

Multi-frequency Radar Analysis using NASA GPM Ground Validation Observations

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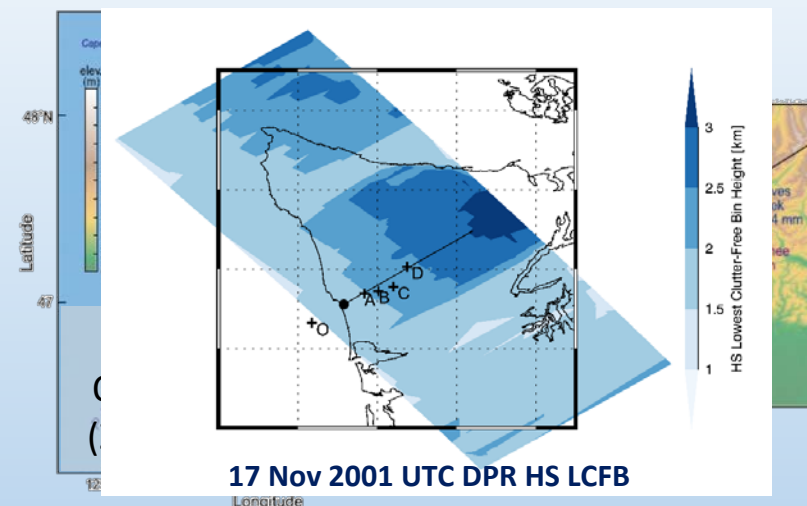


Image: Stacy Brodzik



Motivation

- GPM GV Observation Diversity
 - Core Observatory
 - Constellation Partners
 - Field Campaigns

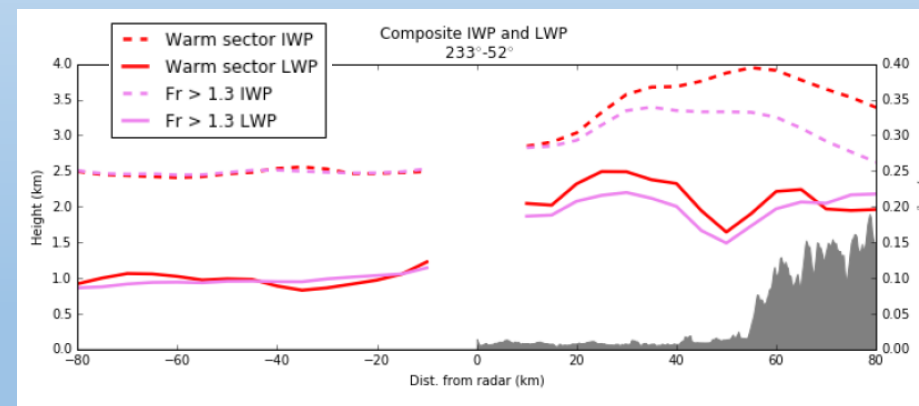


Goals:

Focus on OLYMPEX

Atmospheric River (AR) Events:

- Integrative approach/building atmospheric column
 - DPR LCFB often above 0°C in high terrain
- Compositing vertical slices
- Multi-frequency analysis via ground-based radars



Land/topo **impact ice/liquid** precipitation processes – **unblocked (large Froude) & warm sector** flow regimes (Hunzinger 2018/Petersen et al. 2018)

Methodology

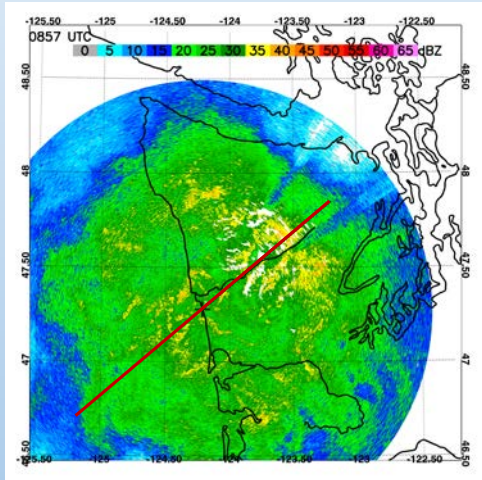
Case Criteria

- ARs with unblocked terrain-normal component flow: $WS, Fr > 1.3$
(Hunzinger 2018/Petersen et al. 2018)
- 6 AR cases, 8 GPM OPs
 - 13 Nov 03-00 UTC (20%)
 - **17 Nov 10-21UTC (10%)**
 - **3 Dec 14-00 UTC (10%)**
 - 6-7 Dec 00-02 UTC (25%)
 - 8-9 Dec 13-10 UTC (20%)
 - 17 Dec 08-00 UTC (15%)

