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Profiling Supercooled Liquid Water Clouds with Multi-Frequency Radar

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Motivation

Mixed-phase clouds are an important variable in the Earth system

- Important component in microphysical processes
- Key parameter in climate radiation budget
- Impactful condition in aviation safety

Quantification of mixed-phase clouds on wide scales lacking

- Ground-based radar/lidar combinations provide some information
  - Observations are localized, e.g., Barrow, Alaska
  - Droplets typically at or below radar detectability limits
  - Lidar returns rapidly extinguished by liquid

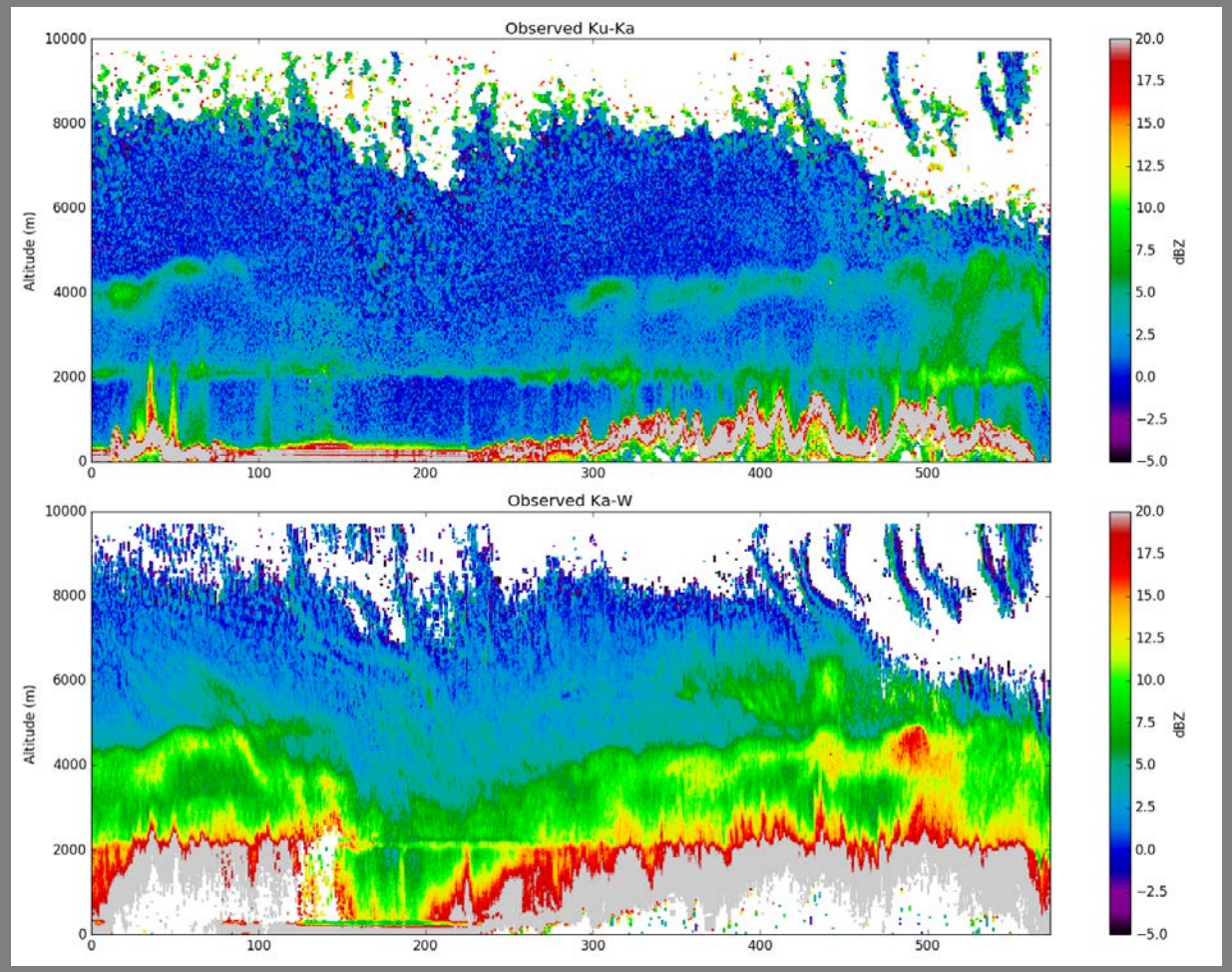
Approach

Exploit differential measurements

- Backscatter (Rayleigh vs. non)
- Extinction (mainly gasses, cloud)

Multiparameter estimation

- Mass-weighted mean size (D_m)
- Precipitation water content
- Cloud water content
- Pristine / aggregate fraction



