solving the inverse problem:

$$PSD.\boldsymbol{m} = \boldsymbol{IWC}$$
$$J(\boldsymbol{m}) \overset{\text{def}}{=} \|PSD.\boldsymbol{m} - \boldsymbol{IWC}\|^2 + \lambda.R(\boldsymbol{m})$$

With $\lambda \in \mathbb{R}^{*+}$ regularization parameter

$R(\boldsymbol{m})$ regularization function

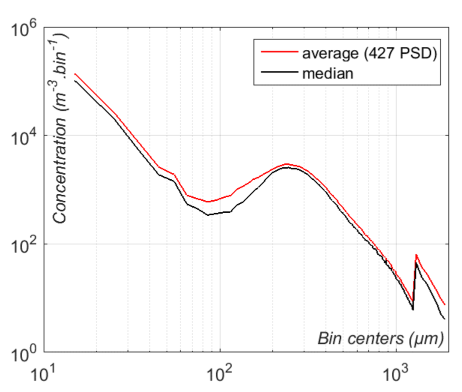
Particles are sized using the area equivalent diameter D_{eq}. For each bin, the « ***effective density*** » is defined as the bin's reference mass (m_i) divided by the volume of a spheres of equivalent diameter equal to the bin midpoints (D_i):

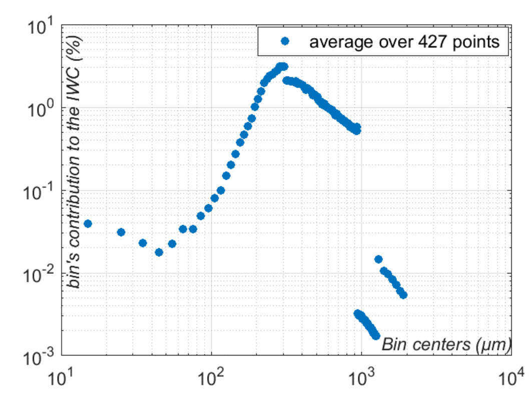
$$\rho_i = \frac{m_i}{\pi/_6 \, {D_i}^3}$$

Test case: Populations of synthetic crystals are used to:

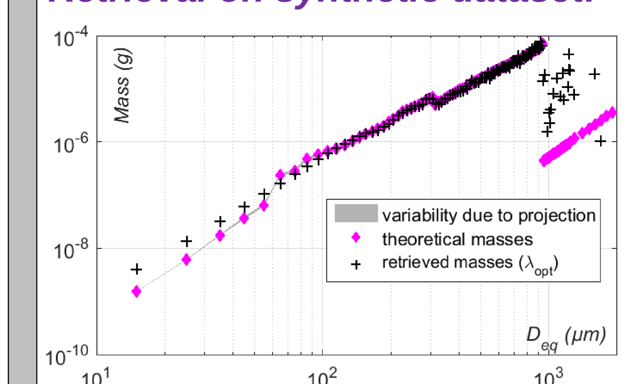
- Validate the retrieval method
- Identify weaknesses of the retrievals and build up knowledge on the influence of input data on the retrievals.

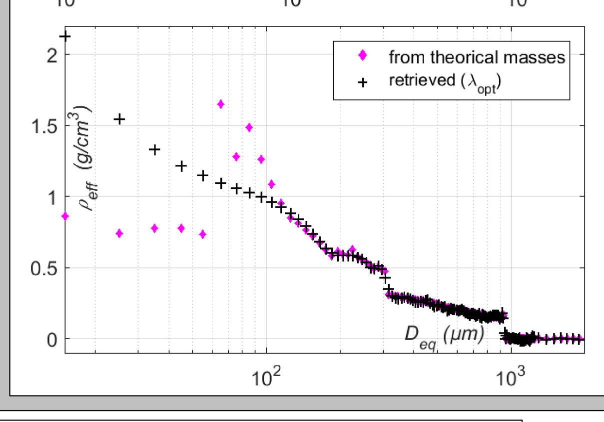
	Size range			
	10 -55	65 - 305	315- 935	935 - 2000
Size distribution	427 PSD measured during Darwin #9 flight at 244K, bin's width = 10µm until 1250µm , 100µm above			
Crystal habits	Stellars, hex. Columns and plates, spheres	Needles	hex. Plates, spheres, Capped Columns	Spheres
Ice density	0.917		0.45	0.001

