A Microphysical Classification of Mixed-Phase Clouds in the Liquid-Ice Coexistence and Wegener-Bergeron-Findeisen Regime

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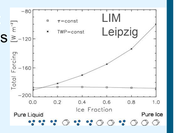
Mixed-phase clouds

- Temperature regime between **273K and 235K**
- Supercooled liquid water and ice can **coexist**
- **Wegener-Bergeron-Findeisen** process possible
- **Precipitation** building area

Motivation

- Highly **dynamical** system, many **interactions**: phase transitions, energy fluxes, mass changes
- (precipitation) => **not yet fully understood**
- **Radiative effects**, depending on ice water content (see graph), will have to be implemented in climate models (IPCC 2013)



Cloud regimes

Wegener-Bergeron-Findeisen-Regime (WBF)

- Believed to be the **dominant** regime (e.g. IPCC 2013, p.611)
- **Supersaturation wrt ice, subsaturated wrt water**: Ice grows quickly on the expense of water as droplets evaporate
- Large ice particles: **precipitation**

Coexistence Regime (CoEx)

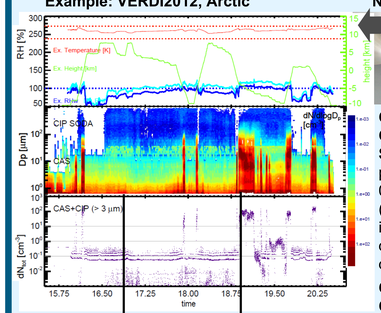
- Supercooled water and ice coexist
- **The saturation wrt both is >100%** Liquid droplets don't evaporate

Issues for the in-situ classification

Temperature and humidity measurements:
Uncertainties too big or **data point density** not sufficient

NIXE-CAPS: Cloud regime classification

Example: VERDI2012, Arctic

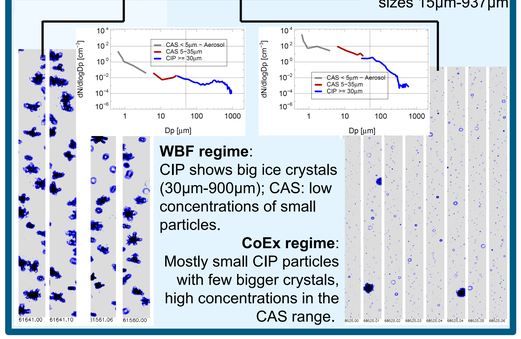


NIXE-CAPS:

CAS-Depol: **C**loud & **A**erosol **S**pectrometer - particle sizes: 0.61µm-50µm (light scattering intensity); shape determination: depolarisation

CIP: **C**loud **I**maging **P**robe – particle shadow images; sizes 15µm-937µm

The two cloud regimes can be classified by their size distributions:



WBF regime: CIP shows big ice crystals (30µm-900µm); CAS: low concentrations of small particles.

CoEx regime: Mostly small CIP particles with few bigger crystals, high concentrations in the CAS range.

Measurement campaigns and results

AIDA 2008

- KIT, Karlsruhe
- CAPS@Cloud simulation chamber AIDA
- Artificial clouds forced by IN, pressure and temperature variations
- Humidity measurement: ApiCT-TDL

COALESC 2011

- **C**ombined **O**bservation of the **A**tmospheric boundary **L**ayer to study the **E**volution of **S**trato**C**umulus
- Exeter, UK
- Mid-latitude campaign
- CAPS@BAE146

VERDI 2012

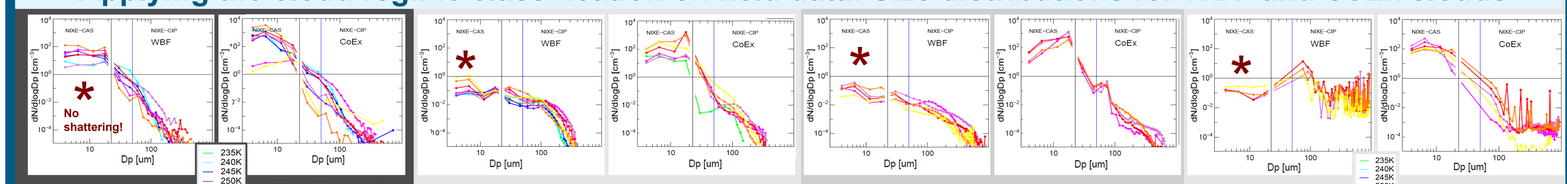
- Study on the **VER**tical **D**istribution of **I**ce in Arctic clouds
- Inuvik, Canada
- arctic campaign
- CAPS@Polar5
- Humidity Measurmenet: CR-2

RACEPAC 2014

- **R**adiation-**A**erosol-**C**loud **ExP**eriment in the **A**rctic **C**ircle
- Inuvik, Canada
- arctic campaign
- CAPS@Polar5 and Polar6

Preliminary Results!

