Titre: Caractérisation in situ de la phase glace

.....
Julien Delanoë
Christophe Duroure
Régis Dupuy
Guy Febvre
Emmanuel Fontaine
Christophe Gourbeyre
Olivier Jourdan
Delphine Leroy
Guillaume Mioche
Florestan Ogheard
Alain Protat
Alfons Schwarzenboeck
.....

1. Intro
2. Growth mechanisms, crystal complexity
3. Instruments for in situ characterisation
4. Properties of ice crystals

1 Intro

2 Growth mechanisms, crystal complexity

3 Instruments for in situ characterization

4 Properties of ice crystals

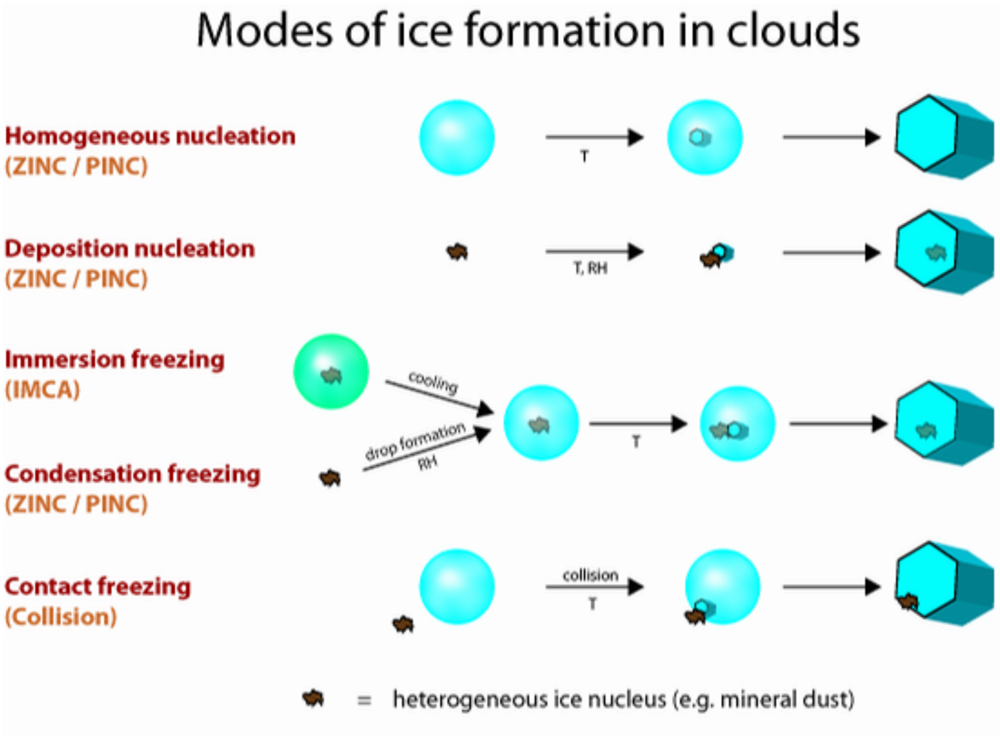
Nucleation modes of ice in the athmosphere:

Deposition:

Immersion freezing:

Condensation freezing:

Contact freezing:



Reference: ETH

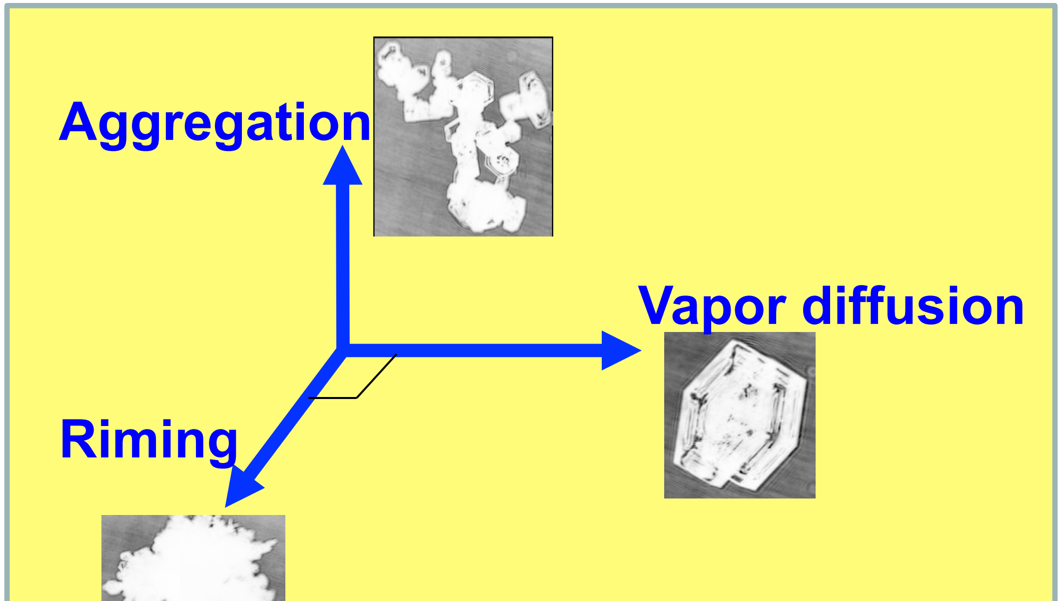
Concept of ice growth

Crystal growth in convective clouds dominated by 3 major growth mechanisms:

-**Vapor diffusion** (≈ ice supersaturation, temp (=max at -12°C)…): pristine ice

-**Riming** (≈ existing crystals, ≈ important supercooled droplet concentration.,..): graupel, hail

-**aggregation** (≈ crystal concentration.,..): snow flakes

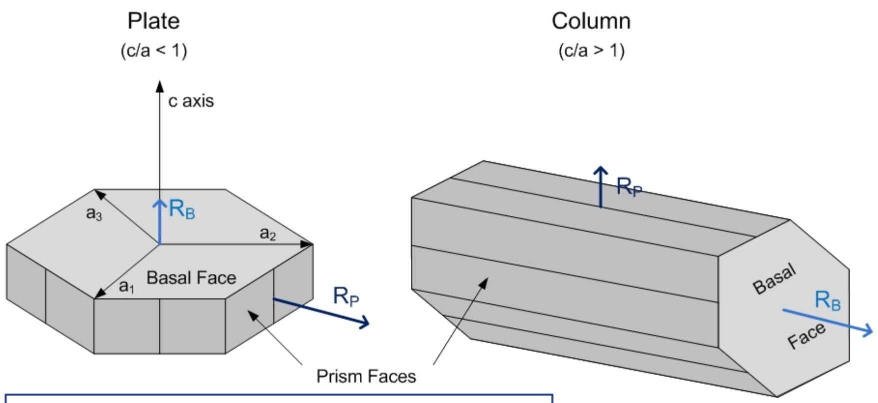


CPI (Cloud Particle Imager): data CNRS-LaMP


cnrs
INSU
Observer & comprendre
UNIVERSITE BLAISE PASCAL
CLERMONT-FERRAND
LaMP

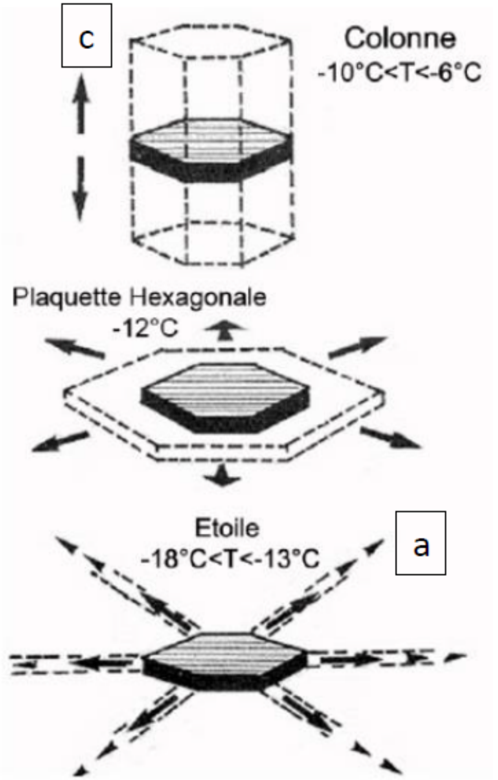
Growth dominated by **vapor diffusion:**

➔ Pristine ice: primary habits of ice



R: linear growth rate [μm/s]

adapted from Lamb and Verlinde (2011)



« Initial » matrix: hexagonale

➔primary habit: determined by c/a ratio

➔growth of top/bottom faces: column

➔growth of 6 edges: plate

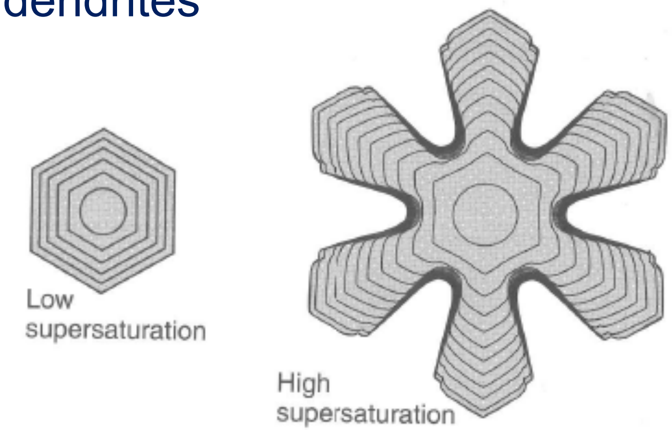
➔growth of 6 points: stellar

Growth dominated by **vapor diffusion:**

➔ Pristine ice

Influence of supersaturation on crystal shape:

- Habit corners reach in areas of higher saturation than prism facets
- low ambient supersaturation: The sateration gradients in the farfield are decent so that the growth rate along the prism facets is continous → plate shape
- high ambient supersaturation: Corners /discontinuities are surrounded by higher supersaturated air than facets → corner growth is accalerated → secondary plates, dendrites



reference: Lamb and Verlinde (2011)

Growth dominated by **vapor diffusion:**

➔ Pristine ice: primary habits of ice

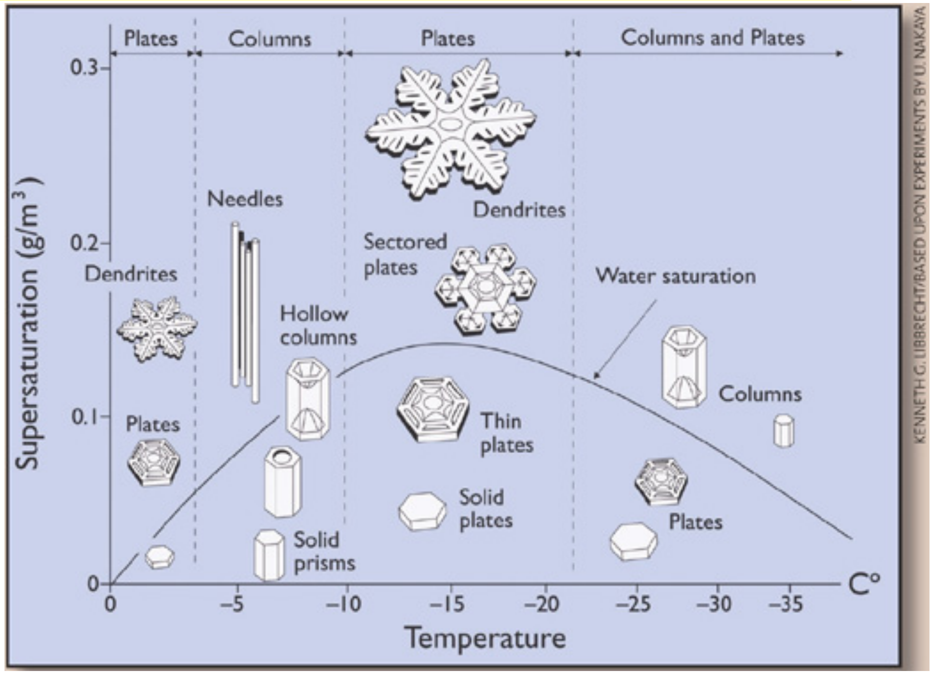


Diagramme morphologique:

-2°C: plaques

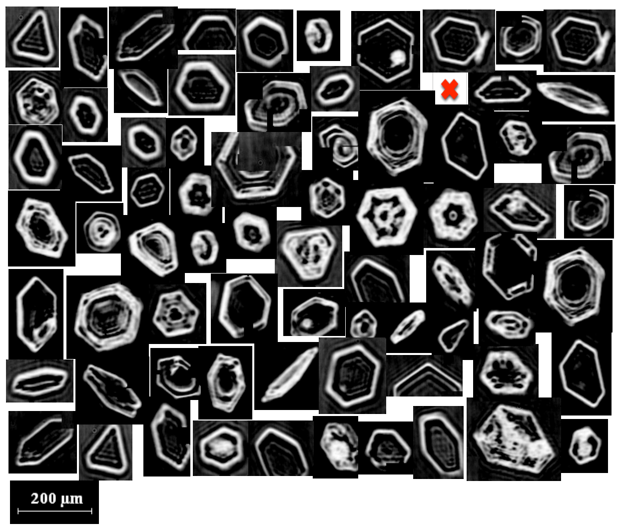
-5°C : colonnes (c>>a)

-15°C : plaques (c<<a)

