

Finding closure – Why we need Radar, Lidar and Solar Radiance Observations to Distinguish different Microphysical Regimes in Ice Clouds



**Florian Ewald¹, Silke Groß¹, Martin Wirth¹,
Julien Delanoë², Bernhard Mayer³**

- 1) Institute of Atmospheric Physics (DLR)
Oberpfaffenhofen, Germany
- 2) LATMOS/IPSL/UVSQ/CNRS,
Guyancourt, France
- 3) Ludwig-Maximilians-Universität
Munich, Germany

NAWDEX – 3rd Workshop
26 March 2019 – Toulouse, France



Knowledge for Tomorrow

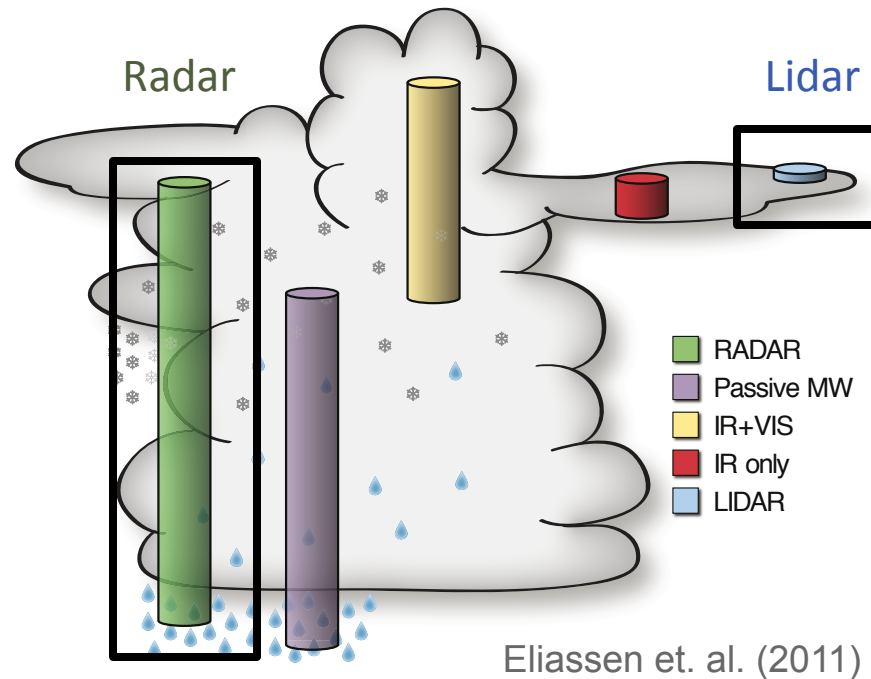
Consistent ice cloud microphysics

>> Why should we care about radiative closure? <<



The challenge – Different cloud penetration depths

Different remote sensing techniques with different sensitivities



Instrument synergy: “While radars are sensitive to *precipitation and optically thicker clouds*, we need the lidar to capture *cloud tops and optically thin clouds*”

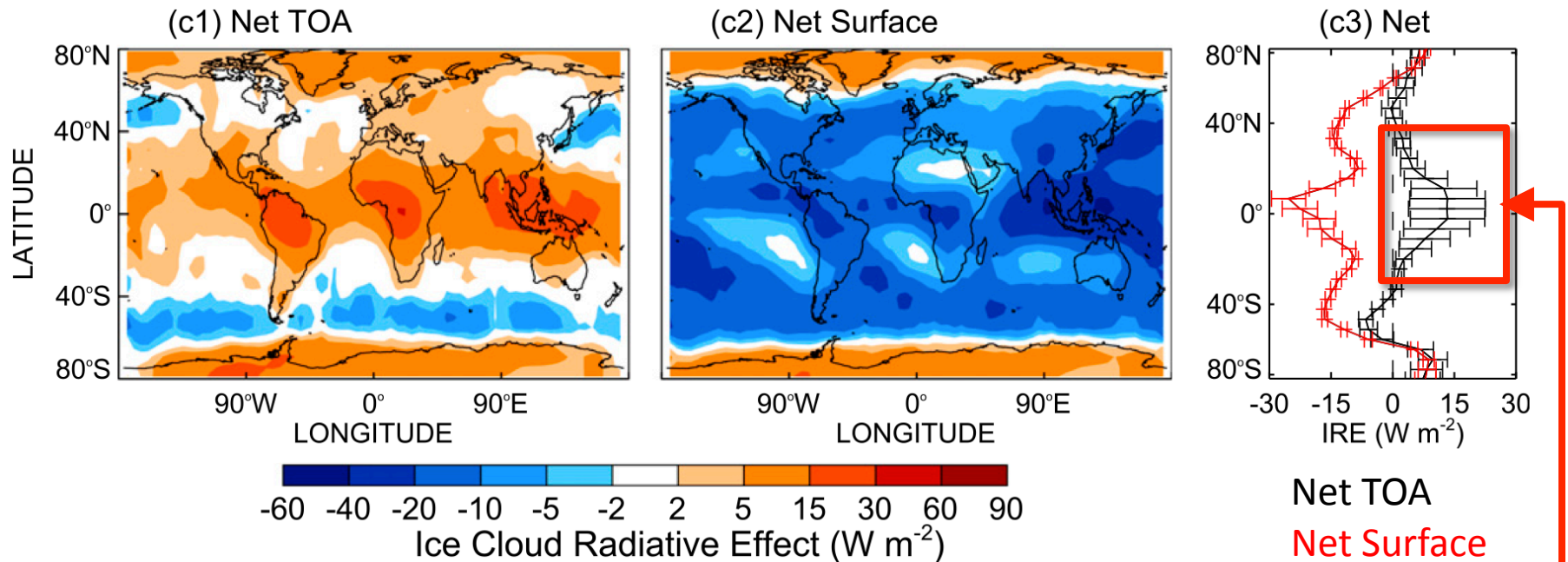


The problem – Uncertainties in ice cloud microphysics

Impact of uncertain microphysics on ice cloud radiative effect

DARDAR + 2C-ICE

Hong et. al. (2016)



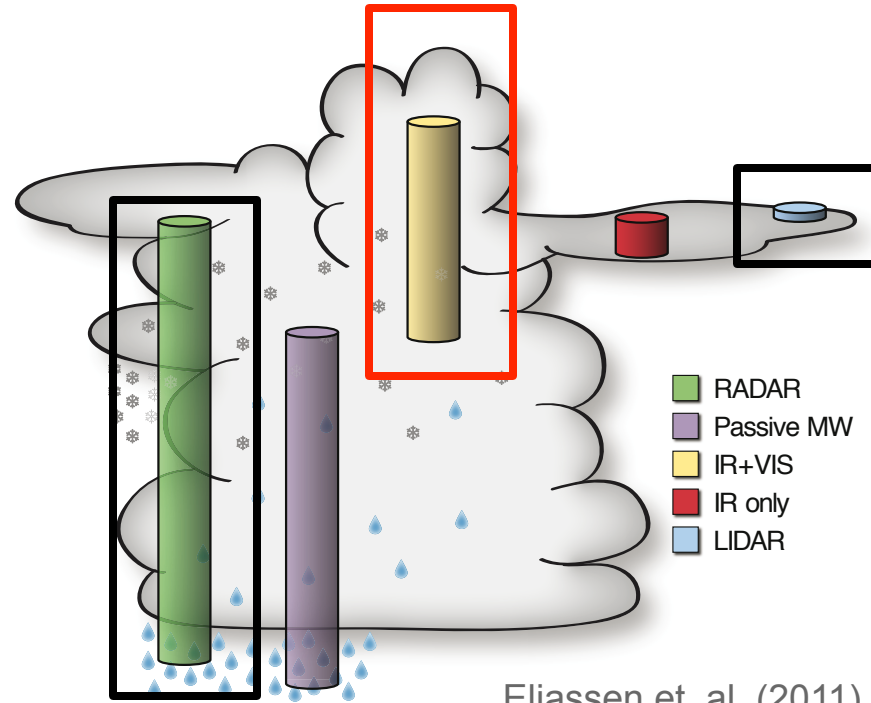
Uncertainty in CRE due to differences between two radar/lidar retrievals

- Difference between DARDAR/2C-ICE of up to 15 W/m^2 at TOA
- Origin: Difference in retrieved ice microphysics at higher altitudes



The challenge – Different cloud penetration depths

Different remote sensing techniques with different sensitivities



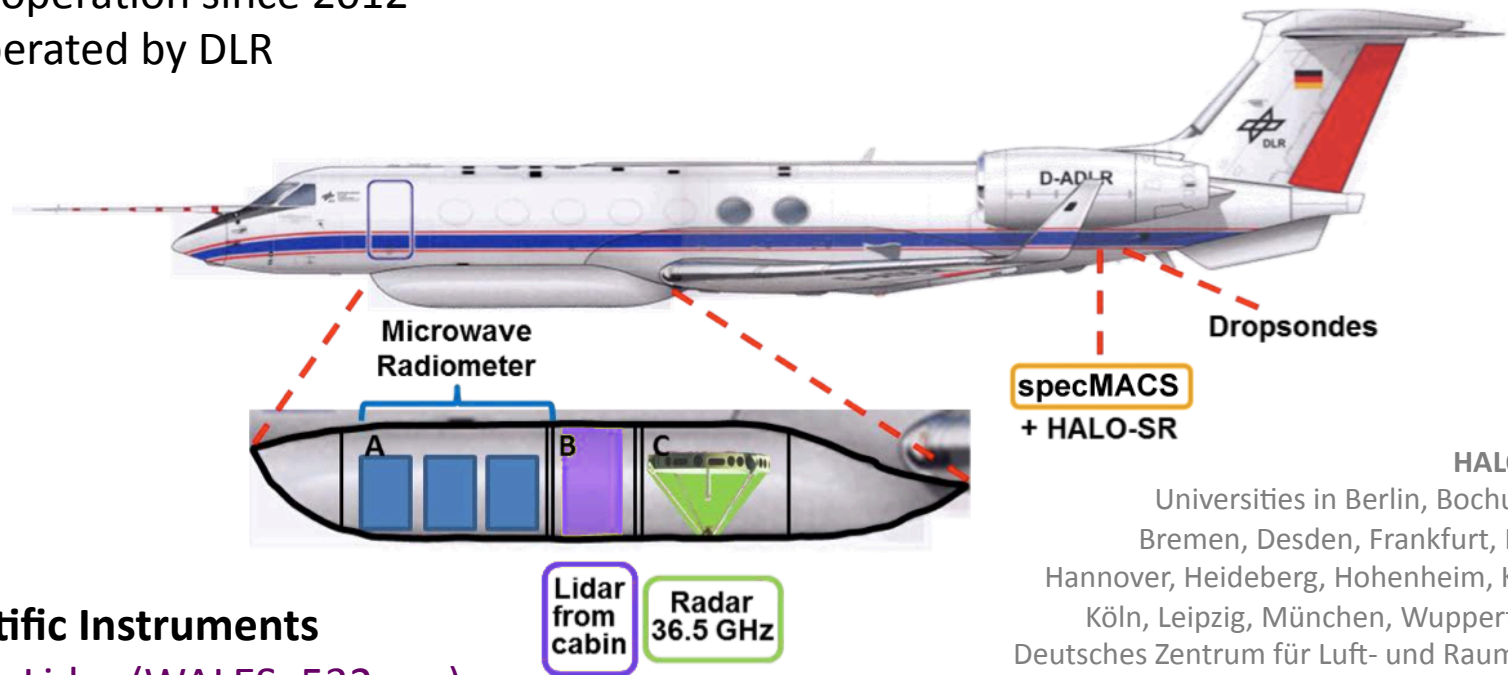
Scientific question: “Can passive measurements of *solar reflectance* bridge the gap between radar and lidar and/or validate radar/lidar retrieval results?”



The solution – HALO Remote Sensing Payload

An airborne testbed to anticipate EarthCARE

- Ceiling altitude: 16 km / Range: 8000 km
- In operation since 2012
- operated by DLR



Scientific Instruments

HSRL-Lidar (WALES, 532 nm)

Cloud-Profiling Radar (MIRA, 35 GHz)

Hyper-Spektral Imager (specMACS)

Microwave Radiometer (HAMP)

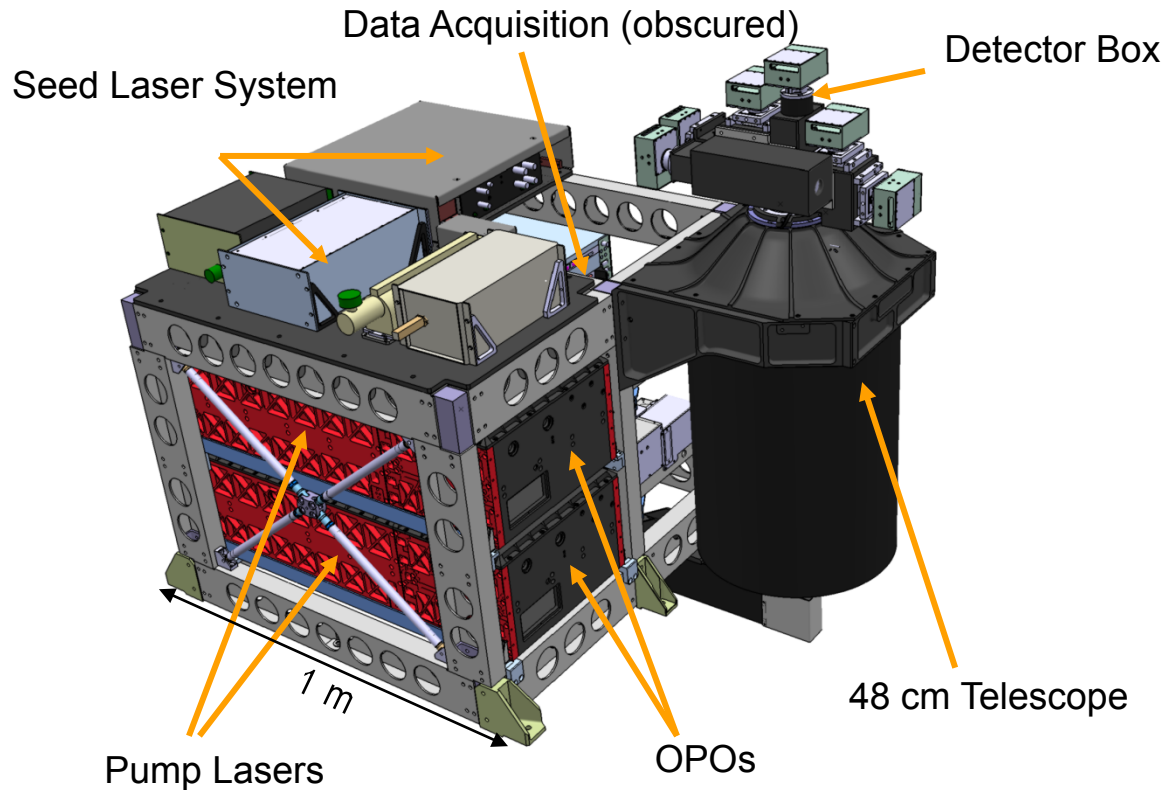
HALO Partner

Universities in Berlin, Bochum, Bonn,
Bremen, Desden, Frankfurt, Hamburg,
Hannover, Heideberg, Hohenheim, Karlsruhe,
Köln, Leipzig, München, Wuppertal, Zürich
Deutsches Zentrum für Luft- und Raumfahrt e.V.
Forschungszentrum Jülich
Karlsruher Institut für Technologie
Max-Planck-Institut für Chemie - Mainz
Max-Planck-Institut für Meteorologie - Hamburg
Institut für Troposphärenforschung
Bundesanstalt für Geowissenschaften und Rohstoffe
Physikalisch-Technische Bundesanstalt



WALES – Water vapour DIAL+HSRL

Water vapor Lidar Experiment in Space



WALES	
HSRL System	532 nm
H ₂ O DIAL	935 nm
Backscatter lidar	1064 nm
Pulse power	48 W
Repetition rate	100 Hz
Range resolution	30 m
Antenna diameter	1 m
Beam width	0.09°
Footprint @ 10km	16 m

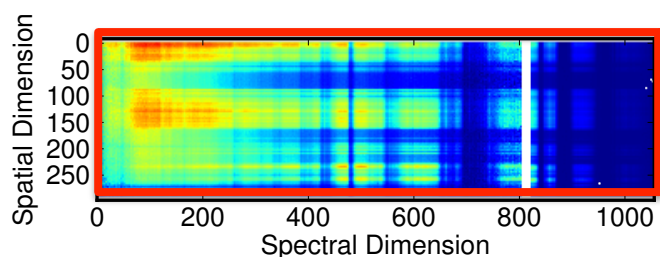
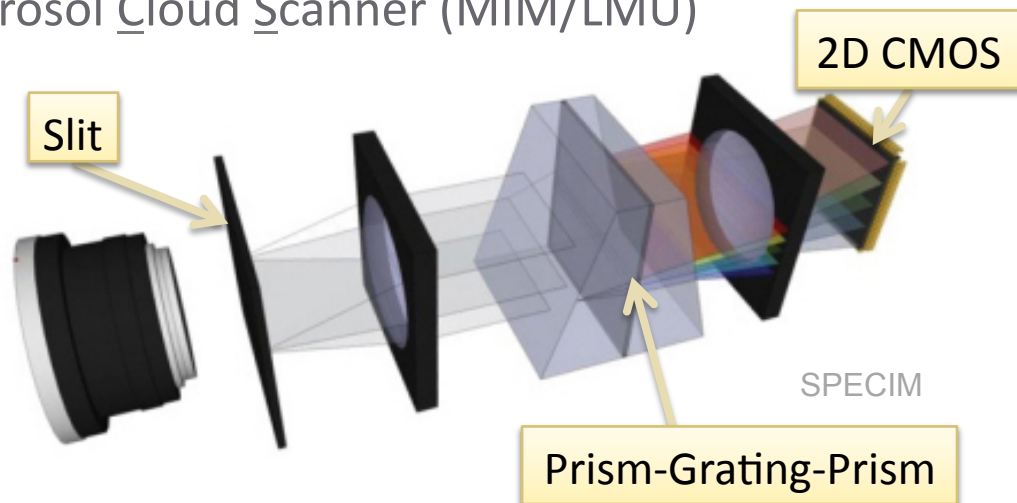
Wirth et al., Appl. Phys. B (2009)



specMACS – Hyperspectral line camera (400 – 2500 nm)

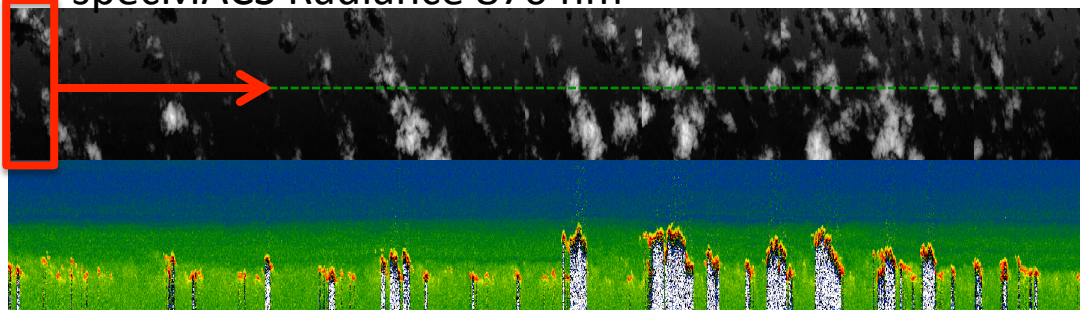
Spectral Imager of the Munich Aerosol Cloud Scanner (MIM/LMU)

specMACS	
Wavelengths	400 – 2500 nm
Spec. Resolu.	2.2 – 12 nm
Spat. Resolu.	0.08°/0.2°
FOV	35°
Sampling	30-60 Hz



specMACS Radiance 870 nm

WALES



Atmos. Meas. Tech., 9, 2015–2042, 2016
www.atmos-meas-tech.net/9/2015/2016/
doi:10.5194/amt-9-2015-2016
© Author(s) 2016. CC Attribution 3.0 License.



