Using combined airborne high spectral resolution and differential absorption lidar and cloud radar measurements for ice cloud characterization

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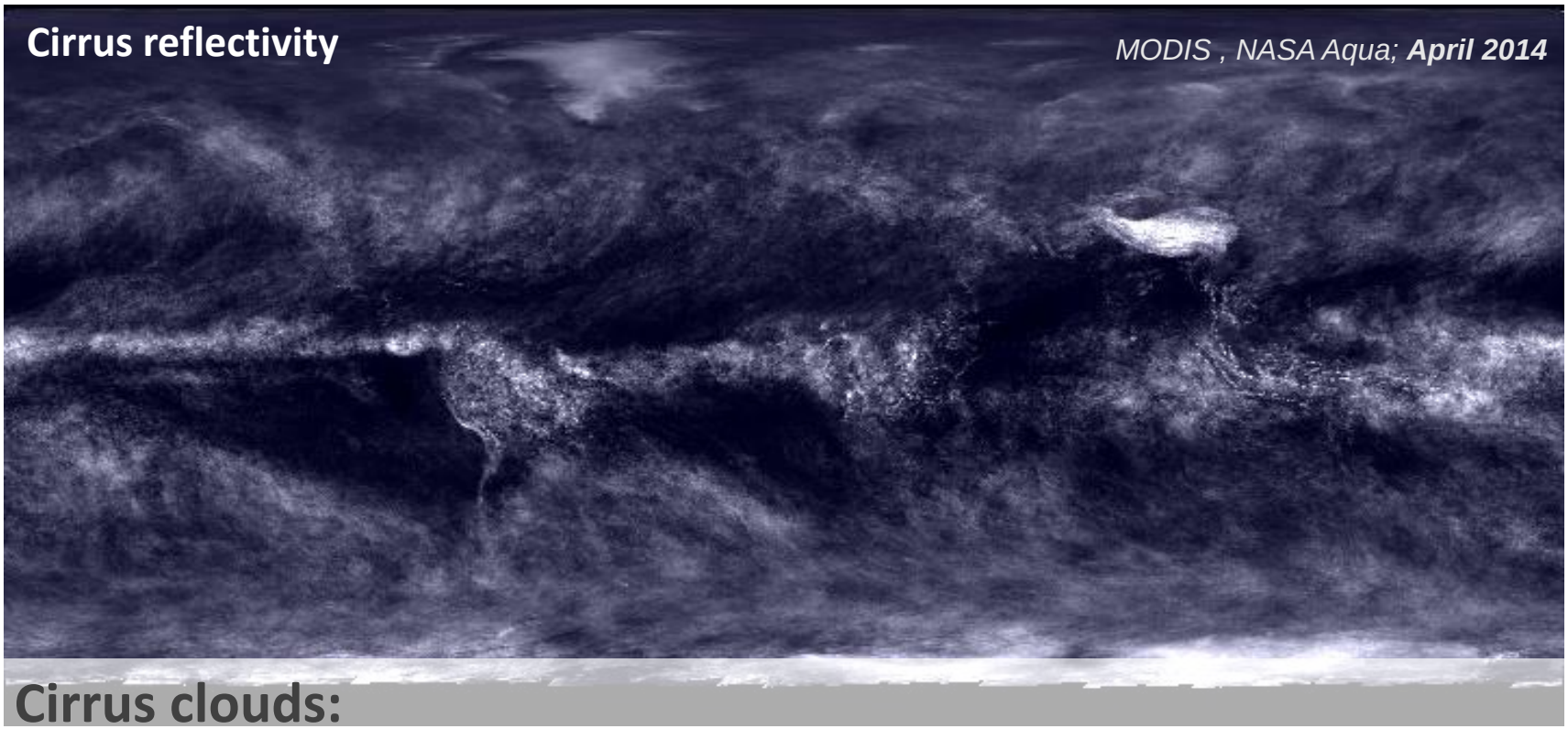
Motivation



Cirrus clouds:

- Wide **global coverage**
- Large **impact** on Earth's **radiation budget**
- Impact **dependent** on **optical**, macro physical and **microphysical properties**
- Dependence of on **life cycle** and **forming conditions highly uncertain**