-30°C : colonnes

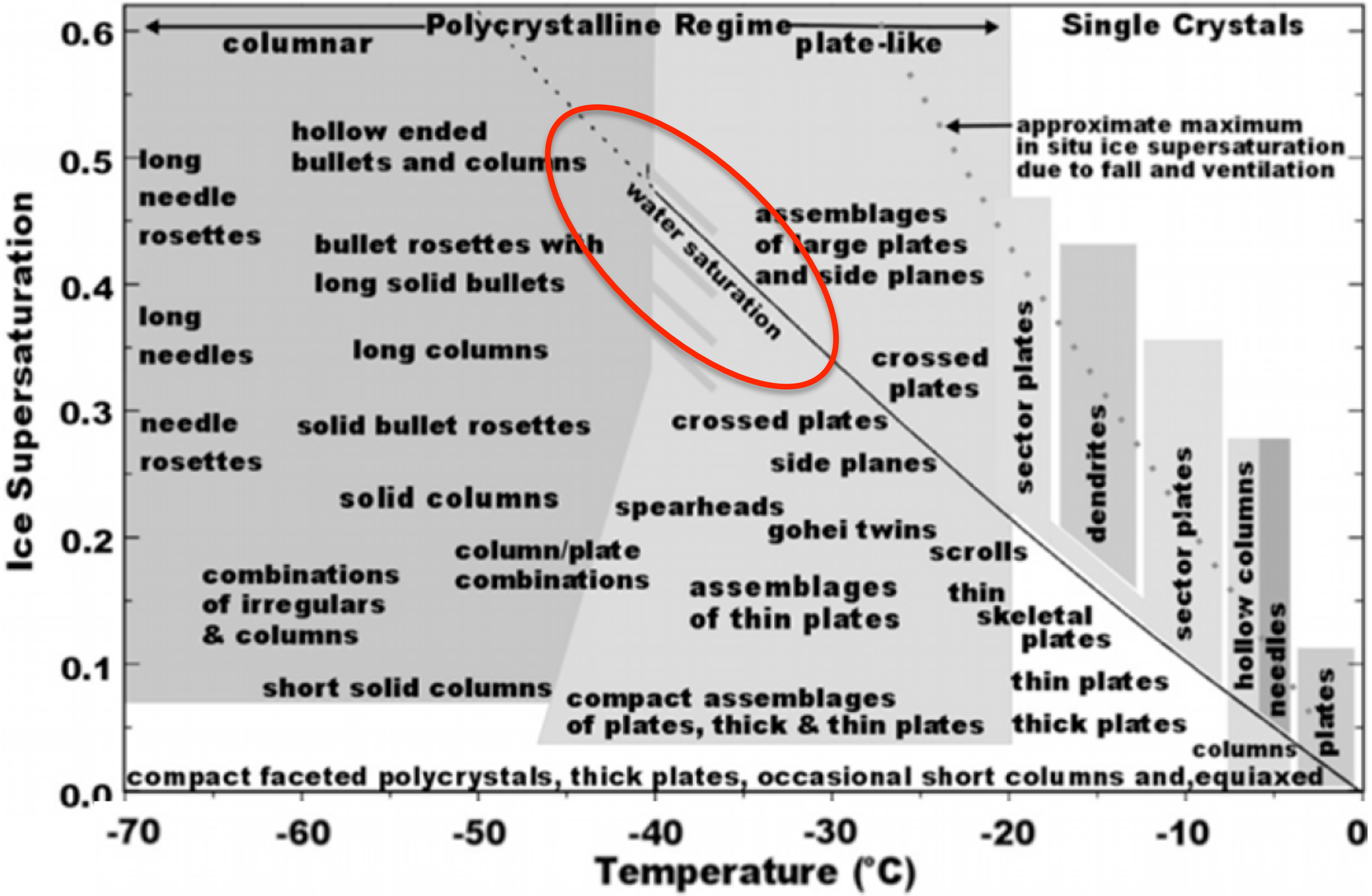
Forte humidité : formes plus complexes (dendrites, colonnes creuses)

Circle-2: Des plaques….



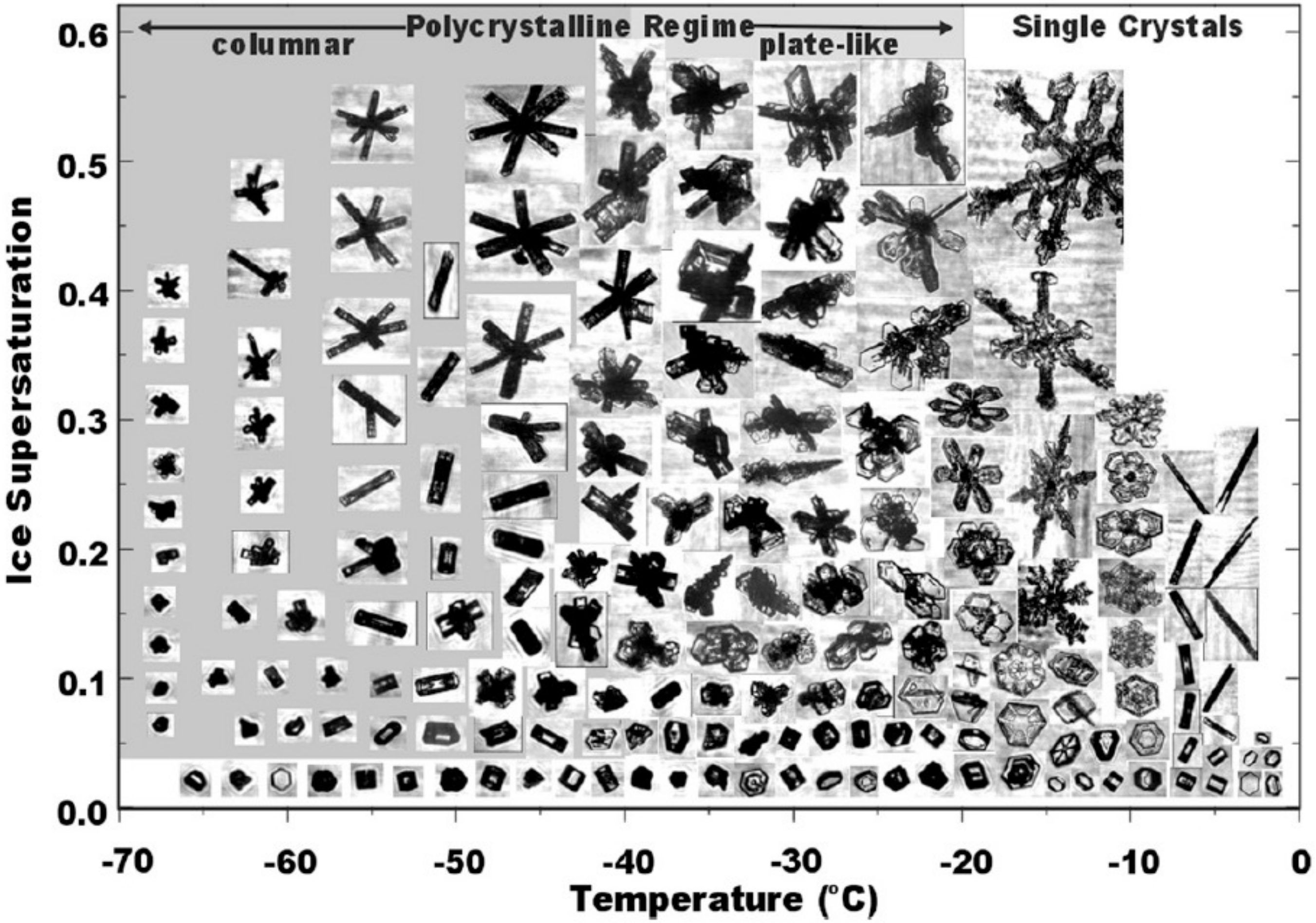
Growth dominated by **vapor diffusion:**

➔ Pristine ice: primary habits of ice



Growth dominated by **vapor diffusion:**

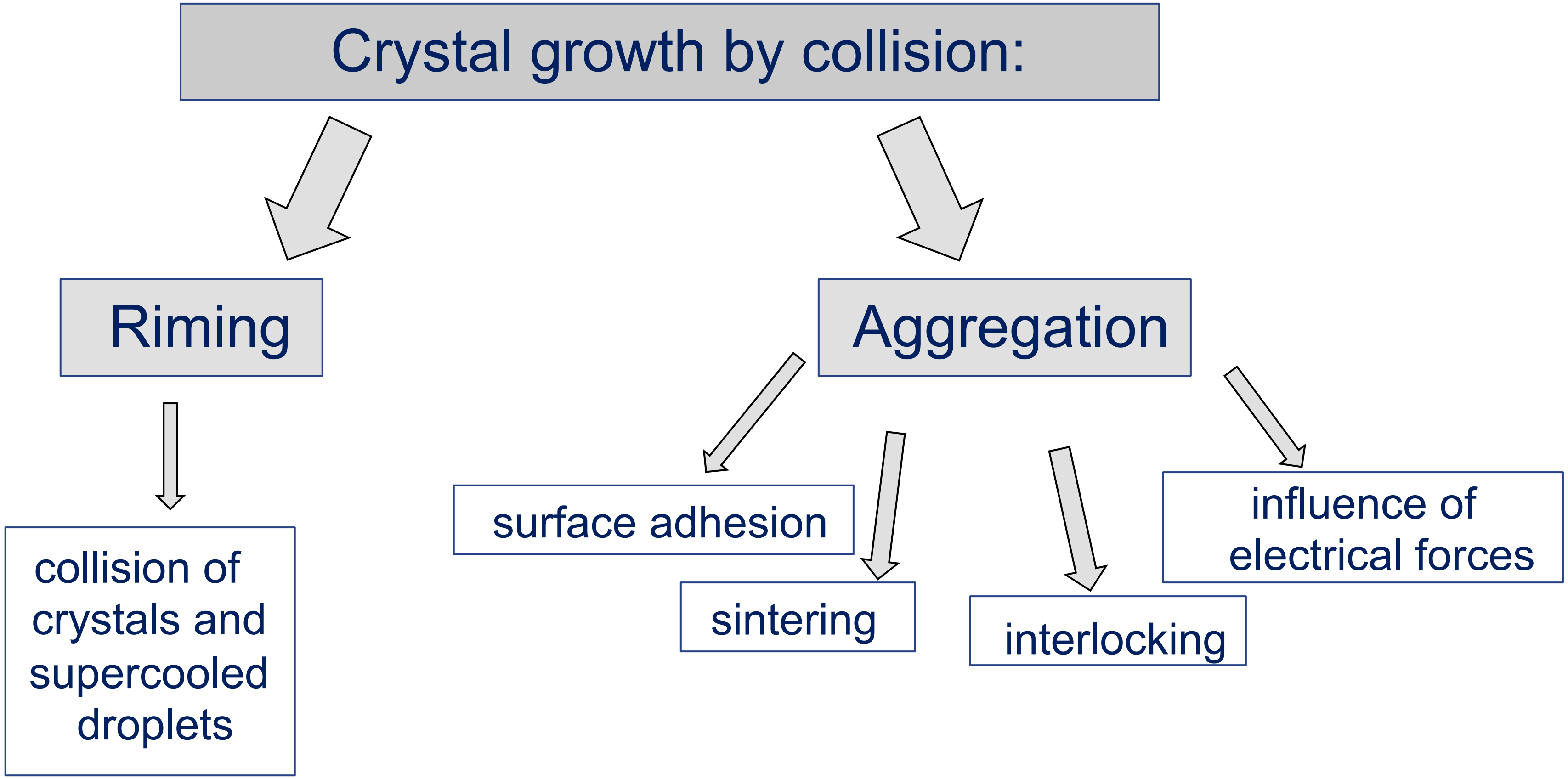
➔ Pristine ice: primary habits of ice



Bailey and Hallett, 2004

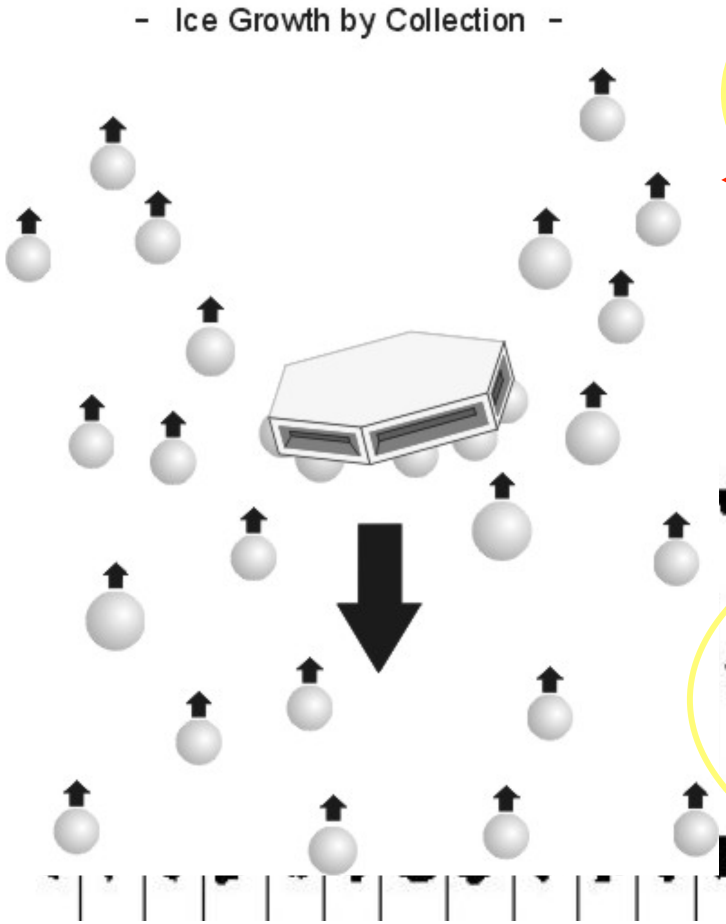
Growth and habits dominated by **collision:**