Atmospheric
Measurement
Techniques



Design and characterization of specMACS, a multipurpose hyperspectral cloud and sky imager

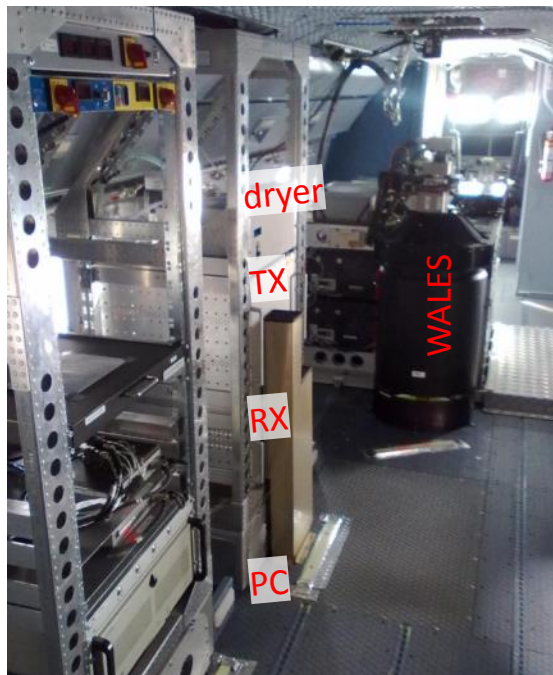
Florian Ewald^{1,3,*}, Tobias Kölling^{1,*}, Andreas Baumgartner², Tobias Zinner¹, and Bernhard Mayer¹



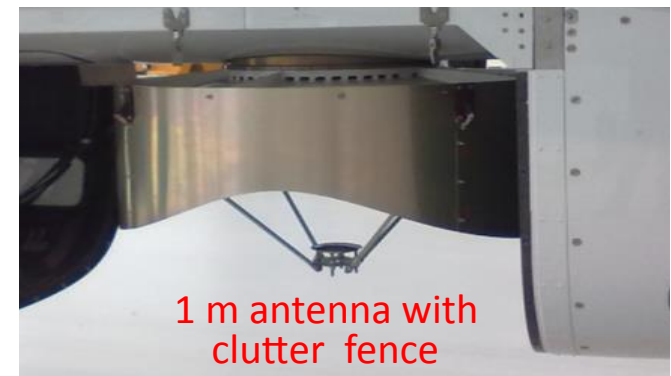
HAMP cloud radar MIRA

HALO Microwave Package

- Modified, airborne METEK MIRA-35
 - Very high peak pulse power
 - Mounted in HALO Bellypod
 - First flown during NARVAL-I (2014)
 - Collocated measurements with WALES

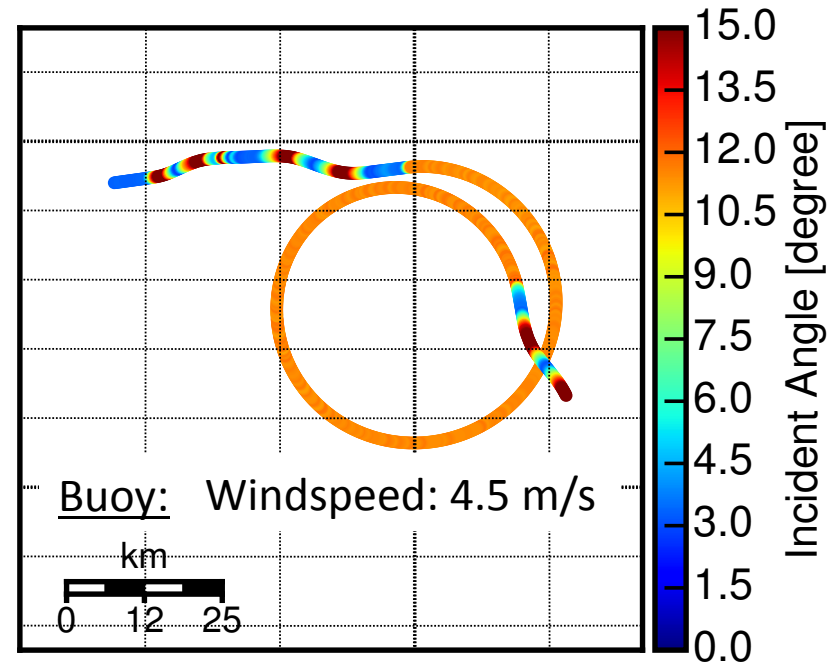
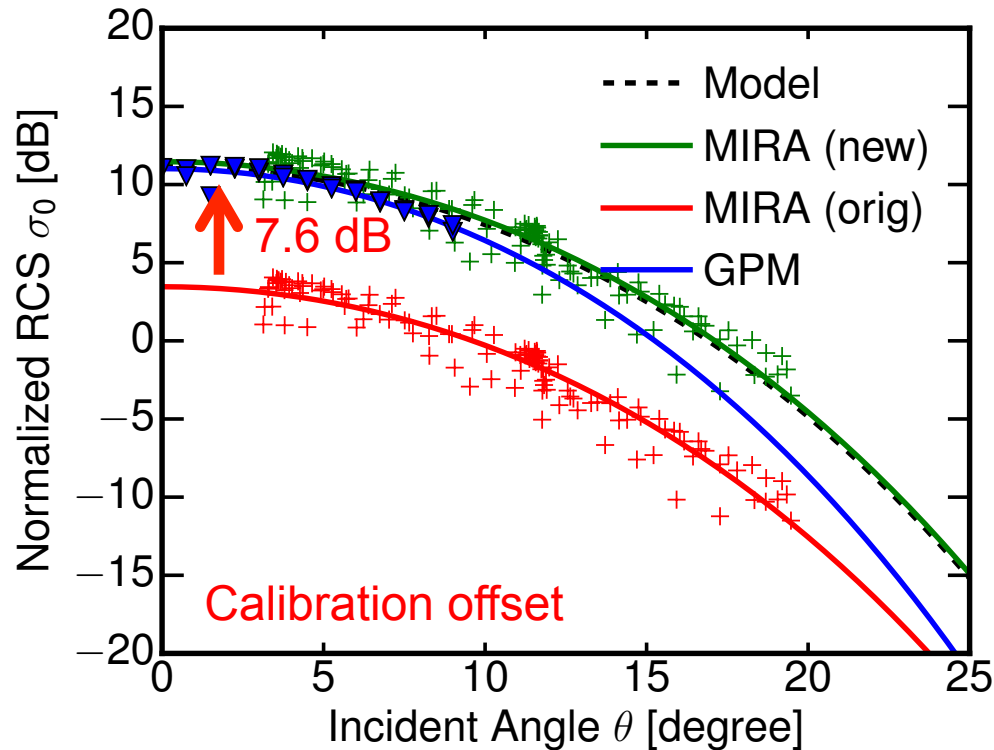


MIRA	
Frequency	35.2 GHz
Pulse power	30 kW
Repetition rate	5 kHz
Range resolution	30 m
Antenna diameter	1 m
Beam width	0.6°
Footprint @ 10km	100 m
Range resolution	30 m
Min. detect. signal @ 5km, 1 s integration	-38 dBz



HAMP cloud radar: Inflight cal. with ocean backscatter

MIRA Normalized Radar Cross Section vs GPM (Ka-band, 35.5 GHz)

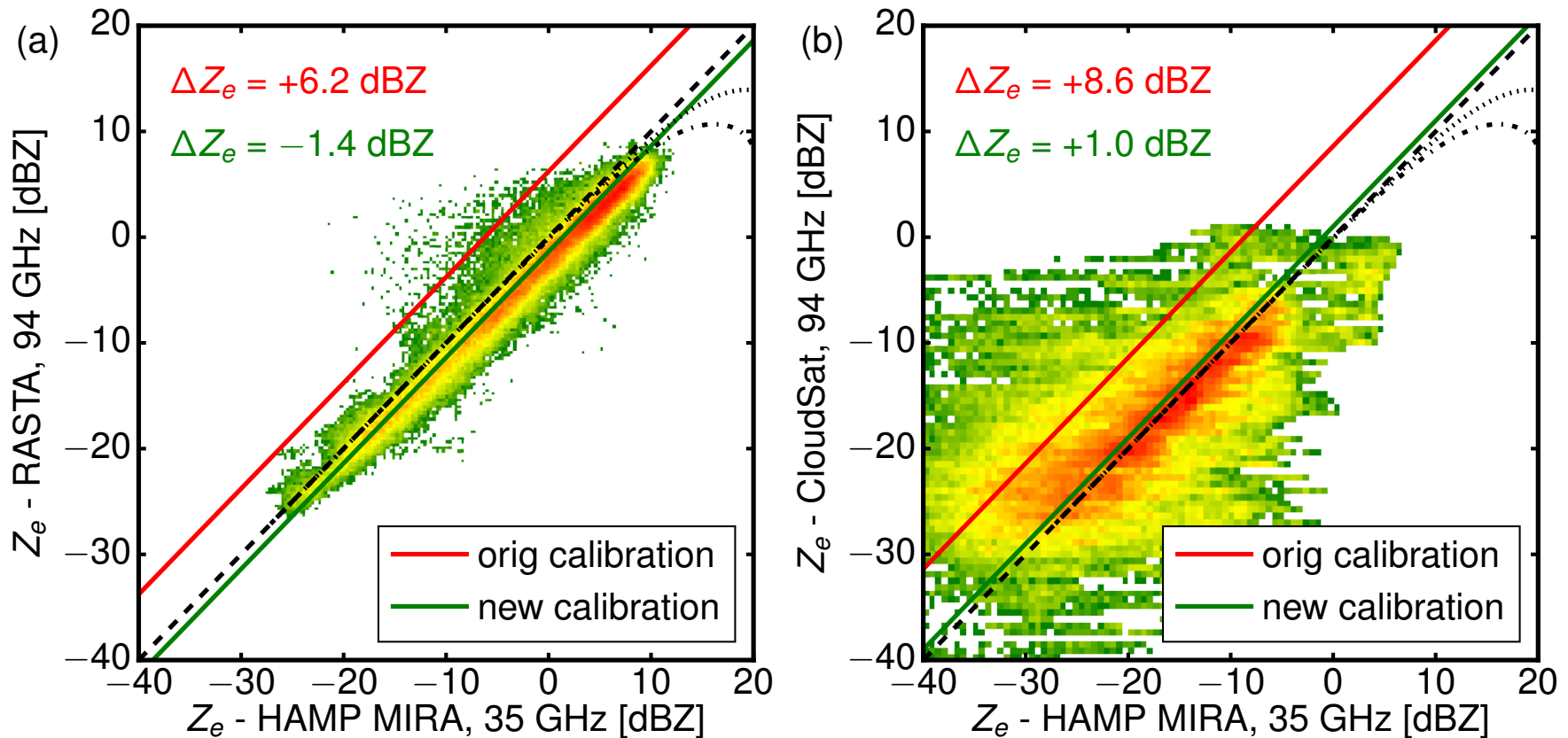


- New calibration validated with sea surface clutter and GPM
- Error in initial receiver calibration + unaccounted attenuation



HAMP cloud radar: Instrument intercomparison

Reflectivity intercomparison with RASTA and CloudSat (W-band, 94 GHz)

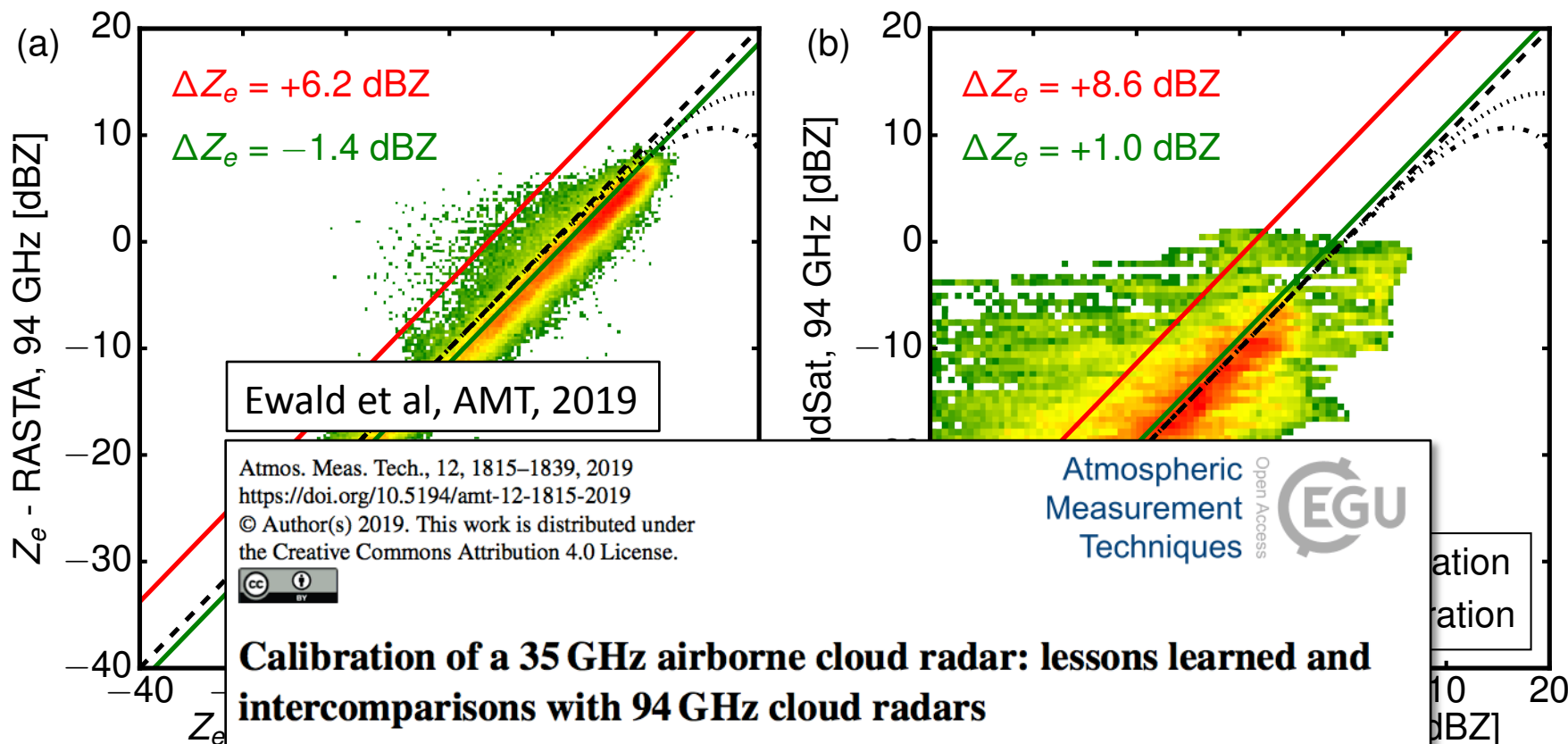


→ Good agreement with RASTA and CloudSat within 1.5 dB



HAMP cloud radar: Instrument intercomparison

Reflectivity intercomparison with RASTA and CloudSat (W-band, 94 GHz)



Atmos. Meas. Tech., 12, 1815–1839, 2019
<https://doi.org/10.5194/amt-12-1815-2019>
© Author(s) 2019. This work is distributed under the Creative Commons Attribution 4.0 License.



Atmospheric
Measurement
Techniques



Calibration of a 35 GHz airborne cloud radar: lessons learned and intercomparisons with 94 GHz cloud radars

Florian Ewald¹, Silke Groß¹, Martin Hagen¹, Lutz Hirsch², Julien Delanoë³, and Matthias Bauer-Pfundstein⁴

¹Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

²Max Planck Institute for Meteorology, Hamburg, Germany

³LATMOS/UVSQ/IPSL/CNRS, Guyancourt, France

⁴Metek GmbH, Elmshorn, Germany

Correspondence: Florian Ewald (florian.ewald@dlr.de)

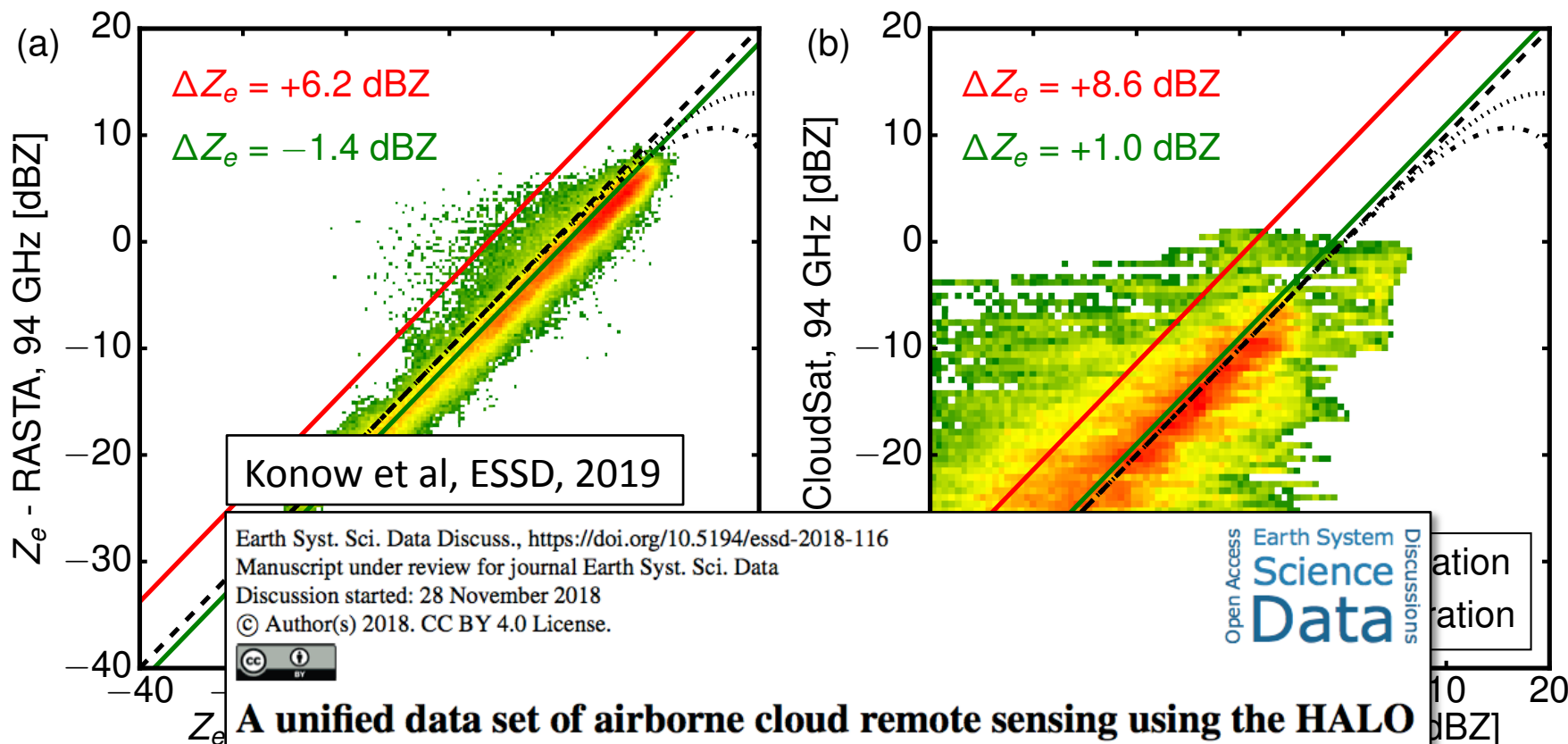
Received: 17 August 2018 – Discussion started: 11 October 2018