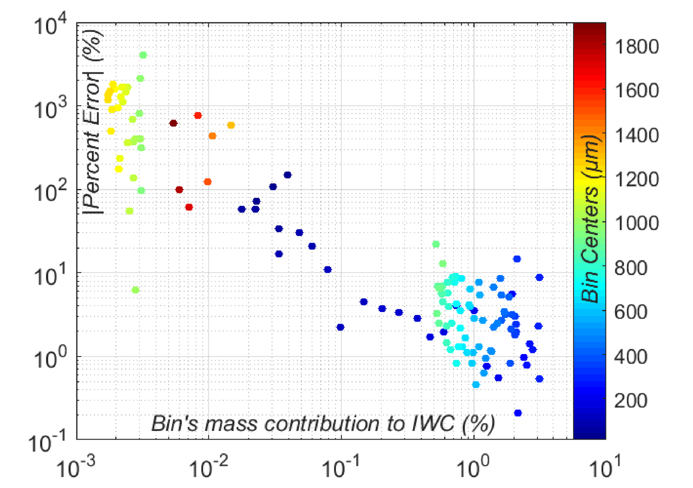




Retrieval on synthetic dataset:







- Reconstruction within 10 % when the bin contributes to more than 0.1% of IWC
- Unreliable values if the bin's masse contribution is less than 0.1 %.

➔ ***Sensibility to data scaling***

HAIC dataset

HAIC/HIWC dataset:

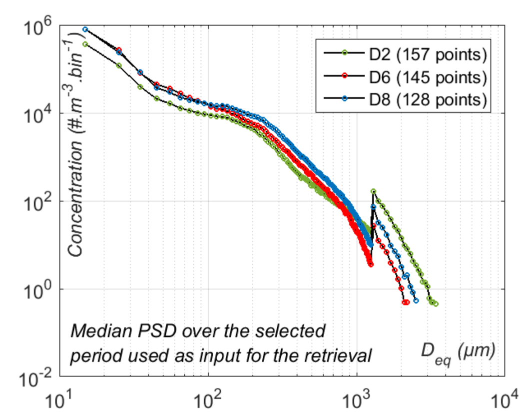
- Field campaign : ***Darwin - 2014*** (17 flights)
  - ***Oceanic*** and ***continental*** MCS
  - Targeted temperature levels :- 30 °C to -50 °C
- Aircraft equipped with state-of-the-art instrumentation including :
  - ***IKP-2*** for IWC measurement*
  - ***2D-S*** and ***PIP*** for 2D ice crystal images / PSD **[2]**

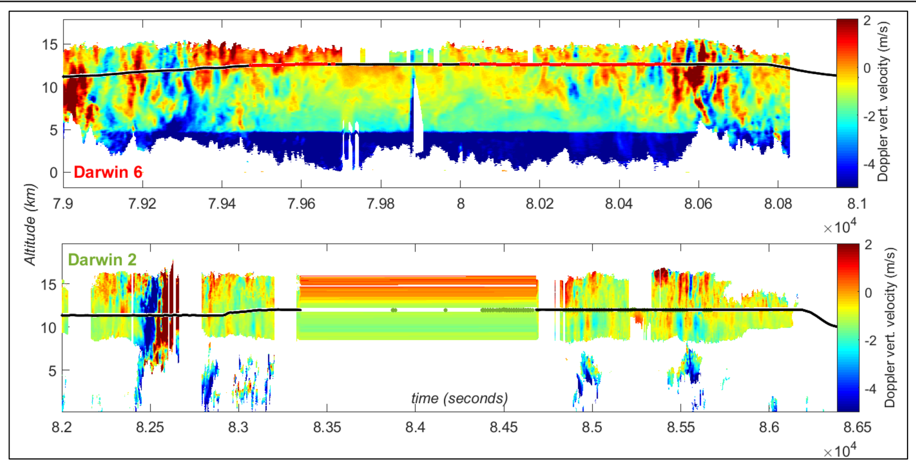
**: IWC values are obtained by subtraction of the background water vapor content from the Total Water Content measured by the IKP probe. Due to ice contamination, the background water vapor measurements are unreliable. Instead, we assume the air is between saturation with respect to ice and saturation with respect to water and subtract the theoretical background water content calculated from ambient T,P*

