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A new method to retrieve ice particles' mass from PSD and IWC measurements

High Altitude Ice Crystals
Contents

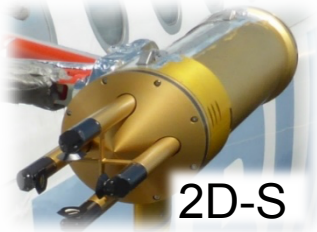
- Retrieval of ice particle mass from PSD and IWC in-situ measurements
  - Recall of context : data processing chain
  - Classical approach currently in use (power law)
  - The new approach at a glance (inverse problem)

- Preliminary results: application to Darwin #16 aircraft data
  - Mass retrieval : comparison with standard method
  - Computation of mass-related parameters :
    - effective density
    - MMD
  - Estimate of IWC from PSD (Darwin #19, Cayenne #26).

- Conclusions and Perspectives

Ice particle mass retrieval: context and needs

Instruments



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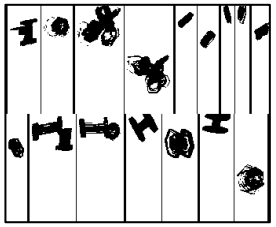
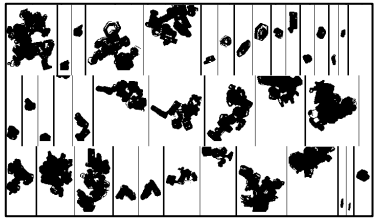
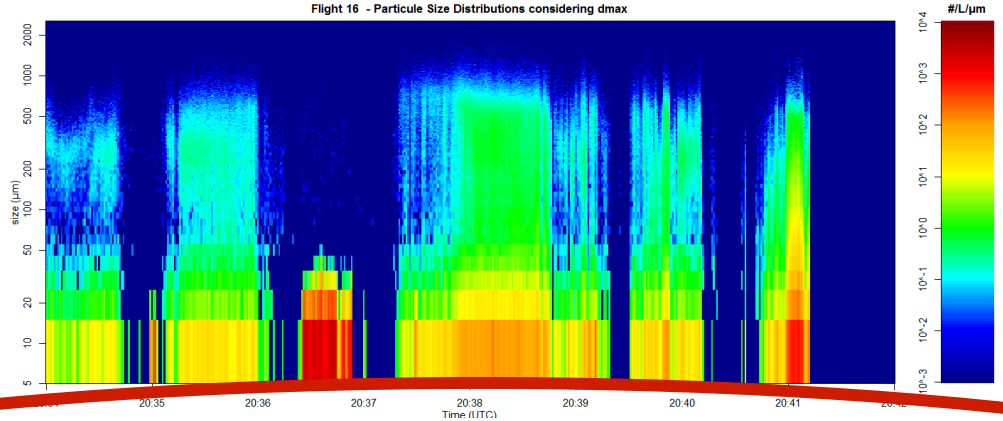
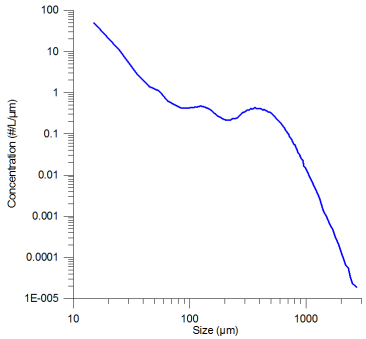
Raw data processing algorithms





Data processing algorithms





M-D retrieval methods

m-D relationship, MMD, effective density

Mass-dimension relationship currently in-use

$m-D$ power law relationship : $\boldsymbol{m=a\cdot D\uparrow b}$

- $\boldsymbol{a,b}$: time-dependent parameters derived for each 5-second average data points
  - $\boldsymbol{b}=f(\sigma,\tau)$ with two geometrical parameters inferred from analysis of 2D projected images of ice particles sampled during 5 second using A-D and P-D relationships established using synthetic crystal data set
  - $\boldsymbol{a}$ such that $IWC\downarrow calc\ (a,b,PSD)=IWC\downarrow meas$

- Bibliography:

- 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, doi: 10.1175/JTECH-D-15-0151.1

- Leroy, D., E. Fontaine, A. Schwarzenboeck, J. Strapp, A. Korolev, G. McFarquhar, R. Dupuy, C. Gourbeyre, L. Lilie, A. Protat, J. Delanoe, F. Dezitter, and A. Grandin, *tbd*: *Ice crystal sizes in high ice water content clouds. Part 2: Statistics of Mass Diameter Percentiles in Tropical Convection observed during the HAIC/HIWC project*. J. Atmos. Oceanic Technol., *tbd*, doi: 10.1175/JTECH-D-15-0246.1. *in press*.