➔Riming versus aggregation

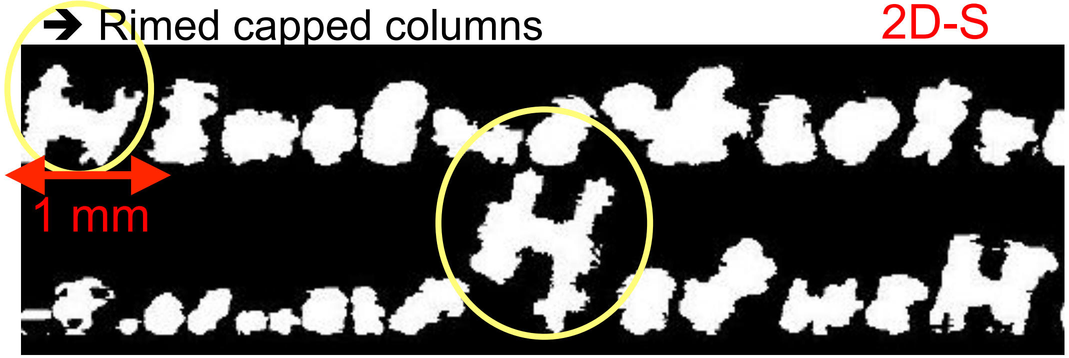


Growth and habits dominated by **collision:**

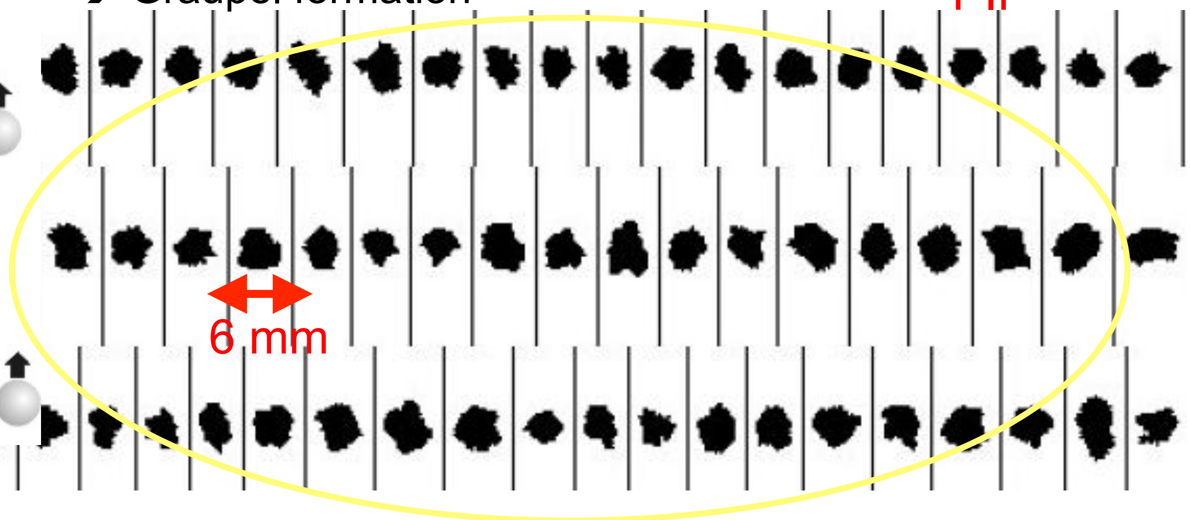
➔Riming = ice + liquid water



➔ Rimed capped columns



➔ Graupel formation



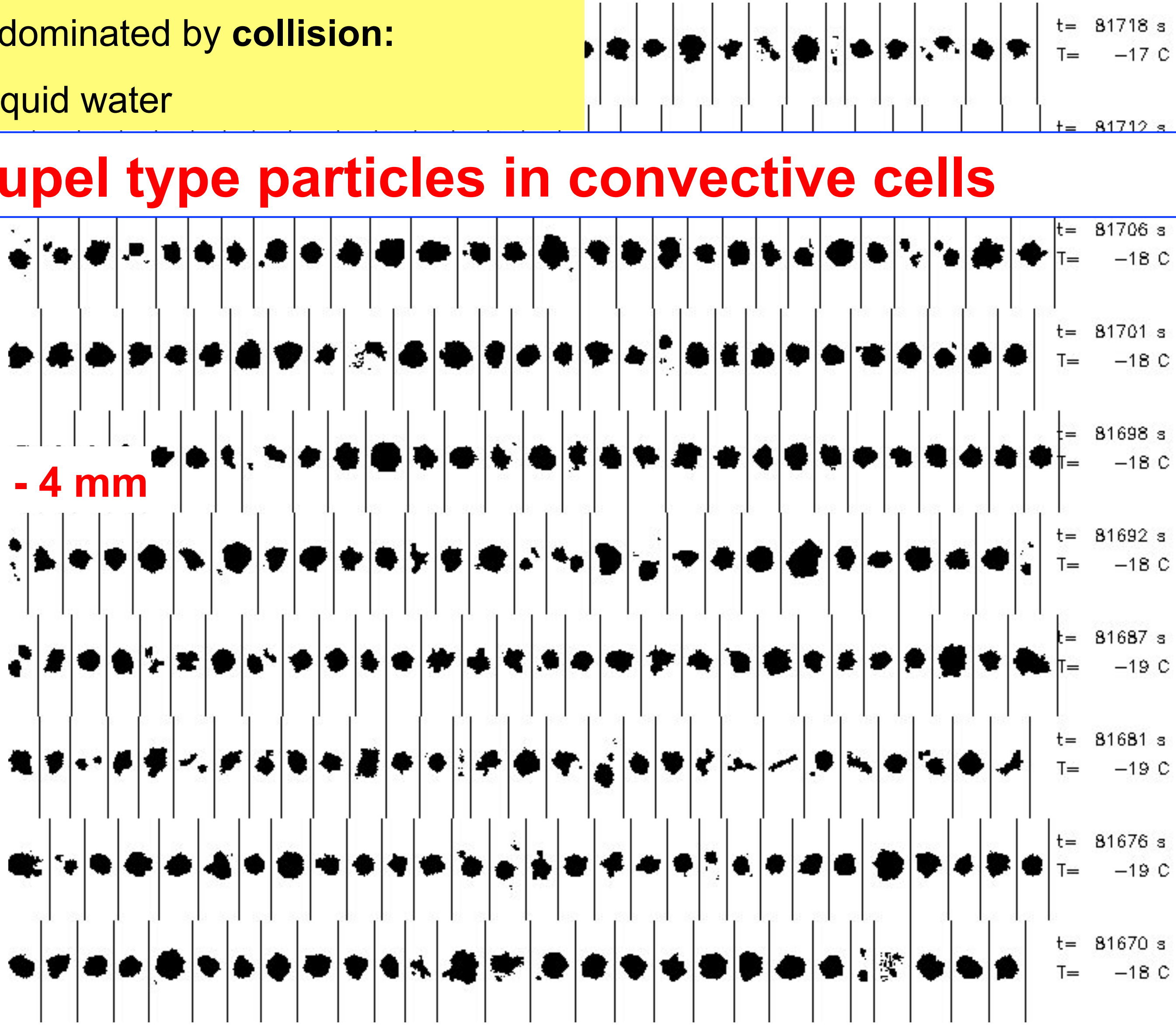
Growth and habits dominated by **collision:**

➔Riming = ice + liquid water

Graupel type particles in convective cells

6 mm

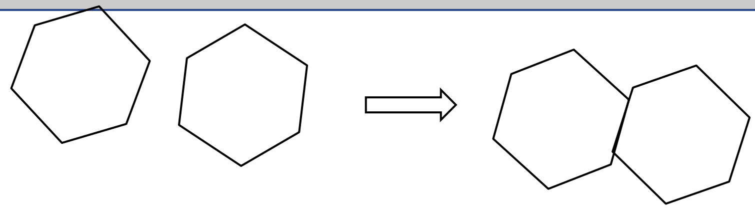
PIP: Particles 2 - 4 mm

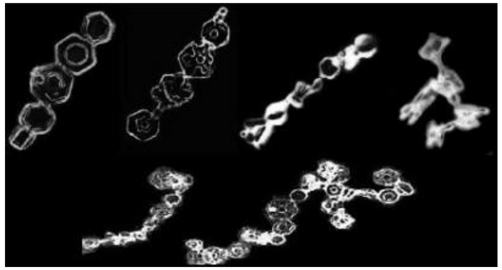


Growth and habits dominated by **collision:**

➔Aggregation = ice + ice

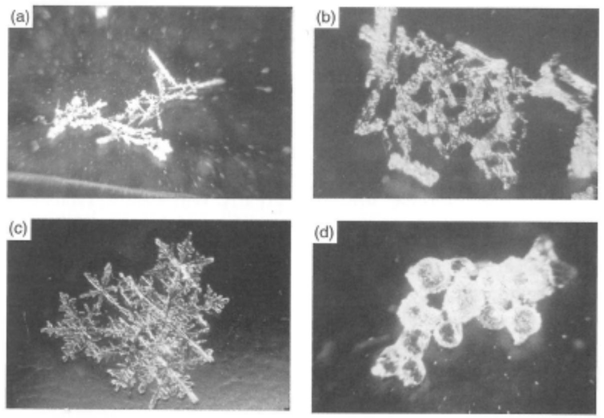
Surface adhesion:





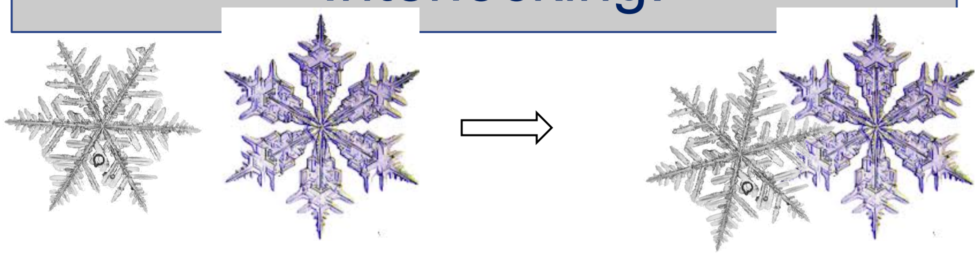
- Occurs at temperatures little below freezing point
  - → Best cohesion efficiency at 0°C → sticky surface

Ice crystal aggregations:



reference: Wallace and Hobbs (2006)

Interlocking:

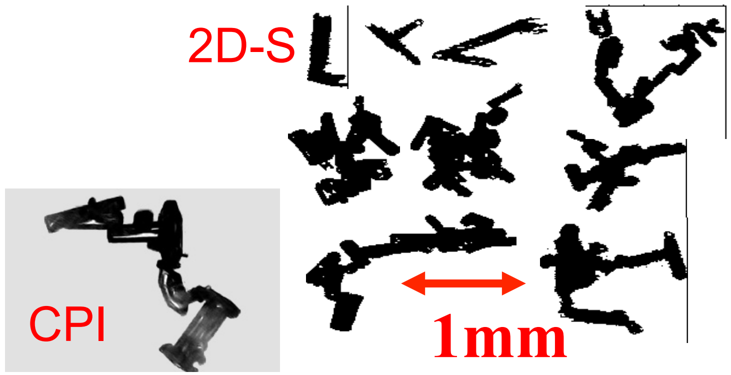


- May occur if crystals have multi-branched surfaces
  - → function of temperature and supersaturation

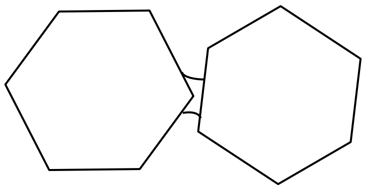
Growth and habits dominated by **collision:**

➔Aggregation = ice + ice

Quasi-random aggregation?

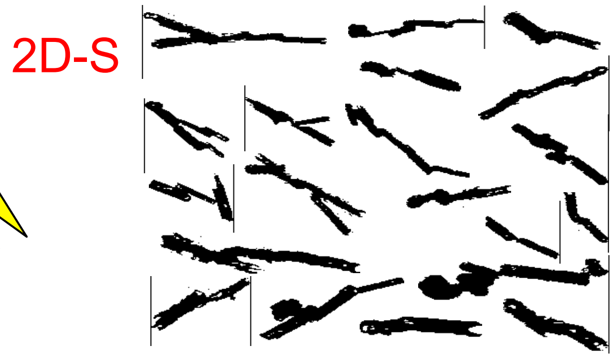


Sintering:

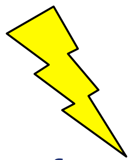


- Loose bonded surface molecules diffuse to a place of high curvature and strenghten the connection between two collided crystals
  → Occurs at temperatures arround 0° C

Dielectric driven aggregation?



Electrical field:



- Electrical forces keep collided crystals stick together for a longer period of time
  → Sinter process is forwarded/ connection can be built at lower temperatures

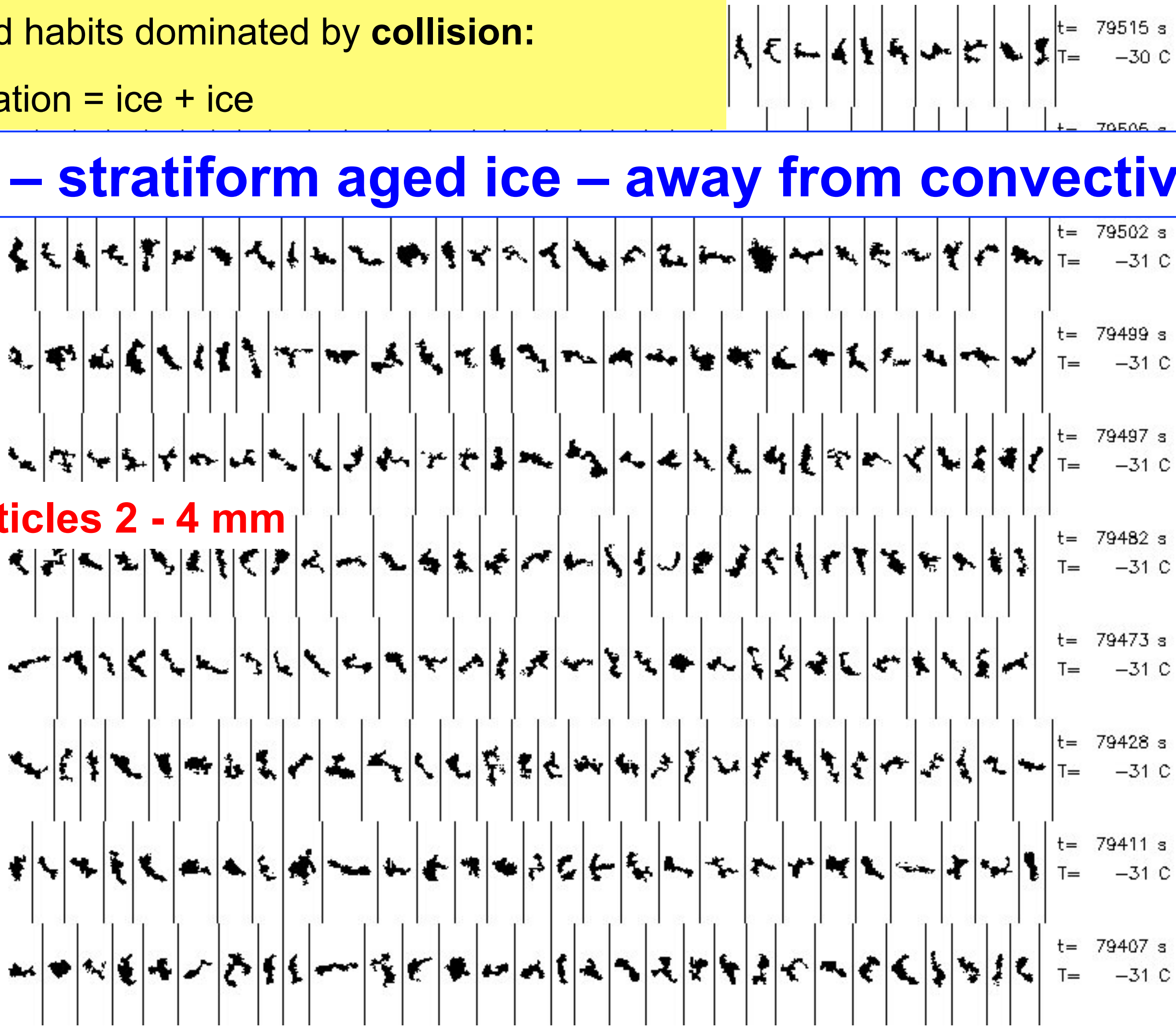
Growth and habits dominated by **collision:**