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The DLR lidar system WALES

Airborne water vapor DIAL and HSRL, developed and build at DLR-IPA

Aerosol

- Backscatter coefficient (532 nm,1064 nm)
- Color ratio (532 nm/1064 nm)
- Aerosol **depolarization** (532 nm,1064 nm)
- Aerosol extinction (**532 nm – HSRL**)
- Resolution: range ~15 m, time = 1s

Water Vapor

- H_2O mixing ratio
  (4 wavelengths ~935 nm)
- Resolution: range ~ 290m, time = 25s
- Relative humidity (in combination with external temperature data)

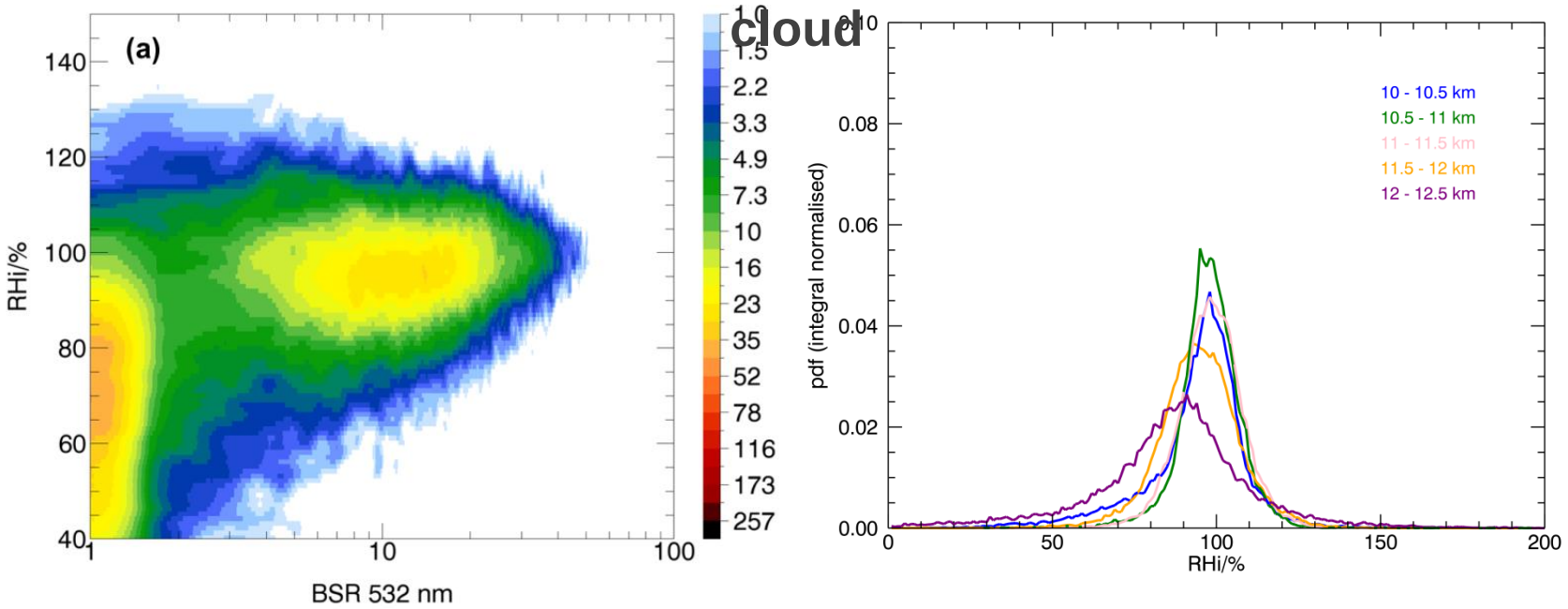
→ **Possibility of aerosol classification**

→ **In-cloud and outside cloud distribution of relative humidity and water vapor**