Applying the cloud regime classification on field data: Size distributions for WBF and CoEx clouds



WBF regime: **0.7h** | CoEx regime: **11.7h** | WBF regime: **3.1h** | CoEx regime: **4.5h** | WBF regime: **2.5h** | CoEx regime: **13.4h** | WBF regime: **3.9h** | CoEx regime: **5.8h**

* **Small particles in the WBF regime confirm the existence of small ice crystals!**

Correlations between size distribution and water saturation

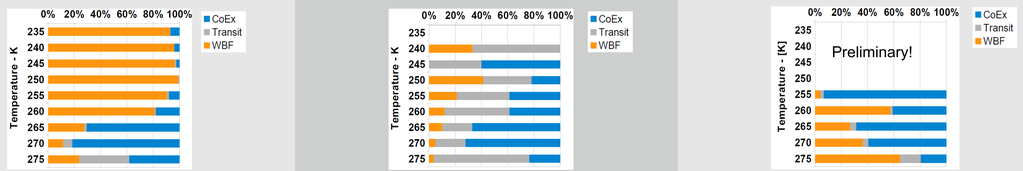
AIDA
- Regimes separated by size distributions
- Humidity measurement: APiCT-TDL
  - →**WBF** regime: **RHi 107.6%** **RHw 89.9%**
  - →**CoEx** regime: **RHi 111.0%** **RHw 100.1%**

Size distributions are correlated very well to the humidity ranges that define the cloud regimes!

VERDI
- Regimes separated by size distributions
- Humidity measurement: CR-2
  - →**WBF** regime: **RHi 104.2%** **RHw 94.2%**
  - →**CoEx** regime **RHi 106.4%** **RHw 98.7%**

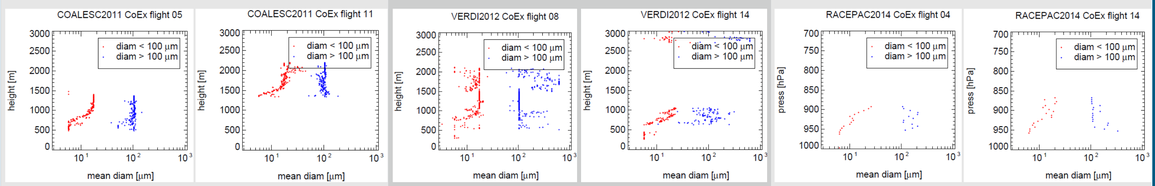
Long adjustment times:CR-2 measurements can't represent the real humidity values at all times – BUT: also in the field campaign the two regimes show significantly different mean saturation values.

WBF cloud occurrence increases with altitude (=> with decreasing temperature)

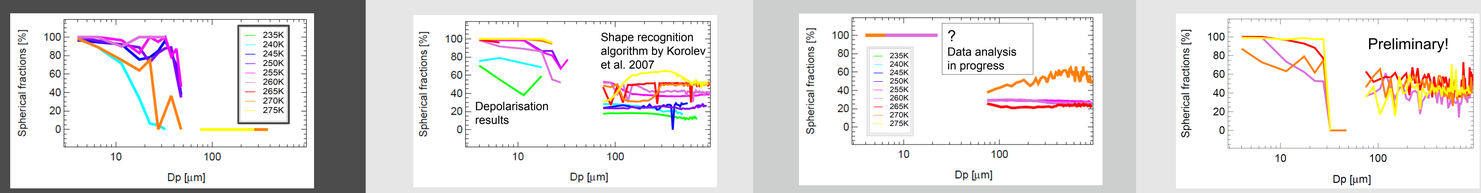


Process visible: Cloud particles* grow with increasing altitude in the CoEx regime

*mean diameter of the cloud particle fraction with the highest concentration (calculated per flight second)



Temperature and size trends of the spherical ice fraction in the WBF regime



Conclusions

Cloud regimes

- The cloud particle **size distribution** gives hints at the **WBF or CoEx humidity regime**
- **Coexistence** regime: **more frequent** than the Wegener-Bergeron-Findeisen regime
- The **WBF cloud percentage increases with increasing altitude**/ decreasing temperature
- Similar particle numbers but **growing particle sizes from the bottom to the top** of the clouds

Small ice crystals

- **Small** spherical and aspherical **ice particles** (3-50 µm) in WBF clouds: Not a result of shattering but **frozen droplets or partly subliminated ice crystals**
- **Spherical ice fraction** seems to **increase with decreasing size**.

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