Revised: 8 February 2019 – Accepted: 14 February 2019 – Published: 20 March 2019



HAMP cloud radar: Instrument intercomparison

Reflectivity intercomparison with RASTA and CloudSat (W-band, 94 GHz)



A unified data set of airborne cloud remote sensing using the HALO Microwave Package (HAMP)

Heike Konow¹, Marek Jacob², Felix Ament^{1,3}, Susanne Crewell², Florian Ewald⁴, Martin Hagen⁴, Lutz Hirsch³, Friedhelm Jansen³, Mario Mech², and Bjorn Stevens³

¹Universität Hamburg, Hamburg, Germany

²Institute for Geophysics and Meteorology, University of Cologne, Cologne, Germany

³Max Planck Institute for Meteorology, Hamburg, Germany

⁴German Aerospace Center DLR, Oberpfaffenhofen, Germany

Correspondence to: Heike Konow (heike.konow@uni-hamburg.de)



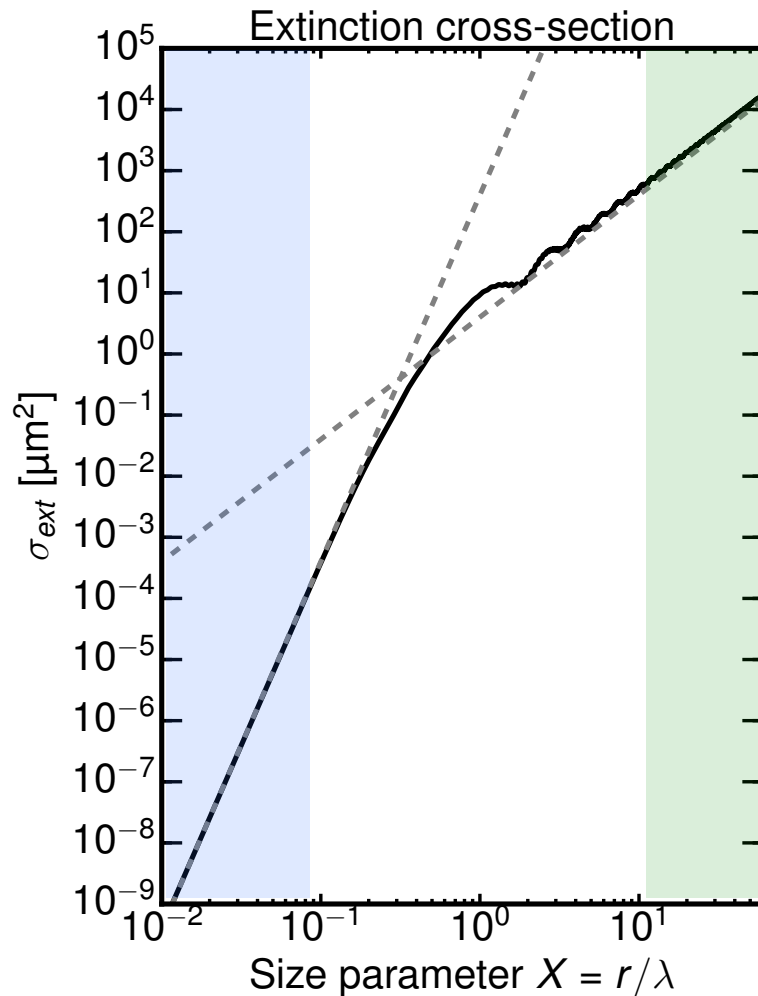
Combined retrieval of ice cloud microphysics

>> Accessing ice cloud microphysics with profilers <<



Combined ice cloud retrieval: Physical basis

Exploiting different scattering regimes by using different wavelengths

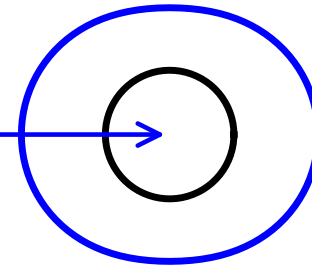


Ice Cloud Crystals: 5 ~ 1000 μm

Rayleigh

$$\sigma_{ext}^R \sim (\sum p)^2 \sim V^2 \sim D^6$$

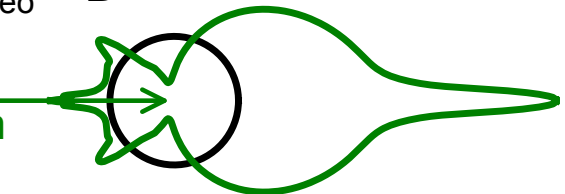
Radar
8850 μm



Mie

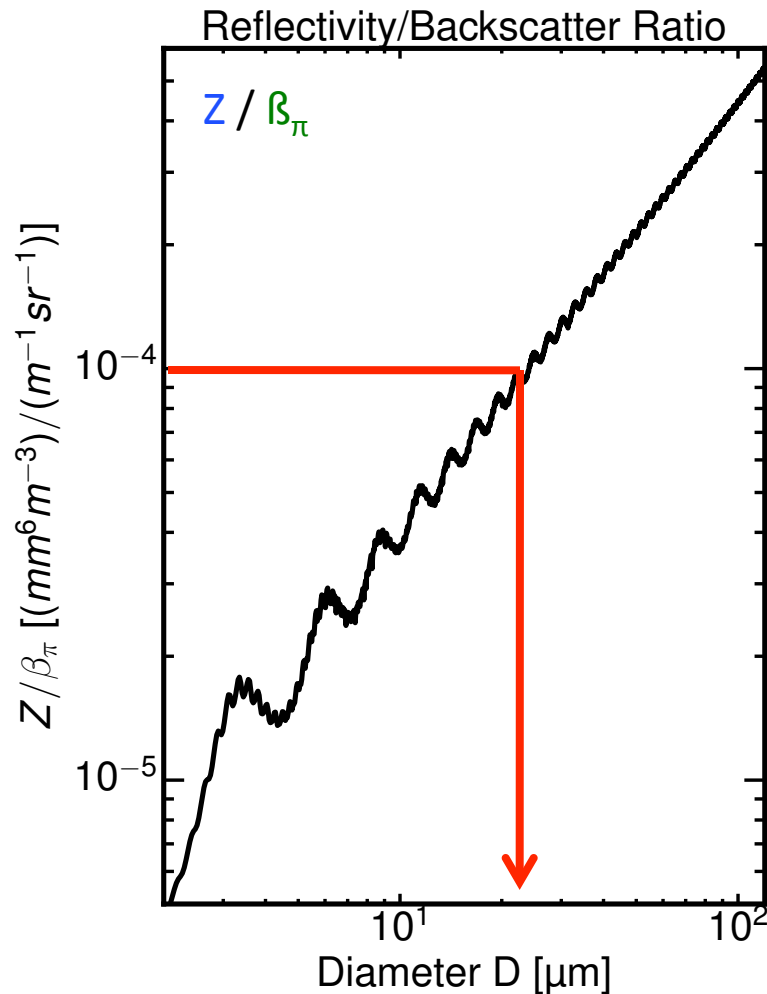
$$\sigma_{ext}^L \sim \sigma_{geo} \sim D^2$$

Lidar
0.532 μm



Combined ice cloud retrieval: Physical basis

Exploiting different scattering regimes by using different wavelengths



Ice Cloud Crystals: 5 ~ 1000 μm

Rayleigh

$$\sigma_{\text{ext}}^R \sim (\sum p)^2 \sim V^2 \sim D^6$$

$$Z \sim \alpha^R / 8.3 \sim N D^6$$

Radar Reflectivity

Mie

$$\sigma_{\text{ext}}^L \sim \sigma_{\text{geo}} \sim D^2$$

$$\beta_{\pi} = \alpha^L / S(D) \sim N D^2$$

Lidar Backscatter

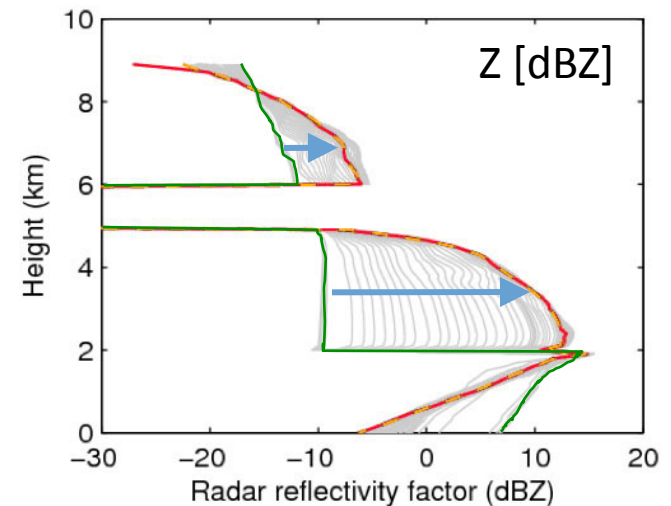
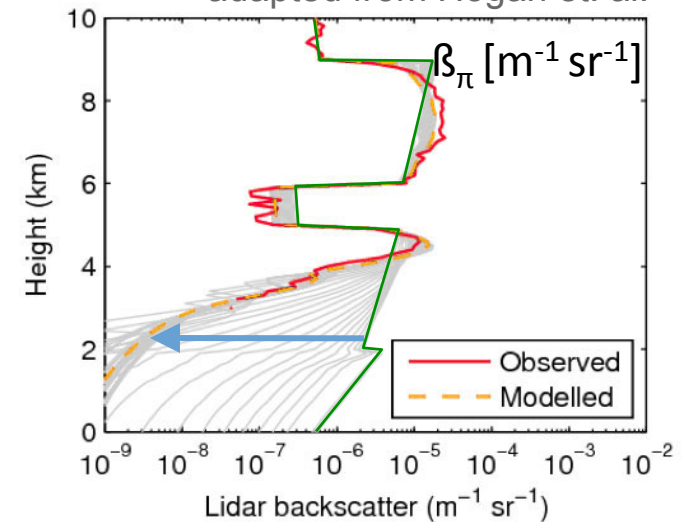
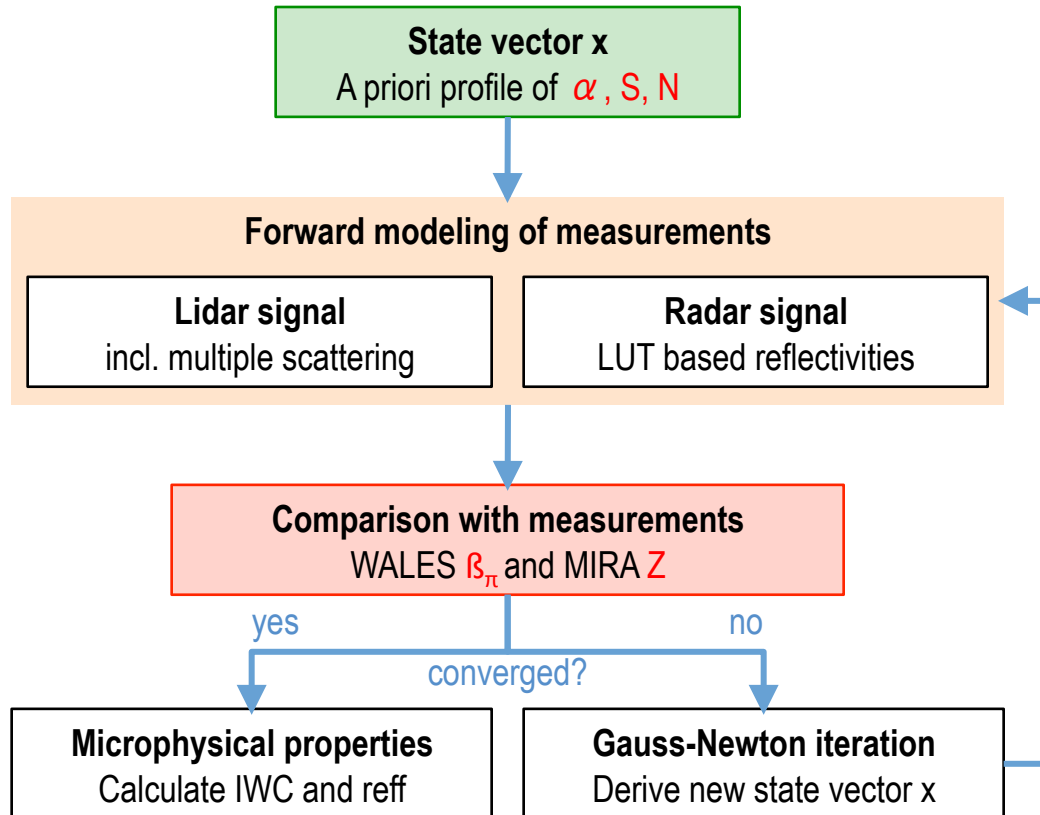


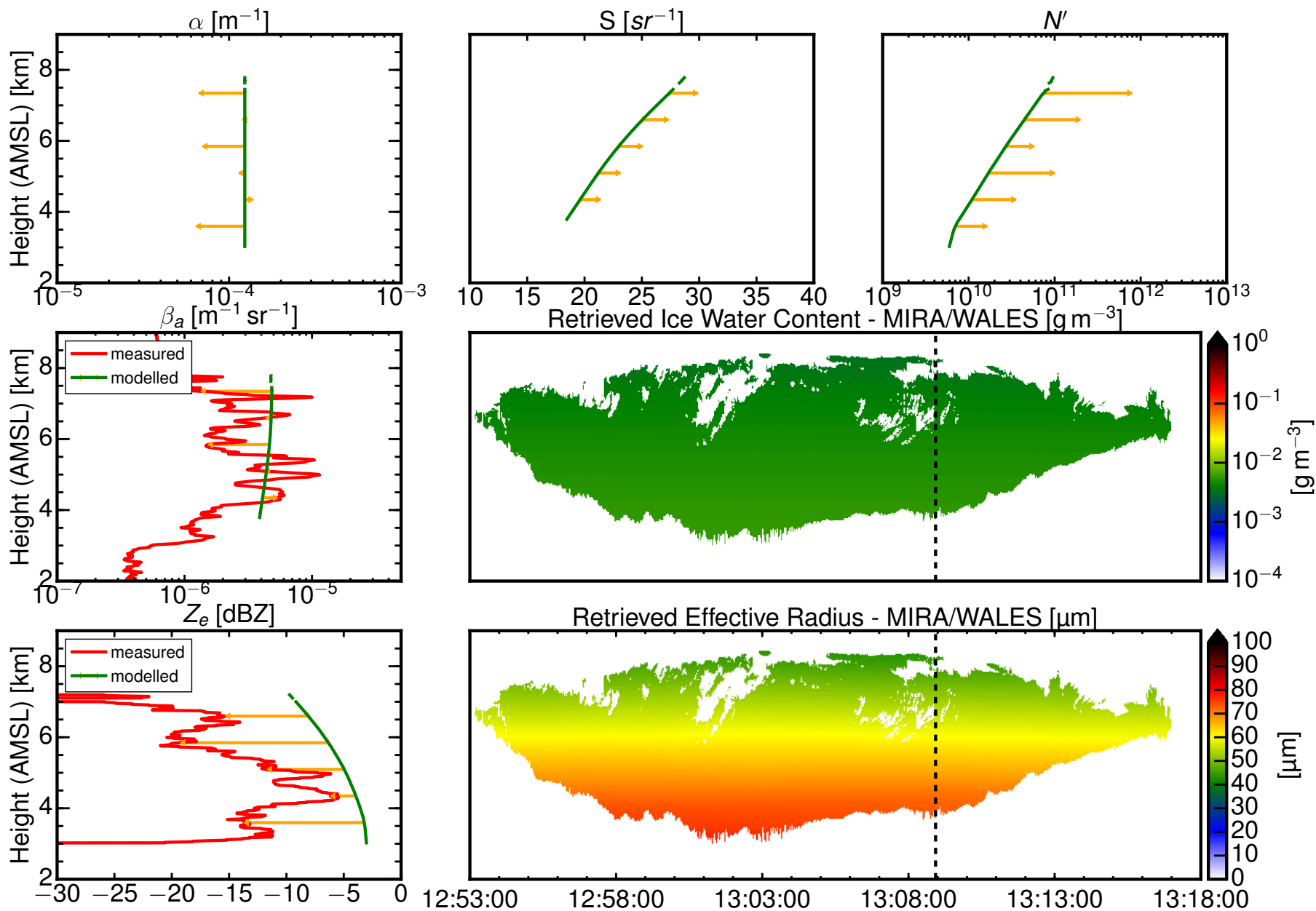
Combined ice cloud retrieval: The algorithm