➔Aggregation = ice + ice

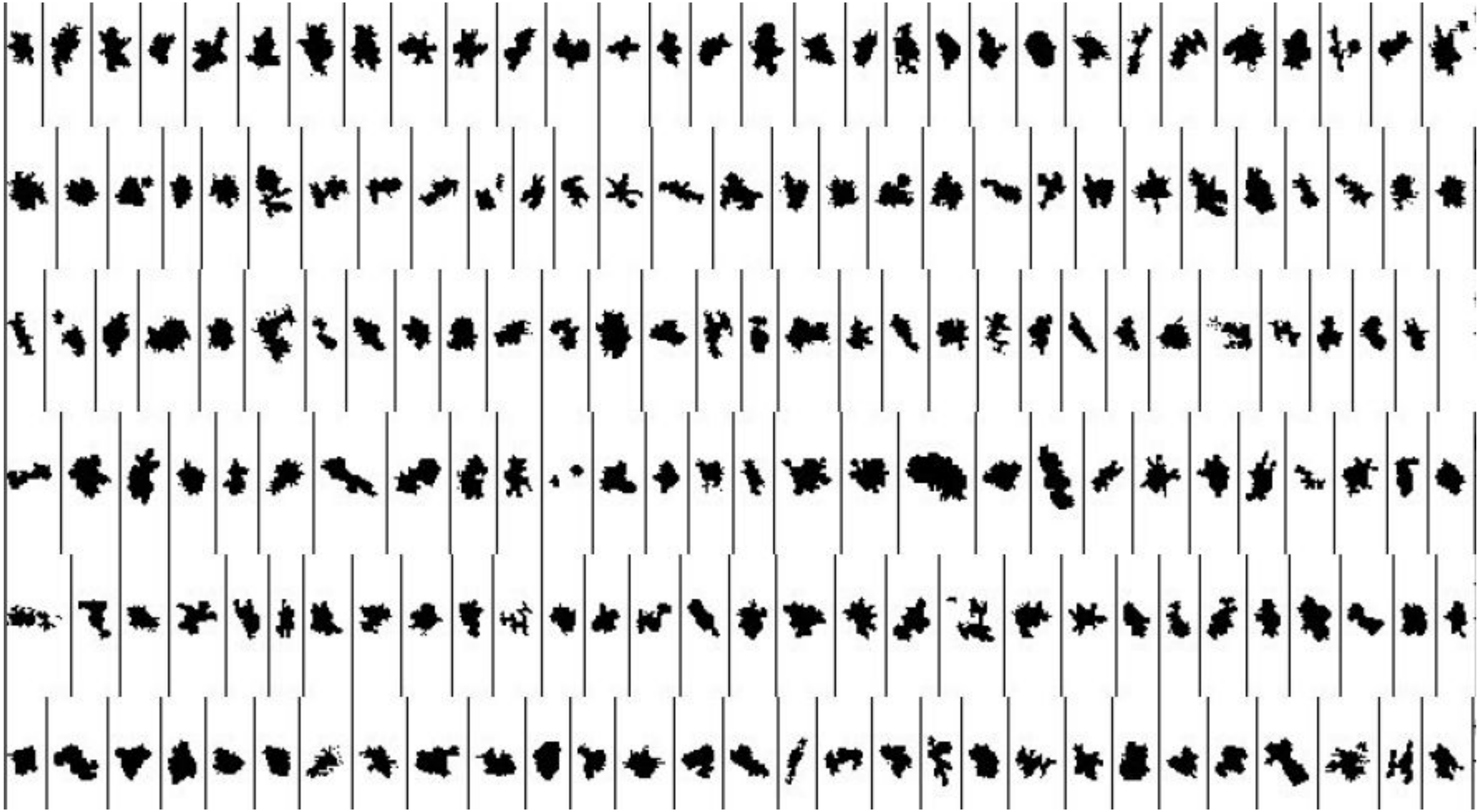
Anvil – stratiform aged ice – away from convective cell

6 mm

PIP: Particles 2 - 4 mm

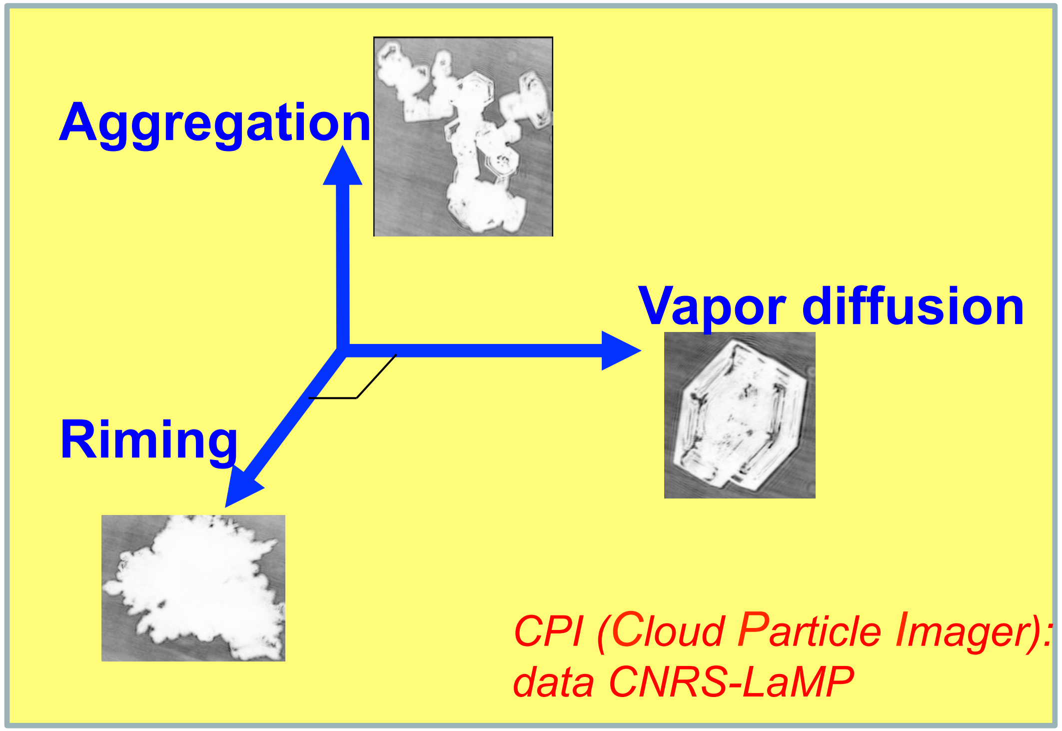


A lot of ice crystals are just irregular !



Concept of ice growth

Conlusion: Growth is endlessly complex…..




cnrs
INSU
Observer & comprendre
UNIVERSITE BLAISE PASCAL
CLERMONT-FERRAND
LaMP

Particle Imagers: Optical Array Probes OAP, CCD camera

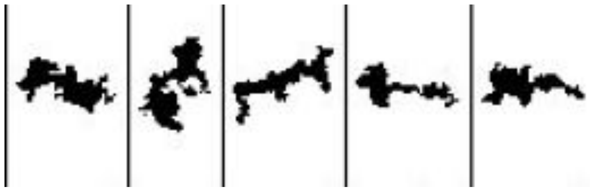
Particule Size Distribution (from 2D images)

Imagers : 2D-S and PIP (+CPI)

(if no IKP)

50-1280 µm
(resolution 10 µm)

500-6400 µm
(resolution 100 µm)



30-2300 µm (resolution 2.3 µm)

Particle spectrometers, bulk condensed water content devices

Particule Size Distribution (PSD, no images) :

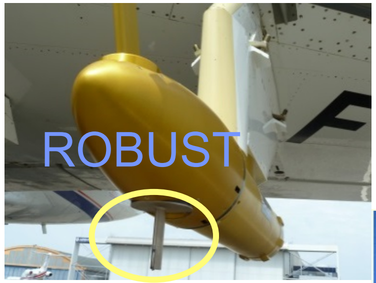
CDP or CPSPD (polarisation)

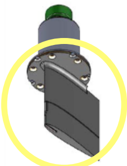
Water Content : TWC - IKP, Robust probe

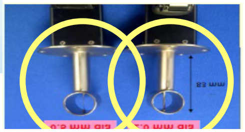
LWC - 0.5 mm or 2 mm (if no CPI)

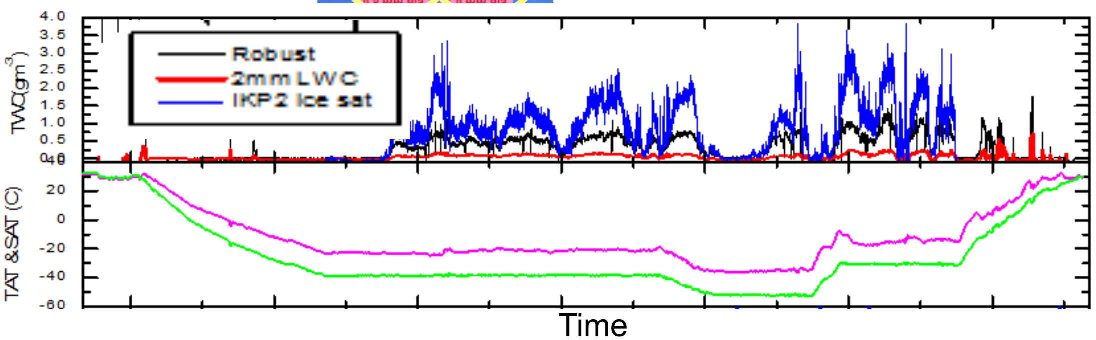
IWC - ICD

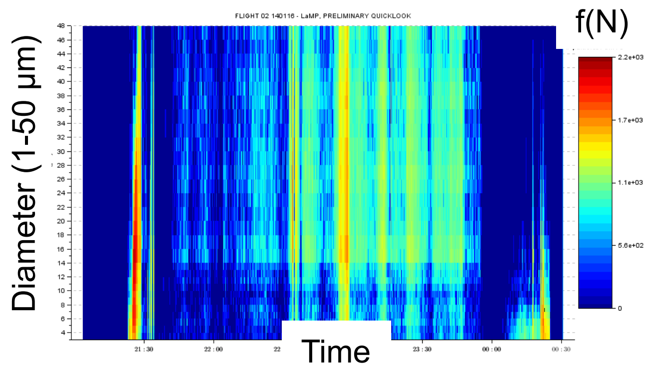
1 - 50 µm









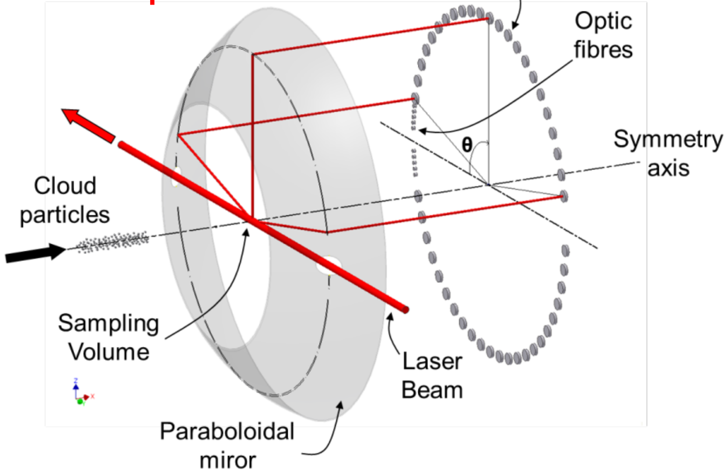


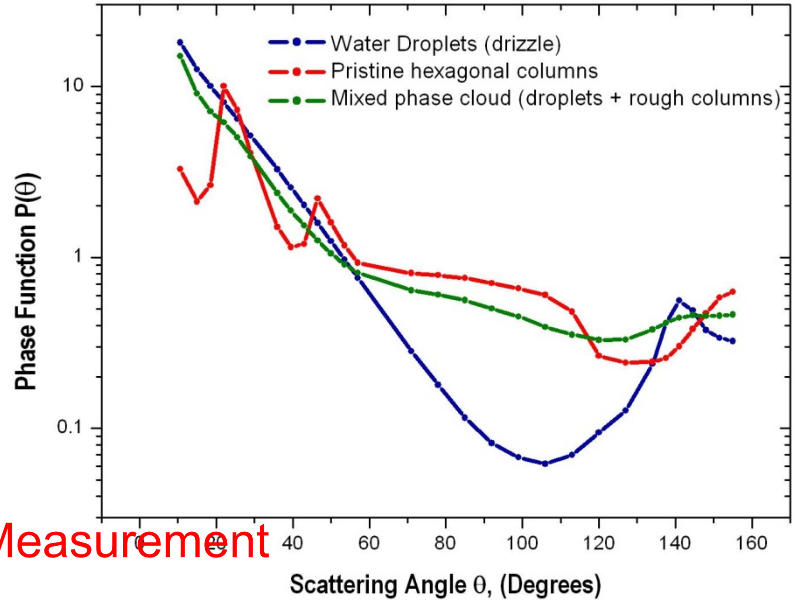
Instruments for optical particle properties

Scattering phase function (extinction, asymetry) :

Polar Nephelometer

Principle





Measurement

1. Intro
2. Growth mechanisms, crystal complexity
3. Instruments for in situ characterization
4. **Properties of ice crystals**

In situ measurement challenges linked to the ice phase

1. Size/Aspect characterisation

Dmax ?