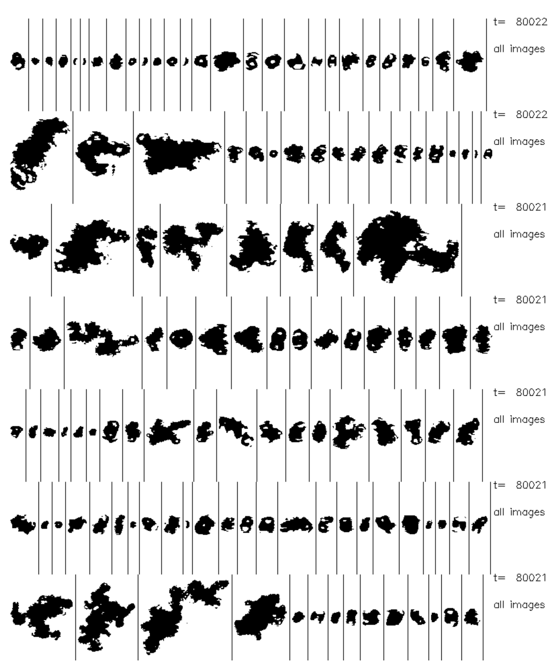
Selected dataset:

- Default filter: Level flight periods & IWC > 0.1 g/m³ only
- PSD with small gradient on the [300 - 1000 µm] subinterval are retained : P_{agg1} < -3.5 (see poster ***250 A***)

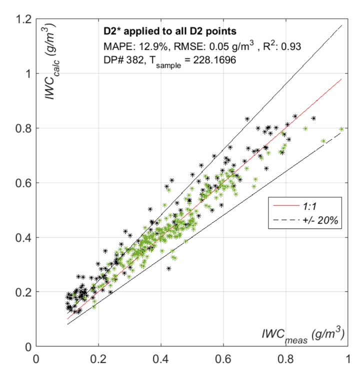
Flight ID	T	Cloud type	Date, selected period (UTC)
Darwin 2	-50°C	Coastal MCS	16 jan, 23:26 - 23:48
Darwin 6	-50°C	Coastal MCS	23 jan, 22:04 - 22:22
	-40°C		23 jan, 21:00 - 21:51
Darwin 8	-50°C	Offshore MCS	23 jan, 22:41 - 23:06
Darwin 13	-40°C	Offshore, tropical storm	03 fev, 04:41 - 05:39
Darwin 15	-30°C	Offshore MCS	06 fev, 00:16 - 01:57
Darwin 16	-40°C	Offshore MCS	07 fev, 21:53 - 23:49





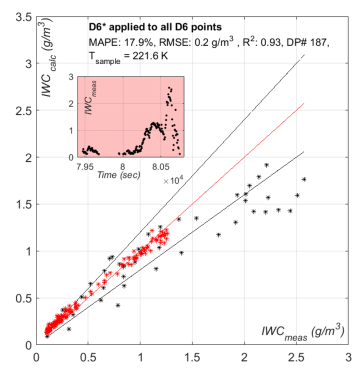


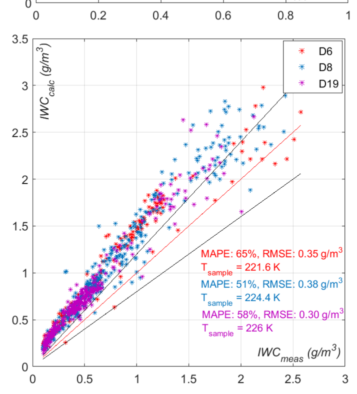
Darwin 6 : random selection of 100 crystals (40 in the 100 – 300 µm size range, 30 between 300 – 600 µm and 30 above 600 µm