Esselborn et al., 2008; Wirth et al., 2009

Correlative Backscatter ratio and Relative Humidity observations

Case study on 4. November 2010 – fully developed cirrus cloud



- **Height-dependent Relative Humidity over ice (Rhi) distributions**
  → Lowest RHi values at upper part of the cloud
- **2-dim distribution of BackScatter Ratio (BSR) and RHi**
  → No RHi values larger 120% outside cirrus cloud / Highest BSR at 100%

Groß et al., 2014 AMT

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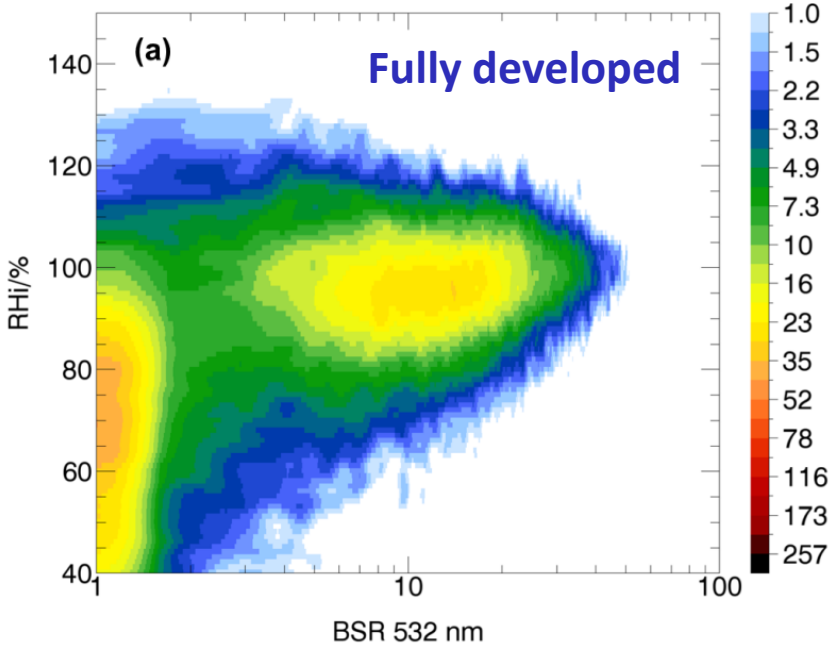
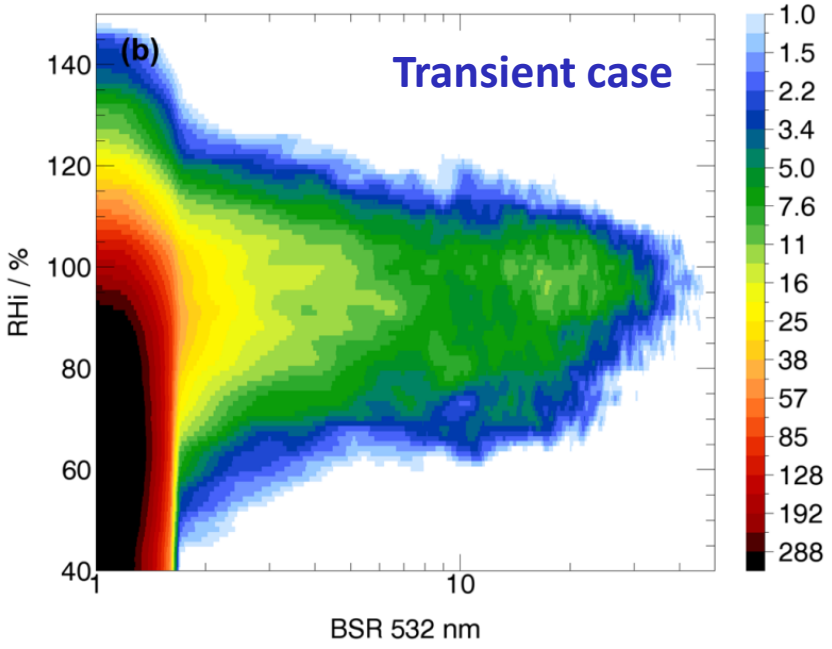
Ice cloud study – HALO Techno mission 2010