New retrieval method: Model and mathematical tools

- Objective:
  - Use common in-situ measurements as inputs (PSD, IWC)
  - Waive the power law constraint so that size dependence of ice particles mass related properties may be captured
  - Be efficient at processing large dataset

- Overview of the method
  - A linear system of equations relating bin reference masses to measured quantities:

$$\mathrm{PSD}.\boldsymbol{m}=\boldsymbol{ikp}$$

  - Inverse problem solved with numerical optimization algorithms: minimization of a composite criterion

$$J(m)=\|PSD\cdot\boldsymbol{m}-\boldsymbol{ikp}\|^2+\lambda\cdot R(m)$$

New retrieval method: Status and references

- Status:
  - ***Proof of concept:*** done on synthetic data (spheres, hexagonal plates)

    ➔ ***poster*** presented at the ***EGU*** GA, 17-22 April 2016, Vienna, Austria
  - ***Validation:*** done on synthetic data (mixed habit population) and in-situ measurements

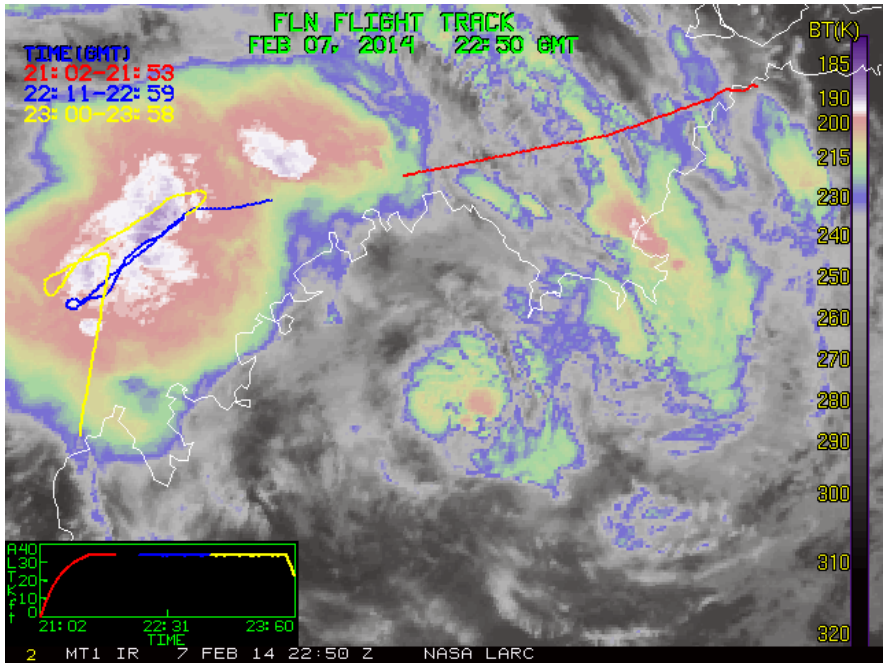
    ➔ ***poster*** presented at the 17th International Conference on Clouds & Precipitation, ***ICCP***, 25 - 29 July 2016, Manchester, UK
  - ***Application to HAIC data set***: in progress

    ➔ ***preliminary results*** based on Darwin #16 data are ***available***

- Foreseen publications:
  - AIAA: Comparison between two mass retrieval techniques
  - JTECH: Presentation of the new method (concepts & mathematical tools, validation)
  - JAS: New method applied to HAIC data