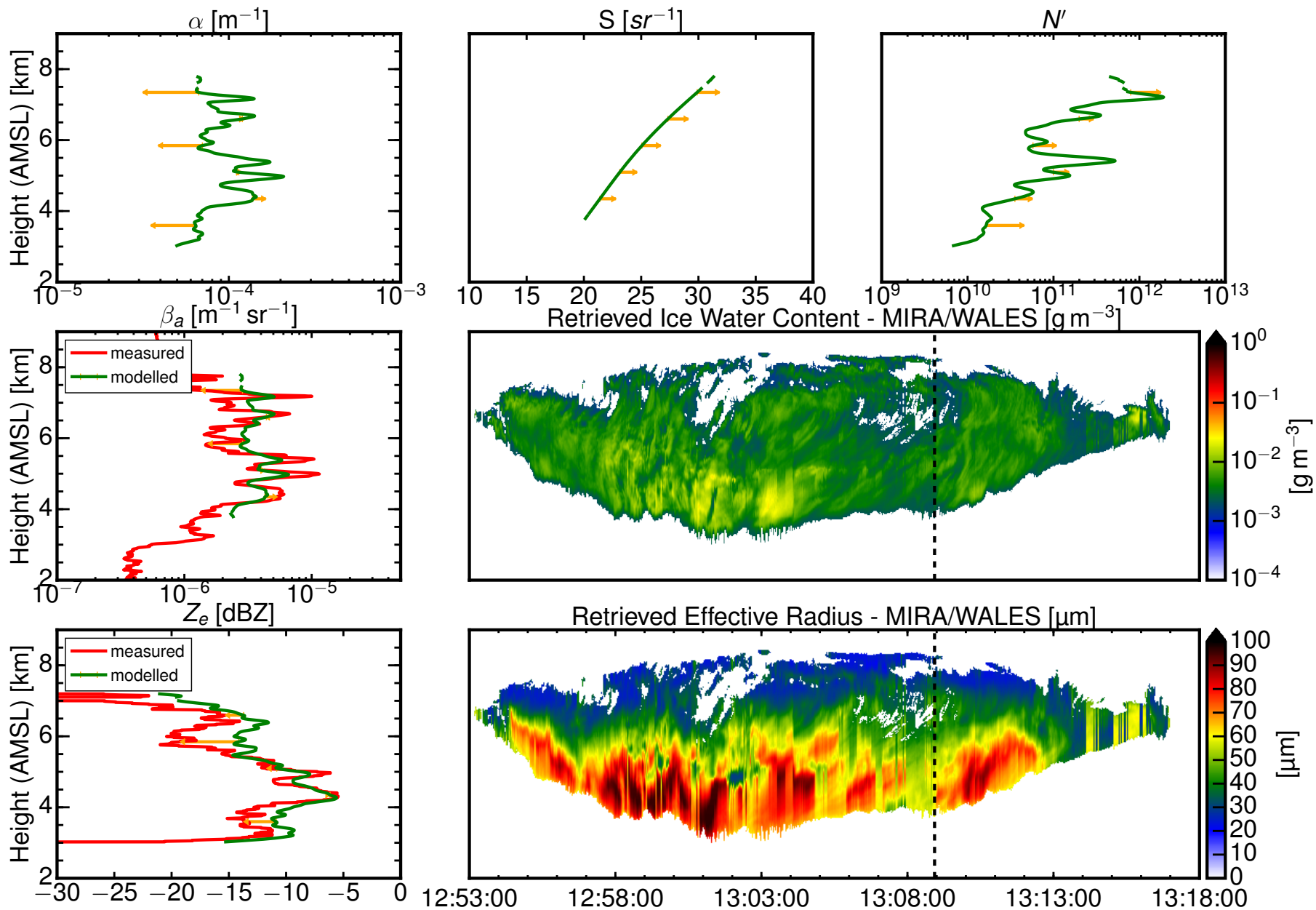
Comparing the measured with forward modeled signals

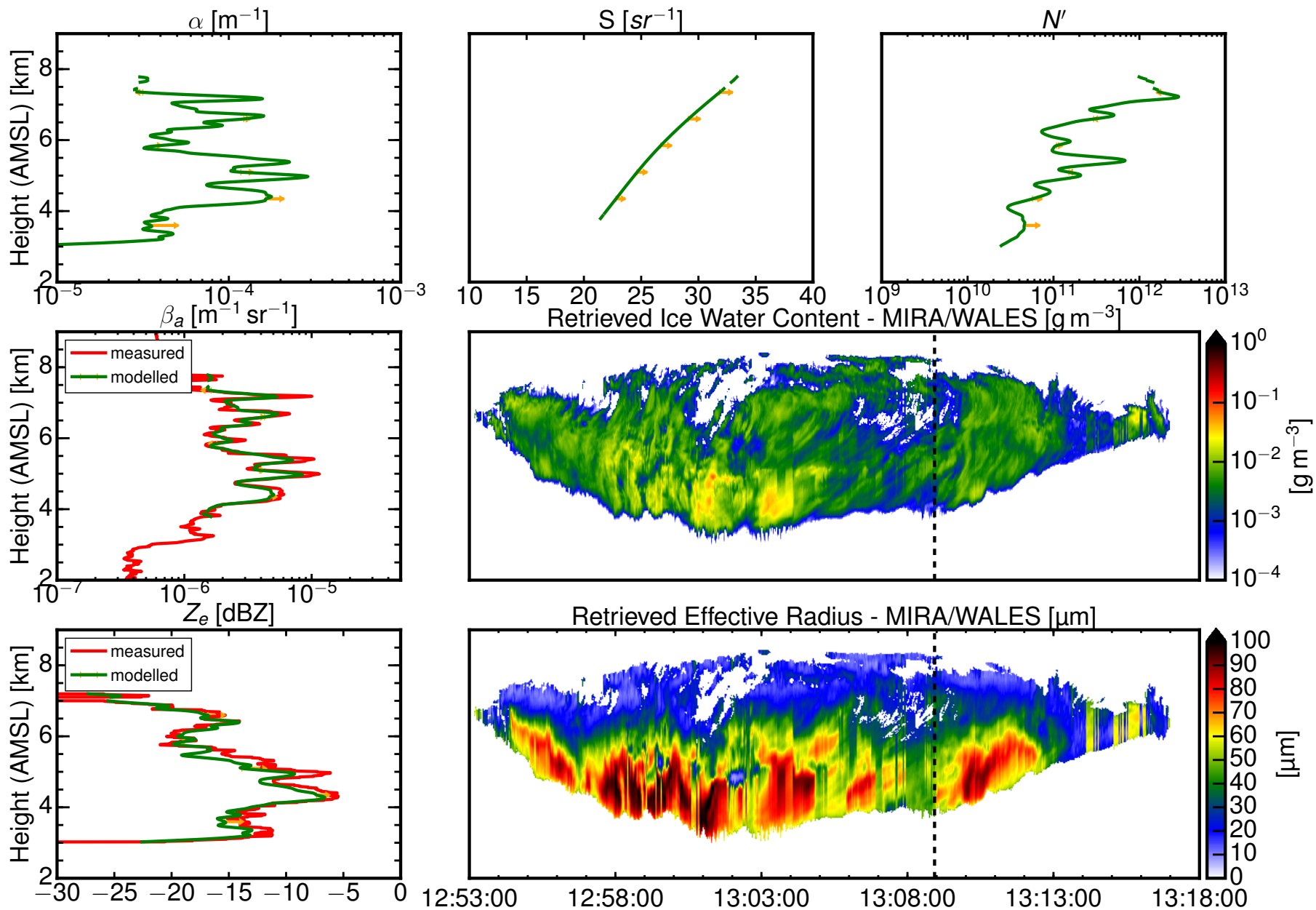
adapted from Hogan et. al.

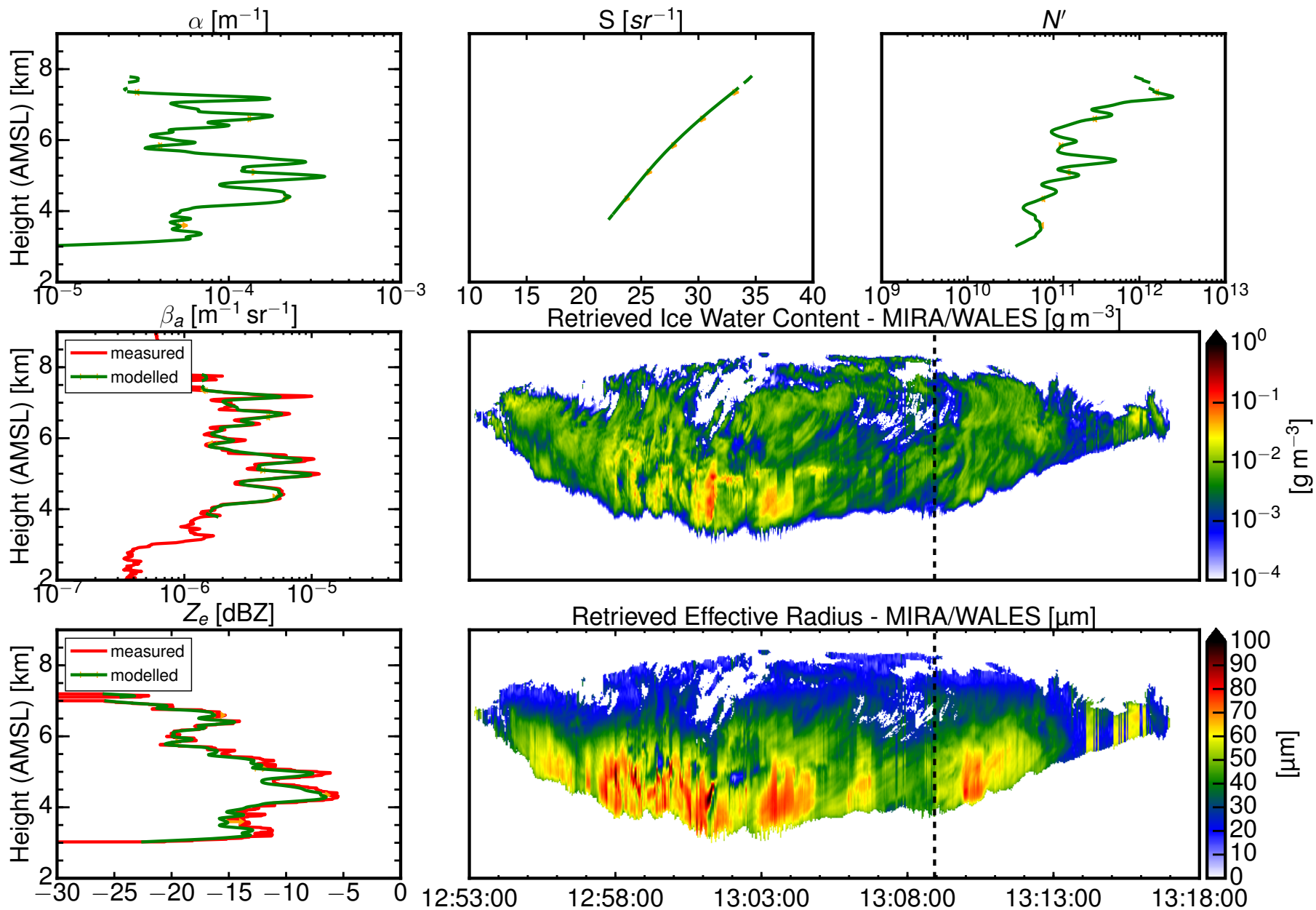
Optimal estimate approach of Delanoe et al., 2008:

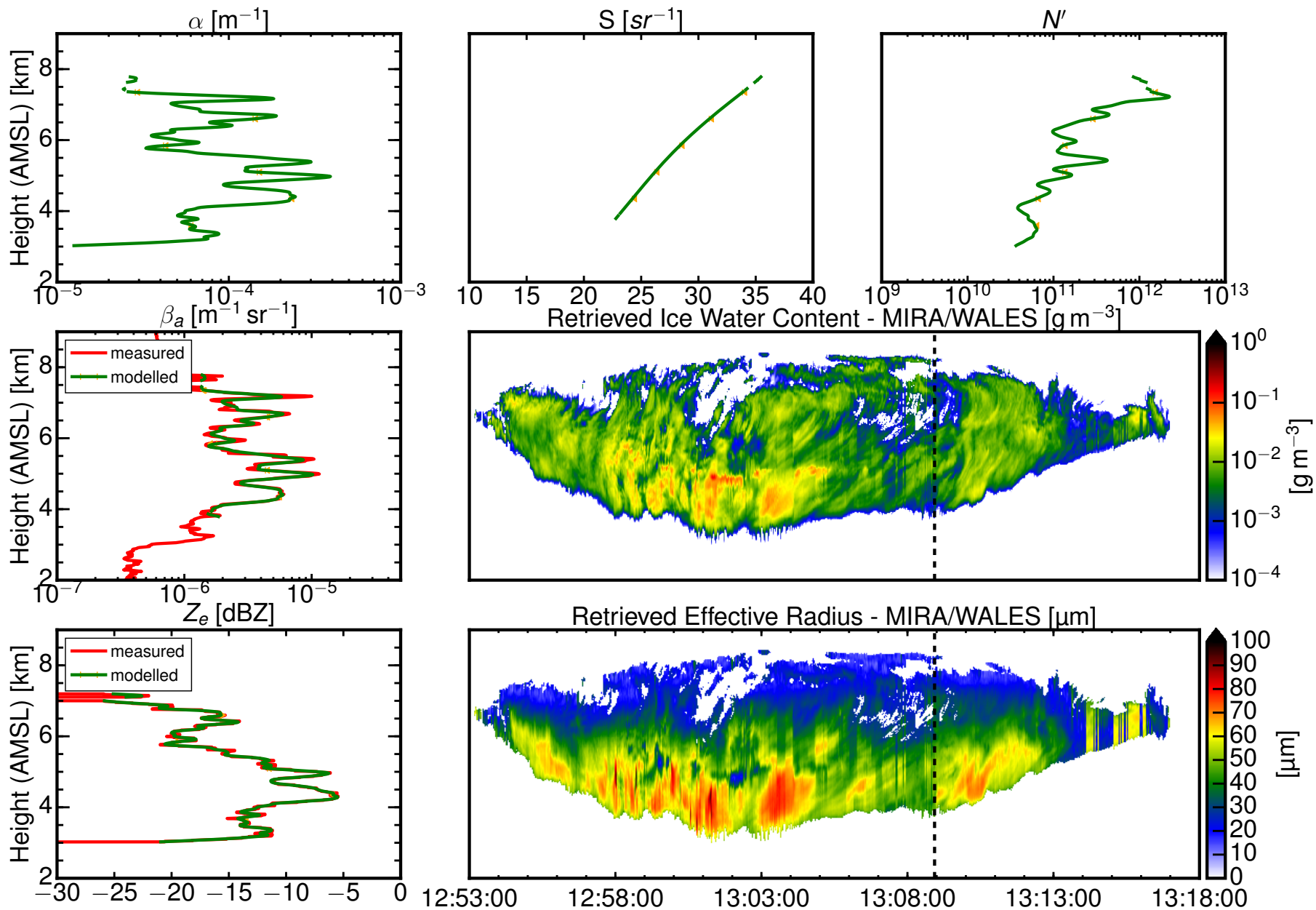






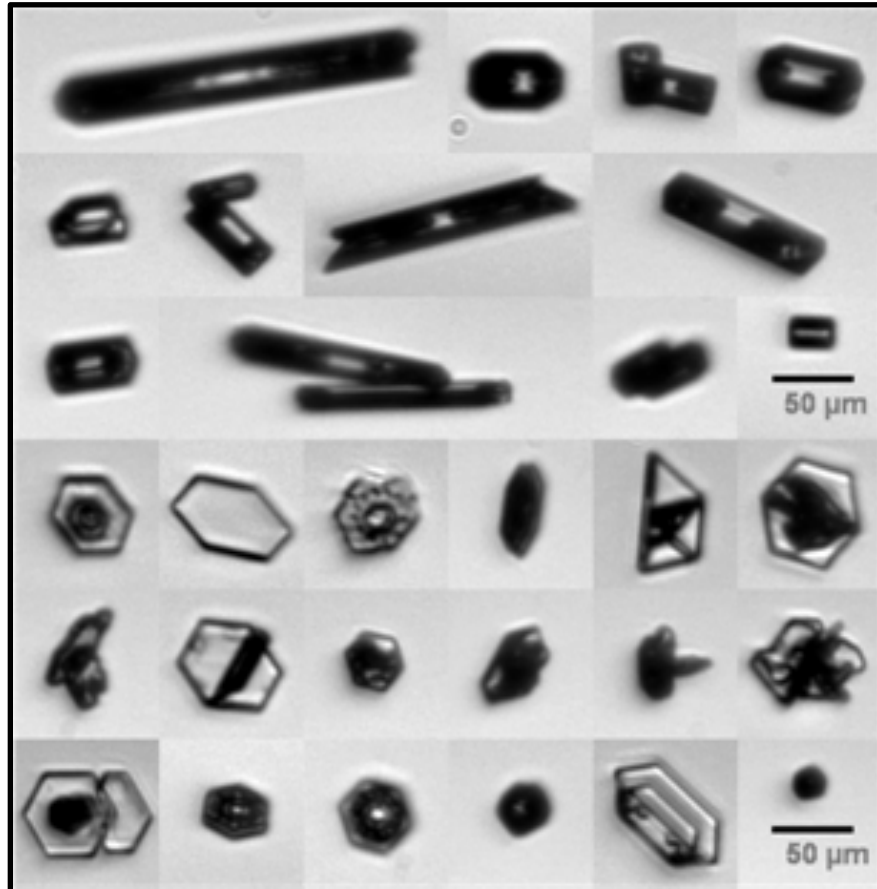






Theory meets reality: Ice cloud particles are not spheres

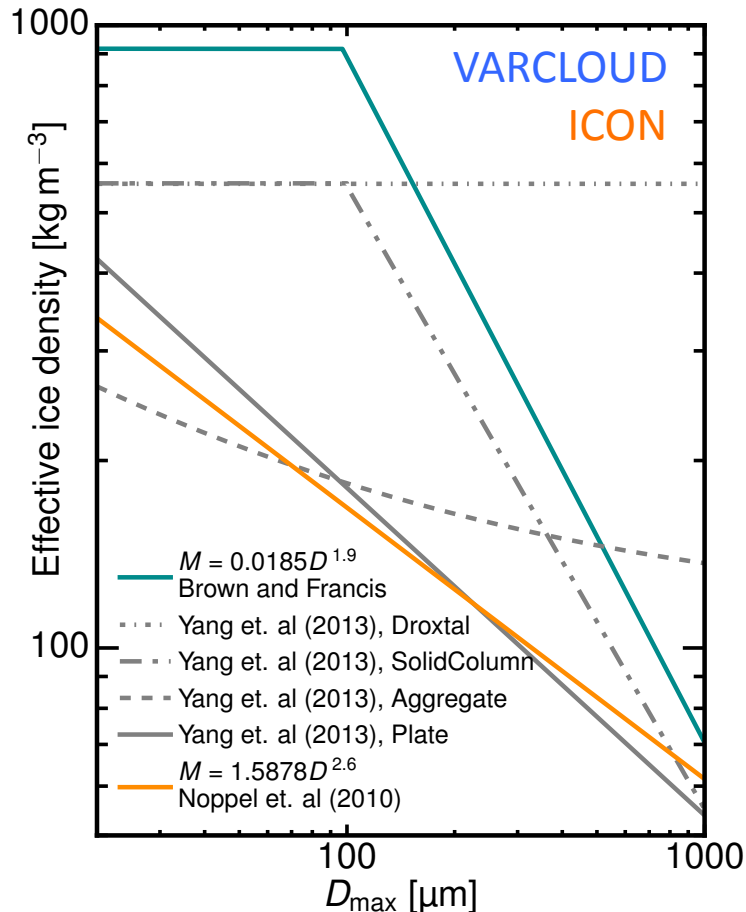
It would have been so nice and easy ...