4. November 2010



3. November 2010



- Different height dependent RHi / joint BSR-RHi distribution for different cirrus clouds
- Differences in different stages of evolution / forming conditions

→ How do microphysical properties differ for different stages of evolution / forming conditions

Groß et al., 2014 AMT

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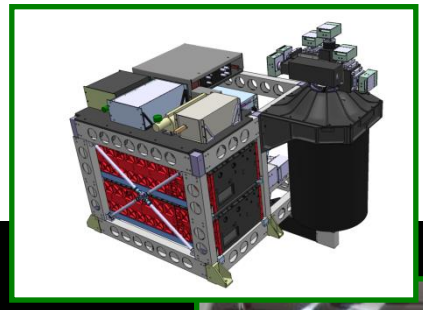
Active remote sensing with HALO

Combining lidar and radar for ice cloud observations



Schäfler et al., 2018

HAMP (Cloud radar)	
Wavelength	8 mm
Transmit power	30 kW
Repetiton rate	6 kHz
Antenna	1 m

WALES (HSR Lidar)	
Wavelength	532 nm
Transmit power	48 W
Repetition rate	100 Hz
Telescope	48 cm

- Sensitive to particle size
- Cloud penetrating
- Doppler velocity

Radar reflectivity

$Z \propto D^6$

Lidar backscatter

$\beta \propto D^2$

- Sensitive to particle concentration
- Resolves cloud tops
- Water vapor DIAL

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Synergistic Radar/Lidar retrieval

Retrieving ice microphysical properties

Optimal estimate approach
(Delanoë et al., 2008)