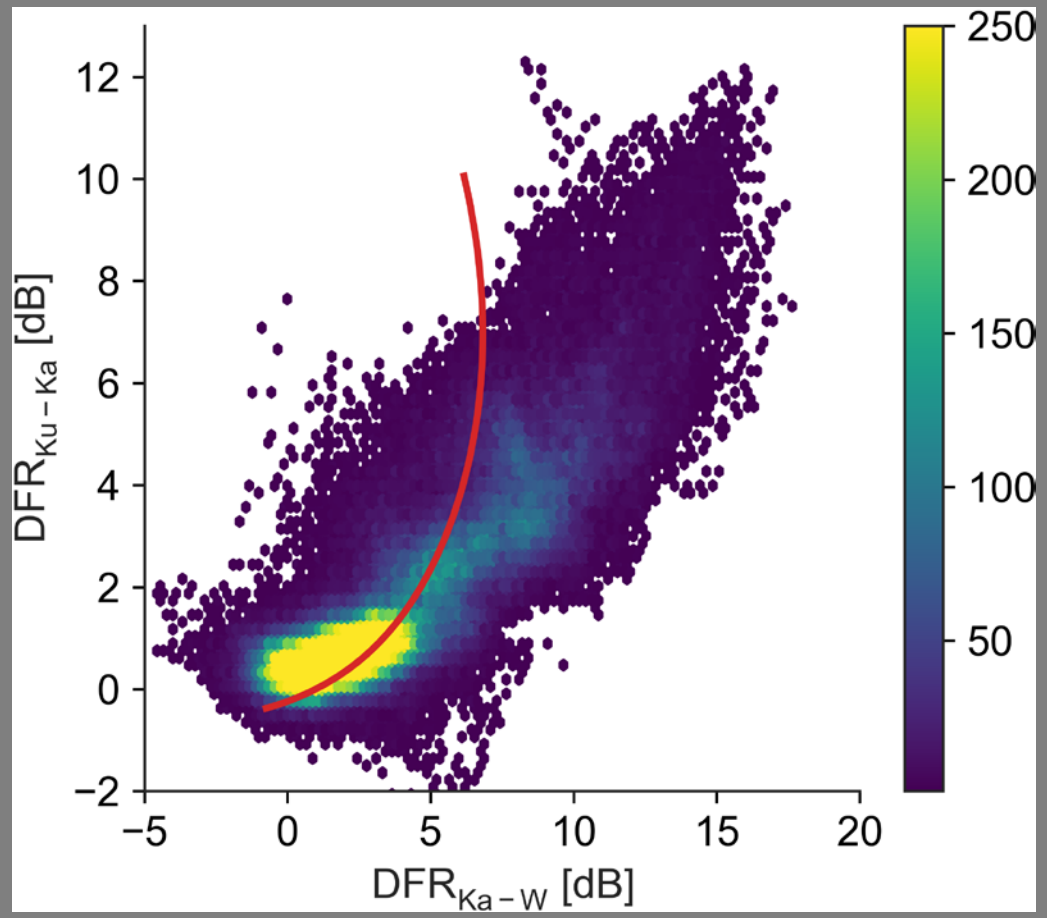
Phenomenology

Triple frequency space

- Particle density
- Extinction

Consistent forward modeling

- Scattering tables
- Rosenkranz gas absorption
  - Move to HITRAN + MT_CKD (AER)
- Liquid Permittivity (Turner et al. 2016)



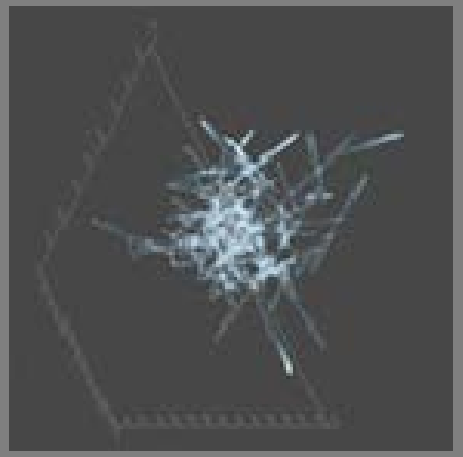
https://storm.pps.eosdis.nasa.gov/storm/OpenSSP.jsp

