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
  o Observations are localized, e.g., Barrow, Alaska
  o Droplets typically at or below radar detectability limits
  o 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
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

https://storm.pps.eosdis.nasa.gov/storm/OpenSSP.jsp
## Olympic Mountains Experiment (OLYMPEX)

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

87/25/18 IGARSS 2018
Results

• Retrievals match probes
  o 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

Multifrequency radar retrievals

• Partitioning of hydrometeor species
  o Pristine
  o Aggregates
  o 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
  o Liquid at cloud tops
Future work

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