State vector x
A priori profile of α, S, N

Forward modeling of measurements

Lidar signal
incl. multiple scattering

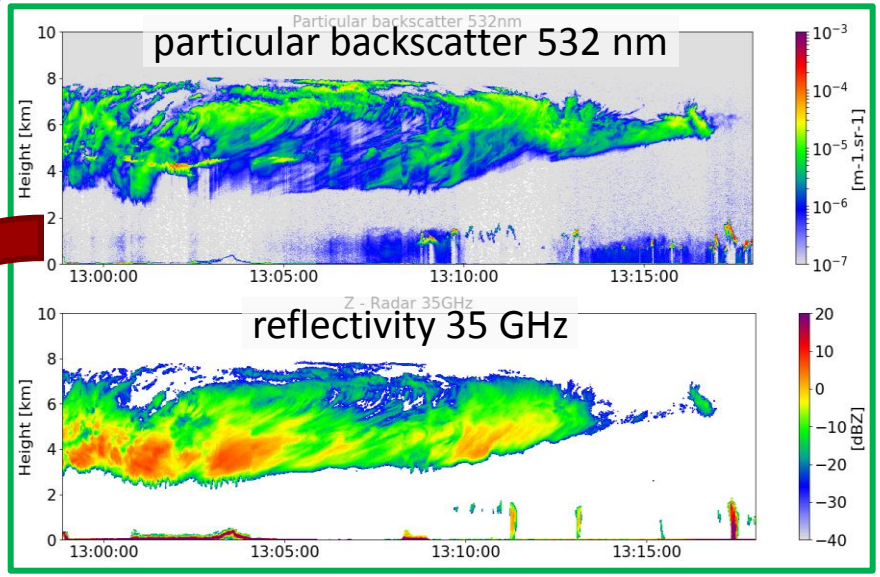
Radar signal
LuT based reflectivities

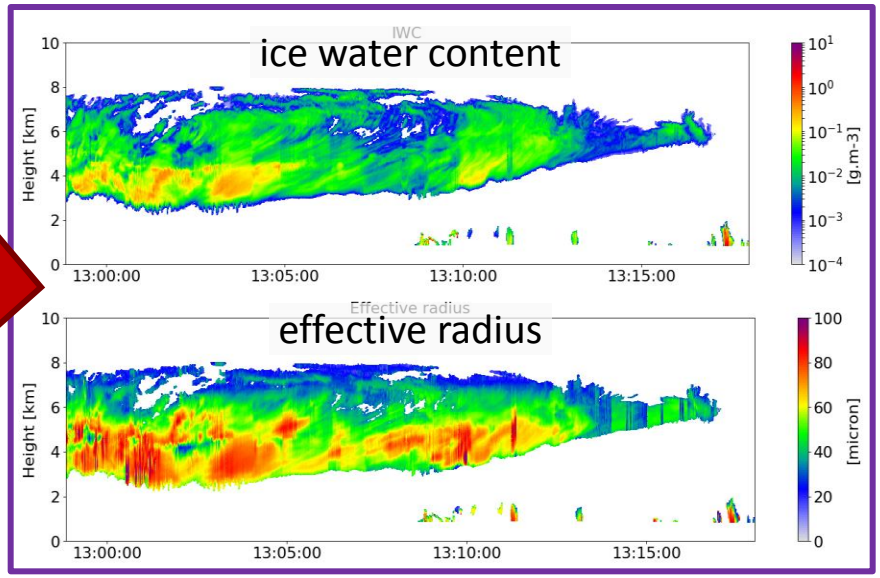
Comparison with measurements
WALES/MIRA or CALIOP/CloudSat

