Remote sensing for aerosol, cloud, and precipitation – Promises and challenges

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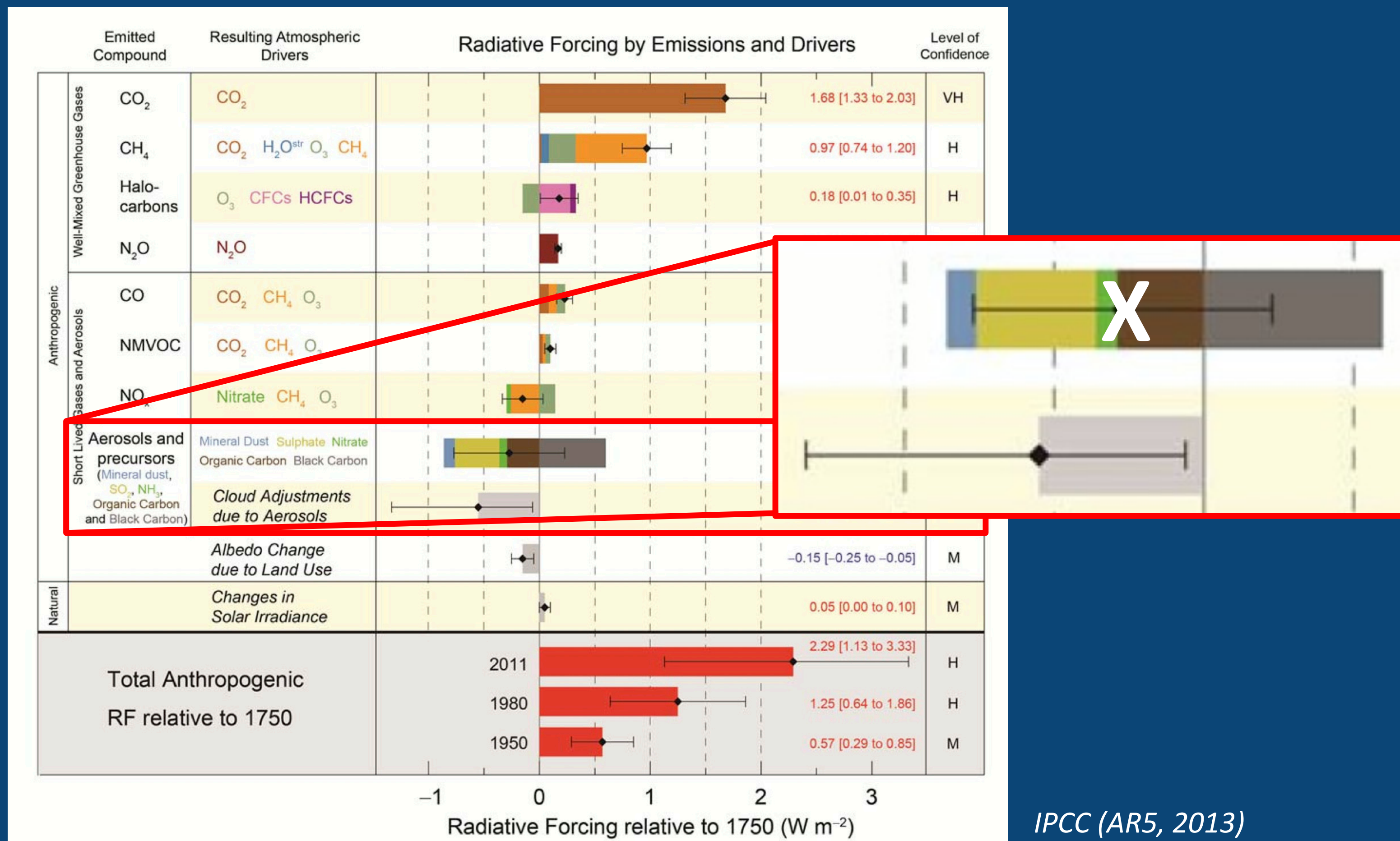
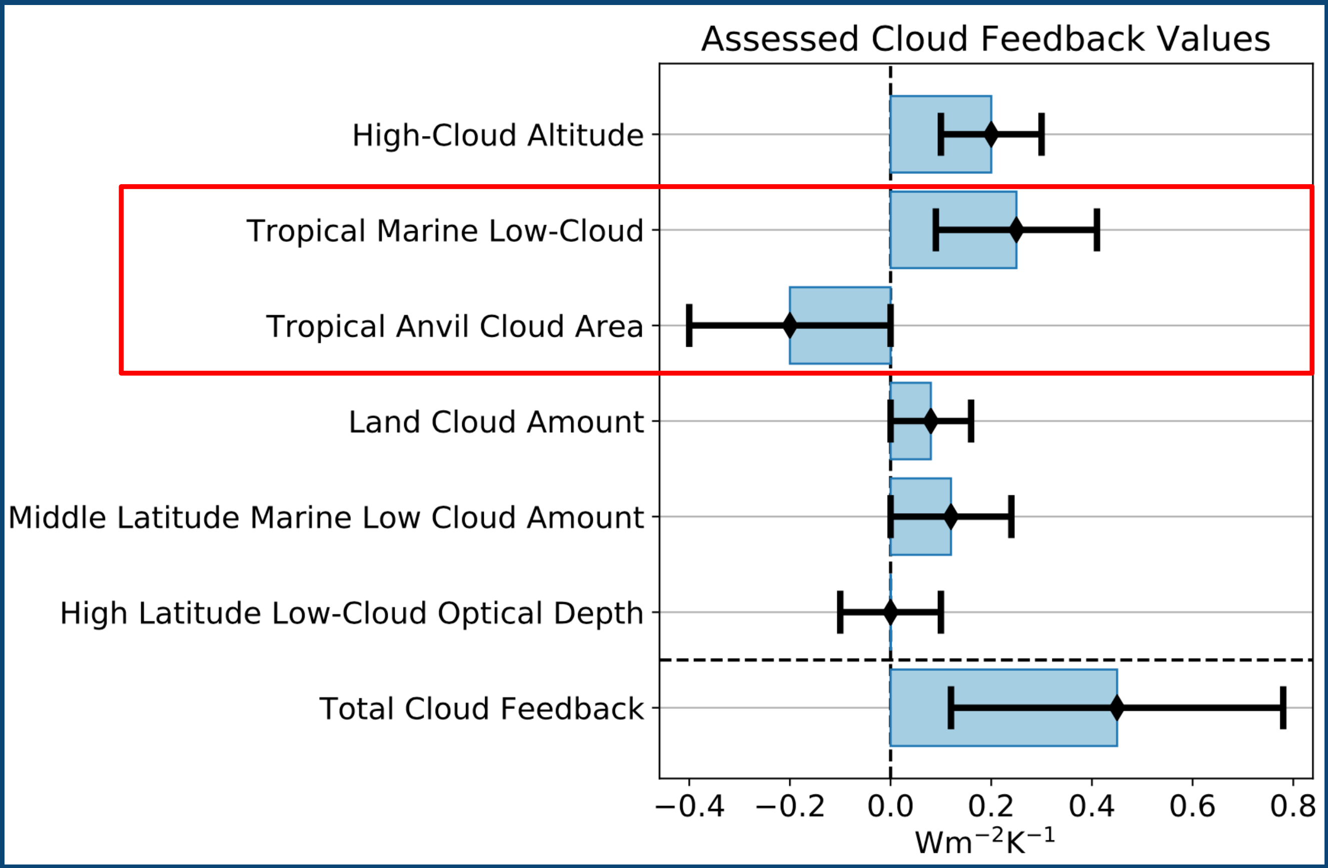
ASR
Atmospheric System Research

Aerosol radiative forcing remains uncertain



IPCC (AR5, 2013)

Uncertainty in cloud feedback remains large



Sherwood et al. (Reviews of Geophysics, 2020)

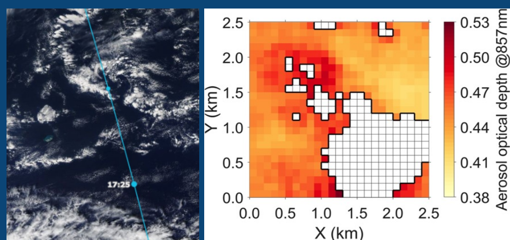
Errors in 1D cloud retrievals remain large, too!