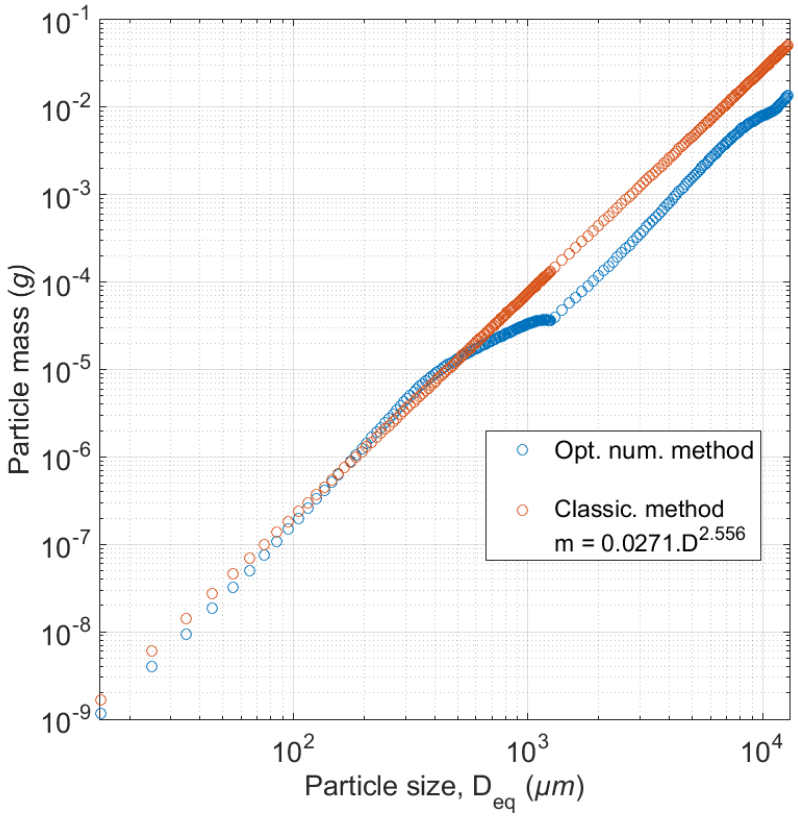
Preliminary results: Application to Darwin # 16 data

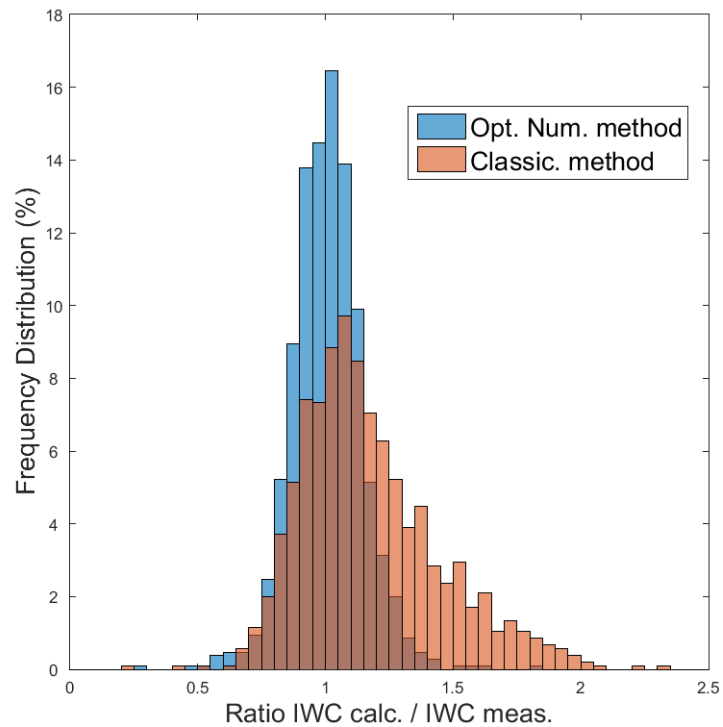
- Darwin #16:
  - February 7th 2014
  - Oceanic convection
  - 1 temperature level (-37°C)



Flight duration	Temperature mean (*std dev*)	IWC mean (*std dev*) min/max	Number of points 5-sec averages (#)
3.6 hours	**236.1** (*0.363*) K	**1.07** (*0.644*) $g.m^{-3}$ 0.10 / 2.74 $g.m^{-3}$	1051