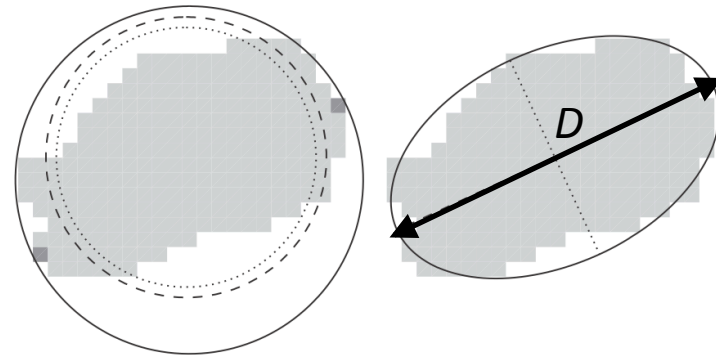
HALO PHIPS measurements (M. Schnaiter)

1st Generalization: Mass-Size Relationship

Effective particle density decreases with size



following Delanoe et. al. 2014



1) Soft spheroid approach, e.g. Hogan et. al. 2011

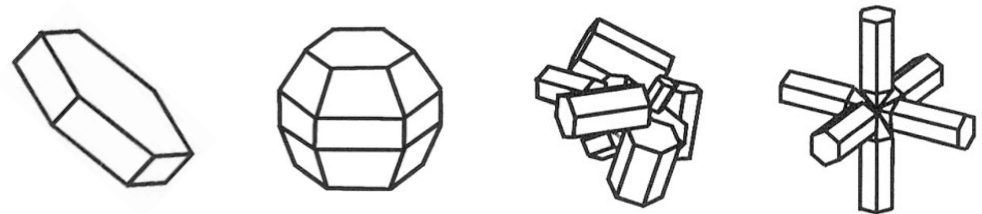
- VARCLOUD: Brown and Francis (1995)

$$M(D) = a D^b, \text{ with: } a = 0.0185, b = 1.9$$

- ICON: Noppel et. al (2010)

$$M(D) = a D^b, \text{ with: } a = 1.5878, b = 2.6$$

2) Explicit habit approach, e.g. Yang et. al. 2013



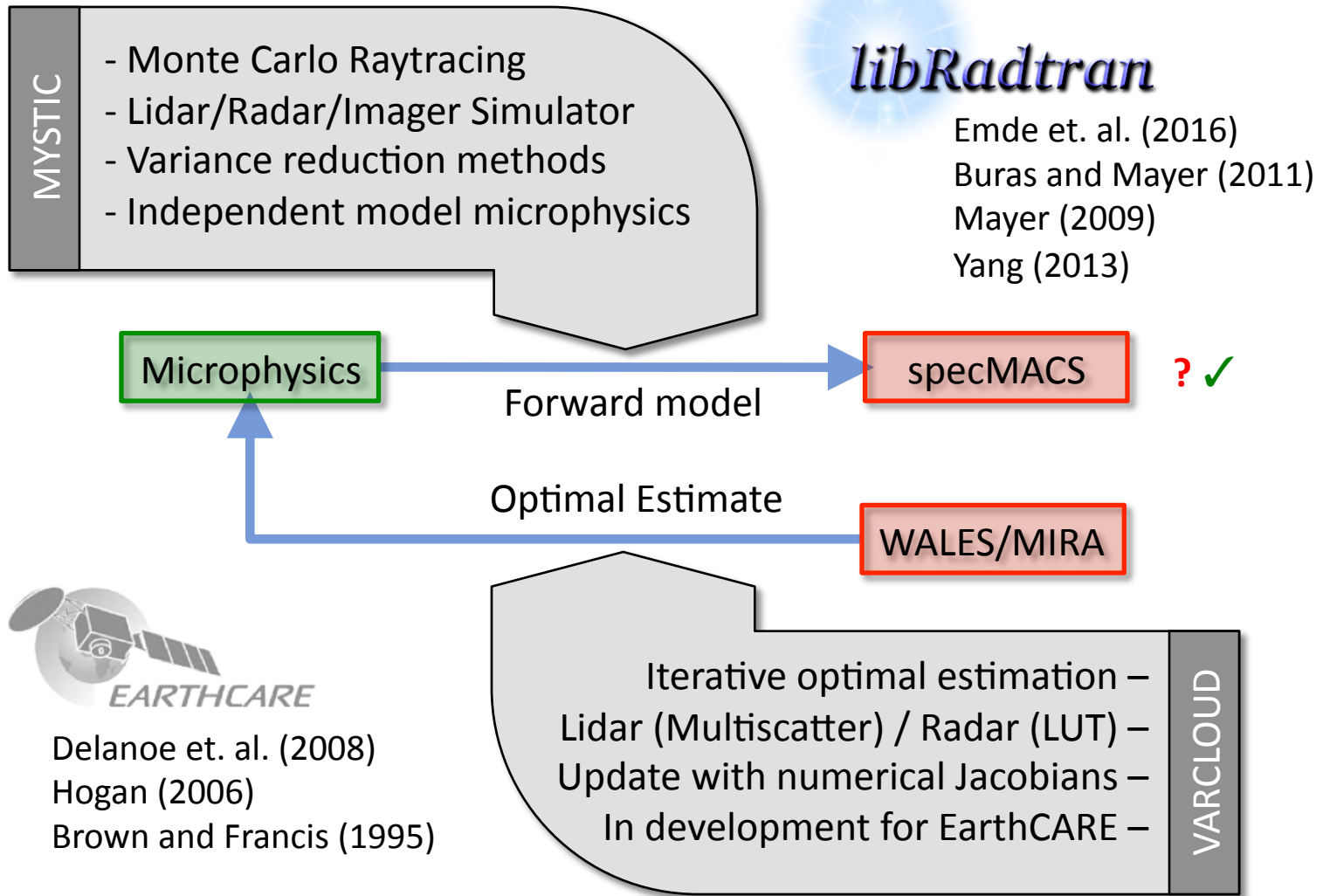
Solar radiance closure study

>> How solar radiances can be used to study VarCloud <<



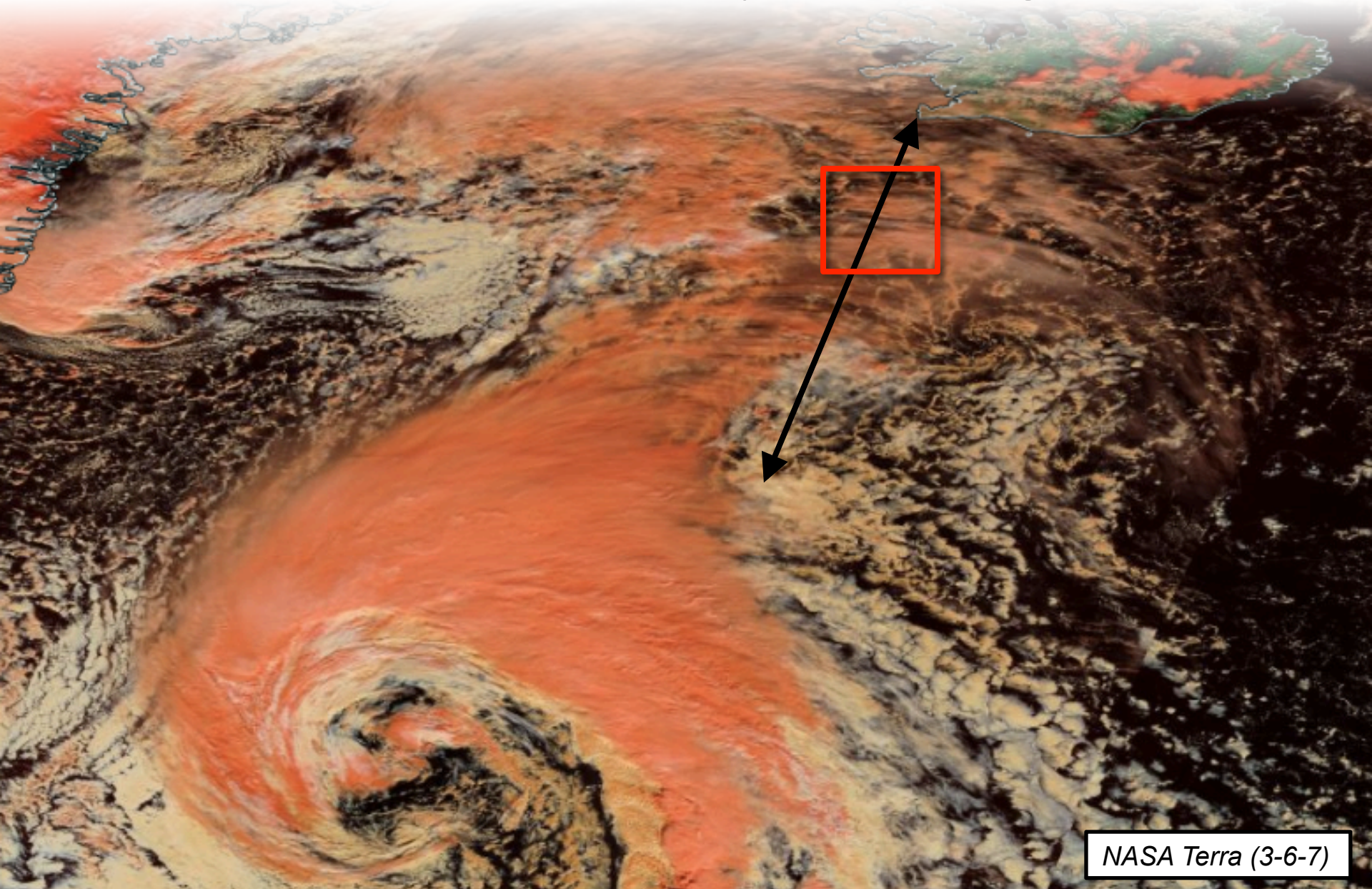
Retrieval Validation – Closure study

Retrieval of unknown microphysics + closure with measured radiances



Retrieval Validation – Comparison with In-Situ

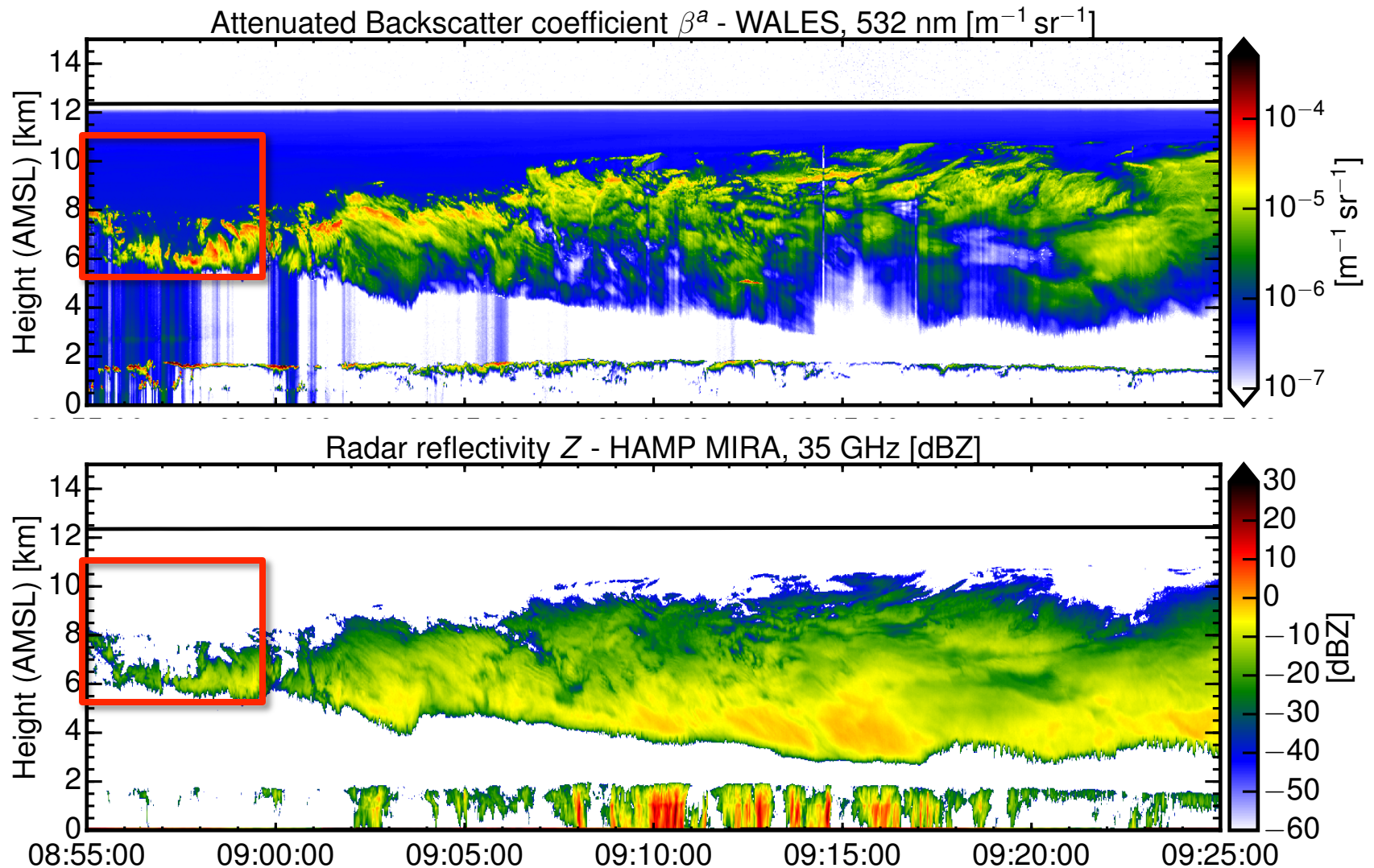
NAWDEX RF06, 2016/10/01 – Stalactite cyclone (aborted flight)



NASA Terra (3-6-7)

Retrieval Validation – Lidar and Radar measurements

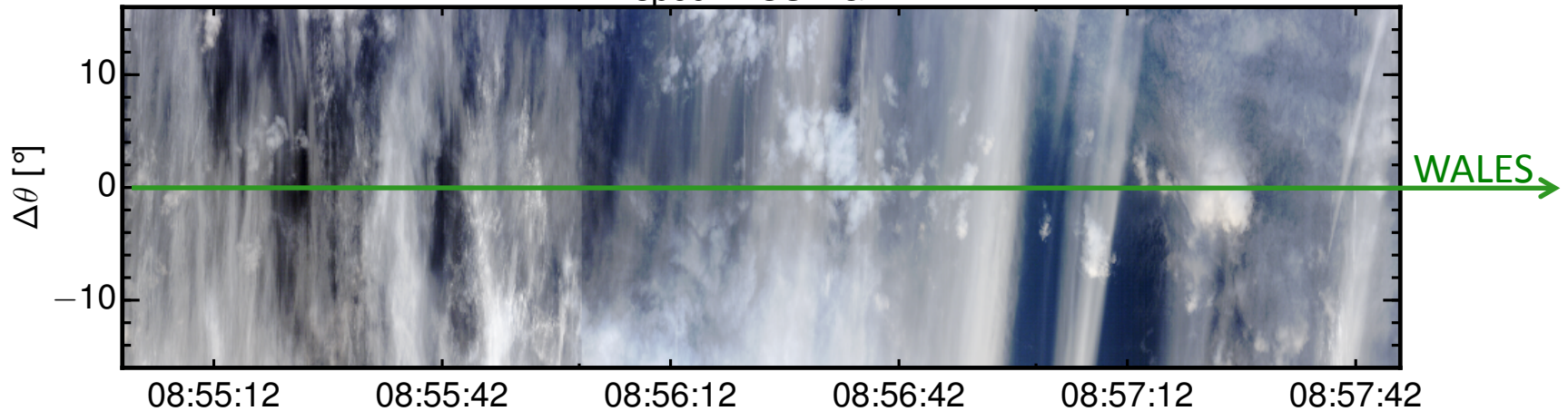
NAWDEX RF06, 2016/10/01



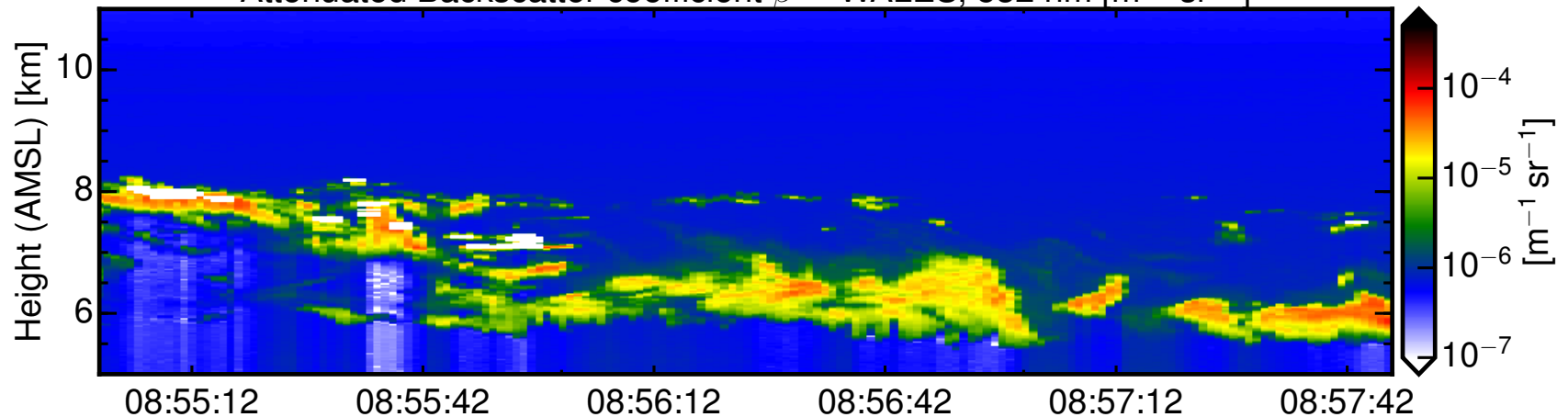
Retrieval Validation – Solar radiance measurements