Retrieval method	Cloud optical depth		Cloud effective radius	
	Open cell	Closed cell	Open cell	Closed cell
1D, SZA=20°	30.7 %	16.0 %	38.3 %	51.2 %
3D, SZA=20°	21.6 %	23.4 %	5.5 %	6.7 %
1D, SZA=60°	74.8 %	50.9 %	51.1 %	55.2 %
3D, SZA=60°	26.6 %	18.7 %	6.5 %	7.3 %

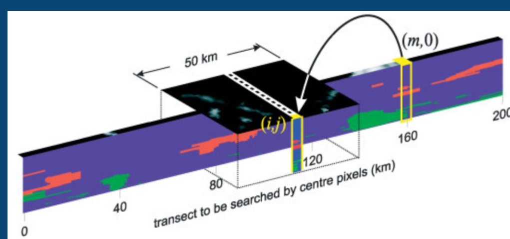
Okamura et al. (AMT, 2017)

And, we still have very limited 3D cloud observations from the ground and none from space!

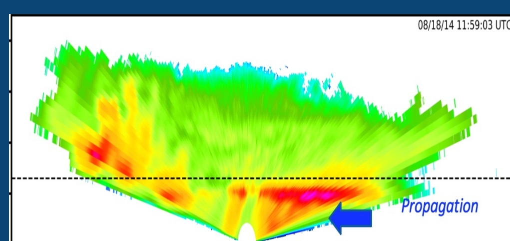
Outline



Advancing aerosol observations on "no man's land"