Deq ? (diameter of a sphere of the same area)

Roughness ? Sphericity ?

2. Particle size spectra

Needed to calculate reflectivities, in satellite inversion methods….

3. Ice density - Relationship between mass and size (and number !)

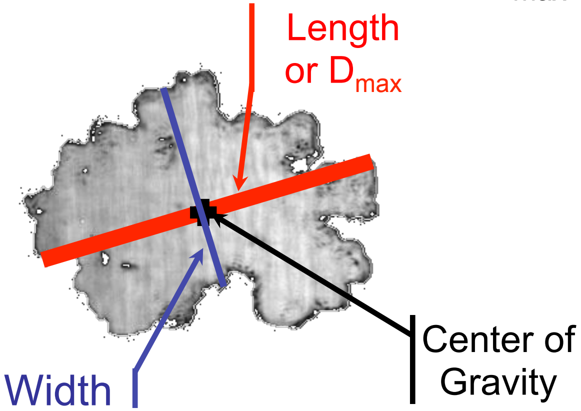
$$m = \alpha \, D_{max}^{\beta}$$

Ice density is a key parameter to link size and mass and also for modelling purposes (ice density is needed to calculate ice crystal growth velocity).

1. Size/Aspect characterisation

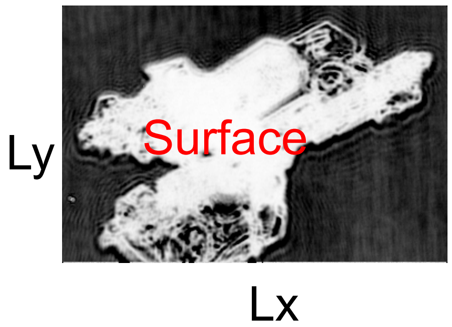
Processing of 2D images :

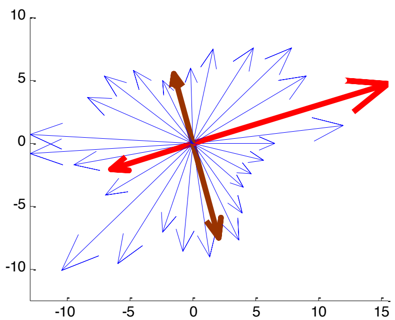
- Extraction of parameters that describe the geometry of all individual hydrometeors: Maximum length (or D_{max}), Width, Surface, Perimeter, Aspect ratio …



- ❑ Length or D_{max}
- ❑ Width
- ❑ Area and D_{eq}
- ❑ Perimeter
- ❑ Sphericity
- ❑ Surface roughness (surface-perimeter)
- ❑ Aspect ratio: $Aspect_{ratio} = \frac{Width}{D_{max}}$

LaMP vector analysis for CPI, 2D-S, and PIP data



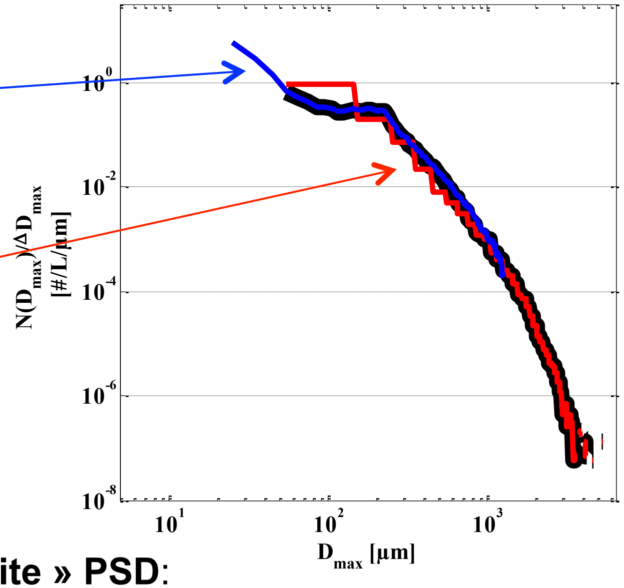


2. Particle size spectra

Particles Size Distributions (PSD) : Concentration of Hydrometeors as a Function of D_{max}:

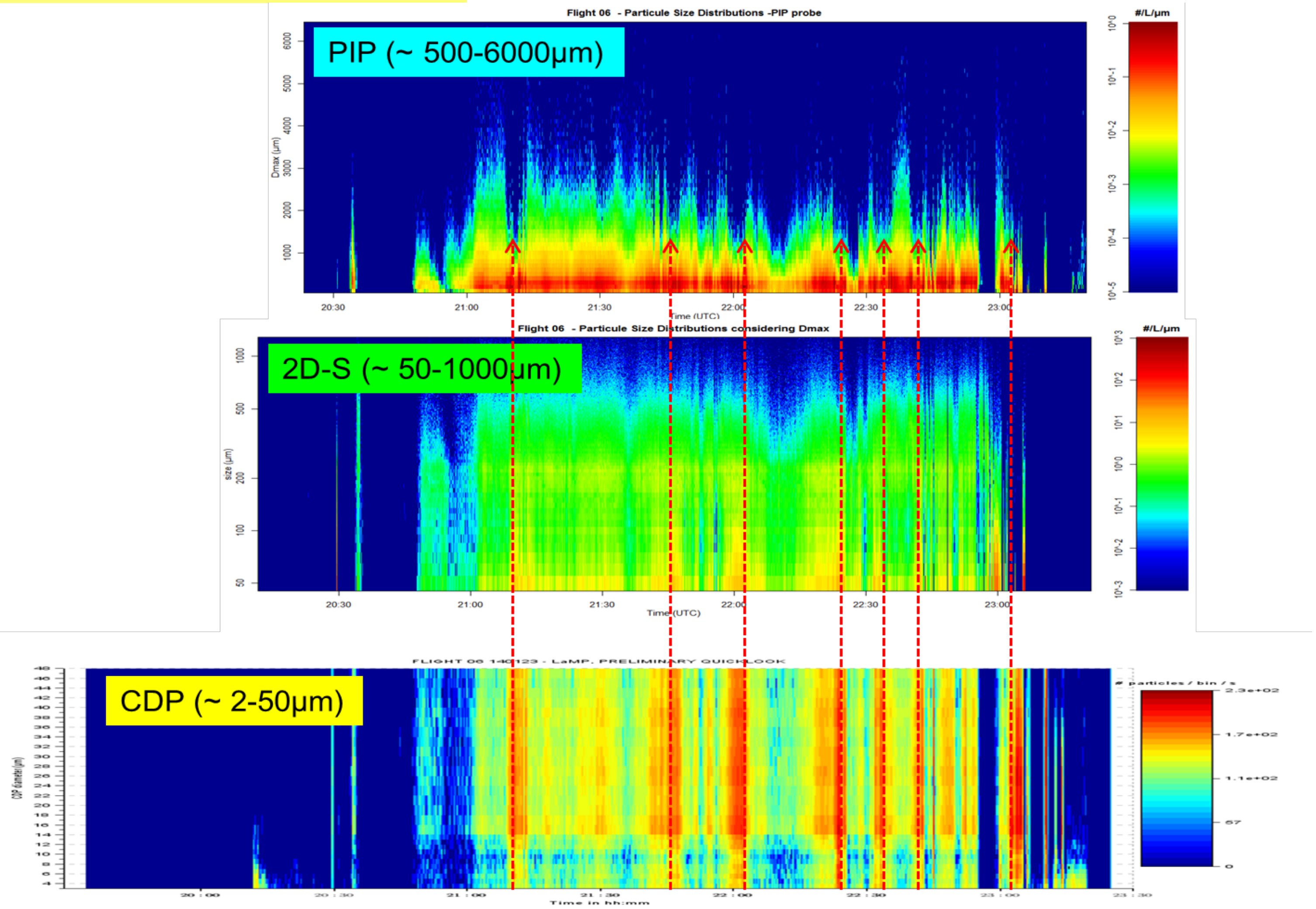
- **2D-S Probe** :
Size range of hydrometeors from 50 to 1280 µm
resolution of 10 µm

- **Precipitation imaging probe (PIP):**
size range from 500 to 6400µm,
resolution = 100µm



⇒ Composition of the two PSDs to built a **« composite » PSD**:
Resolution : 10µm & Size Range: 50-6400 µm
Time resolution 10 seconds (for statistical reasons).

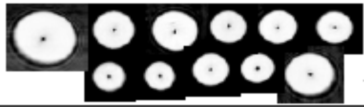
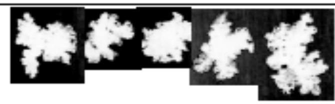
2. Particle size spectra



3. Ice density - Relationship between mass and size

Crystal shape classification according to geometric parameters extracted from single crystal analysis

At LaMP: 10 typical shapes defined

Forme	Exemples	
Gouttes		200
Dendrites		400
Colonnes		400
Rosettes		300
Bullet		400
Plaques		150
Particules givrées		500
Aiguilles		500
Complexes à faces planes		600
Irréguliers		300