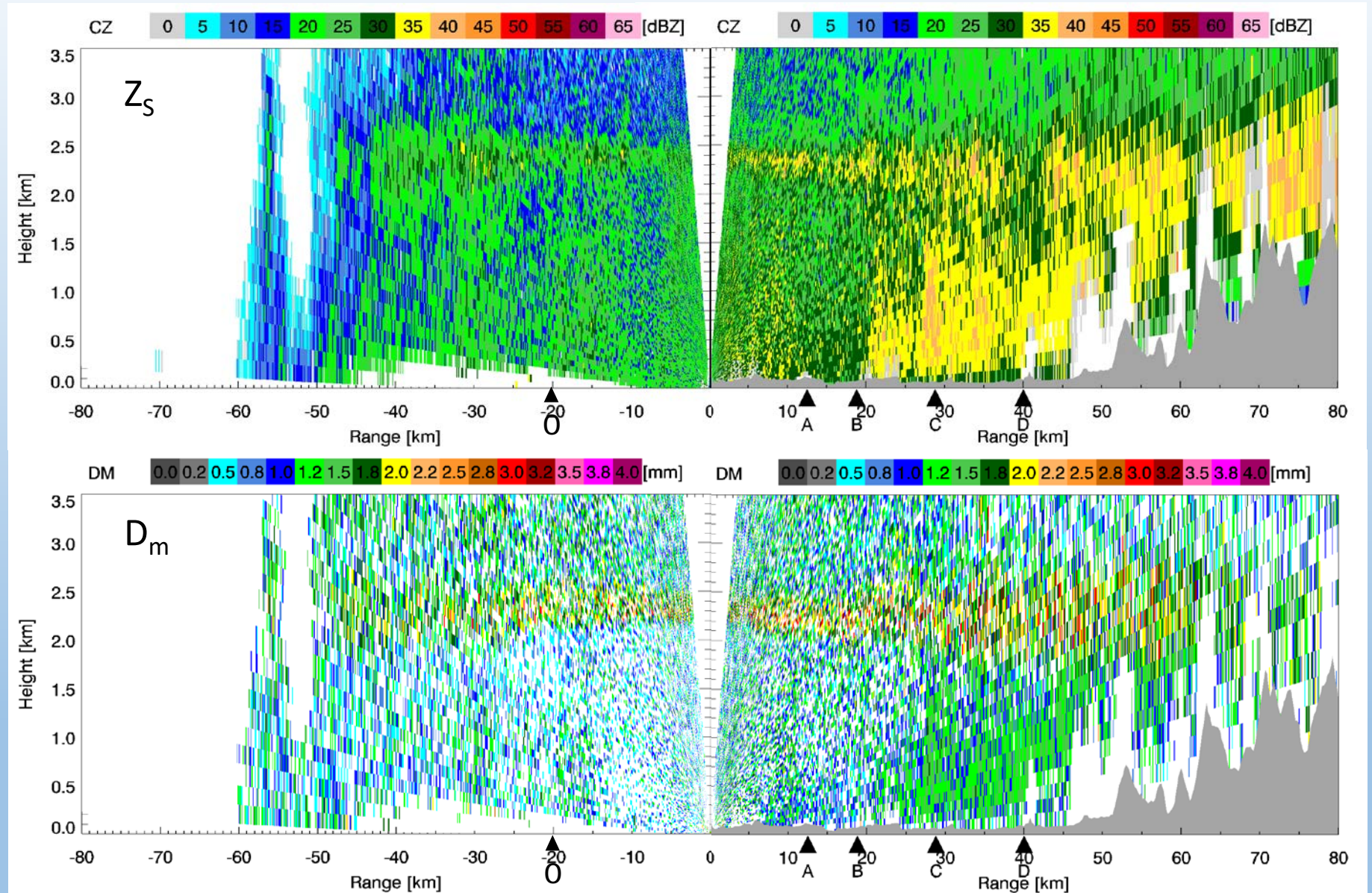
Analysis:

- Vertical slice composites:
 - Z, D_m, RR
- Dual-frequency ratios:
 - NPOL (S-band) & D3R (Ku/Ka-band)
 - 150 x 200 m range-height grid spacing
- Parse results by:
 - NPOL-derived HID (Dolan et al. 2013)
 - LIQ: drizzle, rain, big drops
 - ICE: crystals, aggregates, hail
 - MIX: wet snow, graupel
 - Sea vs. terrain
 - Individual HID type classes