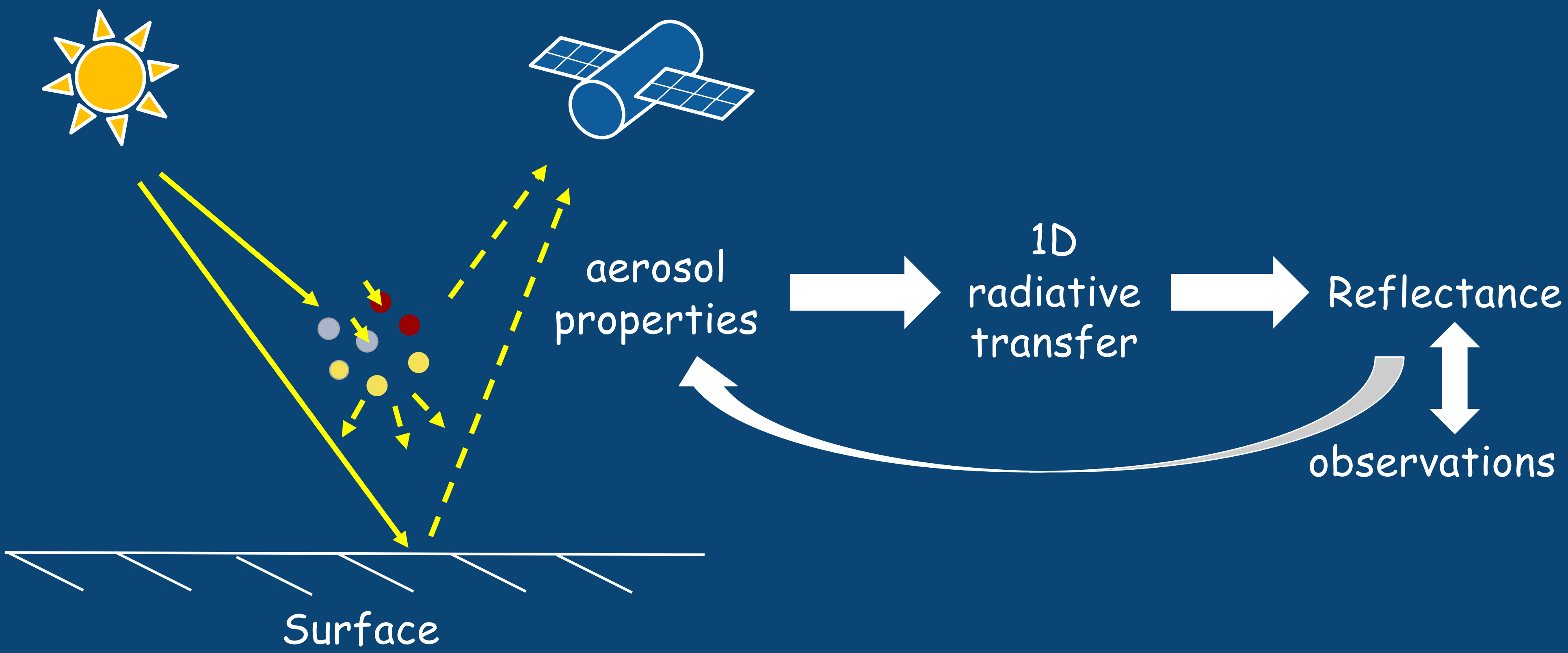


Challenges in observing 3D cloud microphysics

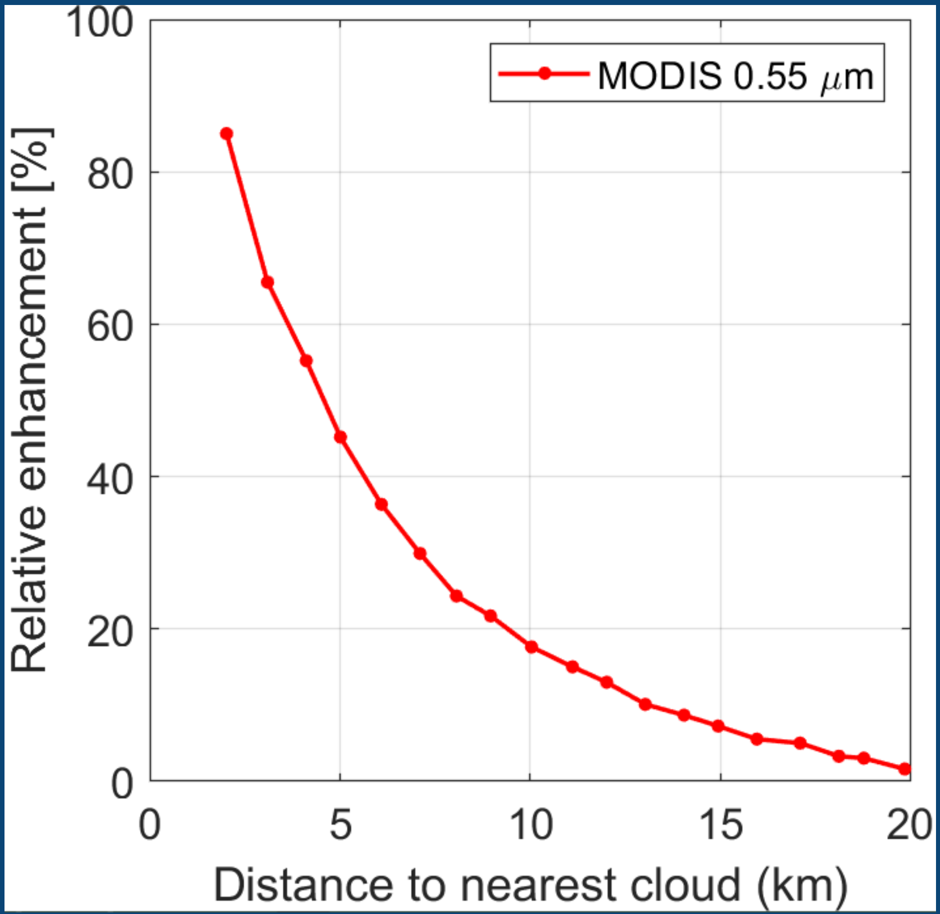


Challenges in observing concurrent species in warm and ice-containing clouds

Constraints on aerosol properties have been largely from satellites measurements



The reflectance near clouds is enhanced