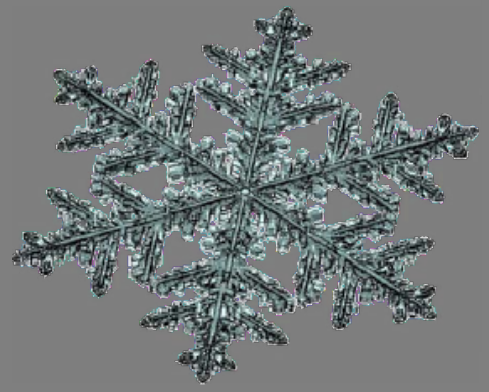
Scattering Tables

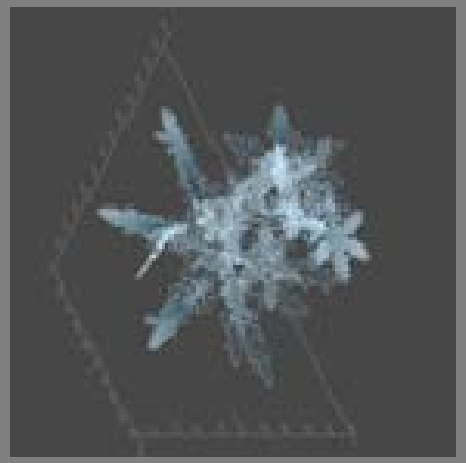
https://storm.pps.eosdis.nasa.gov/storm/OpenSSP.jsp

Consistent hydrometeor scattering tables are necessary for consistent forward modeling of multi-frequency observations

- Depositional growth model
  - Reproduces planar and columnar geometries found in nature
- Aggregation performed heuristically
  - Randomly oriented
- Horizontally-oriented plates
  - T-matrix







Olympic Mountains Experiment (OLYMPEX)

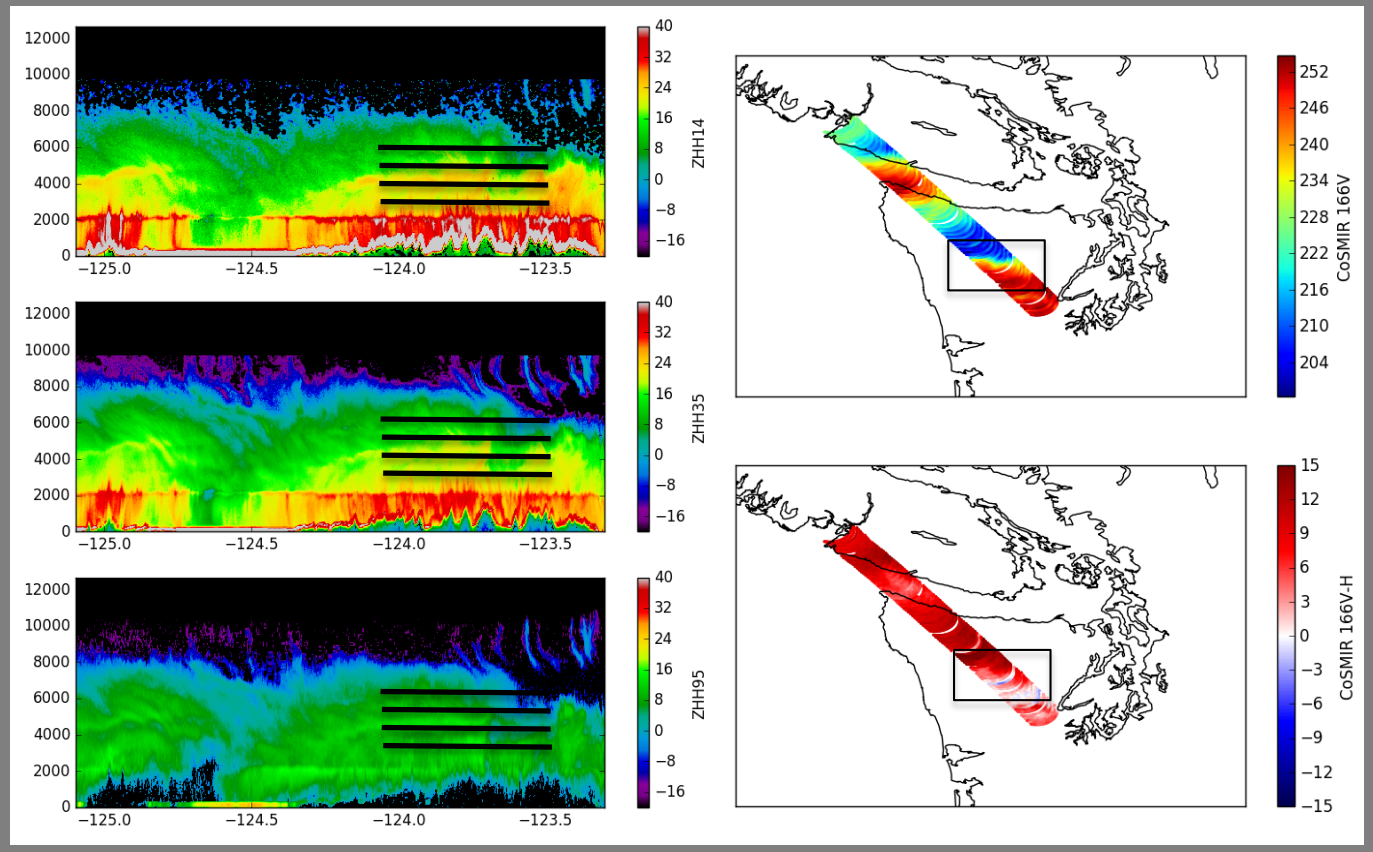
DC-8	Citation	ER-2 (Radar Definition Experiment)
CoSMIR 50, 89, 165, 183 +/- 1, 3, 8 GHz Conical and cross track scans Fixed polarization basis	**King Hot Wire Probe** LWC	**AMPR** 10.7, 19.35, 37.1, 85.5 GHz
	CDP Cloud droplet size distribution	**HIWRAP** Ku, Ka bands; Nadir pointing
	2D-S Particle images	**CRS** W band; Nadir pointing
APR-3 Ku, Ka, W band (dual polarization) Cross-track scan	**HVPS-3 (x2)** Particle images	**EXRAD** X band; Nadir pointing; Conical scan
	Cloud Particle Imager (CPI)	**AirMSPI** 8 bands (355-935 nm)
	CSI Cloud water content	**CPL** 355, 532, 1064 nm
Dropsondes Pressure Temperature Relative humidity Wind	**2DC** Particle images	**eMAS** 38 bands (0.4-15 µm)
	Nevzorov Total water content	
	Rosemonunt Icing Probe	