Darwin #2: good agreement between calculated and measured IWC values

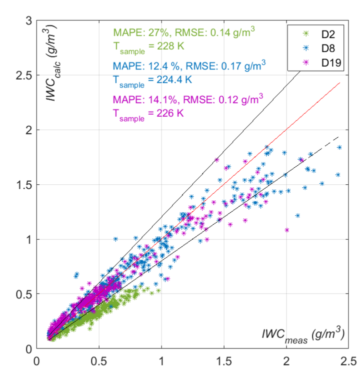
Darwin #6: the masses retrieved over a selected subset (red points) poorly predict the IWC in an embedded convective area (black points)



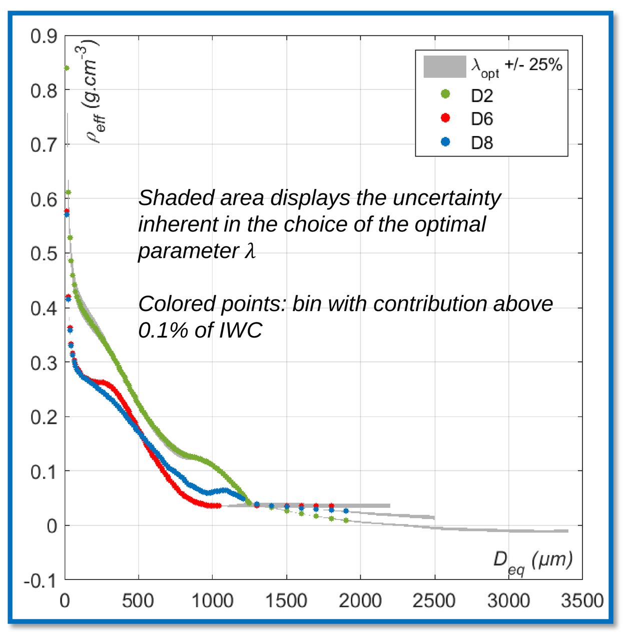


Darwin #2 mass-size relationship overestimates IWC when applied to other flights

Darwin #6 mass-size relationship accurately predicts IWC when applied to other flights, except in high Ice Water Content areas when IWC is consistently underestimated