Preliminary results: *m-D* relationship retrieval

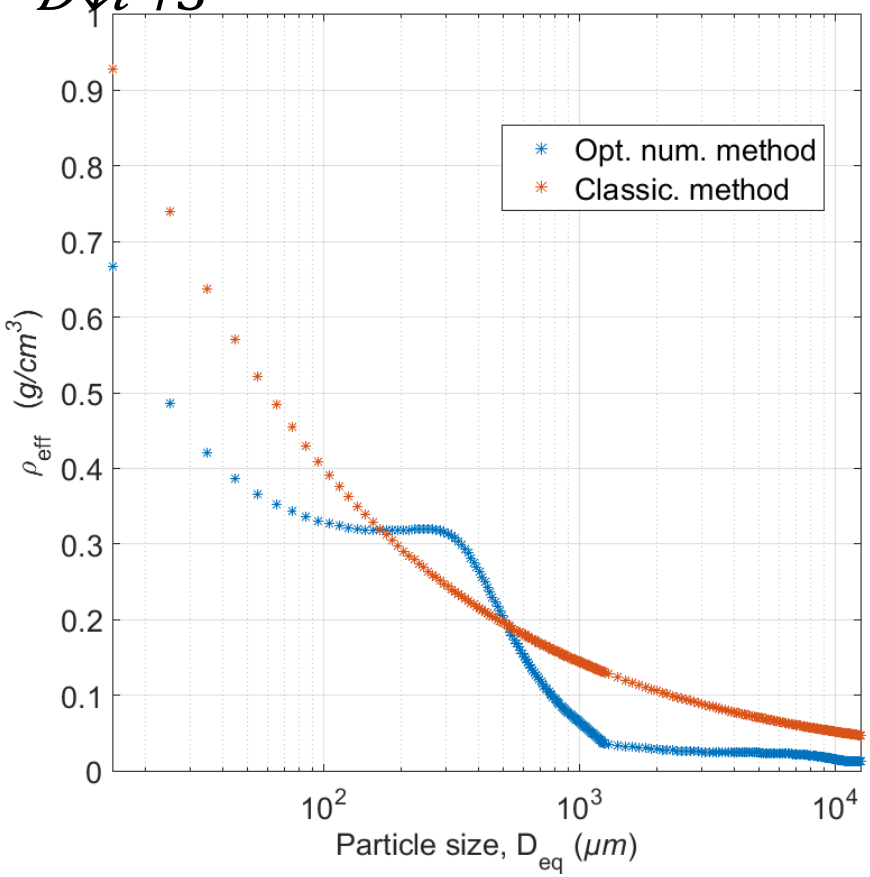




- $Deq < 500\ \mu m$: comparable mass values, although higher slope predicted by the new method
- $500 < Deq < 1300\ \mu m$: transition regime observable on the new method's plot
- $1300\ \mu m < Deq$: mass calculated with the new method are are consistently 60 to 70% lower than those predicted with classical method

Preliminary results: Ice particle effective density

Computation of ice particle effective density: $\rho_{eff}(D_i) = m(D_i)/\pi/6 \cdot D_i^3$



Size (µm)	ρ_{eff} (g.cm^{-3})
15	0.67
300	0.32
1300	0.034
12800	0.012

- Reveals interesting details on the size dependence of the effective density
- Caveat: effective density of small particle (< 300 µm) is strongly influenced by the regularization term defined in the minimization algorithms

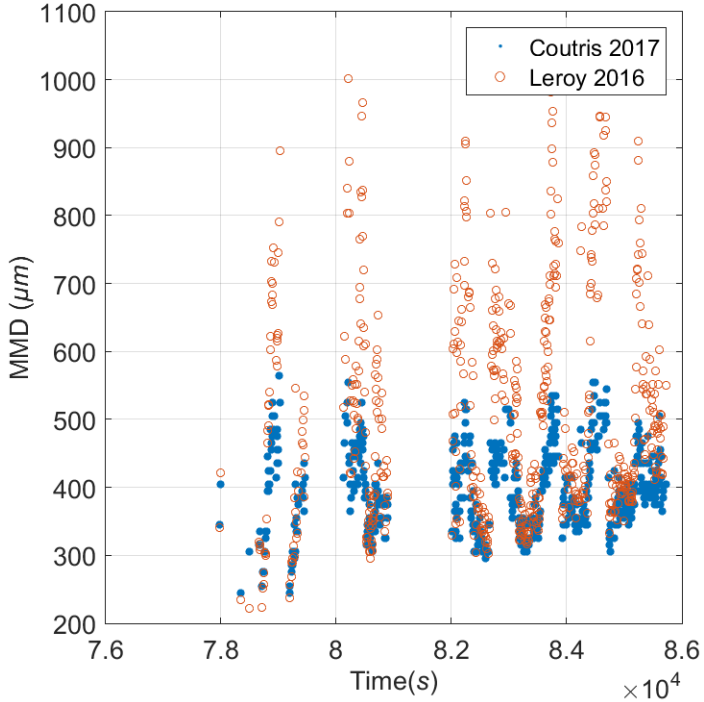
Preliminary results: MMD (1/2)