OLYPEX Case Study

03 December 2015

- DC-8 and ER-2 flights
  - Focus on APR-3 (DC-8)
- Citation
  - Stacked microphysics legs
  - Qualitative comparisons
  - Range of frozen habits
  - Presence of supercooled liquid clouds

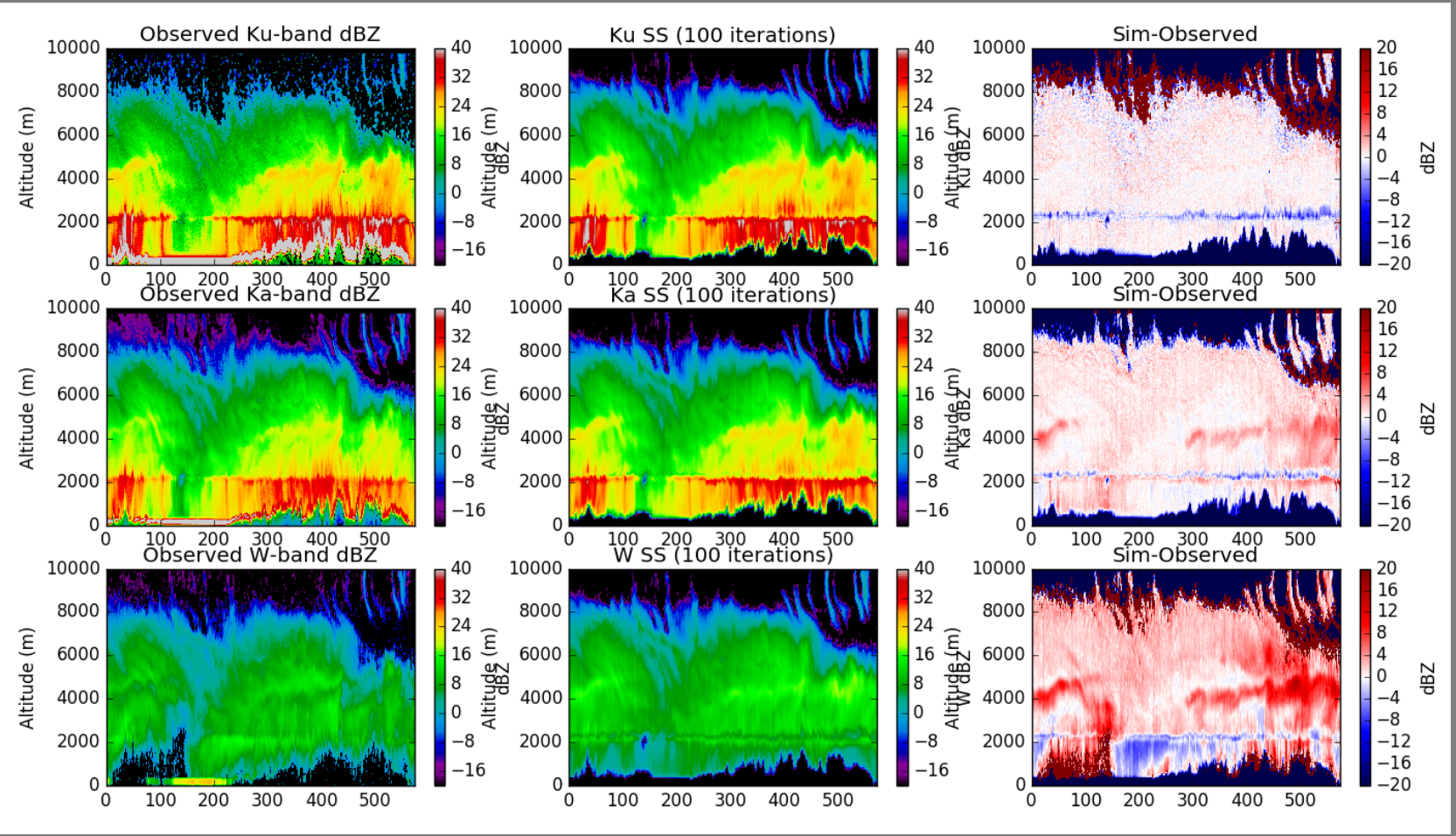
APR-3 CoSMIR



Baseline Microphysics

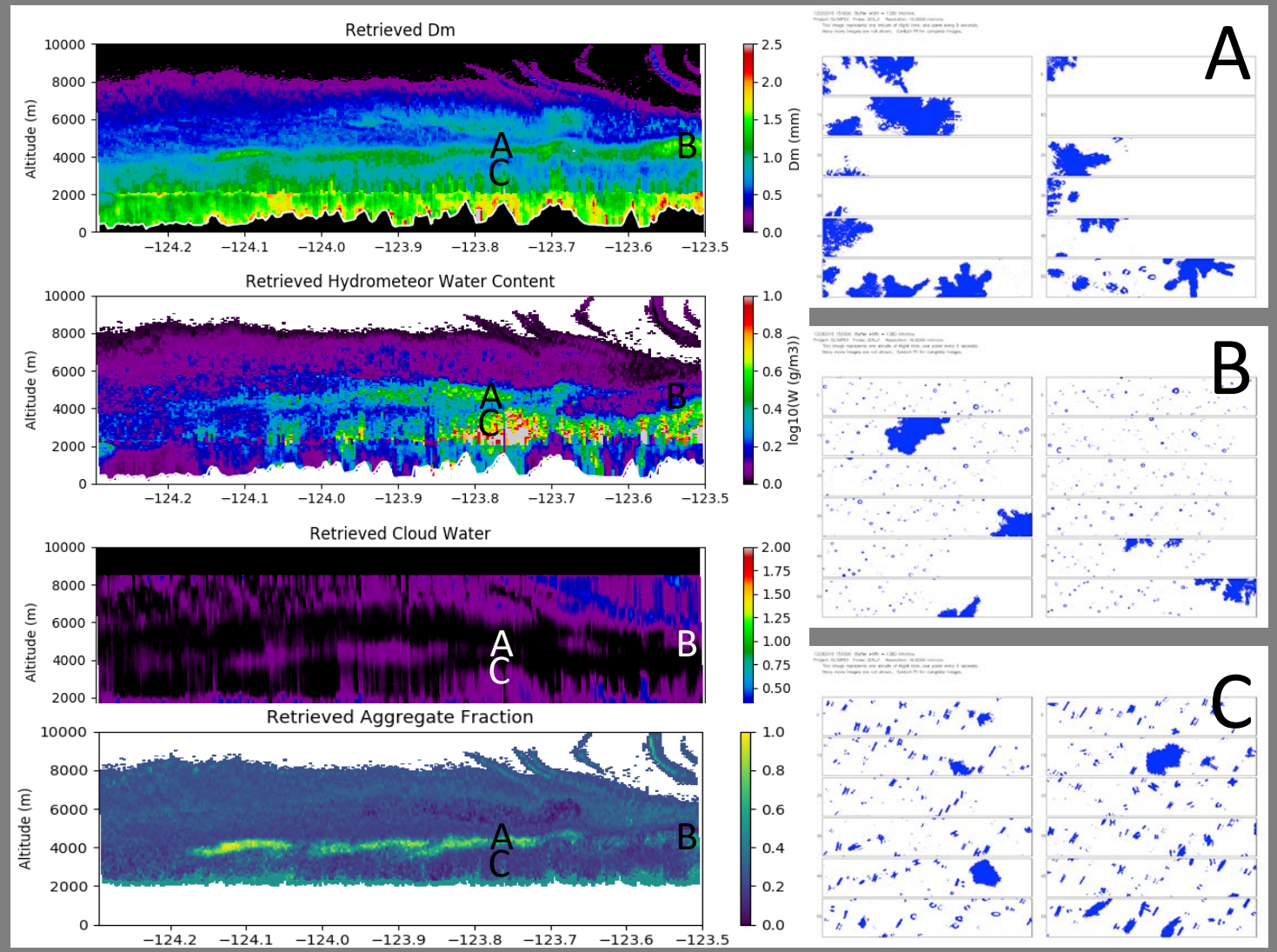
Hitschfeld-Bordan retrieval (1954)