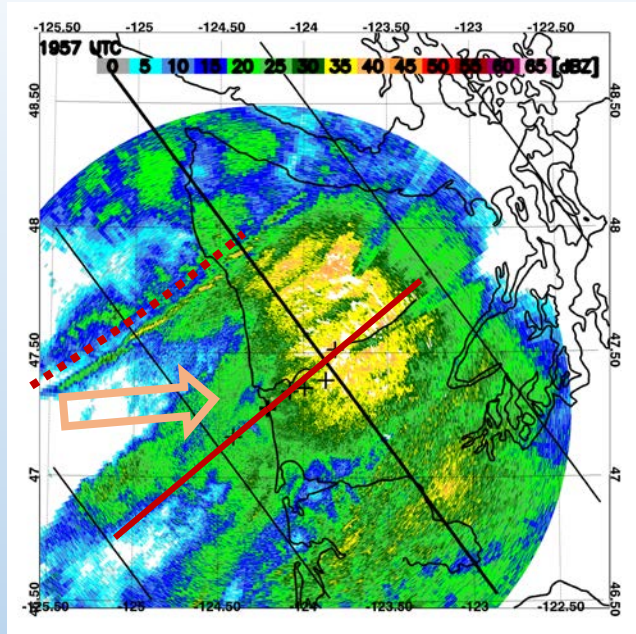
Composites over all ARs



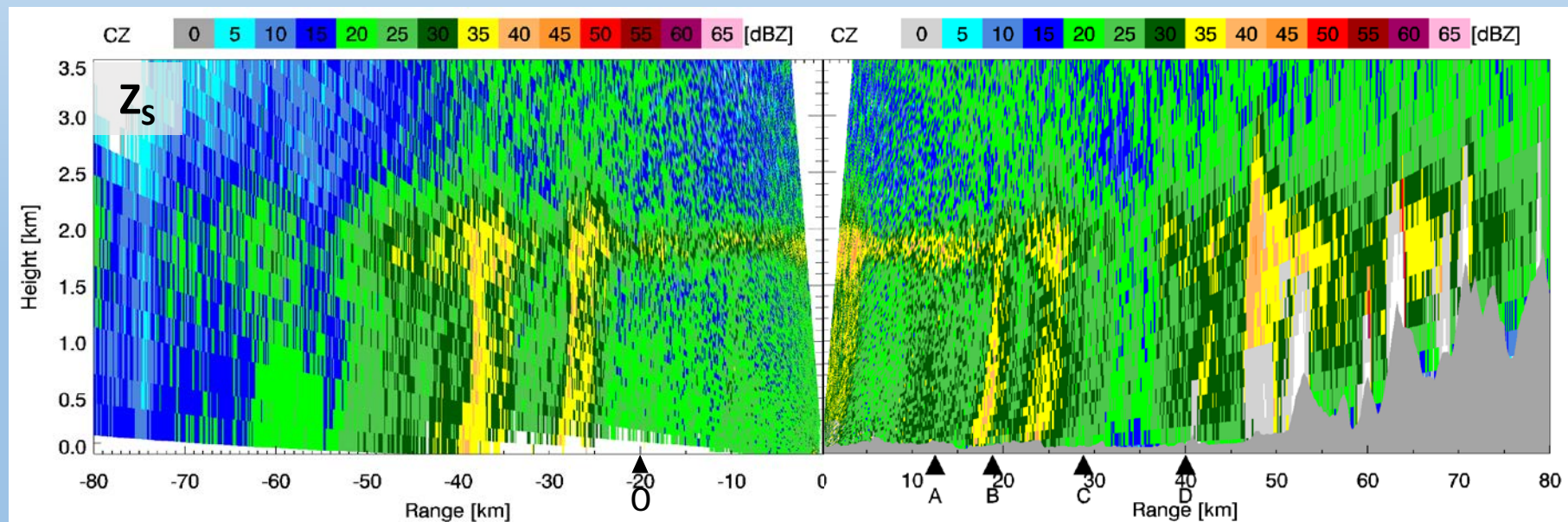
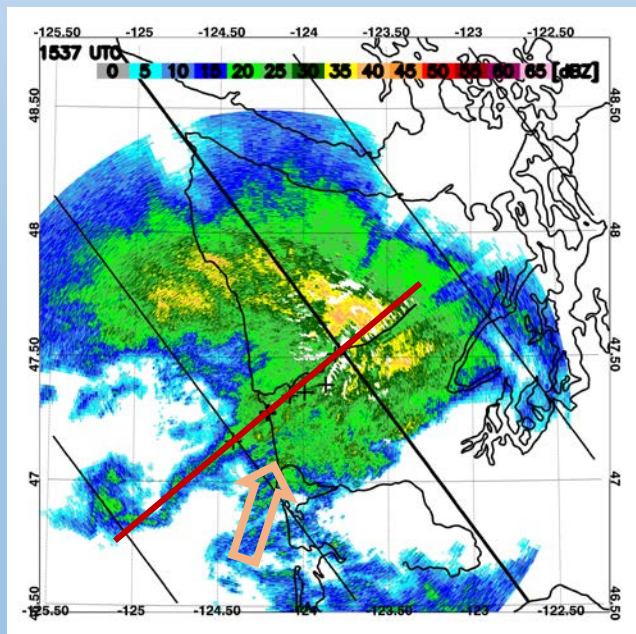