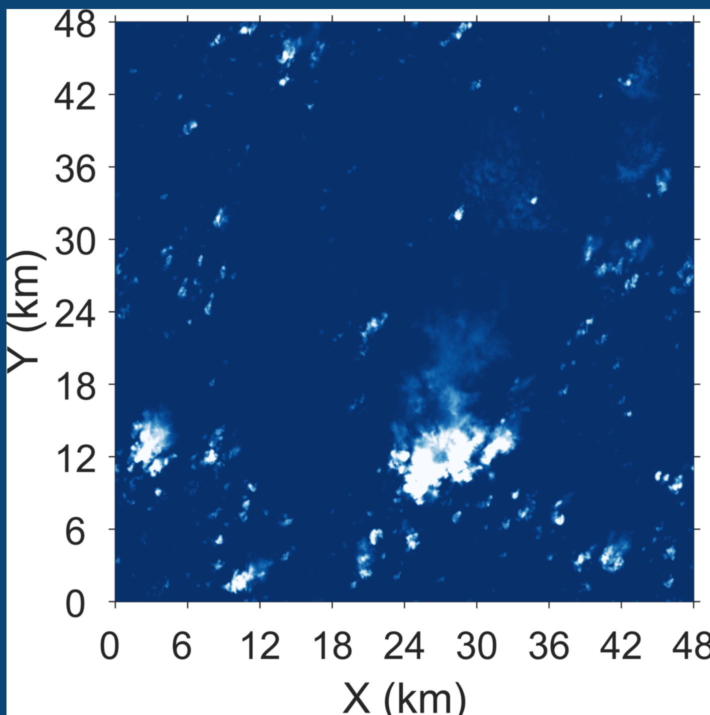


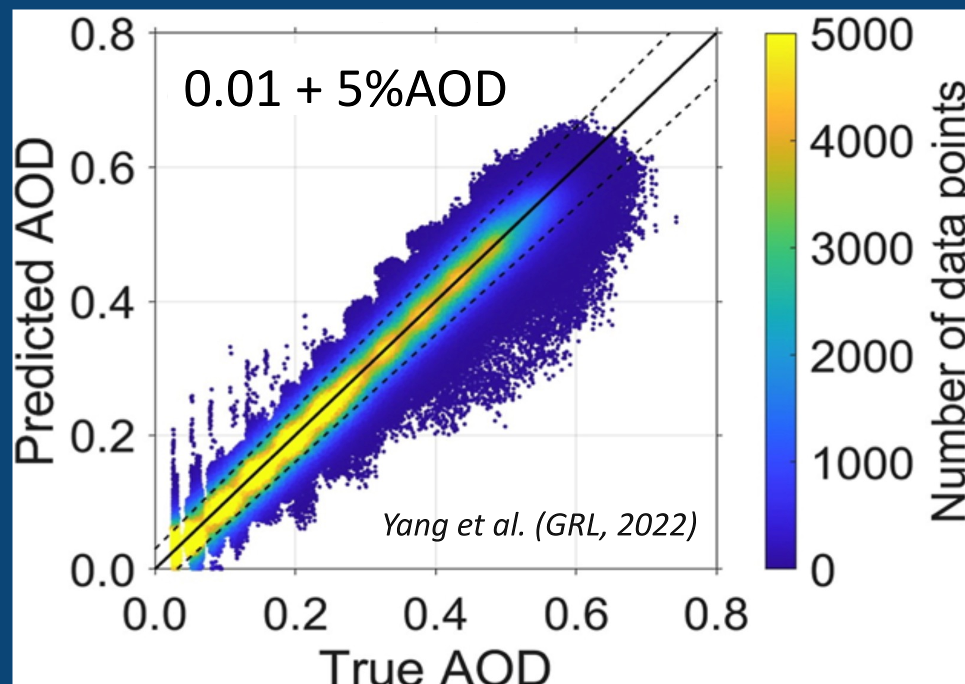
(excerpted from Varnai et al., 2013)

1. The hygroscopic growth
2. New particle formation
3. Chemical processing in clouds
4. Undetected sub-grid clouds
5. 3D Cloud radiative effects

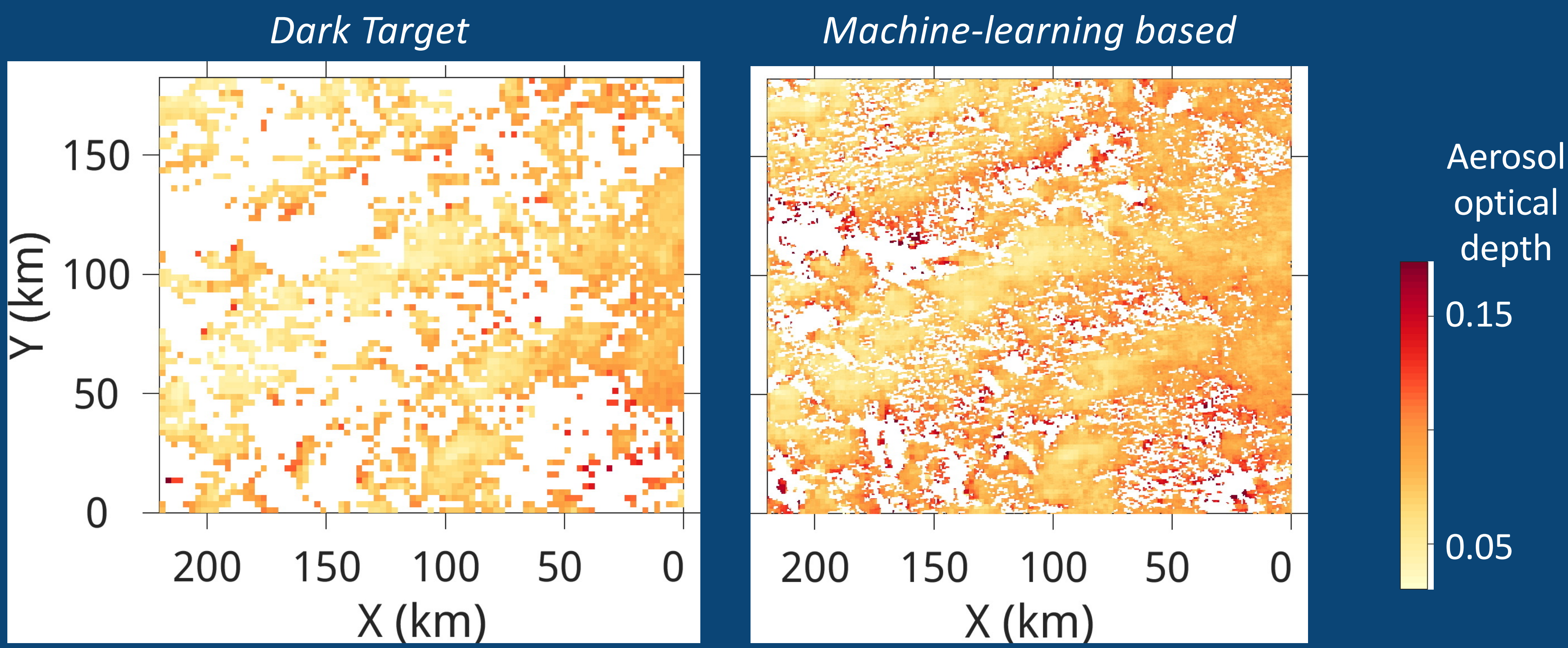
A retrieval method that can handle 3D radiative effects