- Estimate D_m
  - Temperature dependent
- Default N_w profile
  - Depends on D_m
- 50% aggregate / pristine mix
- Mean profiles
  - Temperature
  - Water vapor
  - Cloud liquid water



Results

- Retrievals match probes
  - Good qualitative match
- Bands of increased reflectivity correspond to large D_m and high aggregate fraction
- Significant amounts of supercooled liquid water



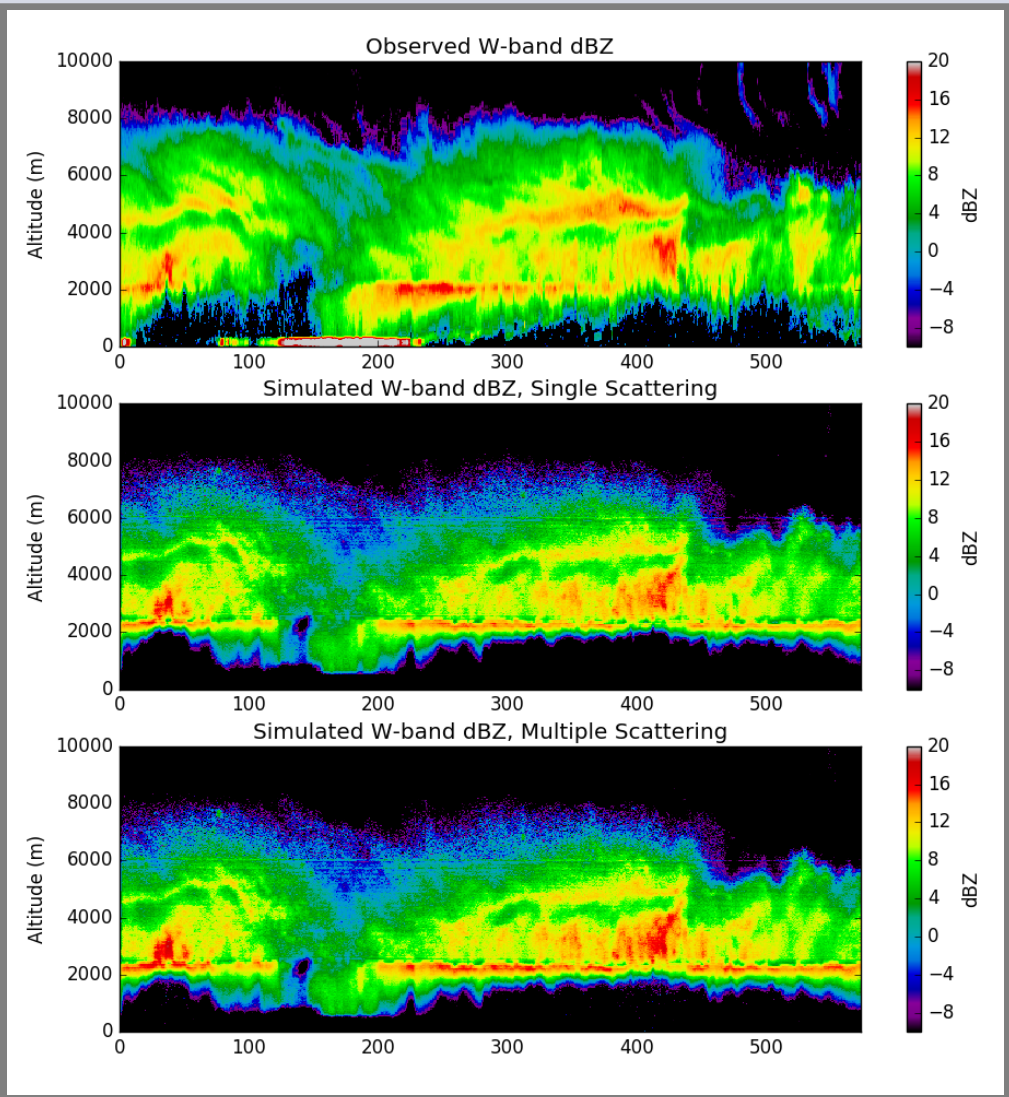
Beyond 1D Radar Retrievals

Three-dimensional effects not usually an issue for narrow radar beams; multiple scattering enhancement apparent at W-band