NAWDEX RF06, 2016/10/01

specMACS RGB

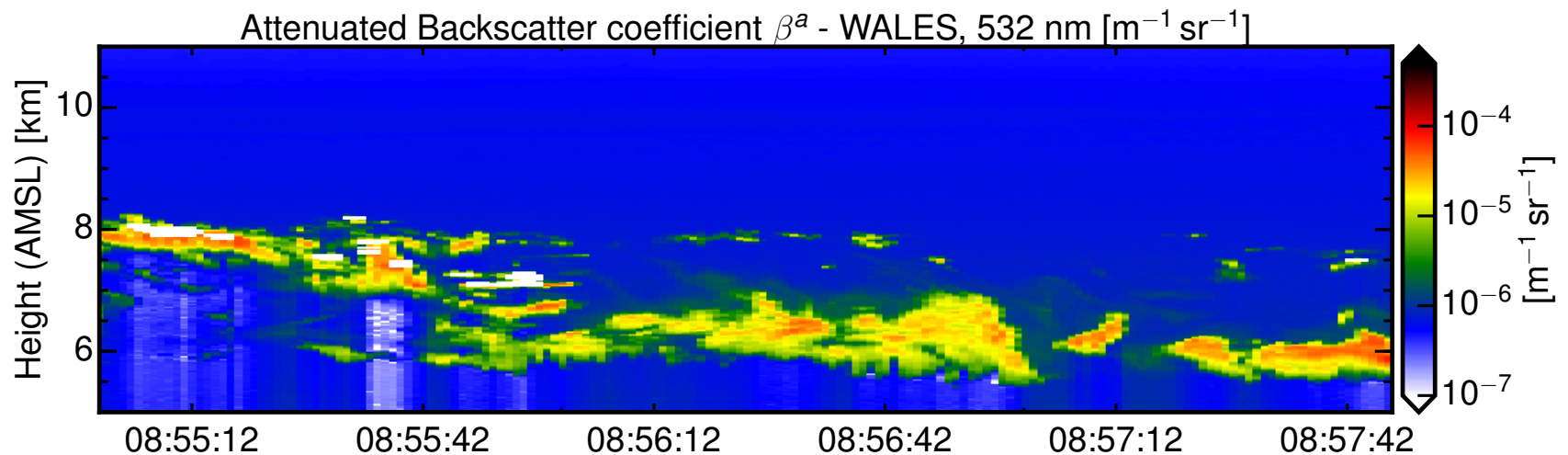
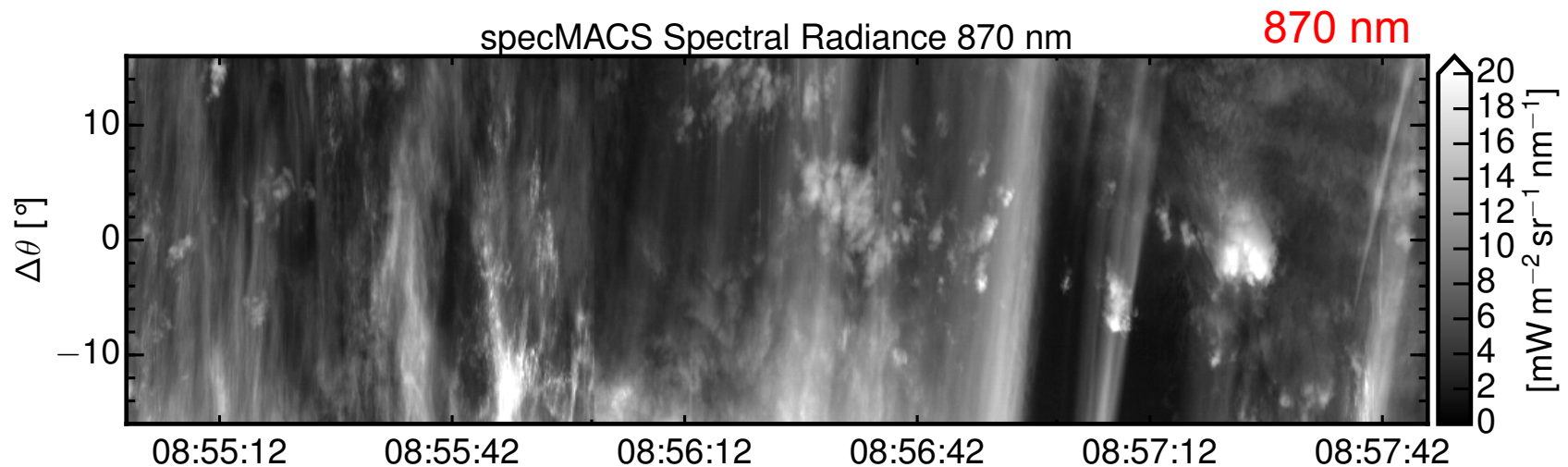


Attenuated Backscatter coefficient β^a - WALES, 532 nm [$\text{m}^{-1} \text{sr}^{-1}$]



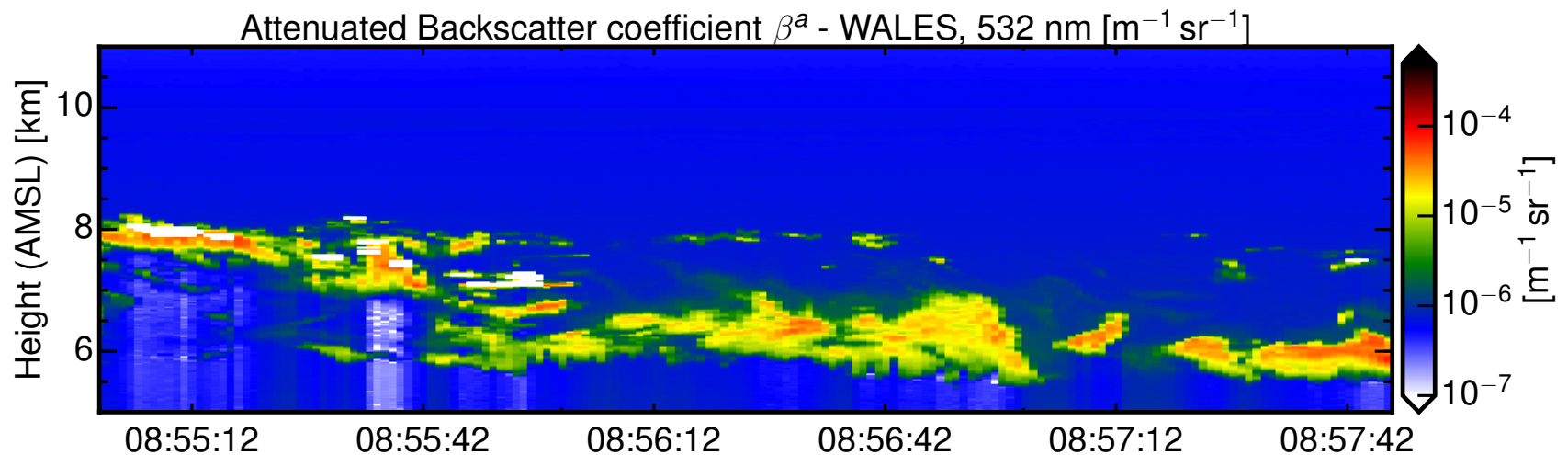
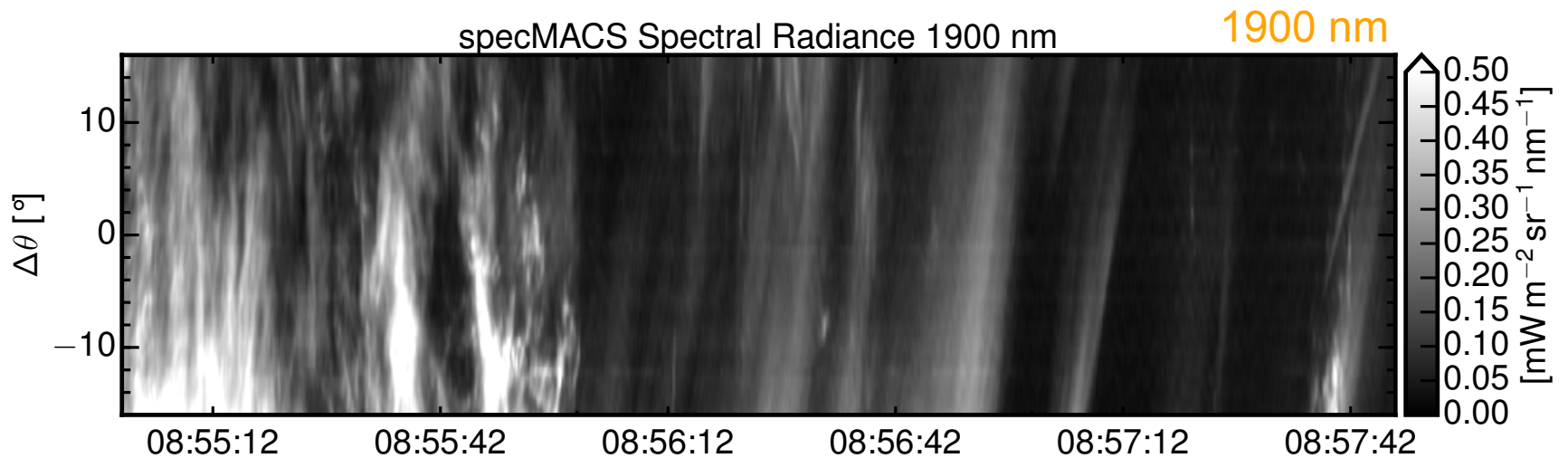
Retrieval Validation – Solar radiance measurements

NAWDEX RF06, 2016/10/01



Retrieval Validation – Solar radiance measurements

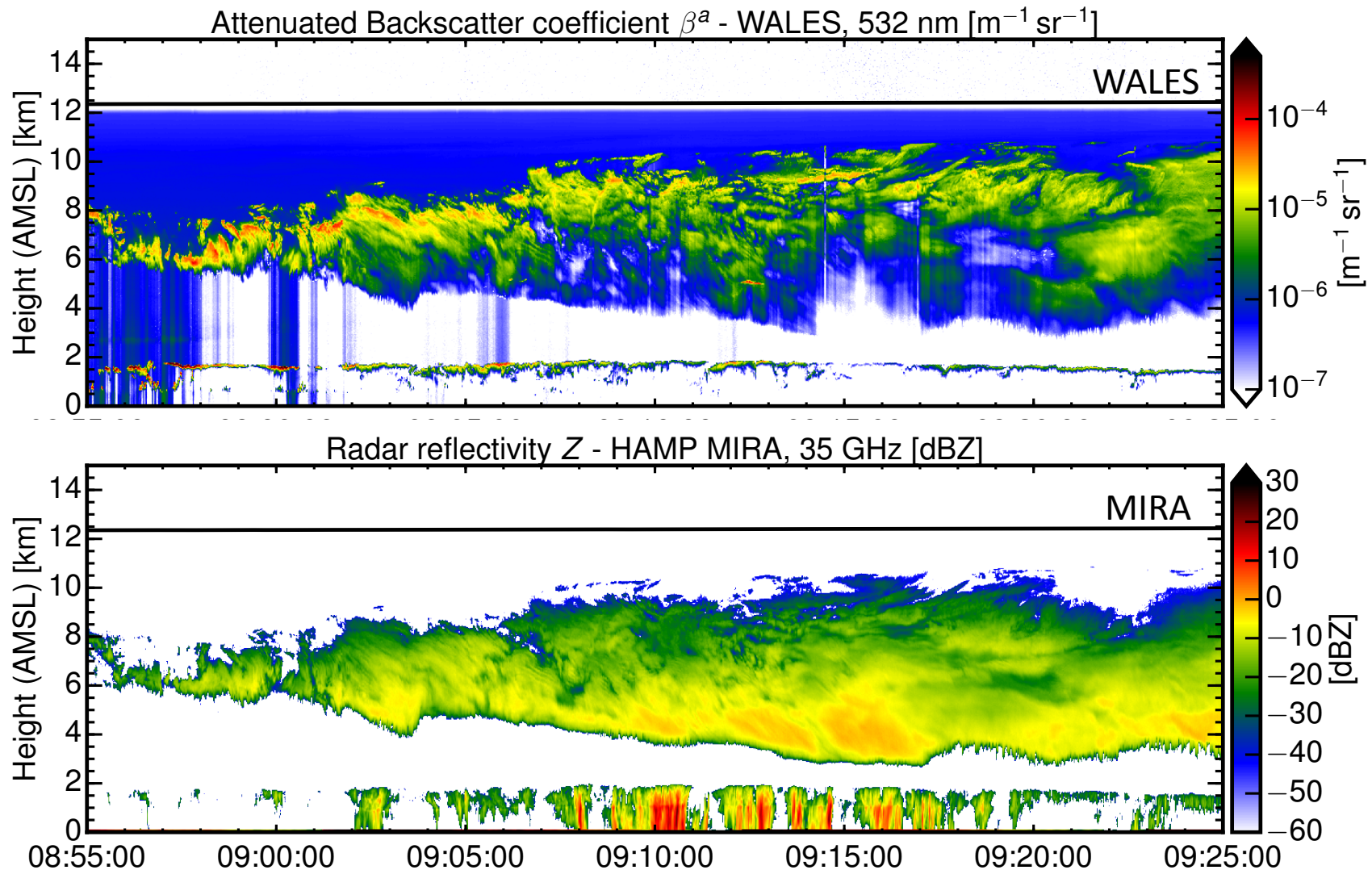
NAWDEX RF06, 2016/10/01



Retrieval Validation – Measurements

NAWDEX RF06, 2016/10/01

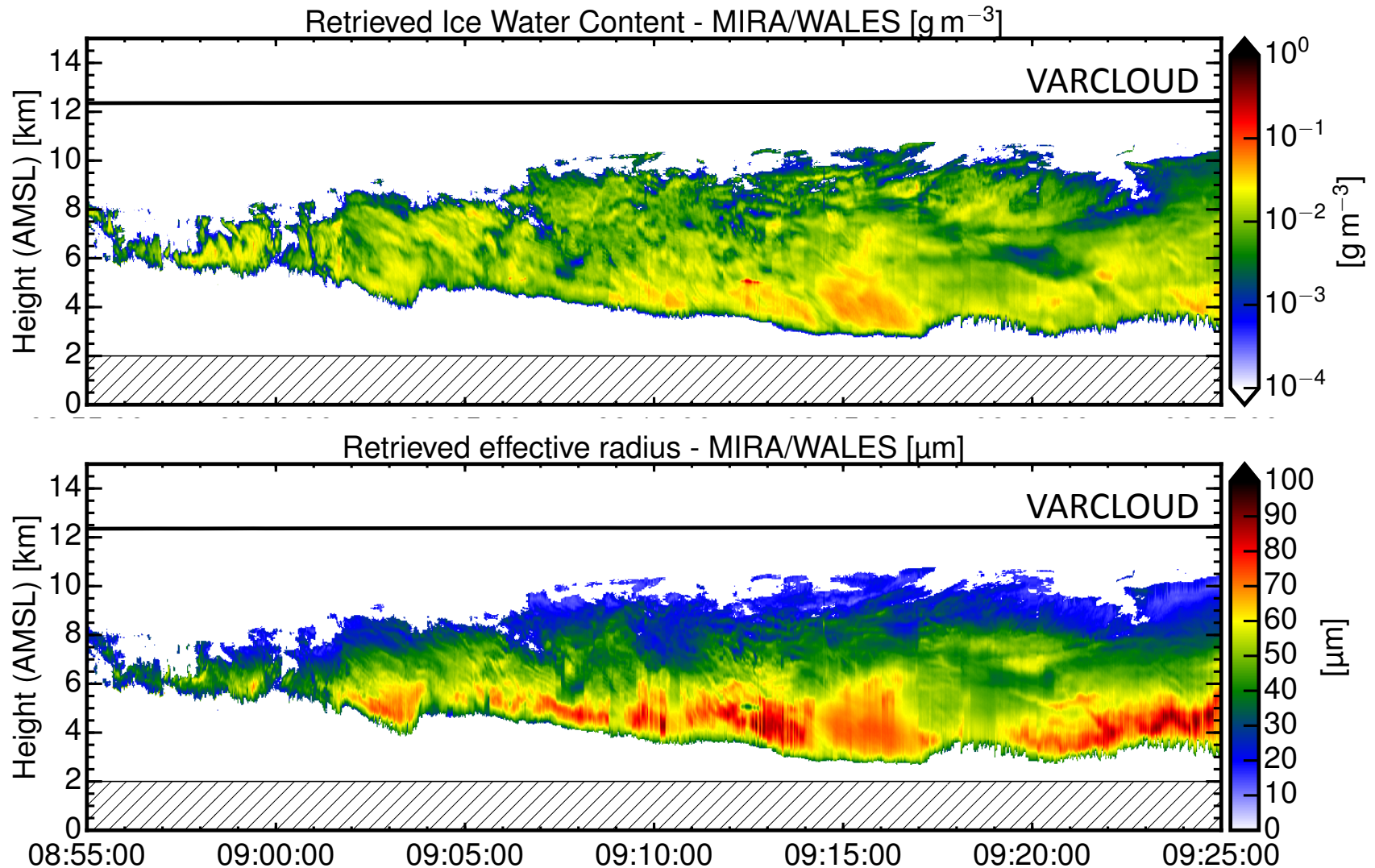
Ewald et. al. (2019), in prep.



Retrieval Validation – Retrieval results

NAWDEX RF06, 2016/10/01

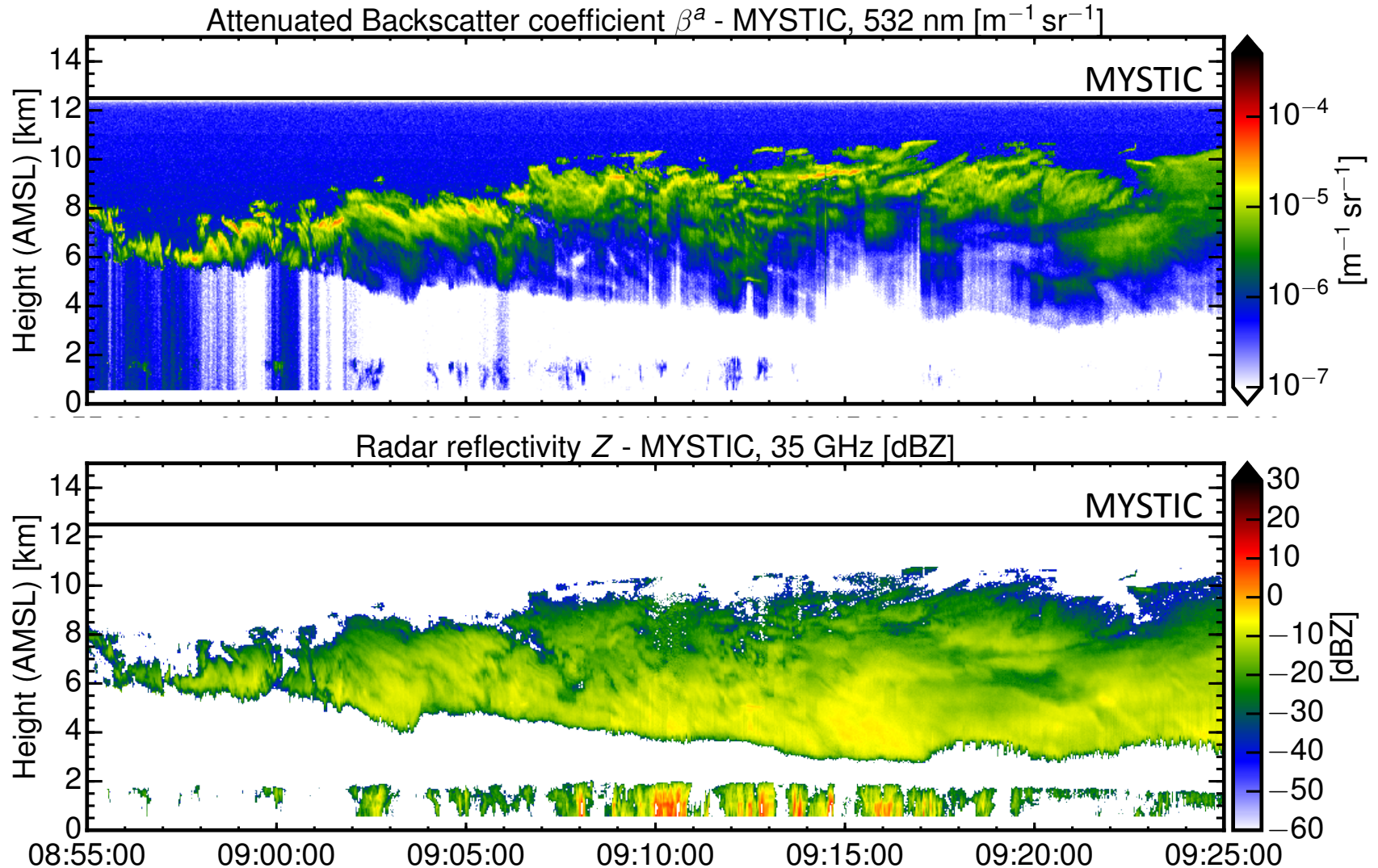
Ewald et. al. (2019), in prep.