- Based on machine learning techniques
- Train reflectance fields generated from 100-m model output and 3D RT



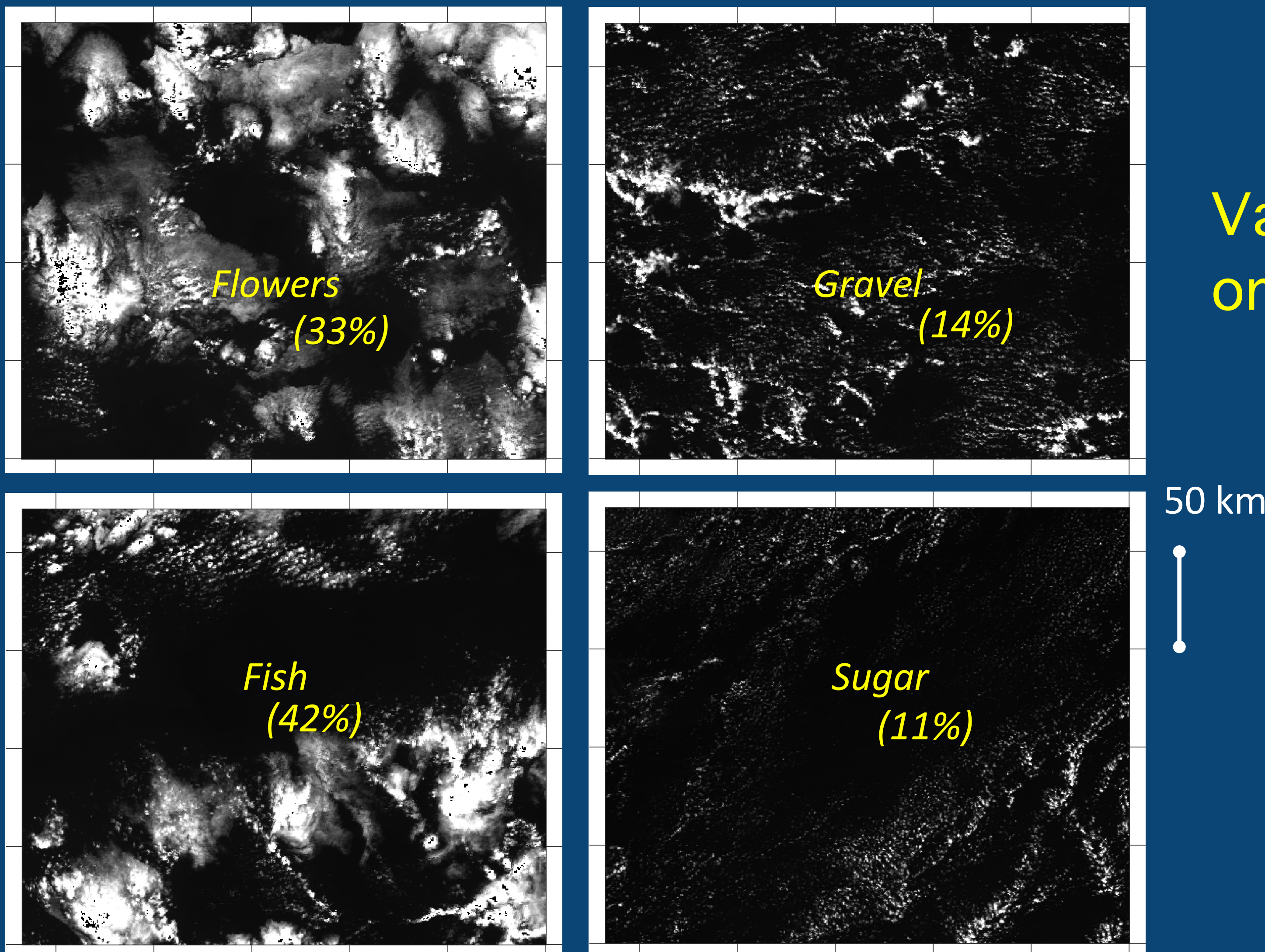


Comparison to MODIS Dark Target 3 km products



Yang et al. (in prep.)