- Spatially dependent phenomenon

Additional information in polarimetric observations

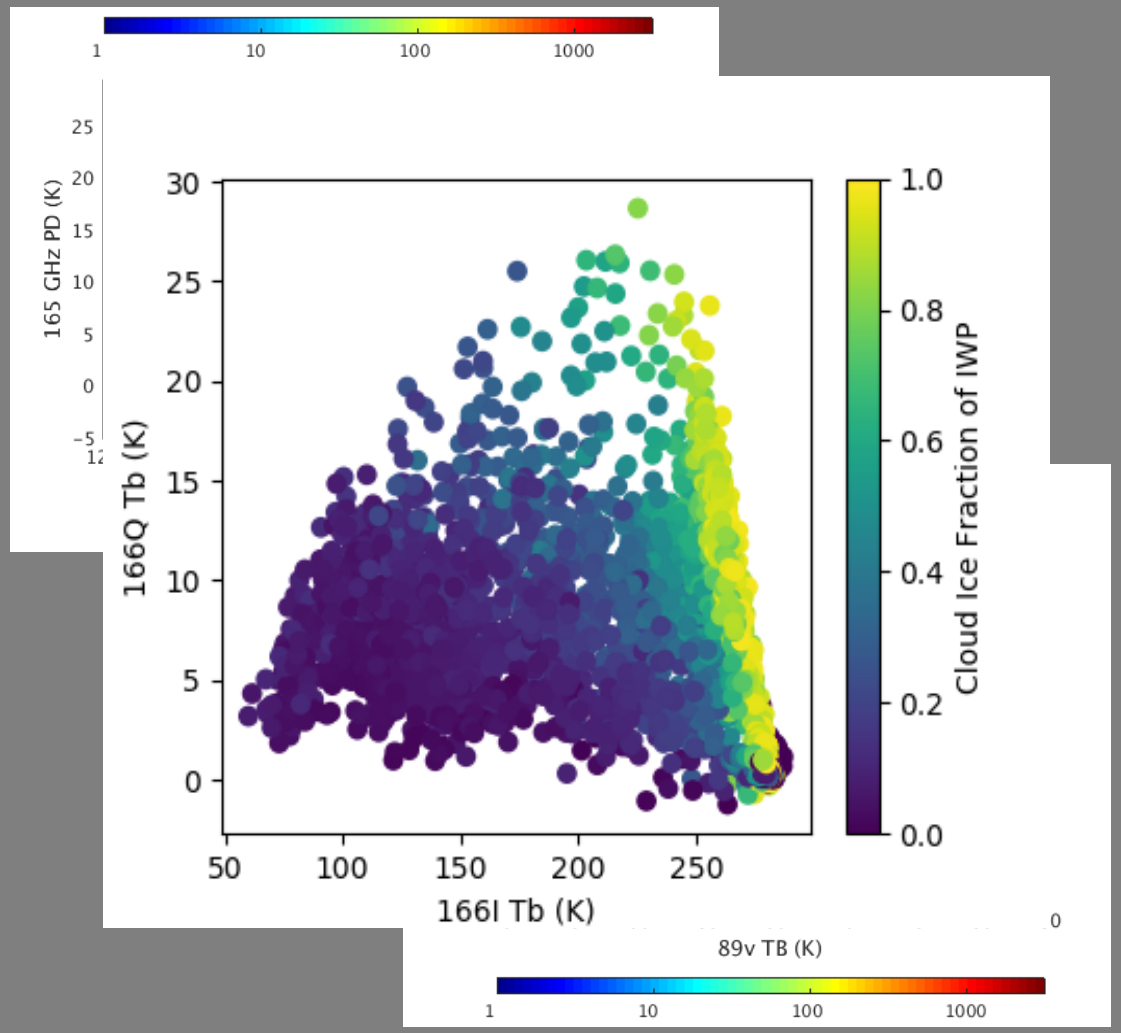
- Particle alignment
- Hydrometeor discrimination
- Melting layer