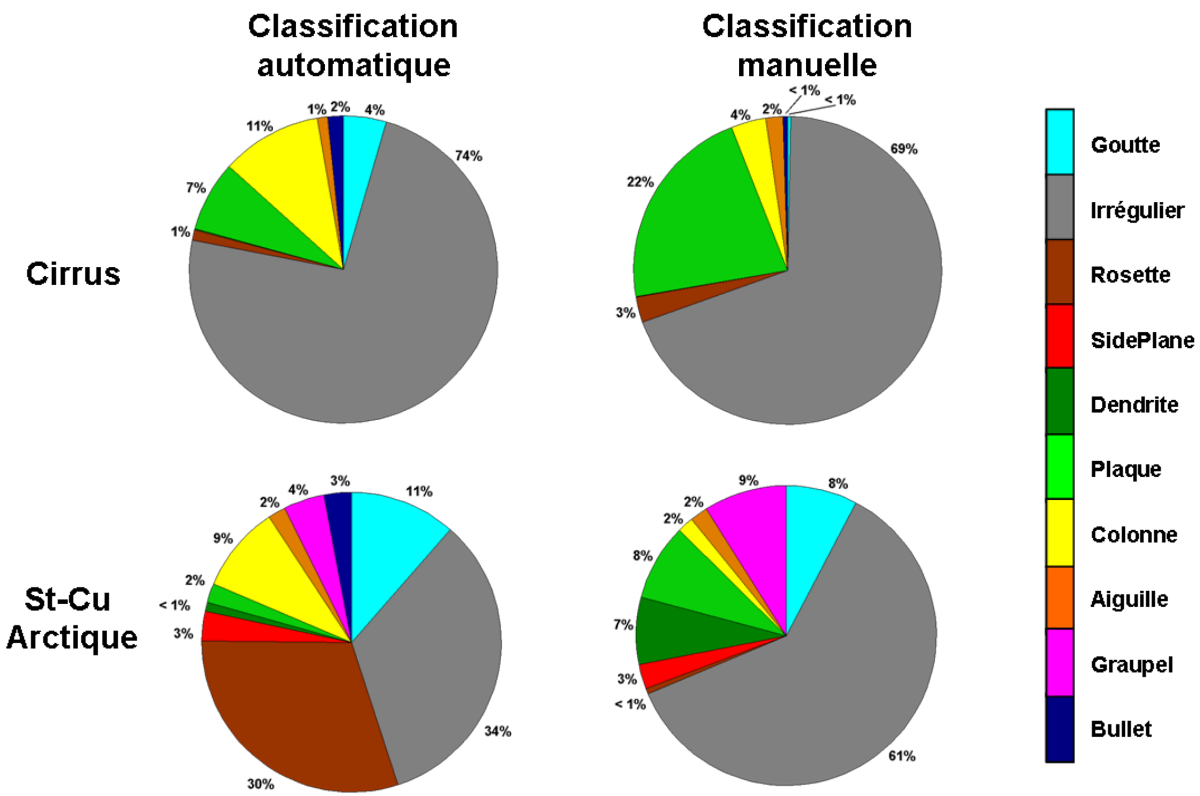
Source : Thesis G. Mioche, 2010

3. Ice density - Relationship between mass and size

CPI imager: Shape classification

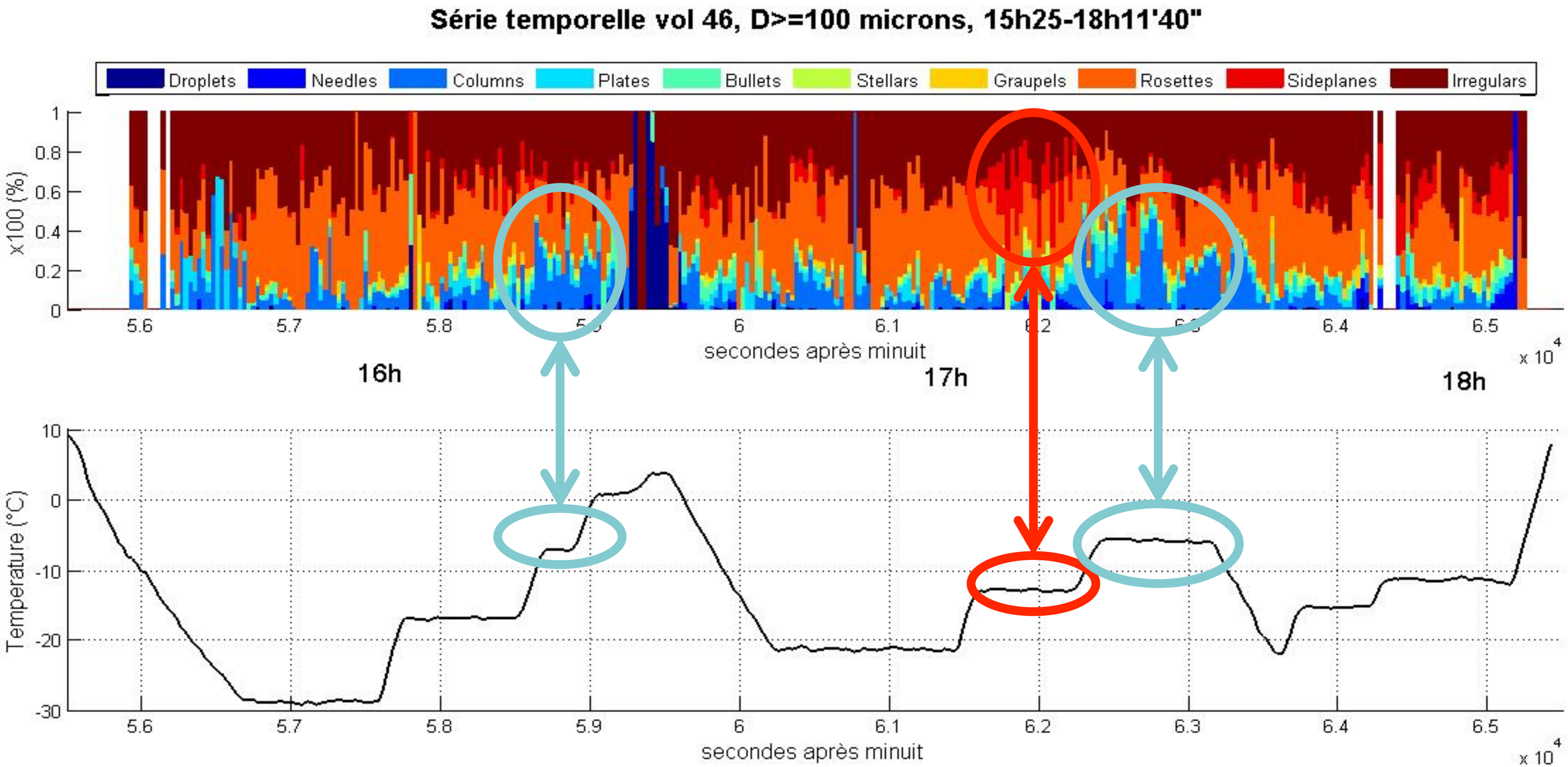
Circle-2

ASTAR

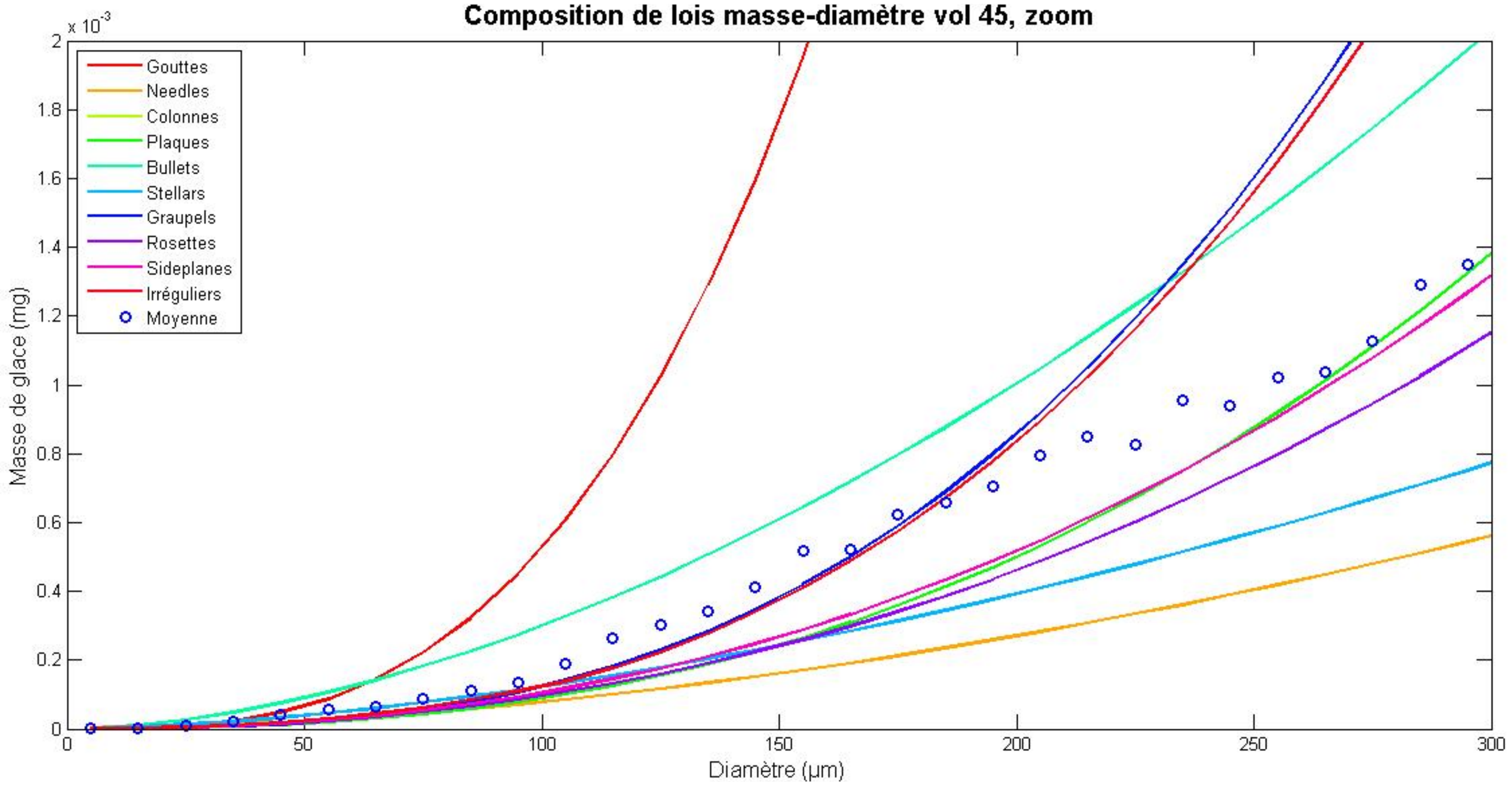


3. Ice density - Relationship between mass and size

Megha-Trophique: Indian Ocean

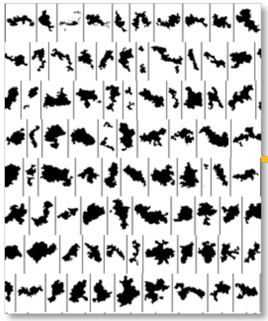


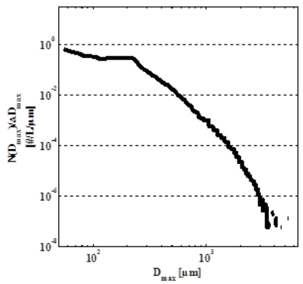
3. Ice density - Relationship between mass and size

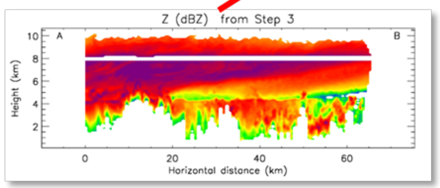


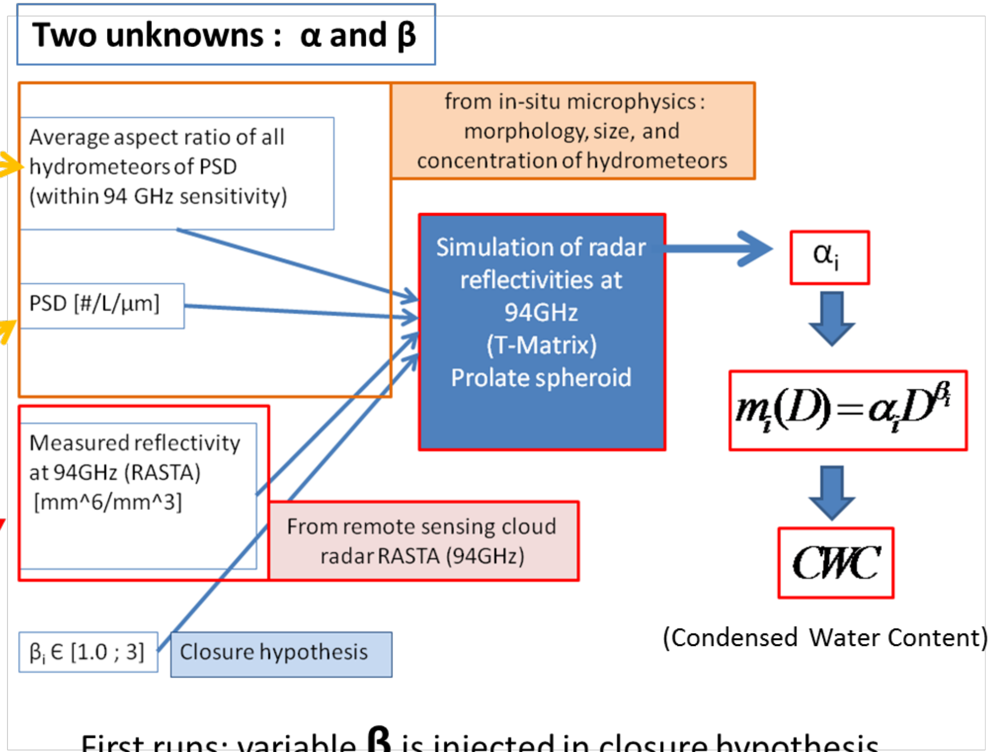
3. Ice density - Relationship between mass and size

Scheme : Time dependent retrieval of m(D) from hydrometeor imagery and cloud radar reflectivities on F20 trajectory.