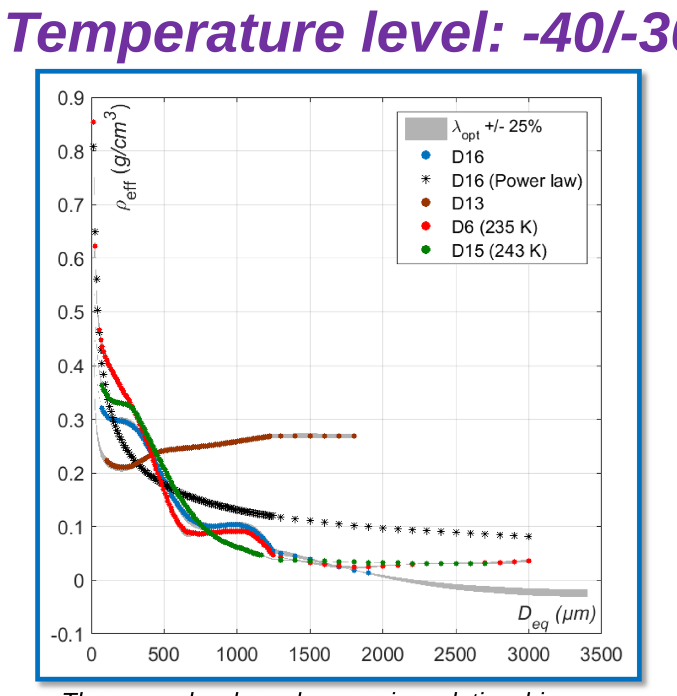


Temperature level: -50°C



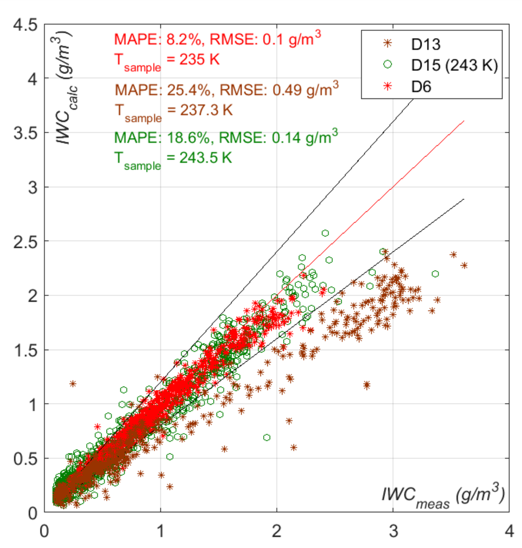
➔ Evidence for ***inhomogeneous mass properties*** of ice particle populations sampled at the ***same temperature*** level in the ***same MCS***

Temperature level: -40/-30 °C

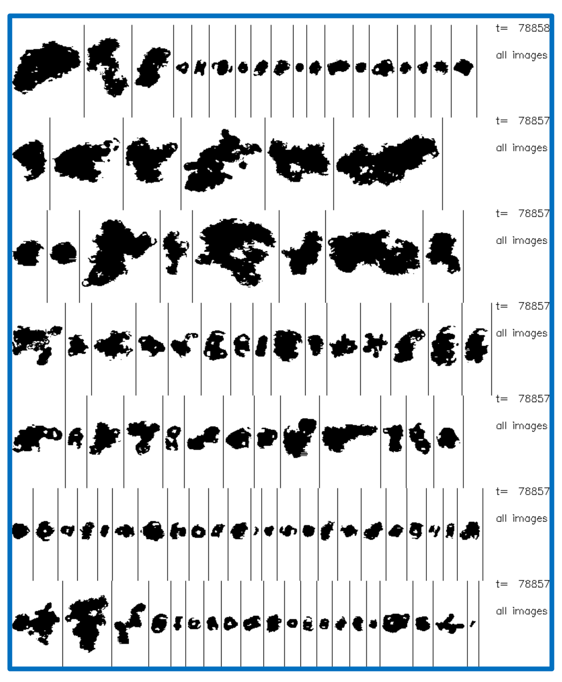


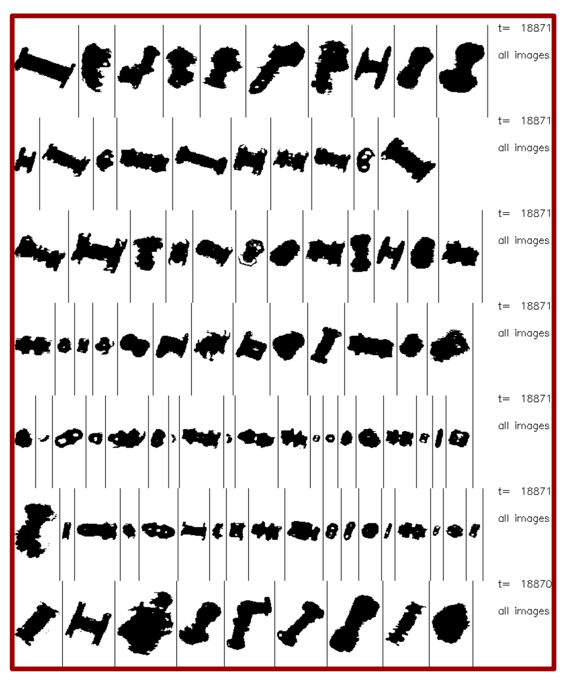
The power law based mass-size relationship is adapted from ***[2]*** *to fit D16 data points.*