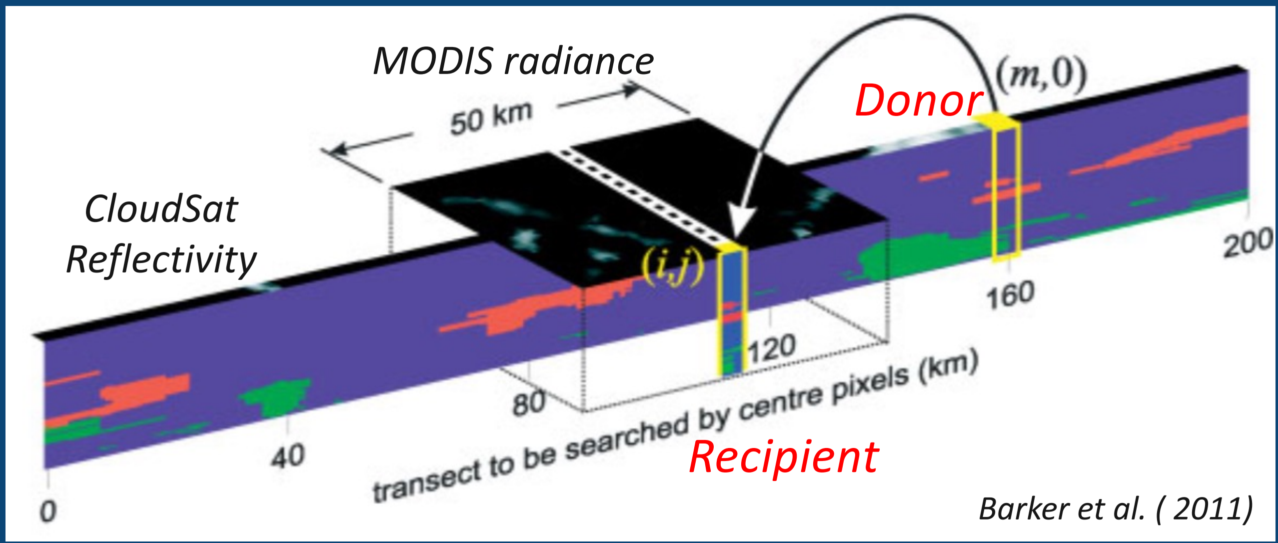
Various cloud organizations



3D Cloud Observations

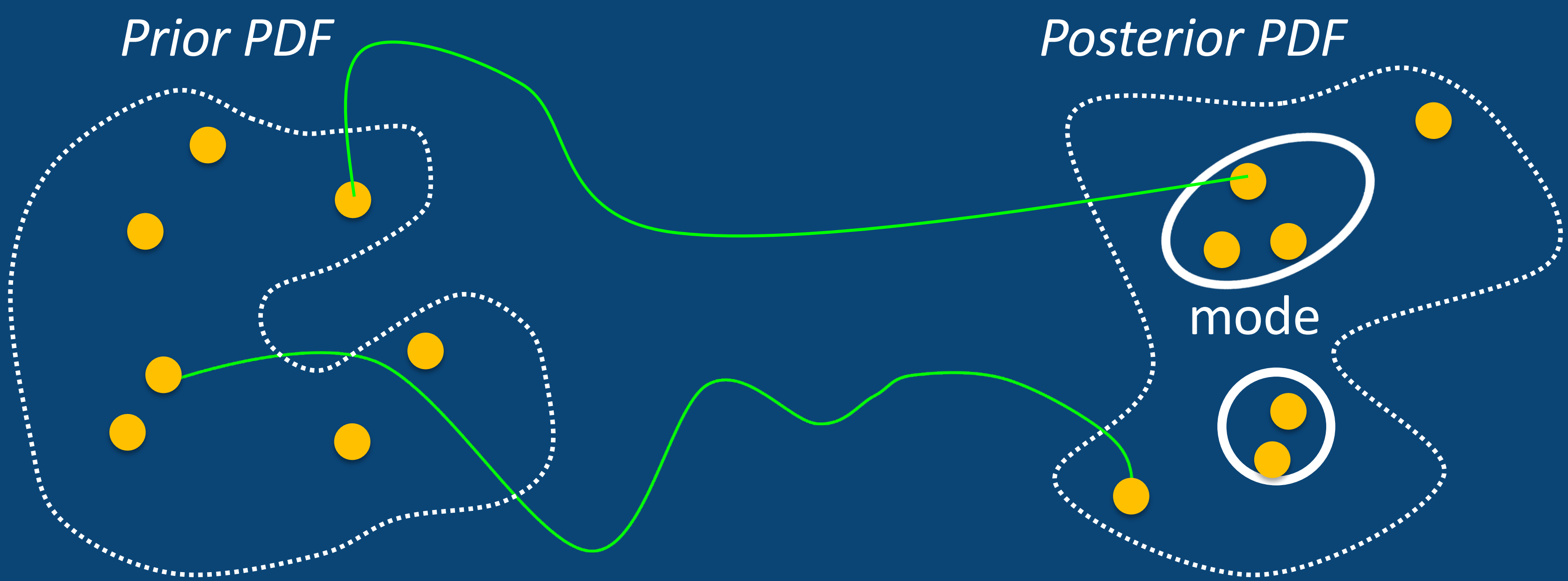
Our approach for retrieving 3D cloud properties

- Combining spaceborne shortwave reflectance and radar reflectivity measurements
- Directly incorporate 3D radiative transfer during the retrieval process
- Use a particle flow retrieval framework



Key advantage of Particle flow method

- It is all about uncertainty!
- Particle flow provides us a complete posterior pdf of retrievals even in a nonlinear system



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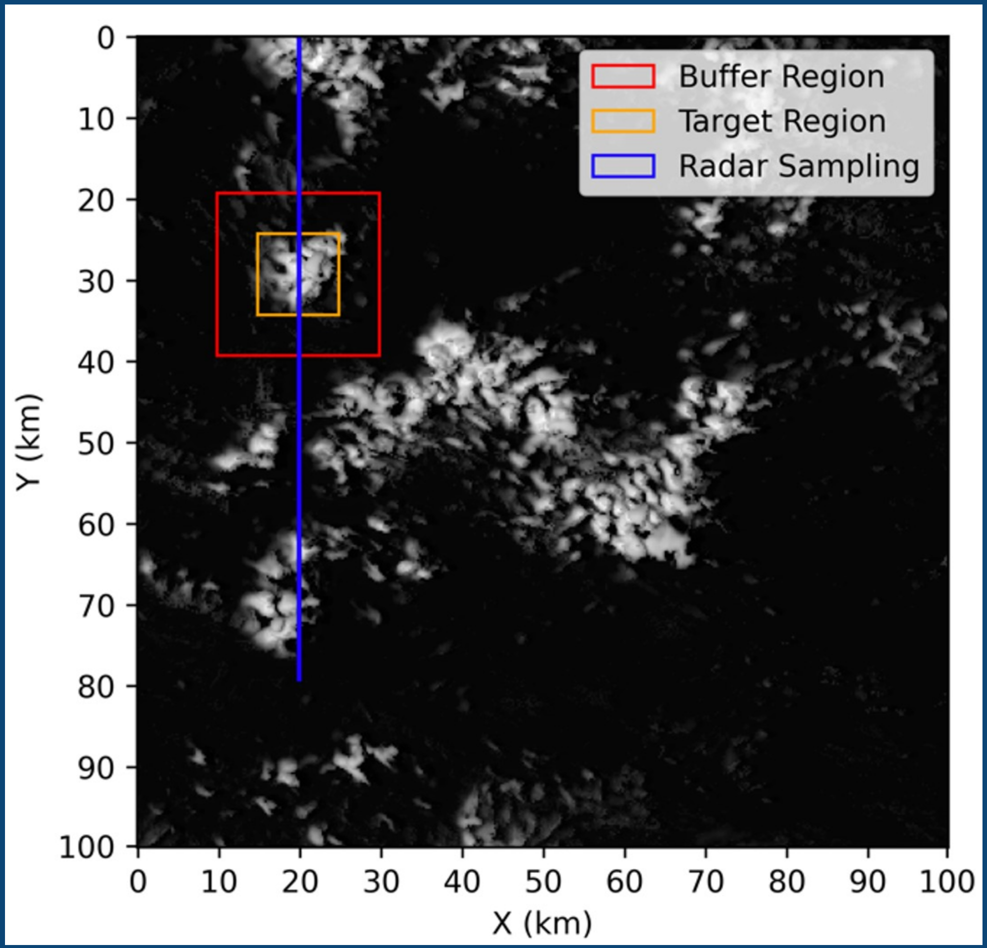
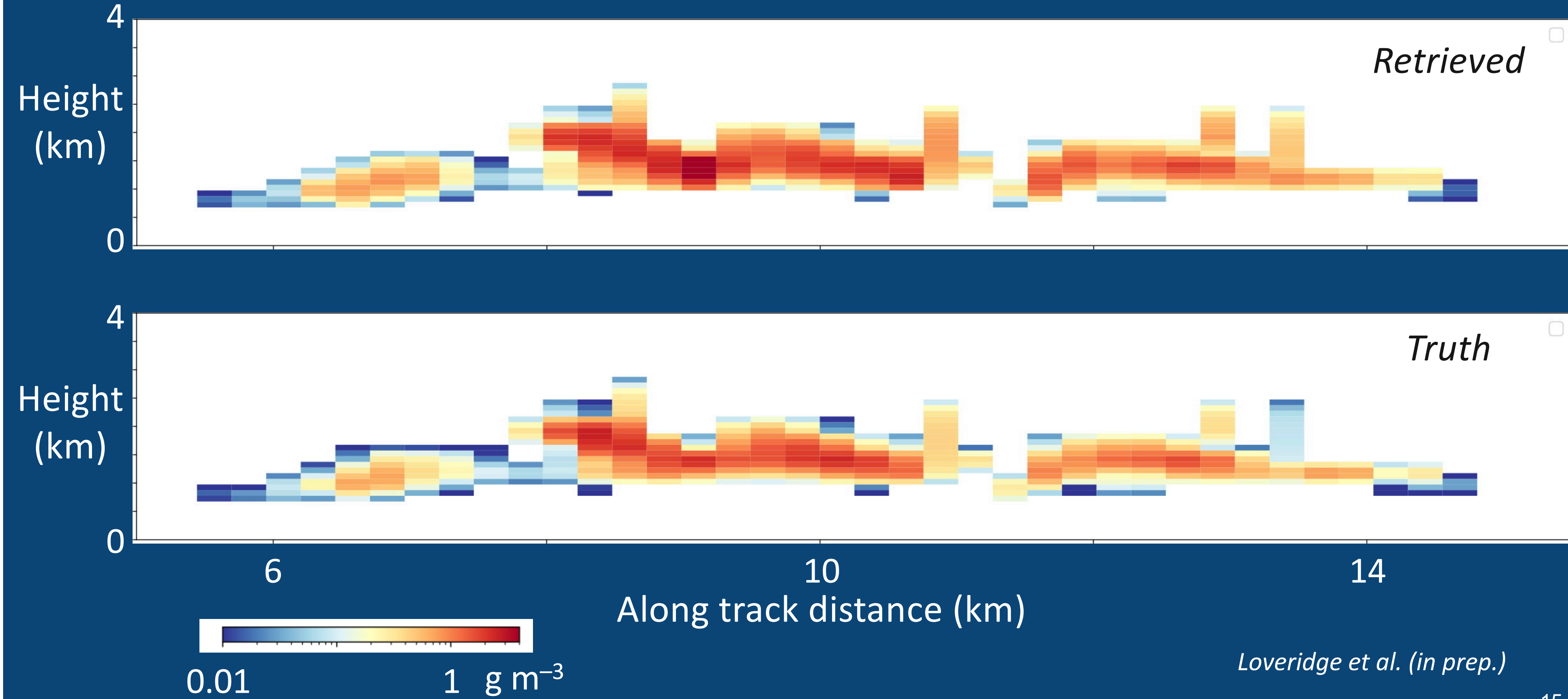
Apply the particle flow retrieval method to one of EarthCARE test scenes