Retrieval Validation – Forward simulations

NAWDEX RF06, 2016/10/01

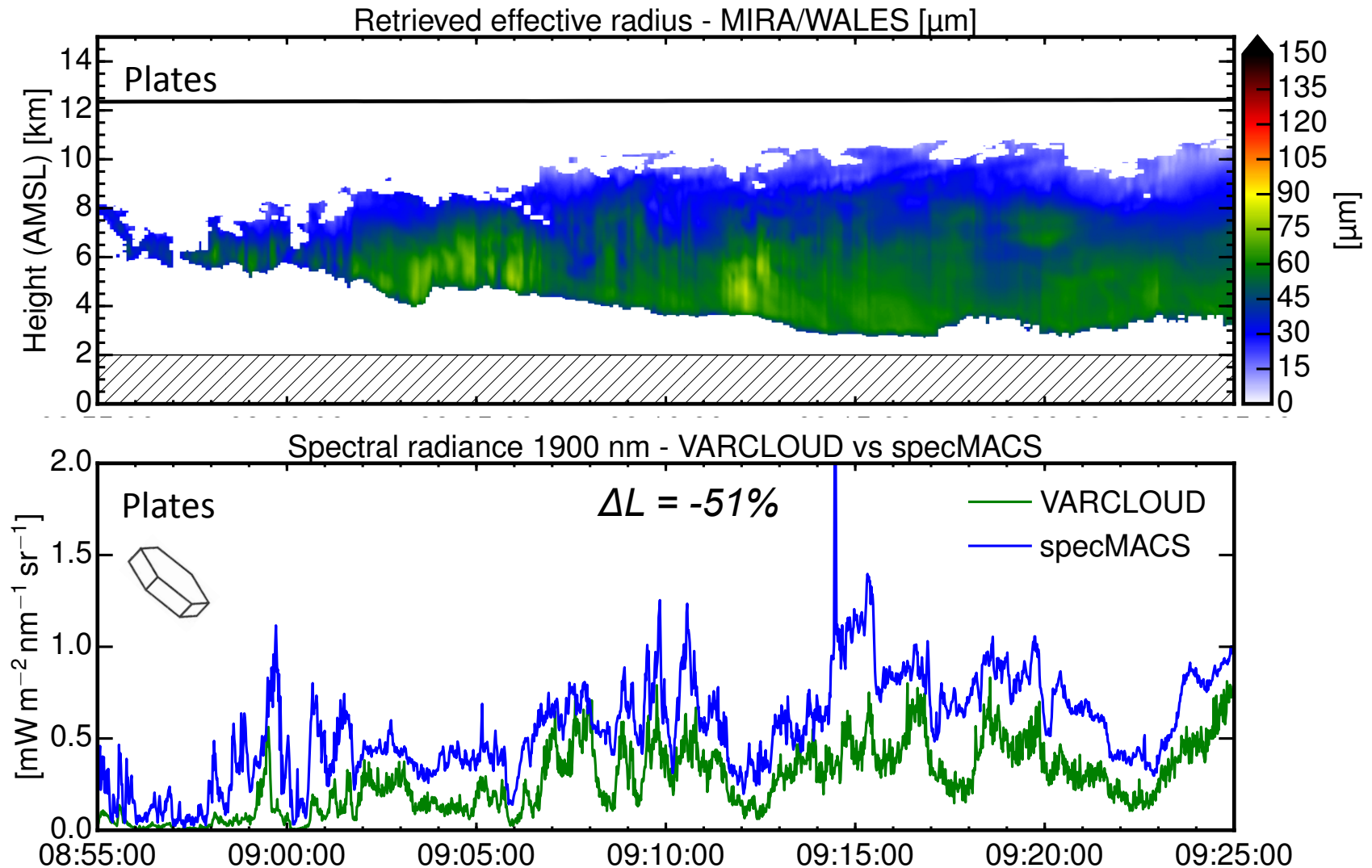
Ewald et. al. (2019), in prep.



Retrieval Validation – Forward simulations

NAWDEX RF06, 2016/10/01

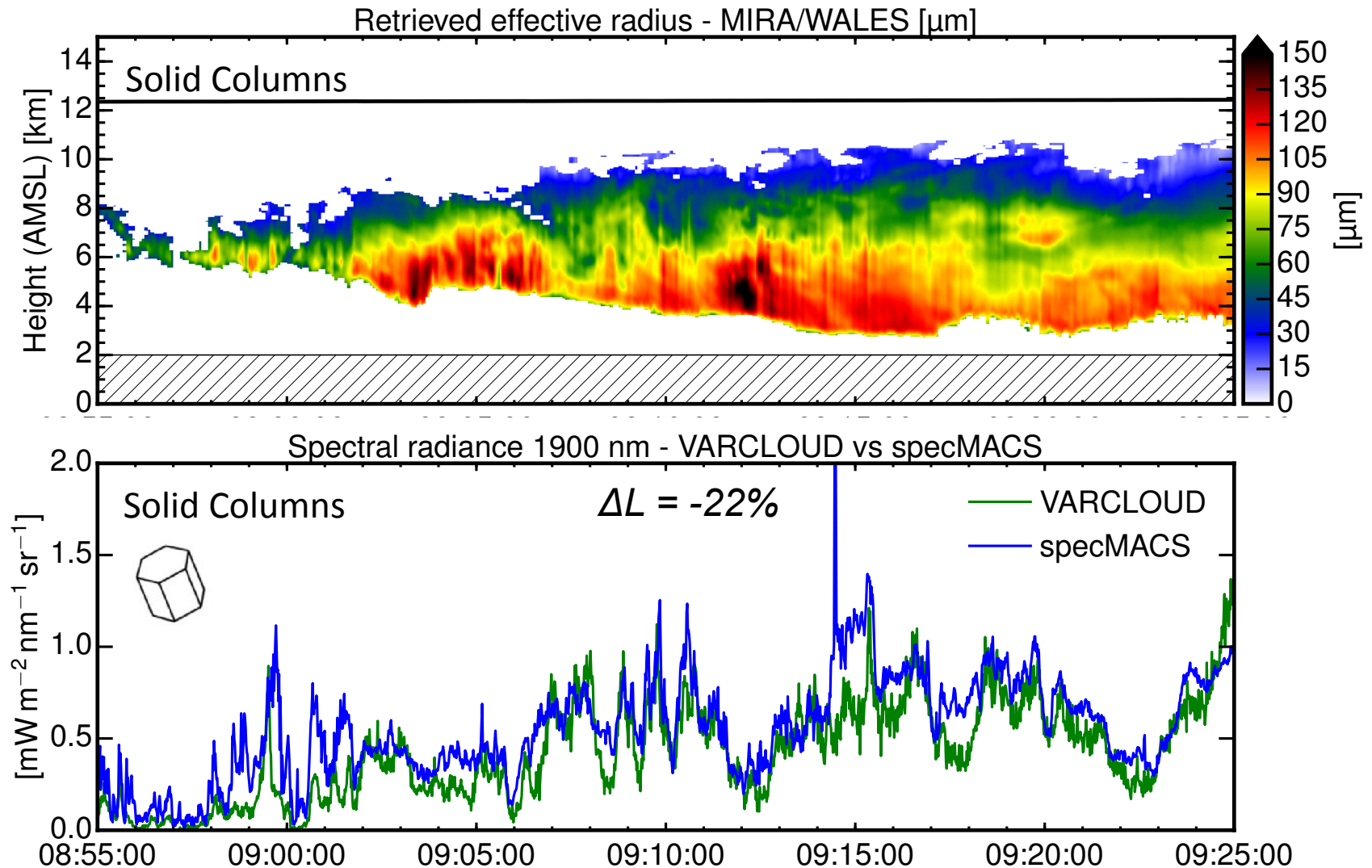
Ewald et. al. (2019), in prep.



Retrieval Validation – Forward simulations

NAWDEX RF06, 2016/10/01

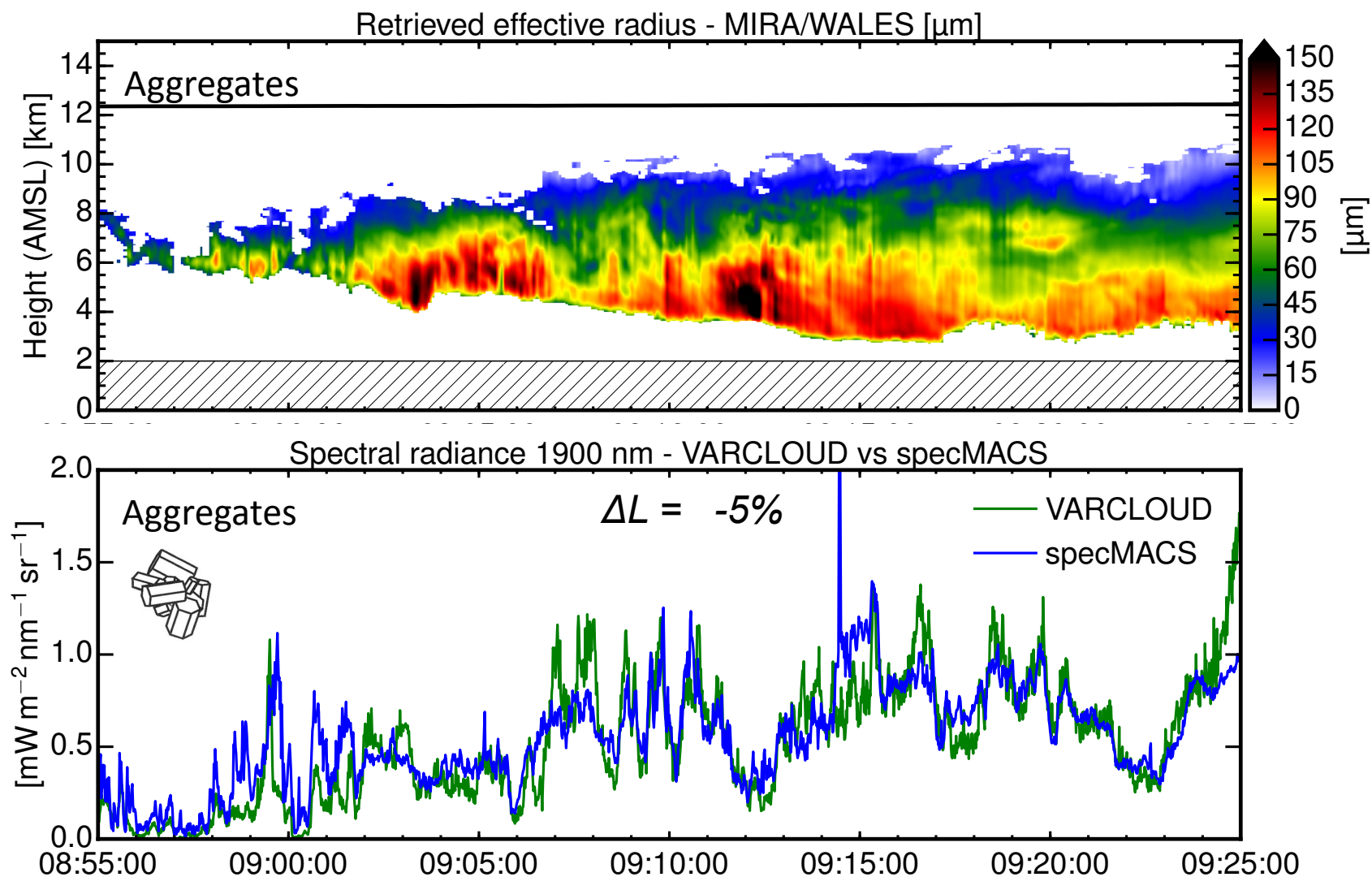
Ewald et. al. (2019), in prep.



Retrieval Validation – Forward simulations

NAWDEX RF06, 2016/10/01

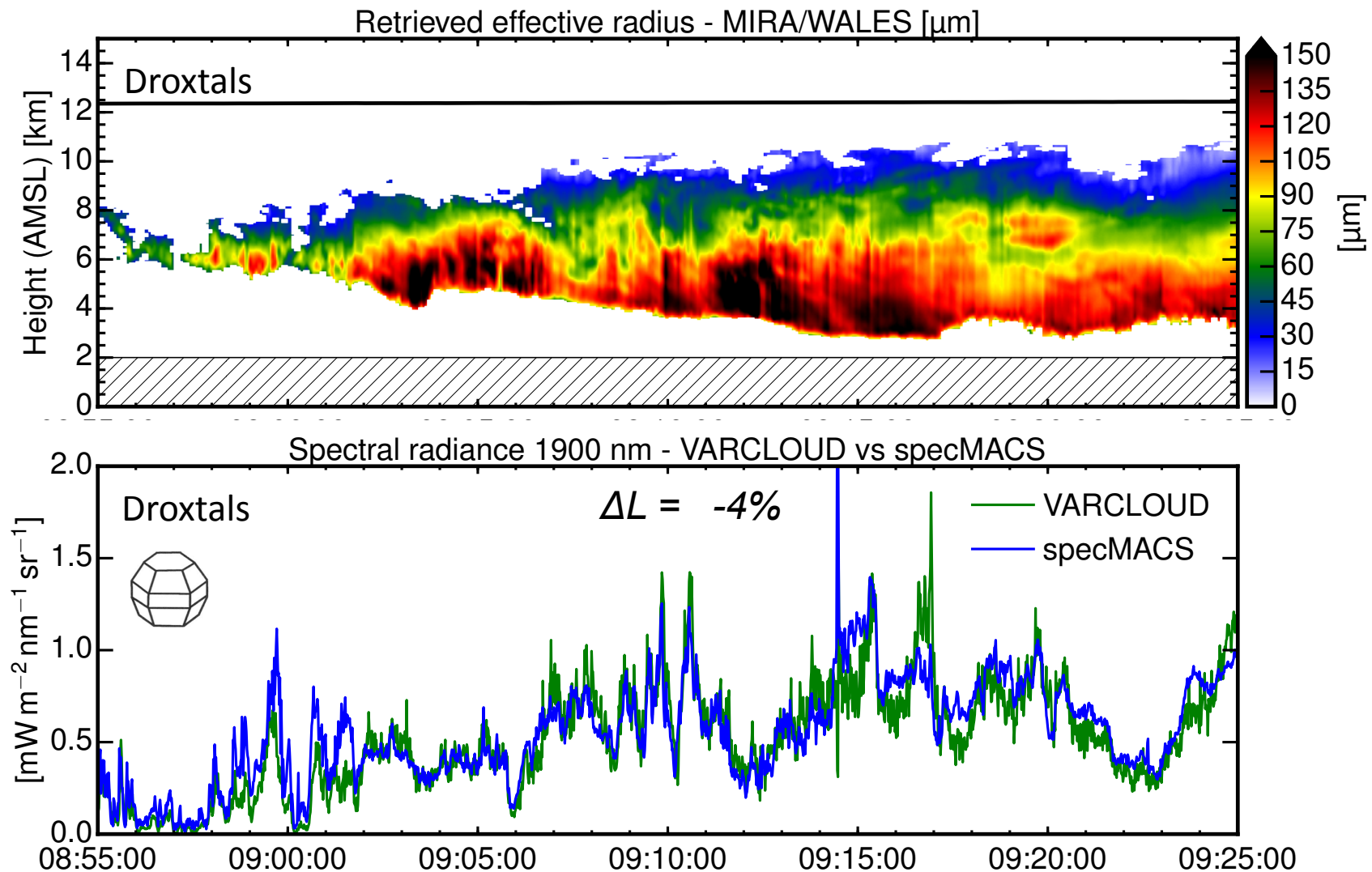
Ewald et. al. (2019), in prep.



Retrieval Validation – Forward simulations

NAWDEX RF06, 2016/10/01

Ewald et. al. (2019), in prep.

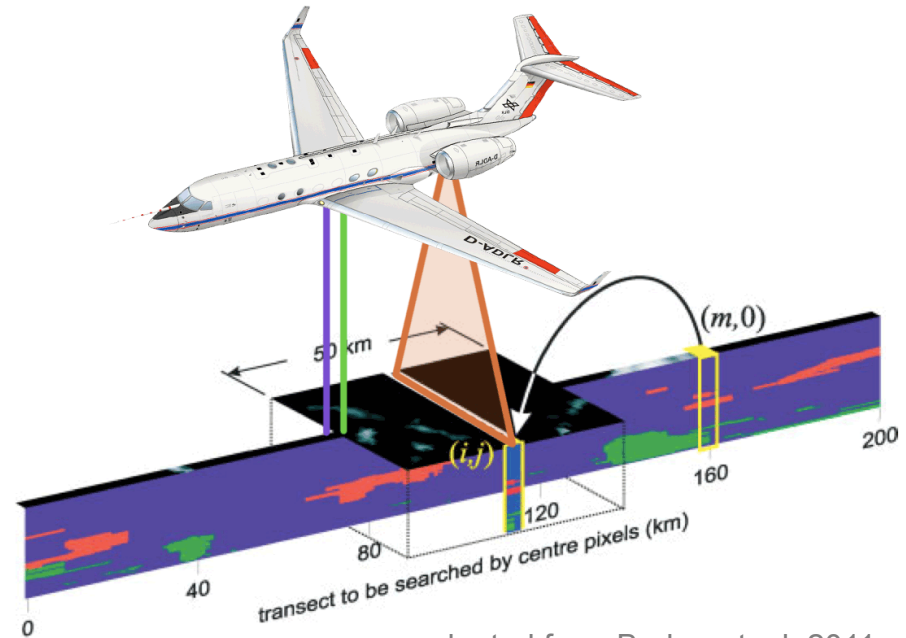


Summary and Prospects

Summary and an outlook on further studies

HALO as EarthCARE-like platform

- **First-time combination** of Lidar, Radar and Imager on HALO
- Retrieval of vertical profiles of **IWC** and **particle size**
- **Solar radiance** observations can help to narrow down crystal habit



adapted from Barker et. al. 2011

Eleni Marinou: VarCloud target categorization

Characterization of the clouds observed during NAWDEX with the synergistic HALO Radar-Lidar observations