Median Mass Diameter = particle diameter which splits the mass distribution in half

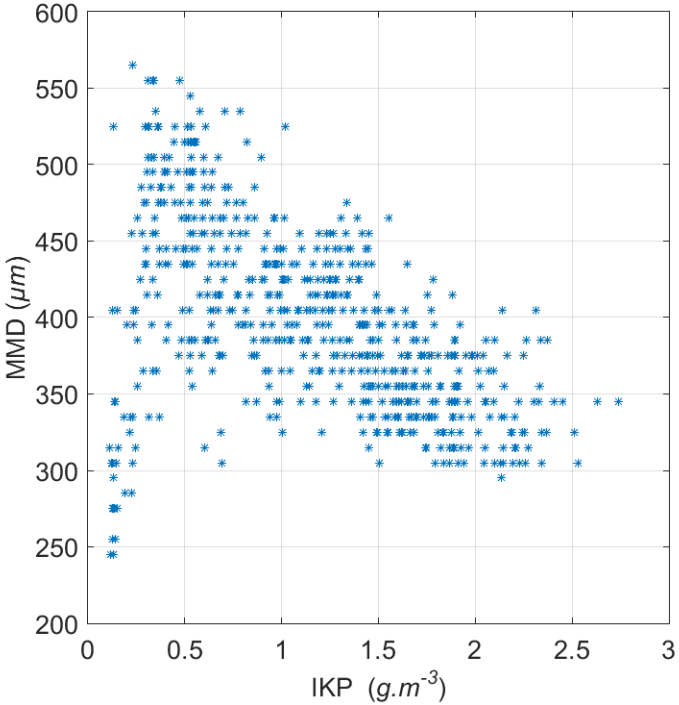
- For each 5-sec point:
  - classic. method: $MMD(t_i) = f(PSD(t_i),\ a(t_i),\ b(t_i),\ IWC_{calc}(t_i))$
  - new method : $MMD(t_i) = f(PSD(t_i),\ m = D(T),\ IKP(t_i))$

- MMD retrieval along flight path (*).
- Variations of MMD with Ice Water Content