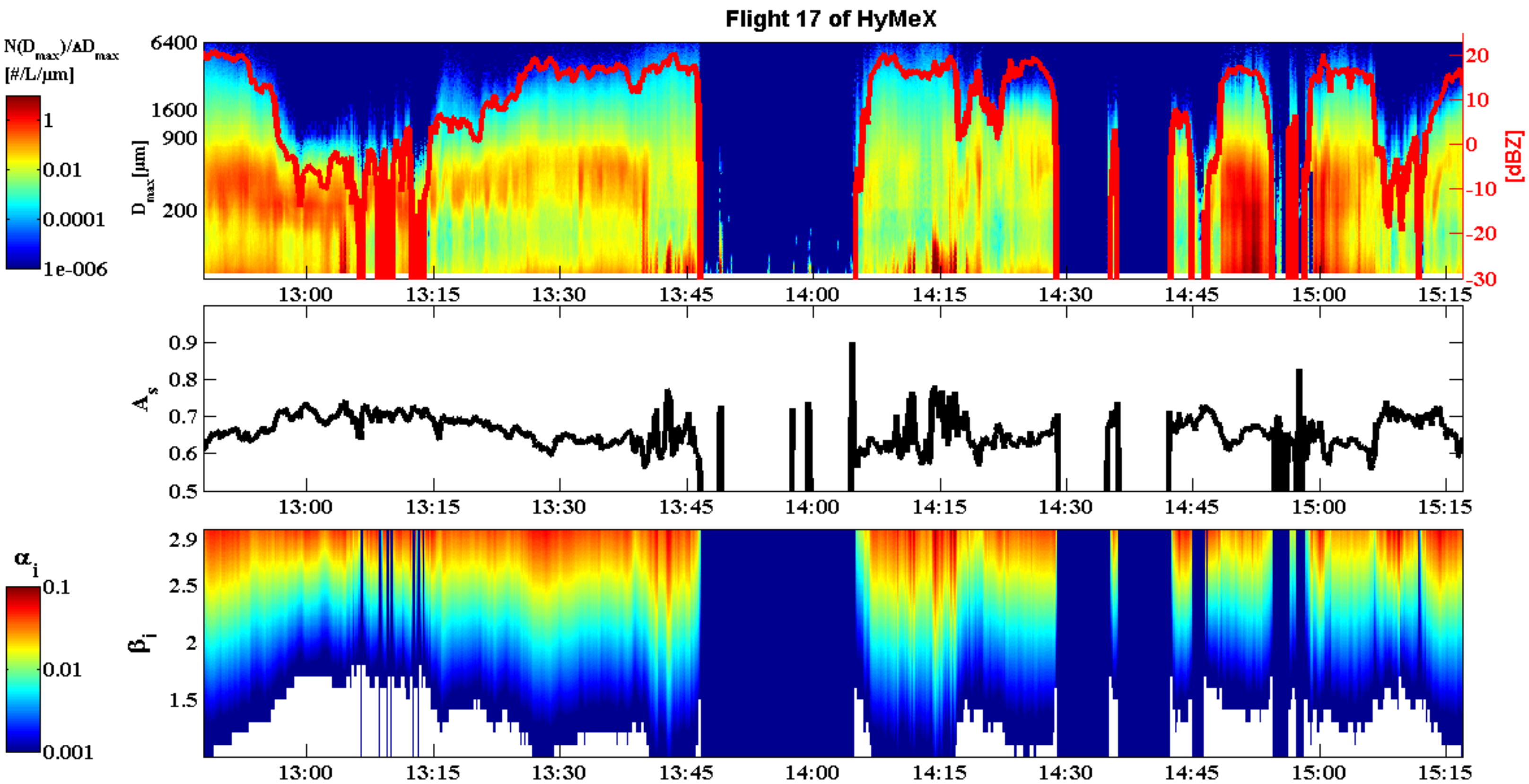


First runs: variable **β** is injected in closure hypothesis

while **α** is constrained from the Tmatrix simulations

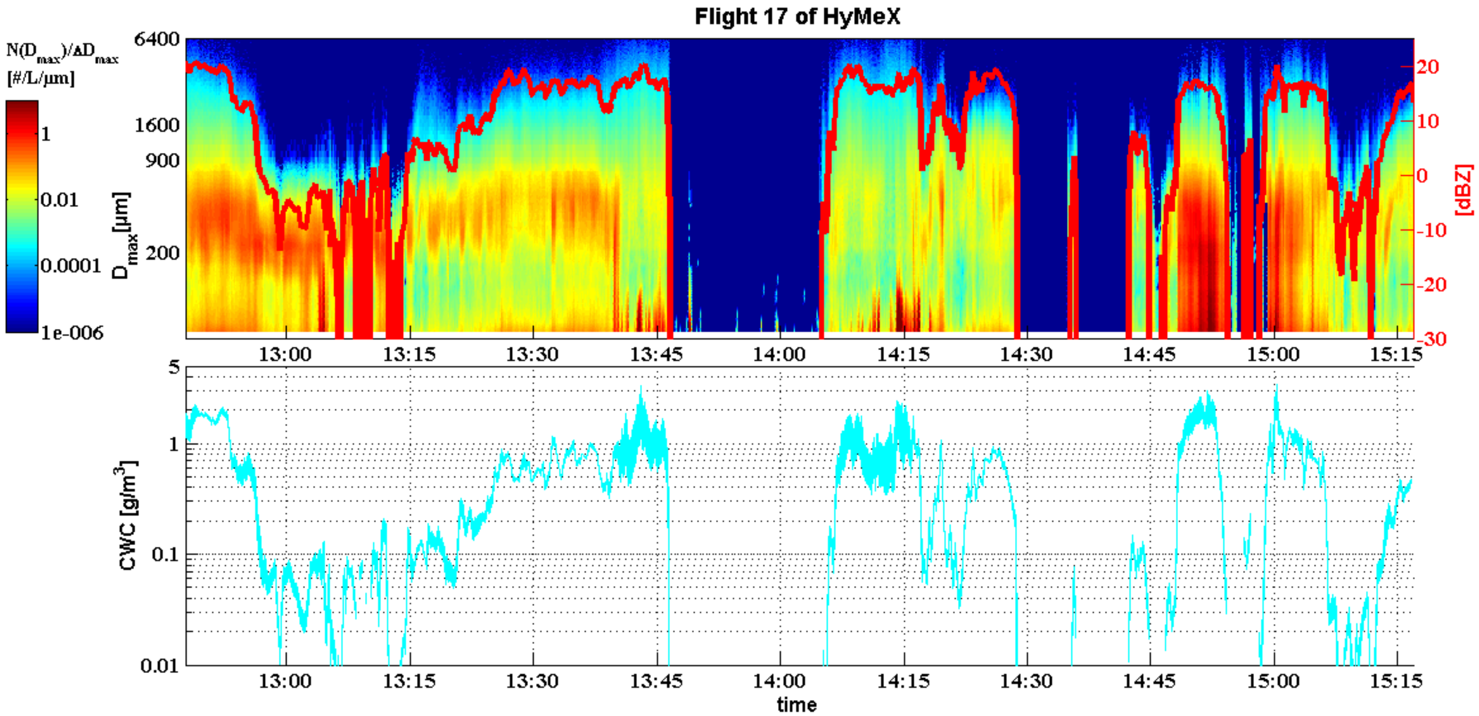
3. Ice density - Relationship between mass and size

First step : all solutions are explored for a β exponent (lower chart) varying between 1 to 3. α corresponding to β is color coded (legend)



3. Ice density - Relationship between mass and size

Second step : all solutions of β and corresponding α (constrained by T-Matrix simulations of RASTA reflectivities) are used to calculate CWC (light blue color below).
Differences relatively "small". Question: what is the most realistic solution?



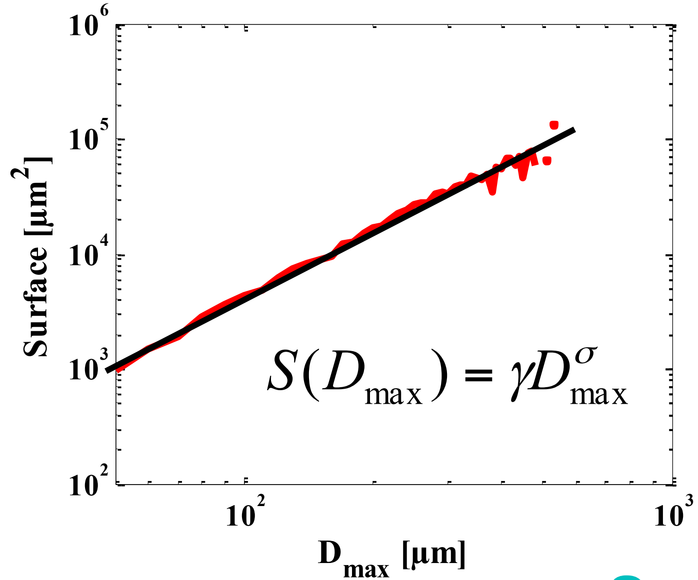
Standard deviation ~ 20%

3. Ice density - Relationship between mass and size

<u>Mass-Diameter law from in-situ observations:</u>

1. Surface of hydrometeors as a function of Dmax :

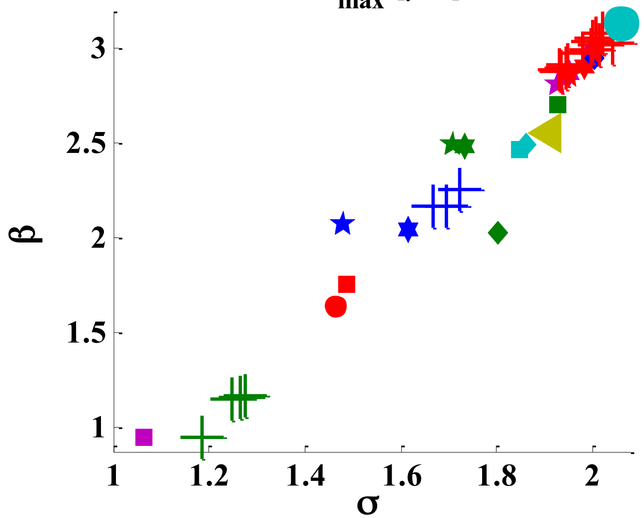
Needed to calculate the terminal velocity of hydrometeors (Rain rate).



Surface-Diameter relationship can be fitted by a power law.

2. Relating the Mass-Diameter law by Surface-Law :

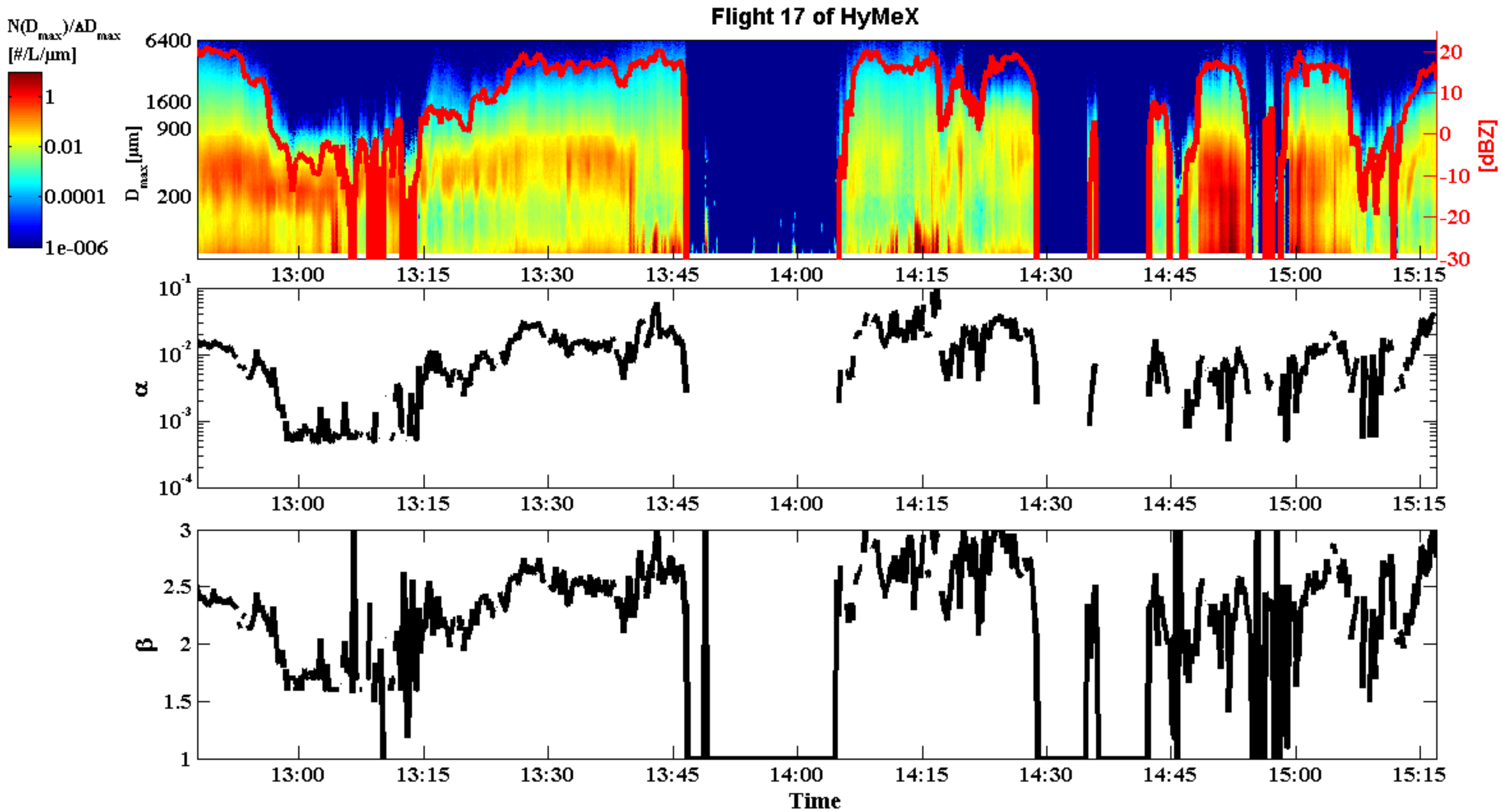
- Numerical Simulations of 3D hydrometeors (42000)
- Each hydrometeor is projected on a plane to simulate the projection of 3D hydrometeors on 2D surface (2D-S, PIP images)



=> linear relationship between σ and β

3. Ice density - Relationship between mass and size

Special solution for β (derived from σ of area-diameter relation) and corresponding α (constrained by T-Matrix simulations of RASTA reflectivities) as a time series.



$$m(D_{\max}) = \alpha \cdot D_{\max}^{\beta}$$

3. Ice density - Relationship between mass and size

Calculation of the IWC (CWC) and comparison of IWC retrievals

a) **Our method: Matching measured with simulated reflectivities via T-matrix**

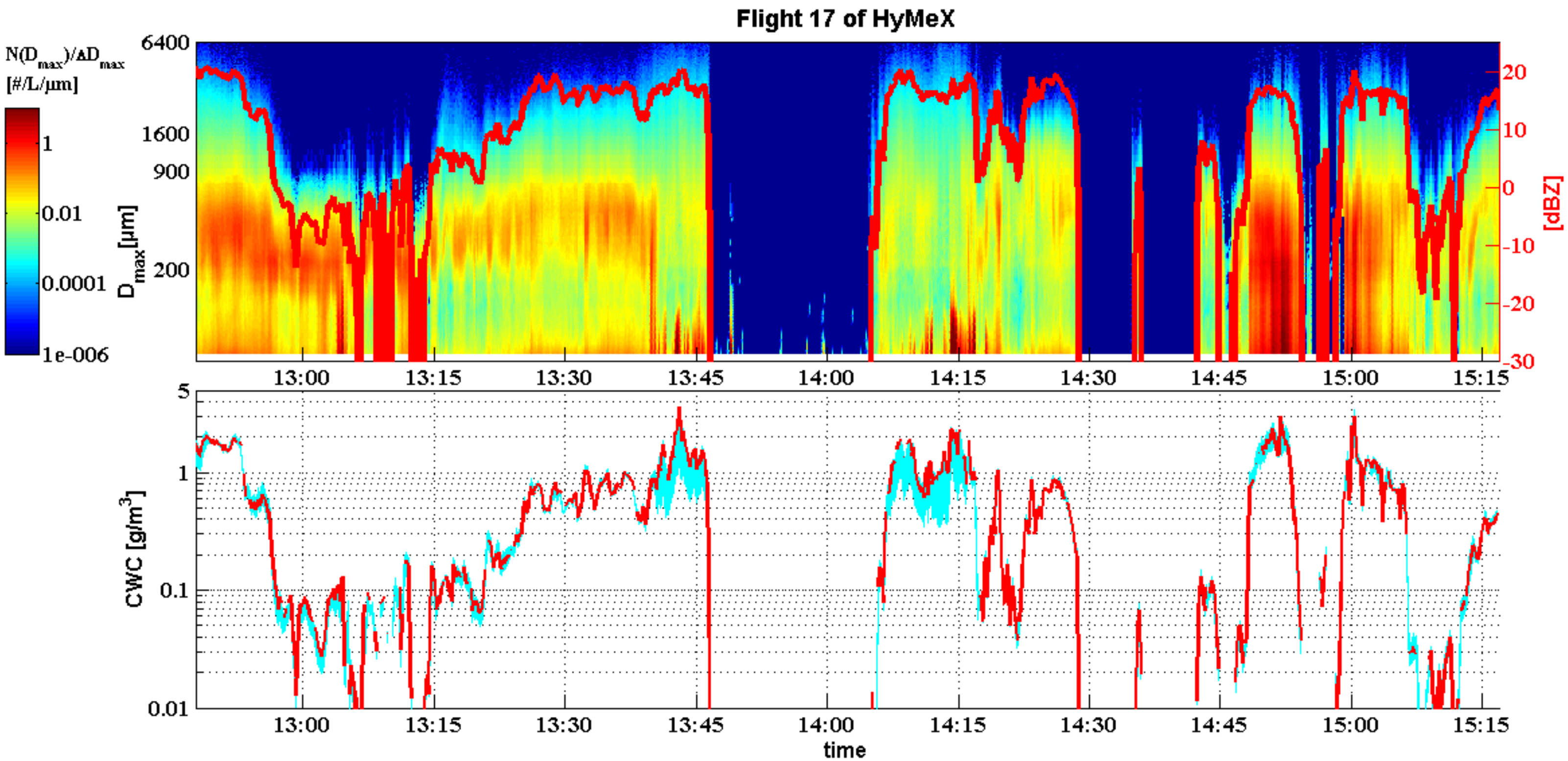
b) **Baker & Lawson (2006) method deriving unique geometric parameter X, then calculating IWC from X (crystal area A, width W, length L, perimeter P, sampling volume V)**