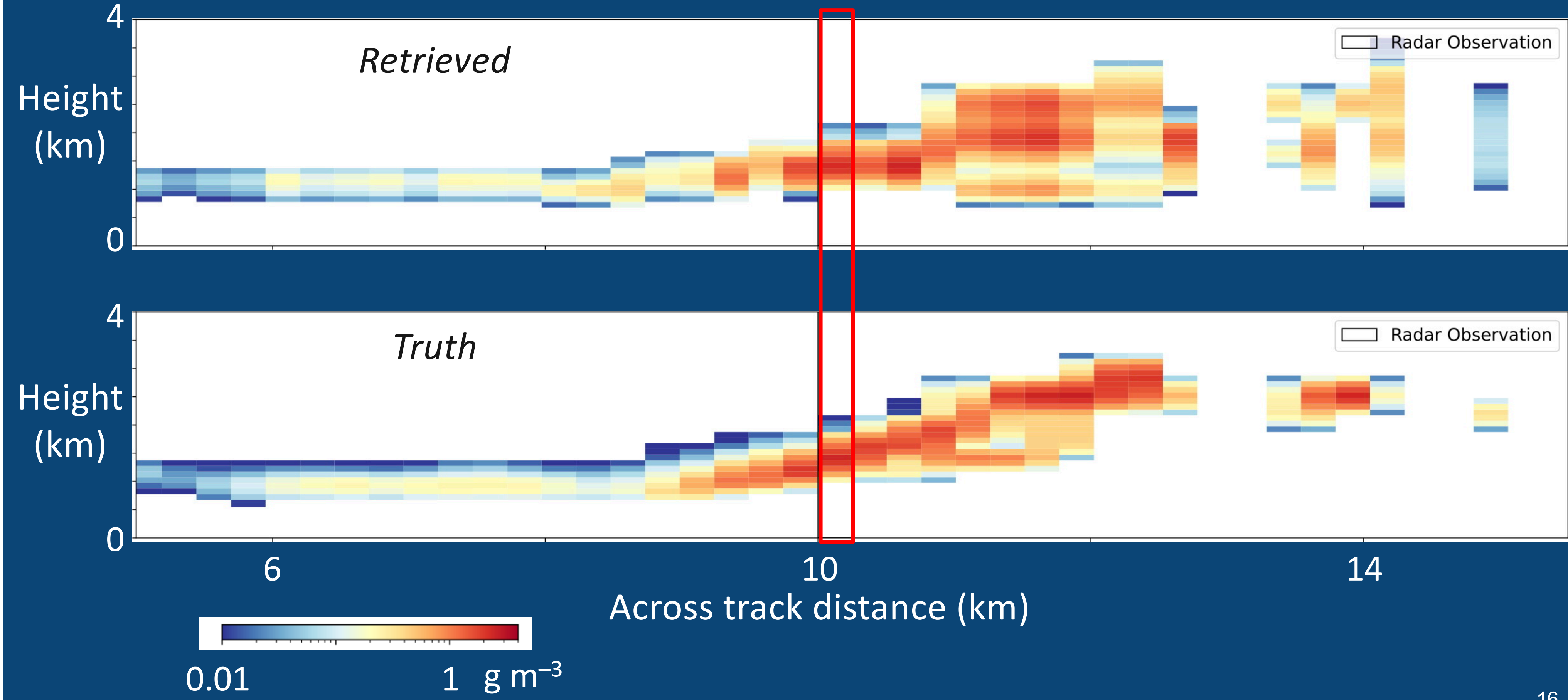


Liquid water content along track

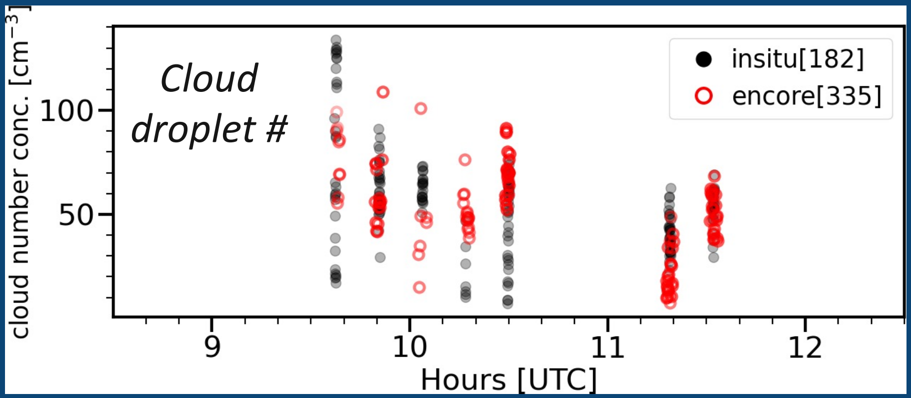


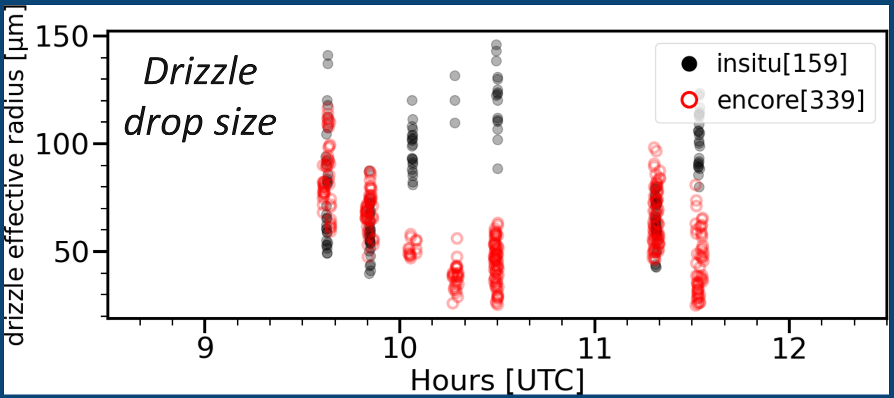
Loveridge et al. (in prep.)