yes converged? **no**

Microphysical properties
Calculate IWC and r_{eff}

Gauss-Newton iteration
Derive new state vector x





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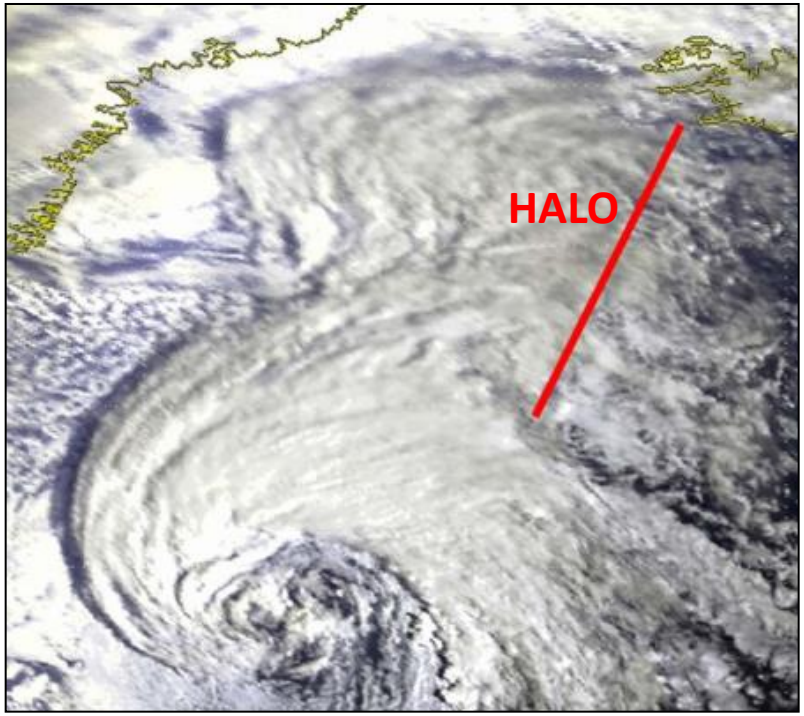
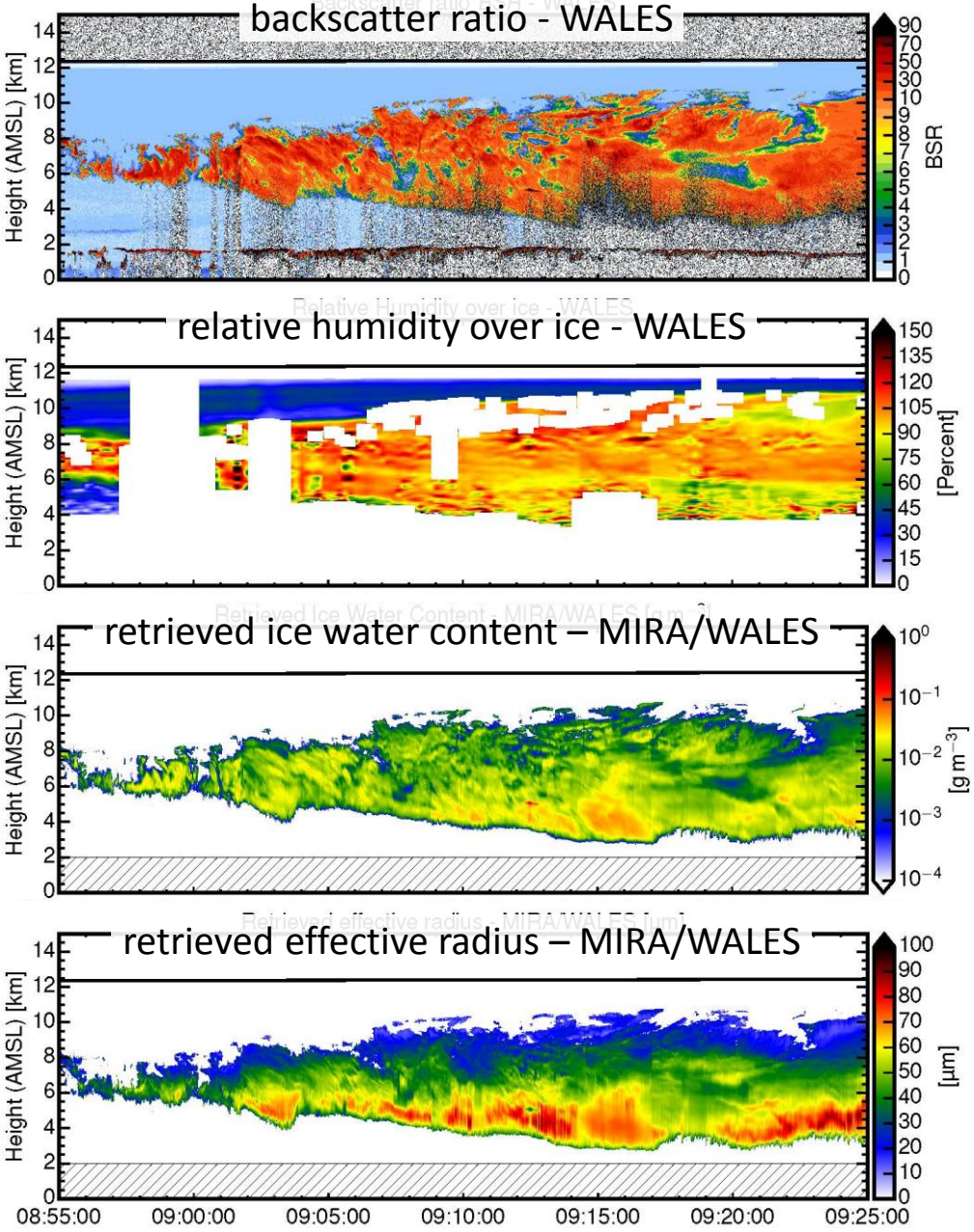
LATMOS