$$X = \frac{2 \cdot A \cdot W(L+W)}{P} \Rightarrow IWC = \frac{0.135 \cdot \sum_i X_i^{0.793}}{V}$$

c) **Constant m-D relation for with α = 0.010 and β = 2.1**

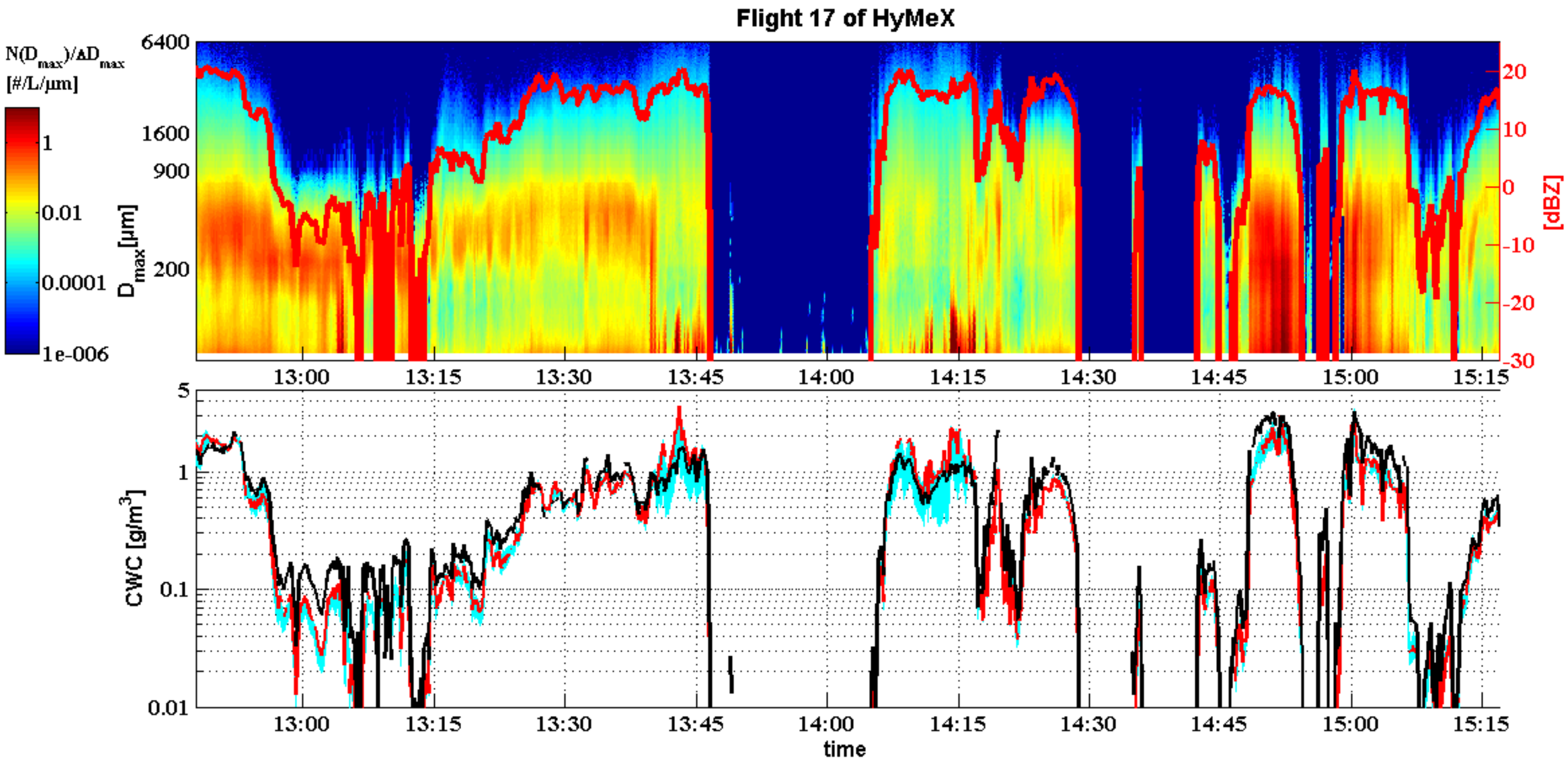
3. Ice density - Relationship between mass and size

Special solution of β and corresponding α used to calculate CWC (red colored curve, below).
In addition: CWC for solutions of β and corresponding α in light blue below.



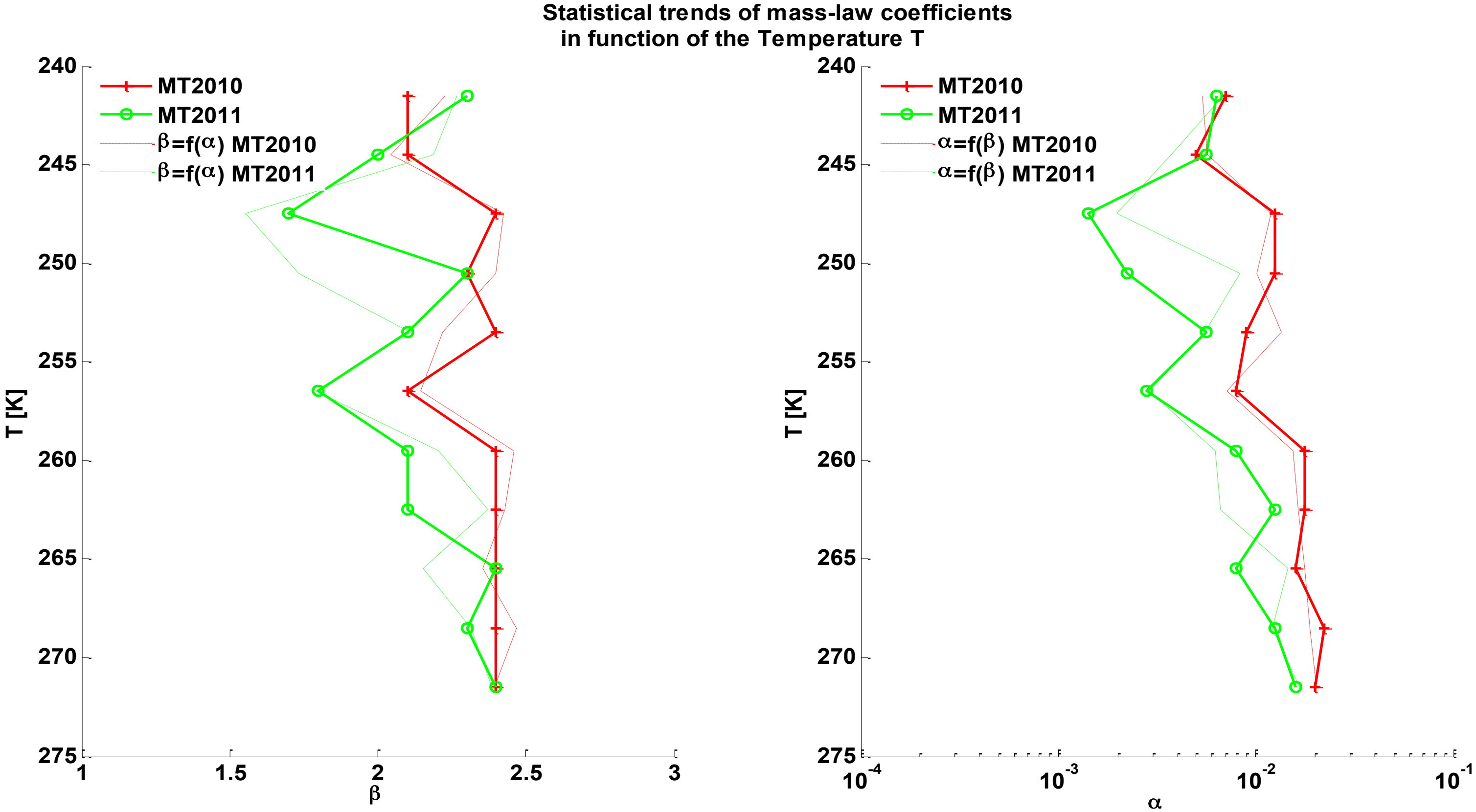
3. Ice density - Relationship between mass and size

As before.
Black curve: Added CWC calculated from Baker and Lawson (2006) CWC parametrisation.



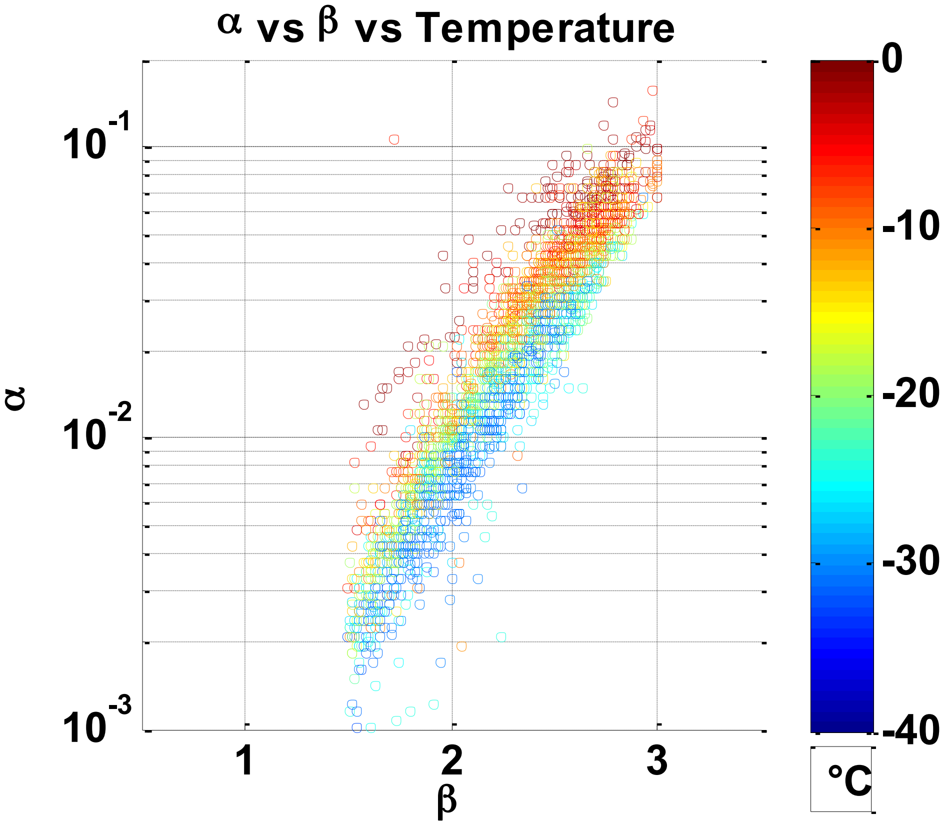
3. Ice density - Relationship between mass and size

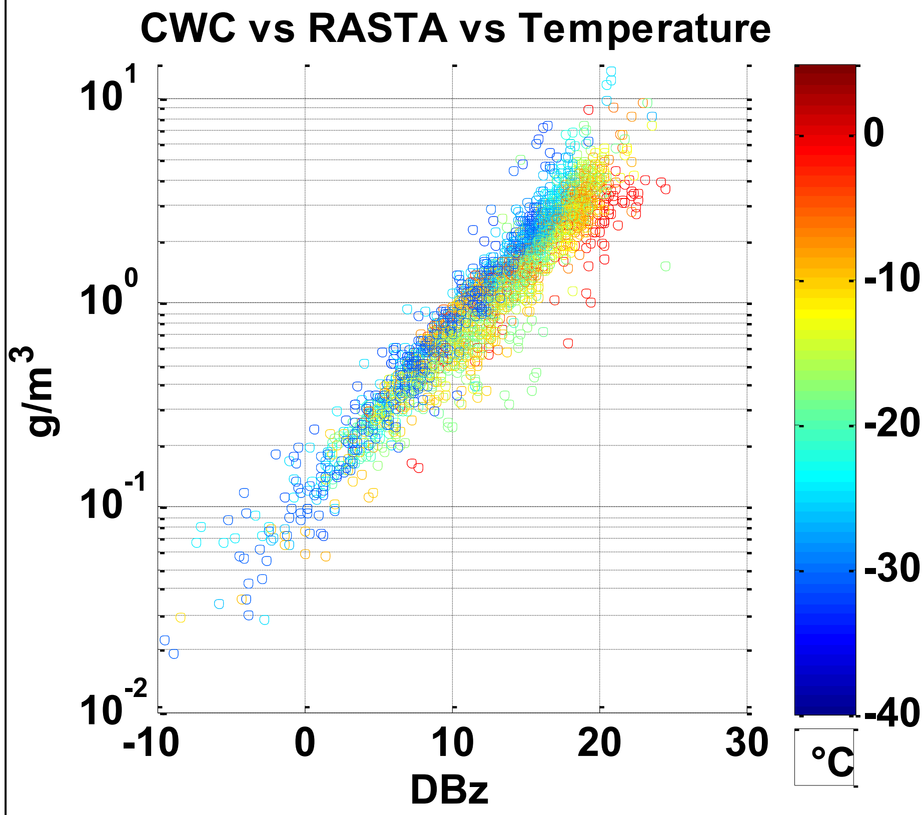
Statistics of pre-factor α and exponent β from m(D) relations calculated for Megha-Tropiques MT2010 (African continent) and MT2011 (Indian Ocean) as a function of T



3. Ice density - Relationship between mass and size

Impact of temperature on m(D) relation and CWC: here for MT1





Sans conclusions