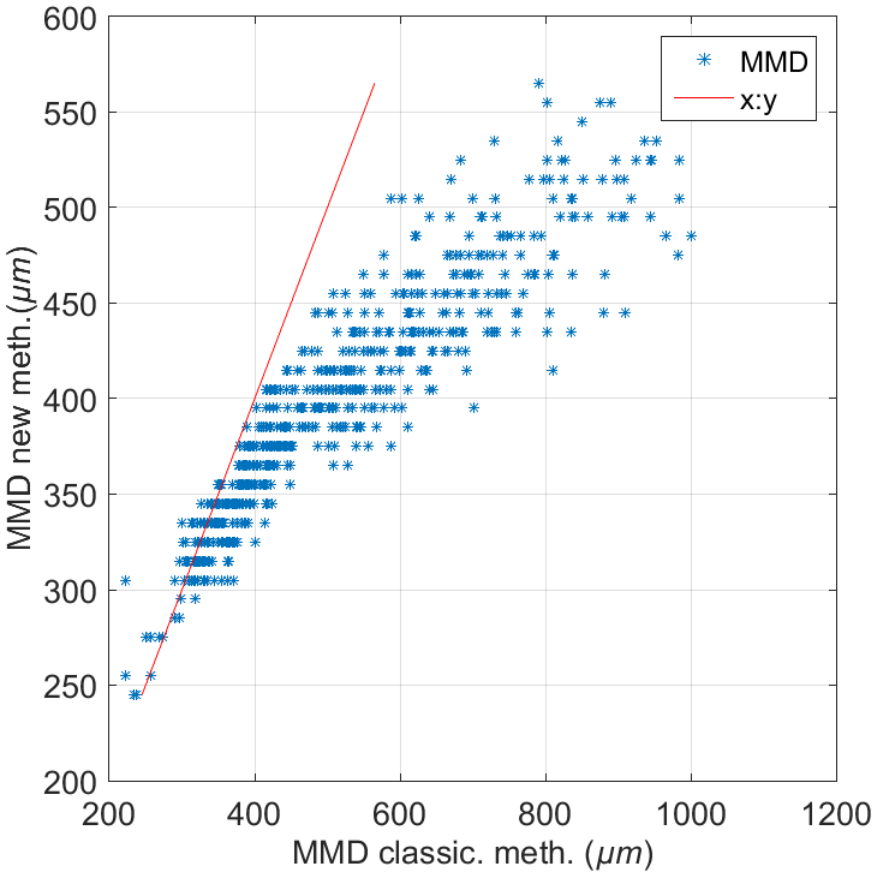
Similar dynamic



Similar tendency : MMD ↘ when IWC ↗



Preliminary results: MMD (2/2)



	New Method	Classic. Meth.
min.	245	125
P25	350	384
median	**395**	**475**
mean	398	519
P75	435	631
Max.	656	1104

- MMD calculated using the new method are ***consistently lower*** than those computed with Leroy 2016 (20% approx.)

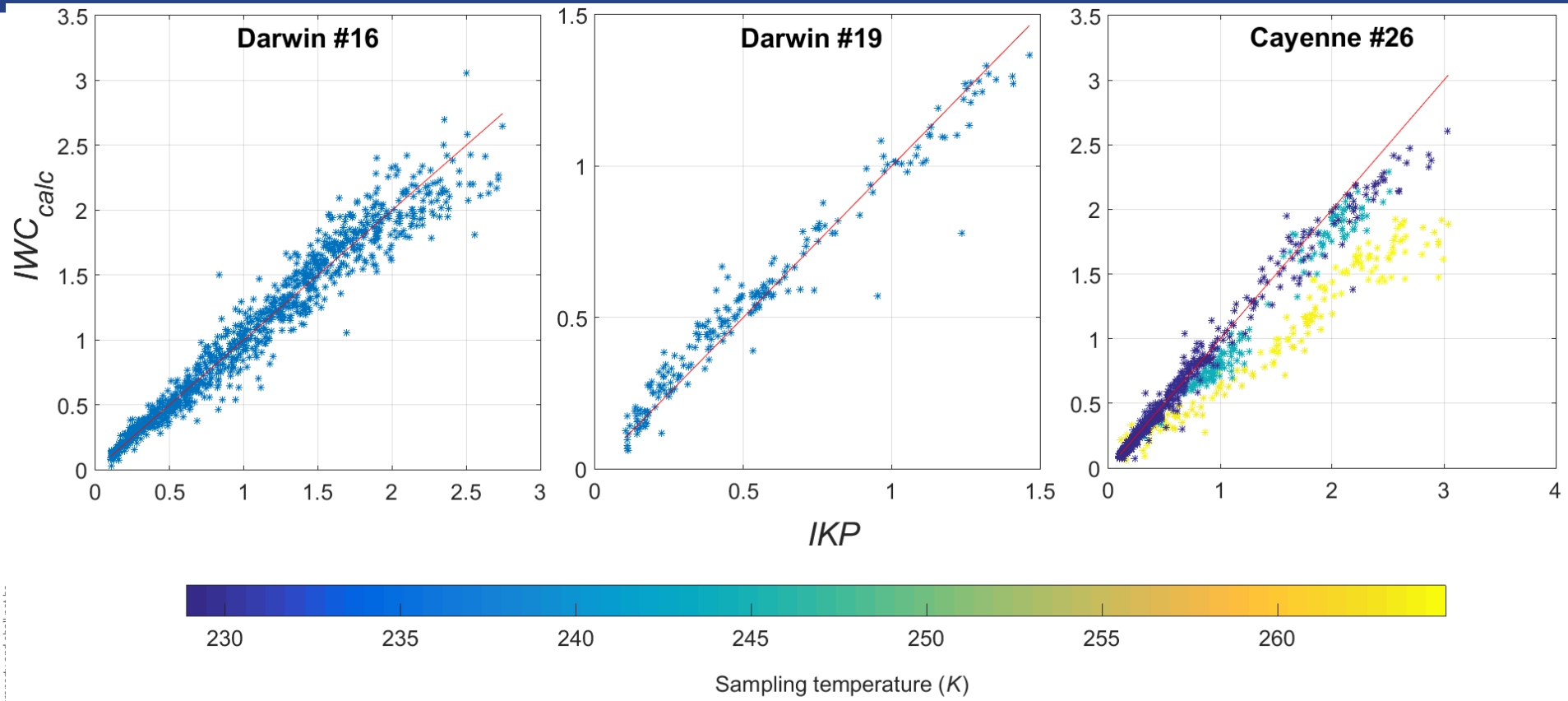
Preliminary results: estimates of IWC from PSD