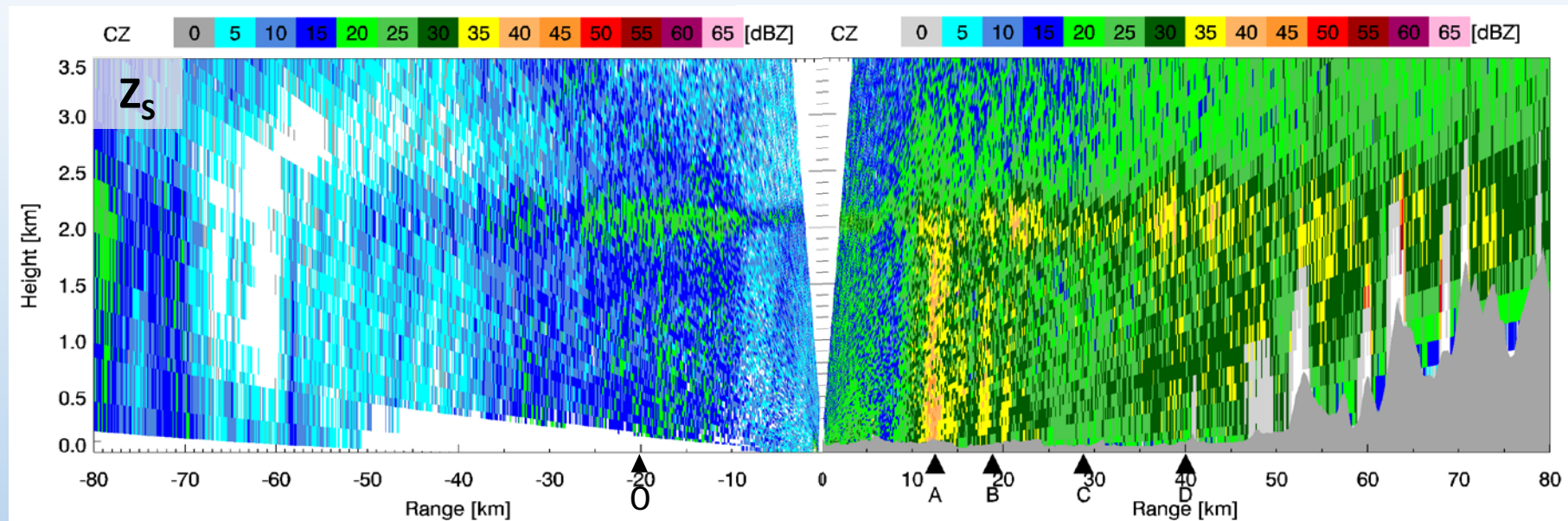
- Along NPOL RHI approaching, through Quinault River Valley
- Terrain, orographic enhancements