Simultaneous measurements of ice cloud properties

NAWDEX RF6 – 1 October 2016





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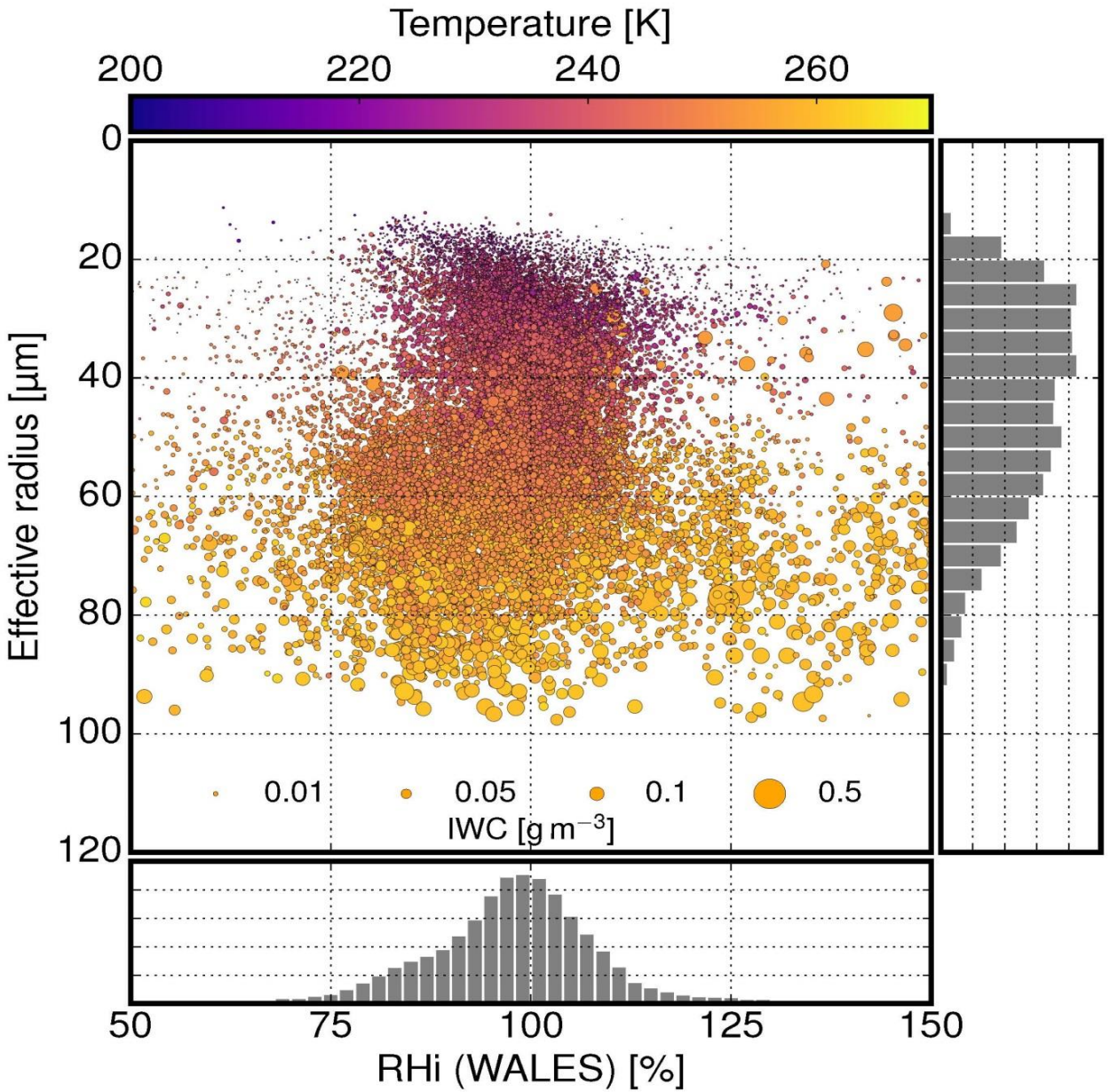
Joint occurrence of RHi and microphysical properties

NAWDEX RF06
01 October 2016

- **Small ice particles** with low IWC in **upper part of the cloud** (low temperature)
- Large IWC/ice particles at **highest RHi values**
- RHi distribution indicates cirrus cloud at **mature** or **dissolving state**