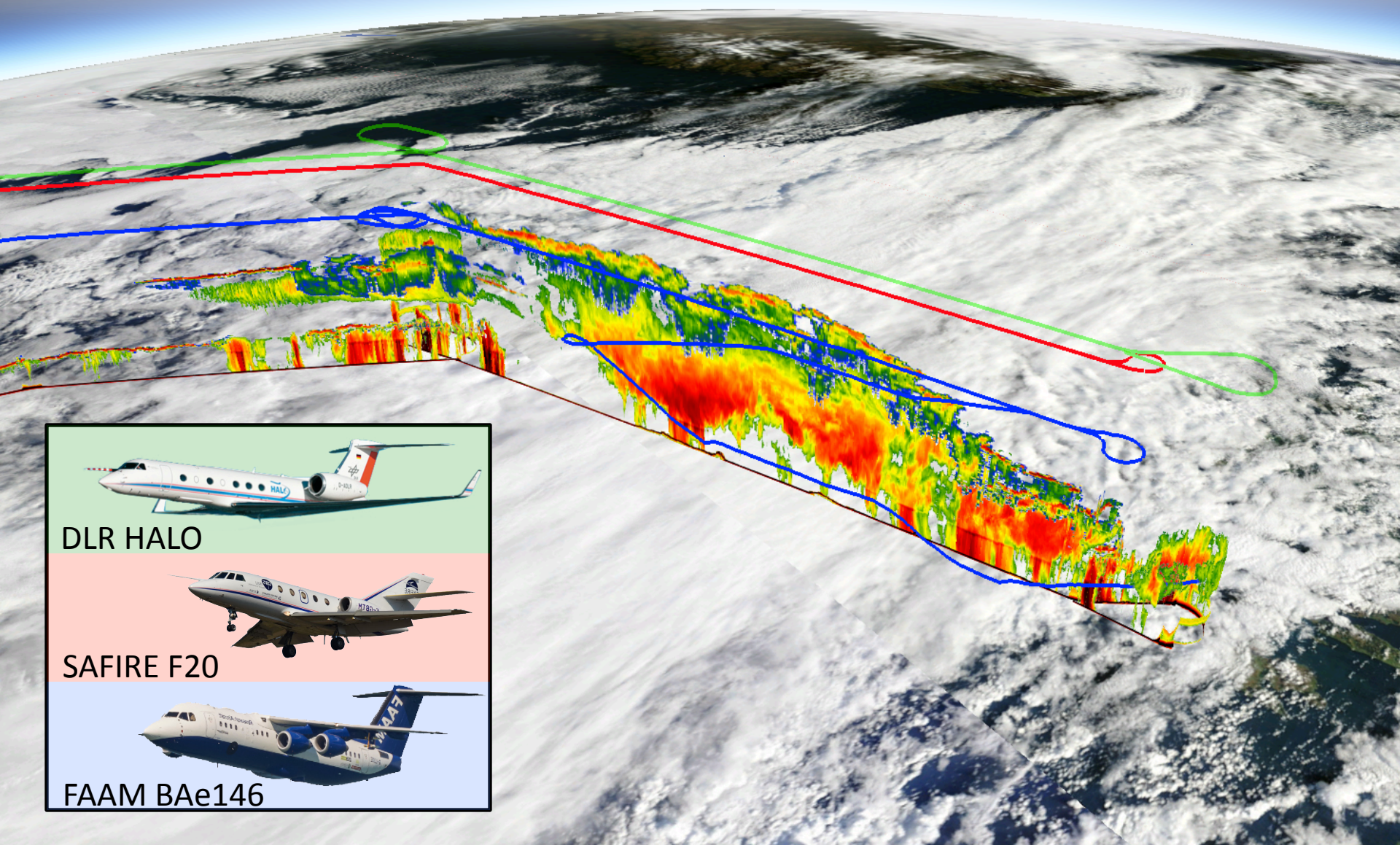
Julien Delanoë: VarCloud results on RALI

Observations with the RALI platform during the NAWDEX campaign



Retrieval Validation – Comparison with In-Situ

NAWDEX RF11, 2016/10/14 – HALO + FF20 + BAe146



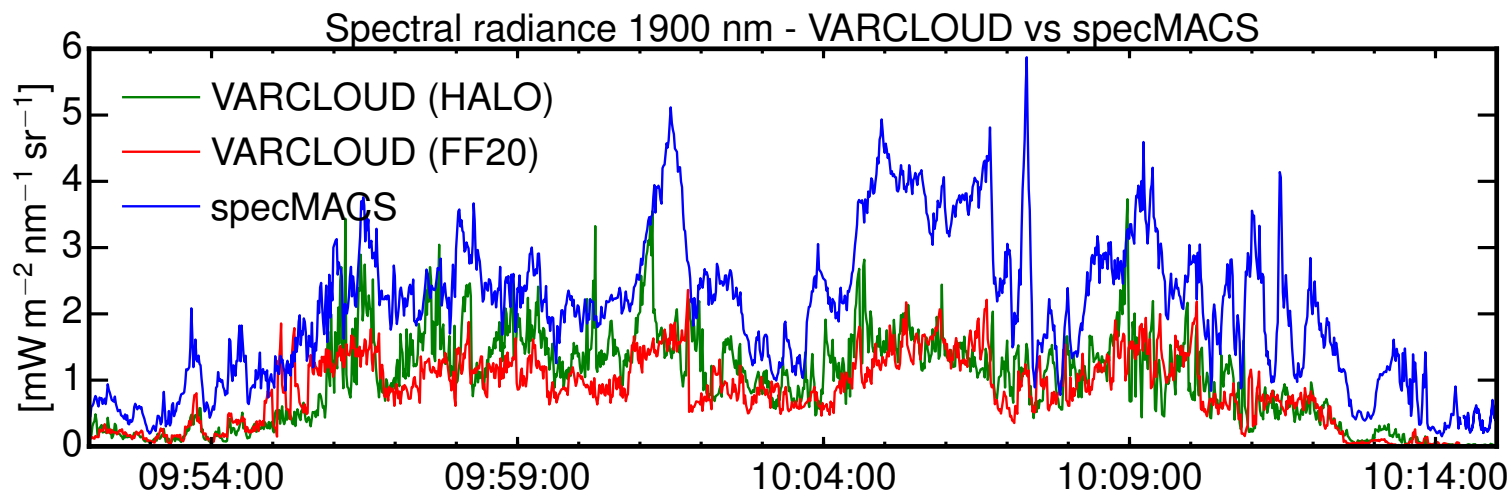
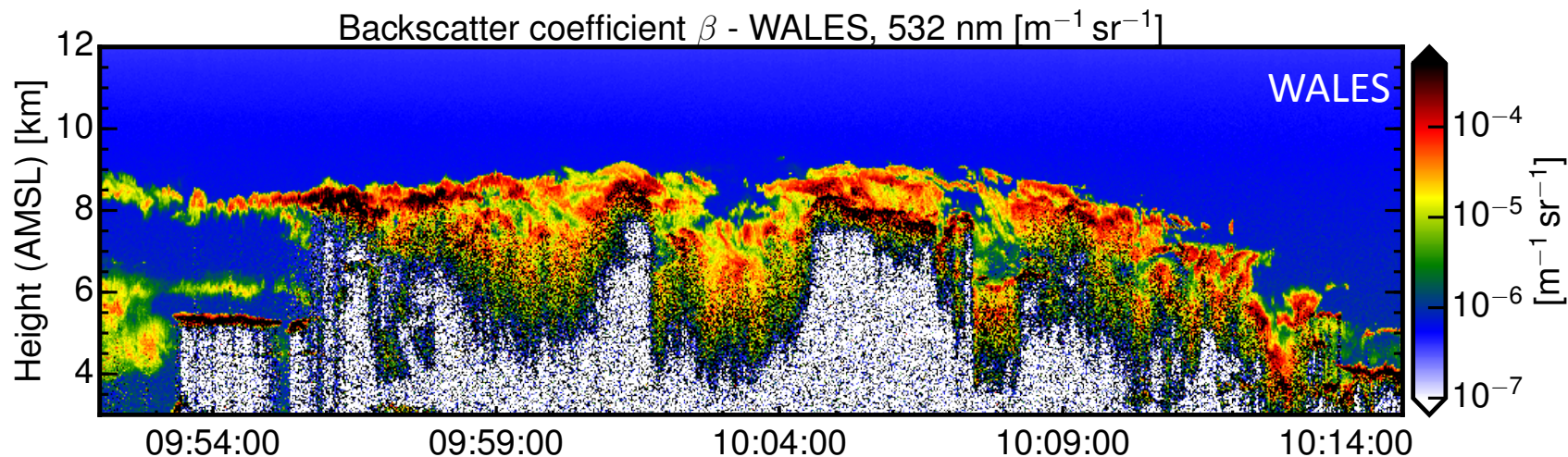
DLR HALO

SAFIRE F20

FAAM BAe146

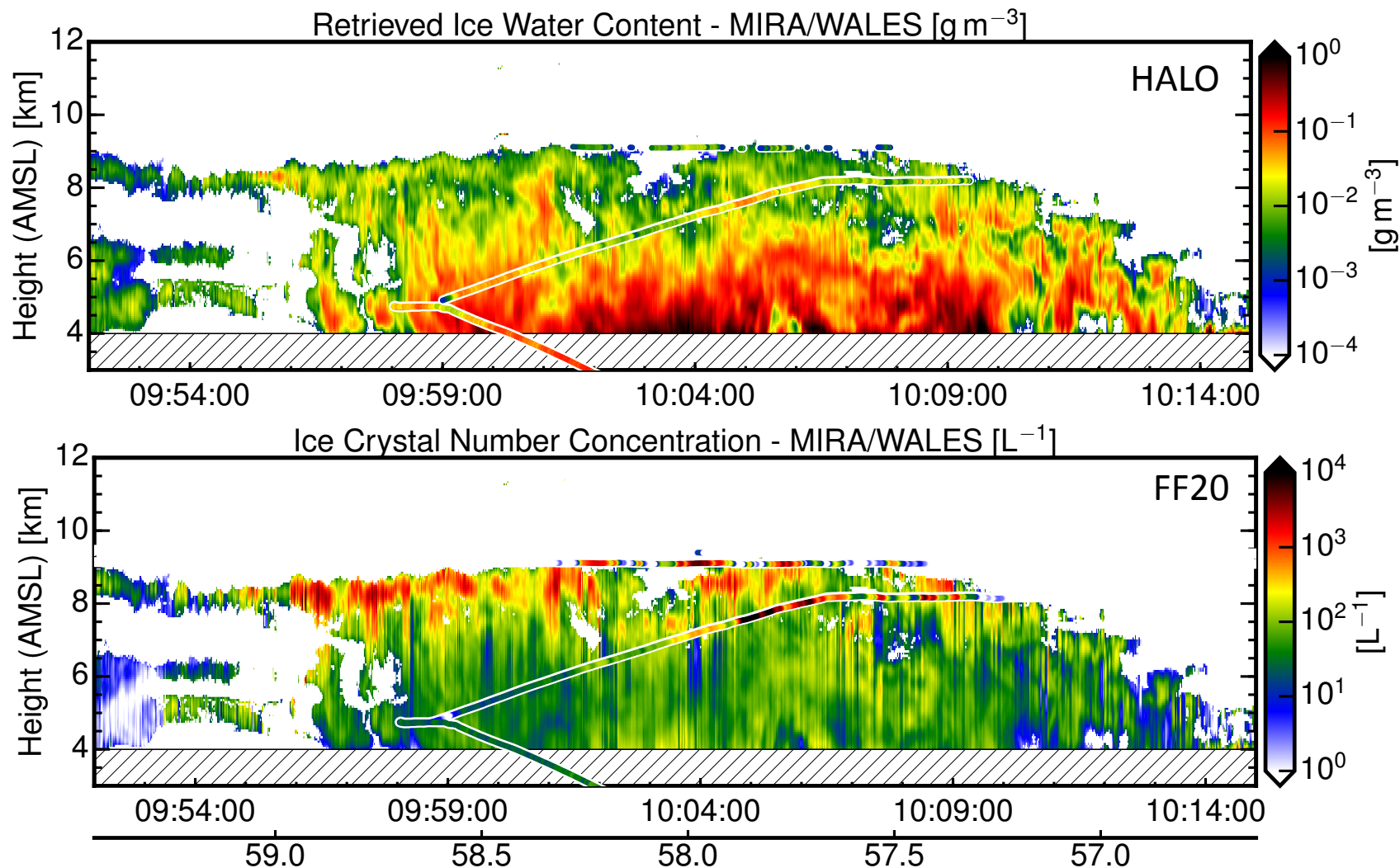
Radar/Lidar Common Flight Leg: HALO + F20 + BAe146

Comparison of ice water content from Nevzorov hot wire probe



Radar/Lidar Common Flight Leg: HALO + BAe146

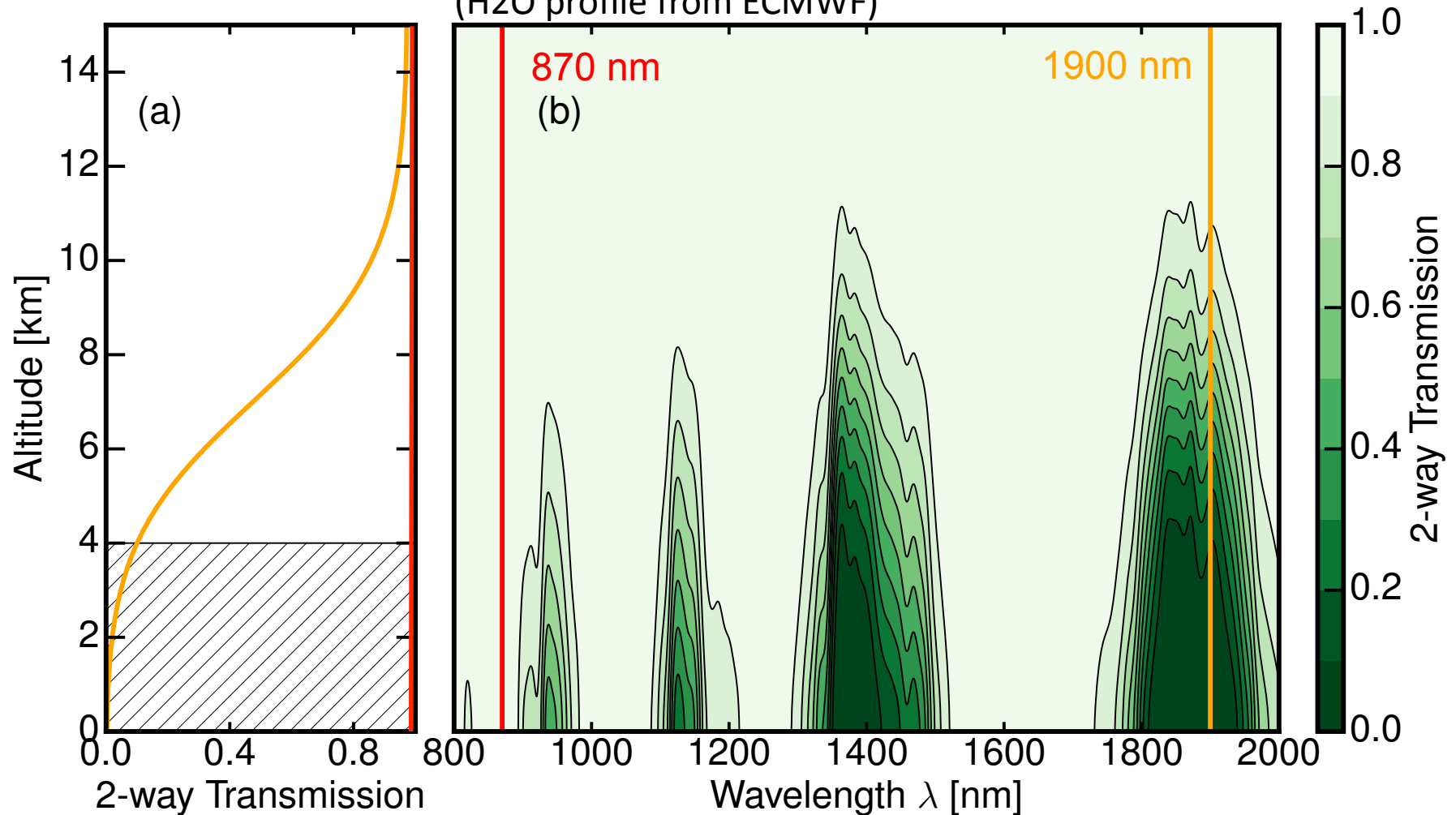
Comparison of IWC from Nevzorov probe and N_t from CIP-15



Retrieval Validation – Solar radiance measurements

How to get rid of low-level water clouds using water vapor absorption

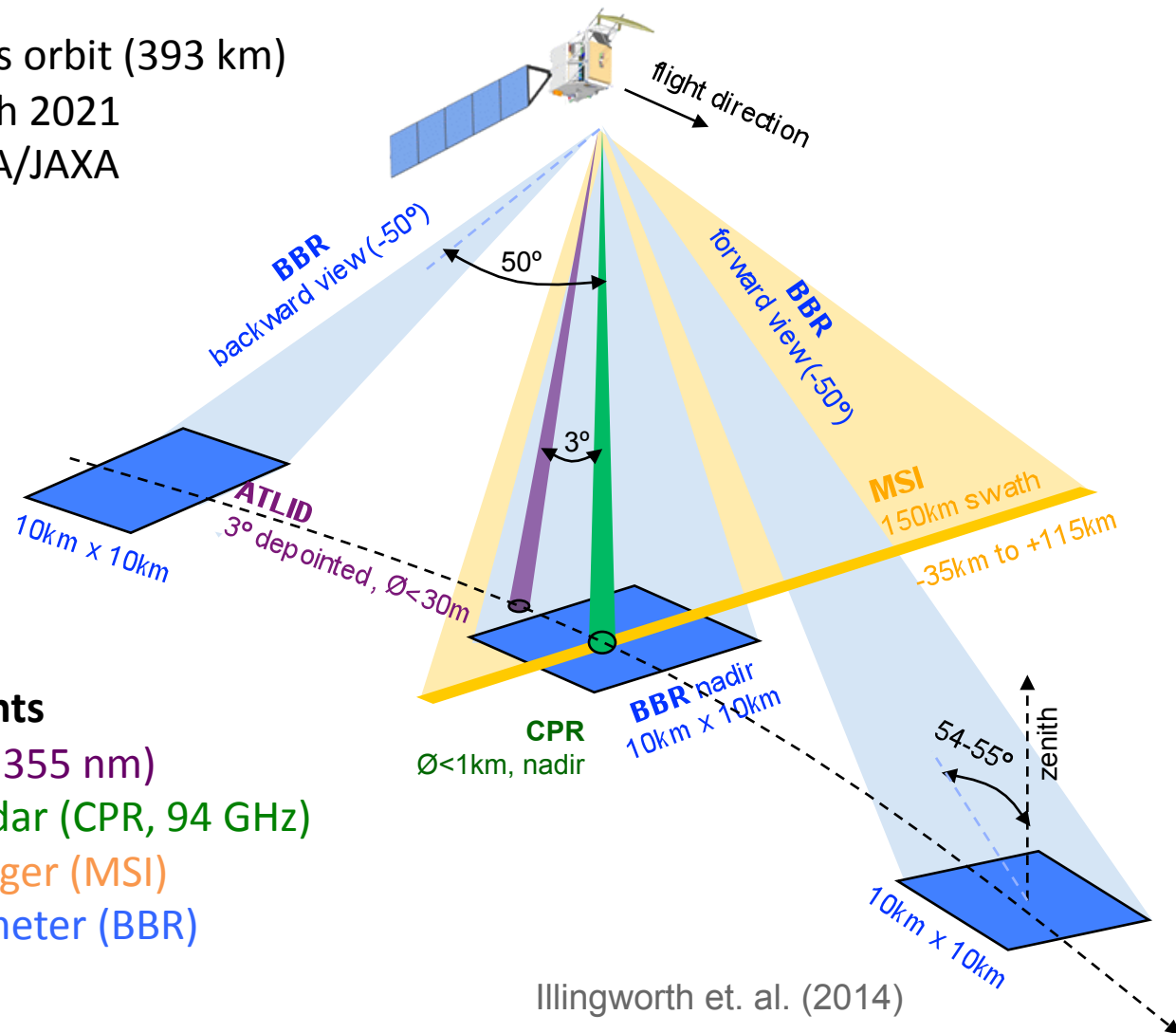
(H₂O profile from ECMWF)



The solution – EarthCARE

Spaceborne platform with multiple instruments

- Sun-synchronous orbit (393 km)
- scheduled launch 2021
- co-operation ESA/JAXA



Illingworth et. al. (2014)

Scientific Instruments

HSRL-Lidar (ATLID, 355 nm)

Cloud-Profiling Radar (CPR, 94 GHz)

Multi-Spektral Imager (MSI)

Broadband Radiometer (BBR)