Example of IWC prediction on two test cases:

- *m-D* retrieved from Darwin #16 (T = 236.1 K)
- Applied to different flight data to predict IWC values from PSD and the preset *m-D*

Test cases	Date & Cloud type	Temperature mean (*std dev*)	IWC mean (*std dev*) min/max	Number of points (#)
Darwin16	Feb. 9th 2014 *Ocean. conv.*	236.1 (*0.363*) K	1.07 (*0.644*) $g.m^{-3}$ 0.10 / 2.74 $g.m^{-3}$	1051
Darwin 19	Feb. 9th 2014 *Ocean. conv.*	236.6 (*0.545*) K	**0.54** (*0.644*) $g.m^{-3}$ 0.10 / 1.46 $g.m^{-3}$	212
Cayenne 26	May 29th 2015 *Coastal conv.*	**229.4** (*0.191*) K	**0.47** (*0.516*) $g.m^{-3}$ 0.10 / 3.03 $g.m^{-3}$	936
		244.2 (*0.2*) K	**1.25** (*0.588*) $g.m^{-3}$ 0.14 / 2.52 $g.m^{-3}$	186
		264 (*0.49*) K (*)	**1.49** (*0.855*) $g.m^{-3}$ 0.10 / 3.04 $g.m^{-3}$	176

Preliminary results: estimation of IWC from PSD



- ***Good agreement*** between IKP measurements and IWC values calculated from Darwin #19 PSDs (sampled at temperature close to that of Darwin #16)
- Consistent underestimation of IWC when *m-D* ($T = 236.1\ K$) is used with PSDs sampled at different temperatures : $T = 244.2\ K$ (light bleu) $T = 264\ K$ (yellow)

Conclusions & Perspective

- A new approach to retrieve ice particle mass from PSD and IWC
  - A forward model based on « reasonable » simplifying approximations
  - The inverse problem solved with numerical optimization algorithms

- Preliminary results (Darwin #16 only) reveal:
  - ***Improved accuracy*** and efficiency in IWC calculation ***when applied to large data sets***
  - Somewhat ***different MMD values***
    - Additional thinking required to conclude on the differences
  - ***Interesting microphysical details*** that need to be further investigated
    - Several regimes in the variation of effective density with size
    - Particle masses markedly influenced by temperature

- Upcoming work

This new data analysis tool + HAIC dataset ➔ Creation of a ***multiparameter model*** (look-up tables) for MCS ice particles

High Altitude Ice Crystals (HAIC, 314314)

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New method: Physical model and mathematical tools

- Physical approximations:
  - It is assume that ice particles' mass depends on a finite number of physical variables, such that particle dimensions, sampling temperature, etc…

$$M = M(V, T, P_1, P_2)$$

  - Time invariance over sampling interval

$$M = M(V)$$

  - Dimensions invariance within a bin

$$M(bin\ n^{\circ} i) = M_{ref,\ i}$$

For every points where T, P_1, P_2 are consistent

➔ one linear equation

$$N_1 \cdot m_1 + N_2 \cdot m_2 + \cdots + N_N \cdot m_N = IWC$$