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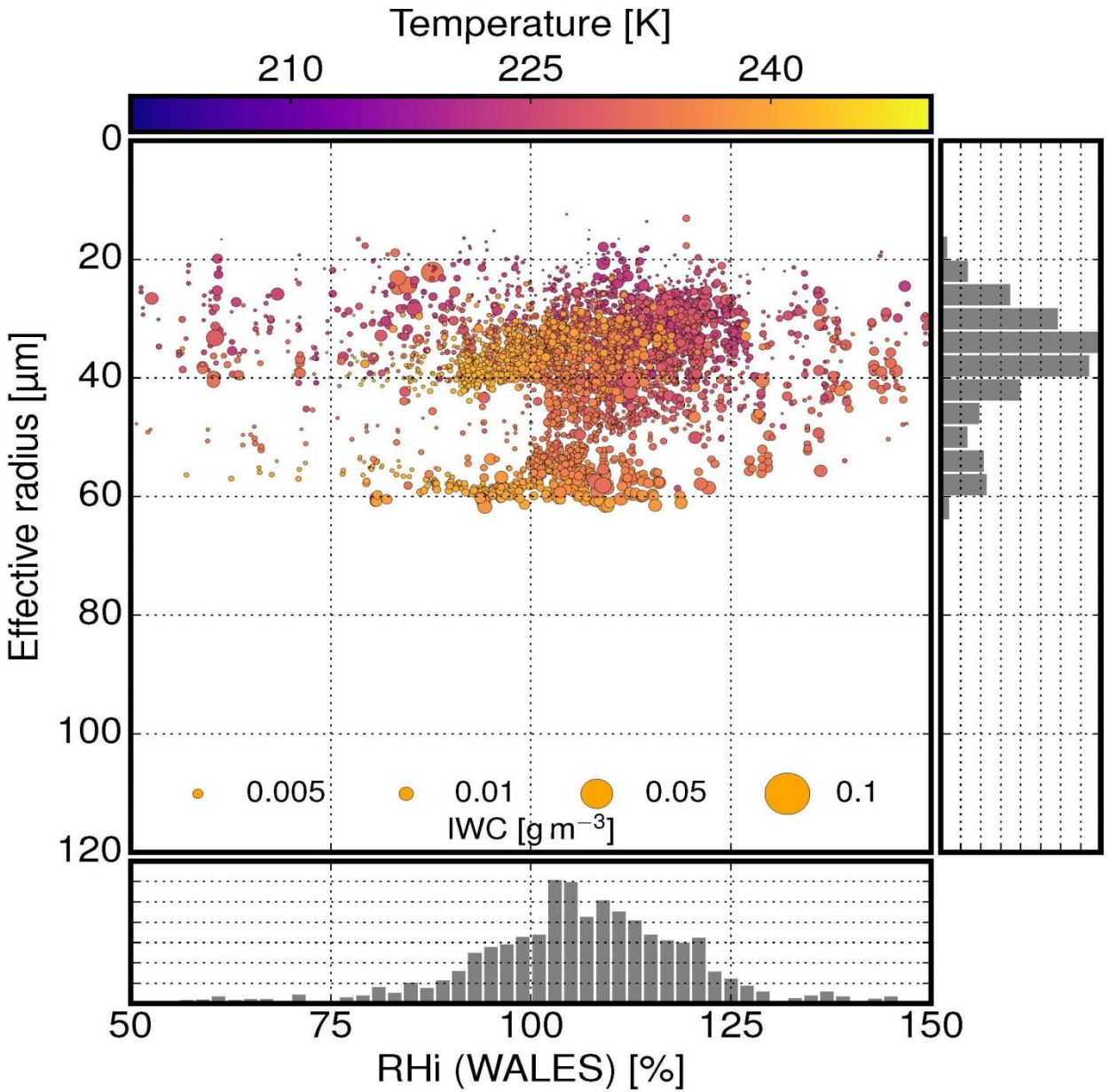
Joint occurrence of RHi and microphysical properties

NARVAL-I RF12

18 January 2014

- **Small ice particles** with low IWC in **upper part of the cloud** (low temperature)
- **Small** IWC/ice particles at **highest RHi values**
- RHi distribution indicates cirrus cloud at **early stage of life cycle**



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Summary

- **Joint measurements of backscatter ratio and RHi**
  → 2-D distribution different for cirrus clouds in different stages of evolution / of different formation mechanism
  But: Information on microphysical properties needed
- **Combined radar and lidar measurements can be used to determine ice cloud microphysical properties**
  → Synergistic retrieval to determine IWC and R_{eff}
- **First analysis of joint RHi-IWC-R_{eff} distribution shows differences for different clouds (dependent on stage of evolution?)**
  → Large IWC/R_{eff} at high RHi values for clouds in dissolving state
  → Small R_{eff} at high RHi for clouds in early stage of evolution
- **More analysis of joint optical properties, RHi and microphysical properties needed and ongoing**

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