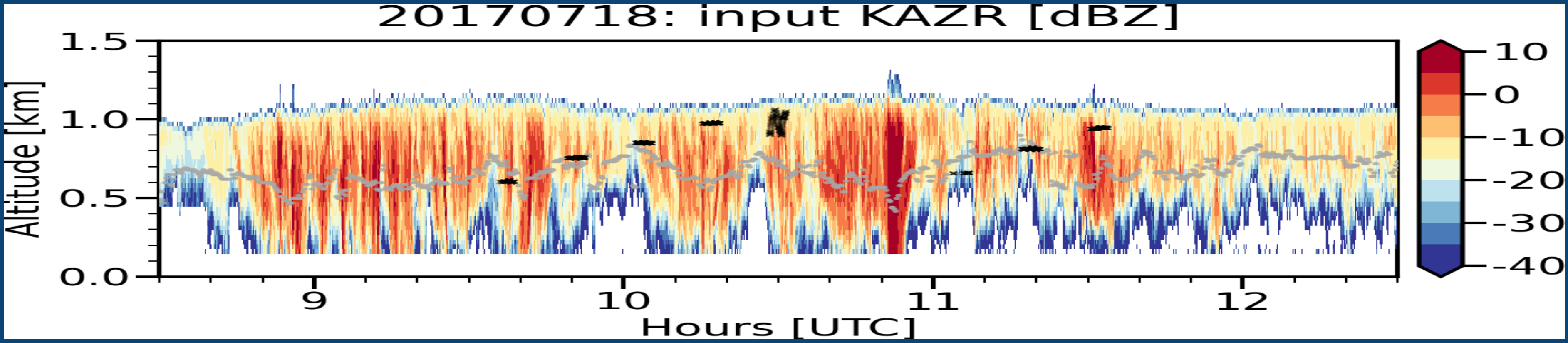
Liquid water content across track



Retrieving concurrent species is challenging

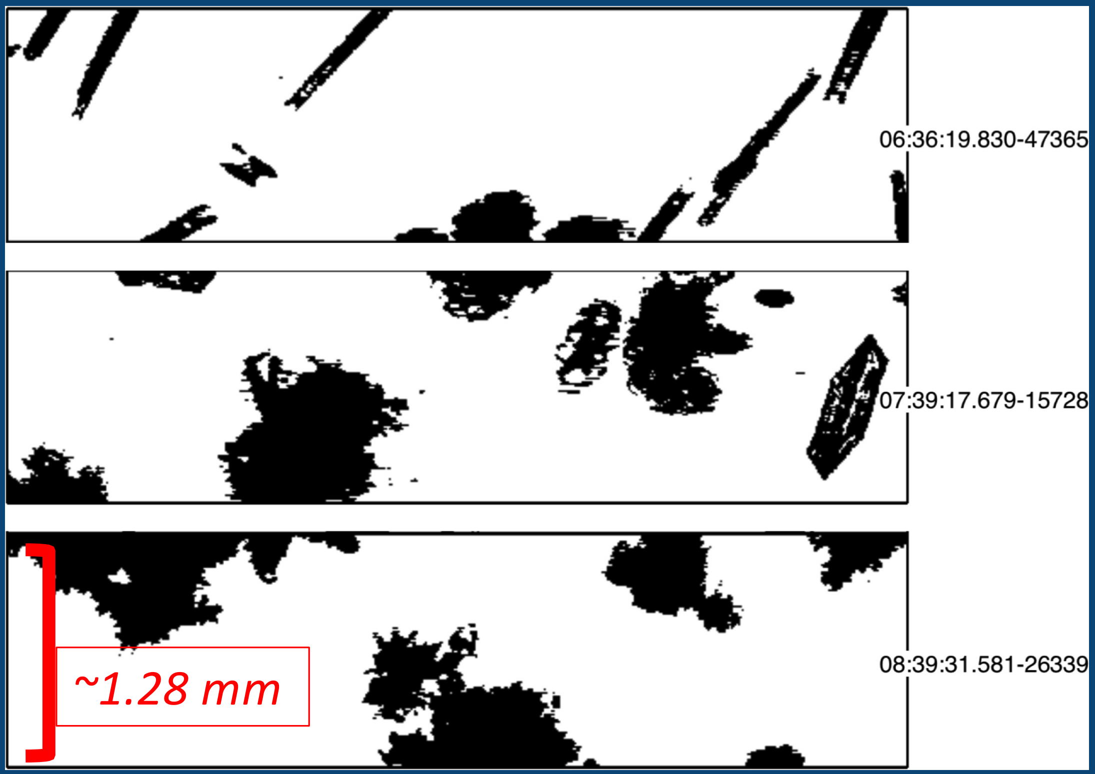


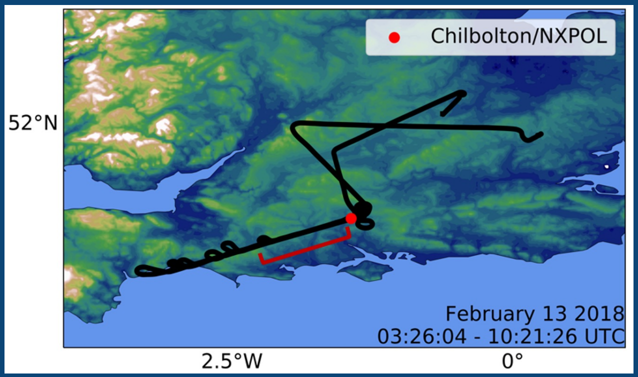




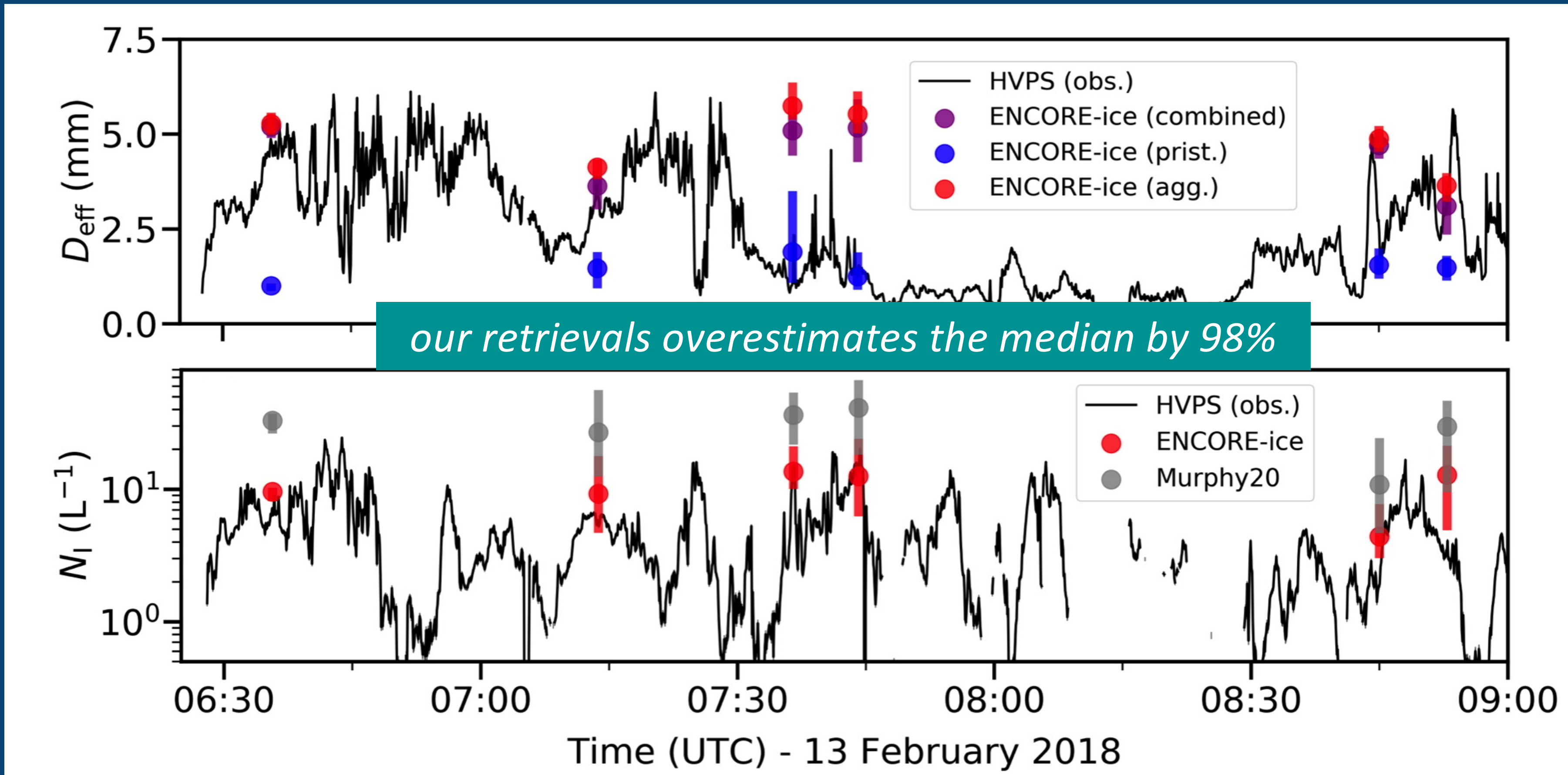
Hung et al. (in prep.)

In-situ cloud measurements from UK PICASSO campaign





Evaluating ice number concentration

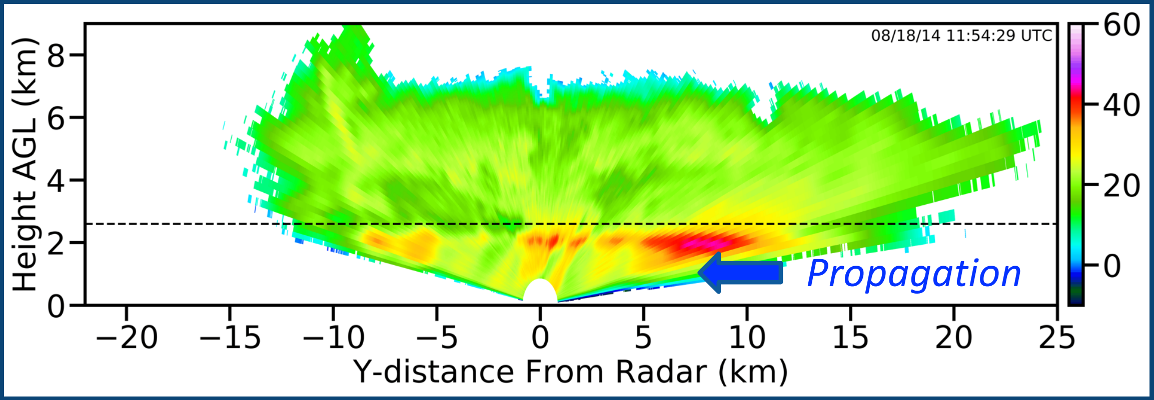


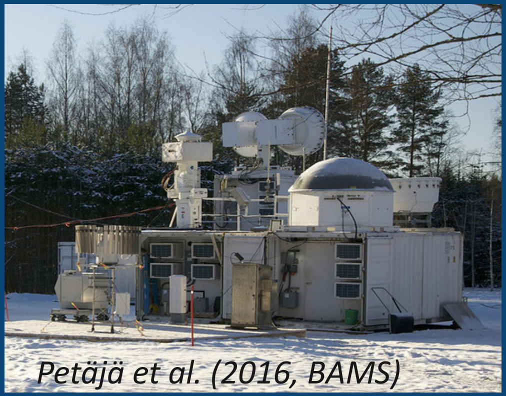
our retrievals overestimates the median by 98%

Kedzuf et al. (AMT, 2021)

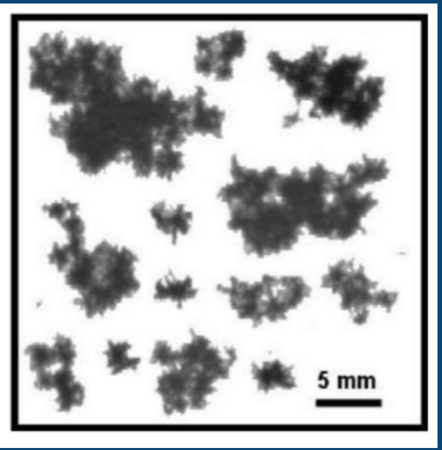
ARM BAECC campaign in Finland 2014

- surface "in-situ" observations are available
- Along-wind X-band radar scans for studying microphysical processes in a Lagrangian sense
- Comprehensive aerosol measurements for predicting primary ice # concentration





Petäjä et al. (2016, BAMS)



Kneifel et al. (JGR, 2015)

Next steps for better observing cloud/precipitation microphysics (property and process)

- Deploy dedicated, coordinated field campaigns (various platforms)
- Develop the capability to observe 3D cloud fields (from the ground and space) that allow Lagrangian analyses
- Define clearer science requirements for key aerosol, cloud and precipitation observables
- Improve quantification of retrieval uncertainty
- Incorporate retrieval uncertainty in analyzing data and constraining models