The good agreement obtained when ***Darwin #16*** mass-size relationship is applied to ***Darwin #15*** is surprising. It indicates that temperature is not in itself determining the density of ice particles



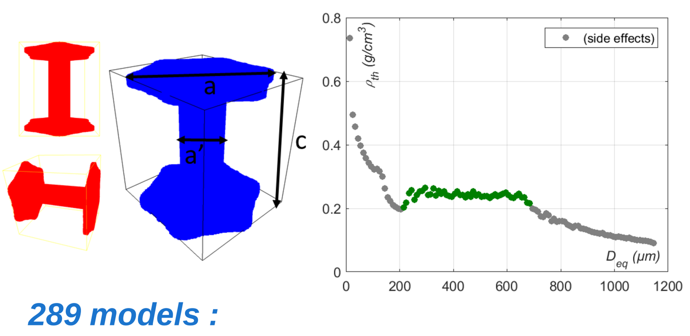
The ice density retrieved for millimetric crystals of ***Darwin #13*** is 5 times larger than for ***Darwin #6***, ***#15*** and ***#16***. As expected, ice density is found to depend on particles' habit and a single mass-size relationship cannot satisfactorily characterize the mass of ice crystals in clouds such as MCS where various microphysical processes come into play.





Darwin #16 and Darwin #13 at -40°C: random selection among 100 crystals observed in 1 second of flight (40 in the 100 – 300 µm size range, 30 between 300 – 600 µm and 30 above 600 µm)

Synthetic capped columns



289 models :

a/a' = 3 ; c/a = 1 ; $a \in [10 - 1000]\ \mu m$

$D_{eq} \in [9 - 1137]\ \mu m$

As suggested on the left picture, the large particles in ***Darwin #13*** *were dominated by capped columns rather than aggregates. The* ***effective density retrieved from in situ data is in good agreement with the theoretical effective density*** *calculated from a population of synthetic capped columns (0.24 g/cm³)*

CONCLUSIONS & PERSPECTIVES

Ice crystal effective density is known to be mainly controlled by crystals' dominant habit which, for a particular cloud area, may vary from one size interval to another. The use of power laws to describe mass-size relationships has proven to be an oversimplification and a surrogate approach is now available. For classical MCS where large crystals are primarily formed by aggregation, results suggest that density is around 0.05 g/cm³ for crystals larger than 1300 µm. In contrast, the density retrieved for large crystals grown by vapor diffusion mainly (*e.g.* capped columns of the tropical storm sampled during Darwin #13) is about 0.25 g/cm³. Few ***caveats*** are associated with these results: the uncertainty associated with the retrieval method (choice of the regularization parameter, scaling issue with the data) is likely optimistic since it is adapted from synthetic data case studies (no input noise added yet). Albeit rather high, the ***uncertainty associated with input data*** (PSD and IWC) are not considered in this poster. Future work will include :

- ***Continuing the retrieval of ice density*** from the HAIC-HIWC dataset: during Cayenne-2015 campaign, both continental and oceanic MCS were sampled at warmer temperatures.
- Identification of the dynamic and thermodynamic conditions conducive to the formation of dense crystals and ***collaboration with modelers*** to test the sensitivity of numerical simulations to different variations of ice density with size as retrieved from the HAIC-HIWC observations.

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[1] Coutris, P., D. Leroy, E. Fontaine, and A. Schwarzenboeck (2017): *An Inverse Problem Approach for the Retrieval of Ice Particle Mass from In Situ Measurements*, J. Atmos. Oceanic Technol., **34**, 2457–2473.

[2] Leroy, D., E. Fontaine, A. Schwarzenboeck, and J.W. Strapp (2016): *Ice Crystal Sizes in High Ice Water Content Clouds. Part I: On the Computation of Median Mass Diameter from In Situ Measurements,* J. Atmos. Oceanic Technol., **33**, 2461–2476.

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