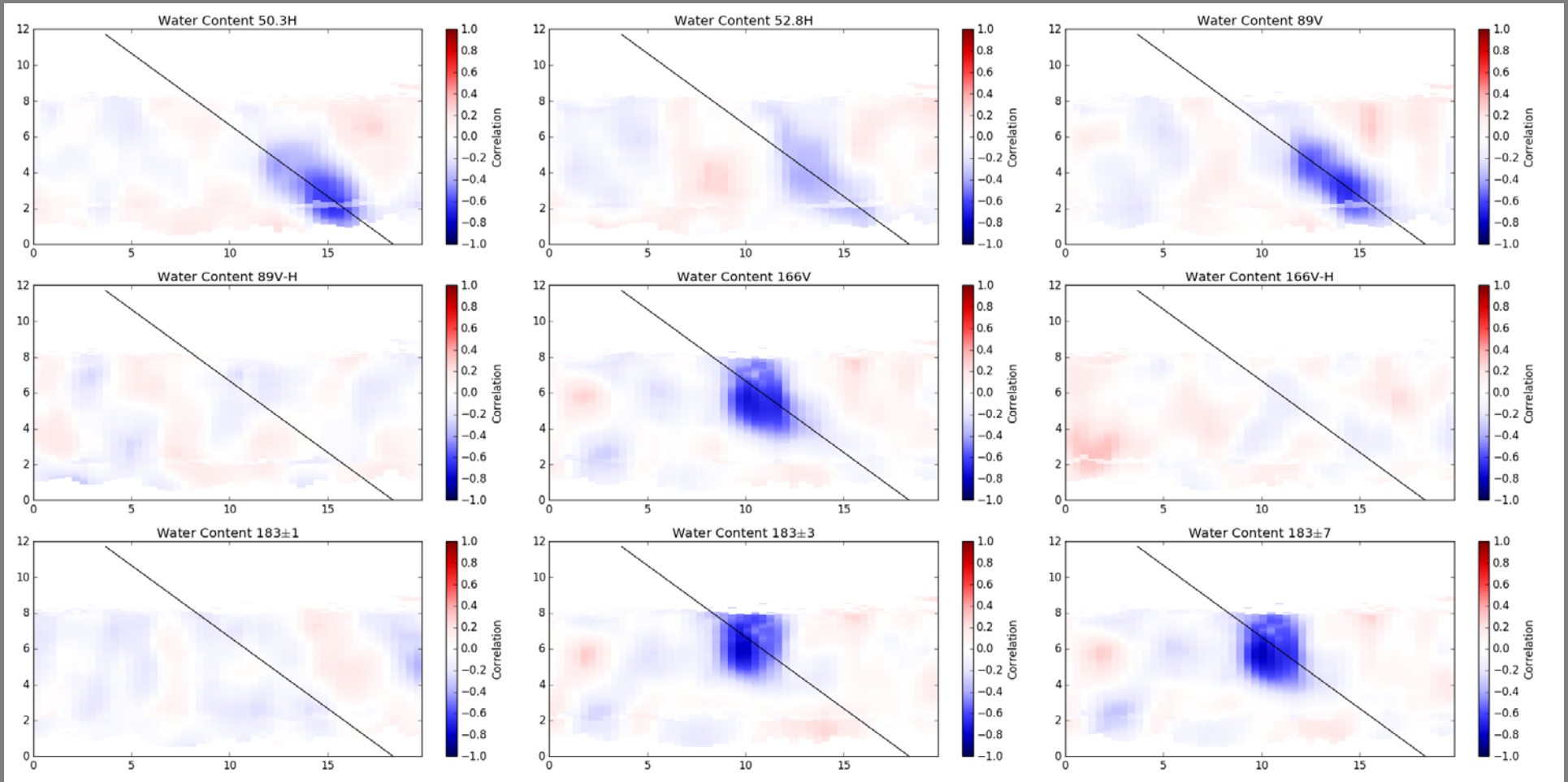
Radiometers

Polarized mmwave brightness temperatures provide additional information on clouds and snow

- Aligned oblate/prolate particles
- Randomly oriented or small aspect ratio
- Differentiation between stratiform and deep convection
- Damping of polarization due to liquid water clouds (Panegrossi et al. 2017)



CoSSIR T_b-W Correlations



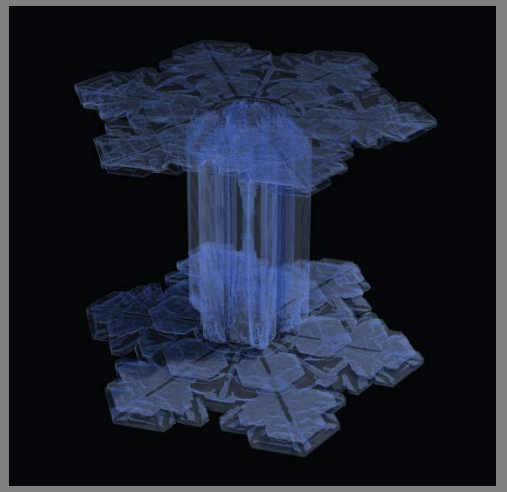
Summary

Mulit-frequency radar retrievals

- Partitioning of hydrometeor species
  - Pristine
  - Aggregates
  - Cloud liquid
- Good qualitative agreement with in situ probe data

Additional information in polarized brightness temperatures

- Aligned versus randomly oriented particles
- Presence of supercooled liquid
  - Liquid at cloud tops

Future work

- Other OLYMPEX cases
  - Interesting microphysics
    - Riming
    - Polycrystals
- Multi-platform observations
  - CRS/HIWRAP on ER-2
- Melting particles
- Aligned ice
  - Scattering using IITM
- Other field campaigns
  - MC3E
  - IPHEx