17 November 2015 10-21 UTC



Z_s – NPOL Composites



3 December 2015 14-00 UTC

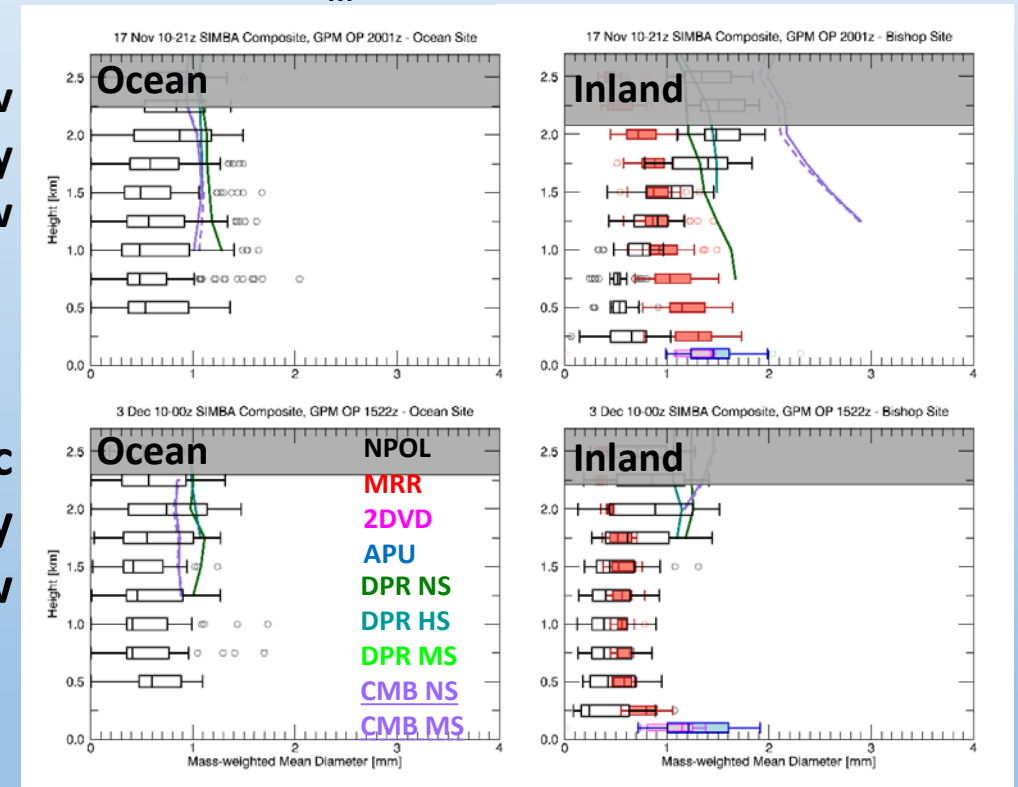
Why Dual-Frequency Ratios for the ARs?

- Previous work:
 - Column-based ARs analyses show best agreement among DPR, GMI, GV observations over ocean
 - Discrepancies increase:
 - As move **up valley/into more complex terrain**
 - **Terrain-normal flow magnitude**
- Precipitation processes & satellite observations involve more than below 0°C level

17 Nov
Westerly
flow

3 Dec
Southerly
flow

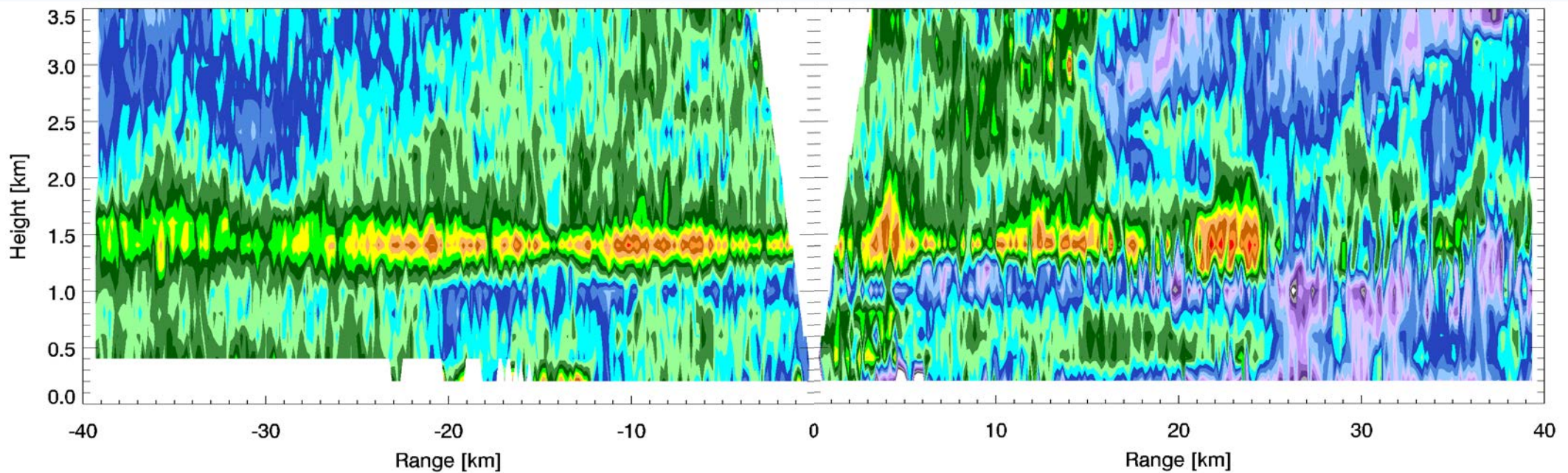
D_m Composite Profiles



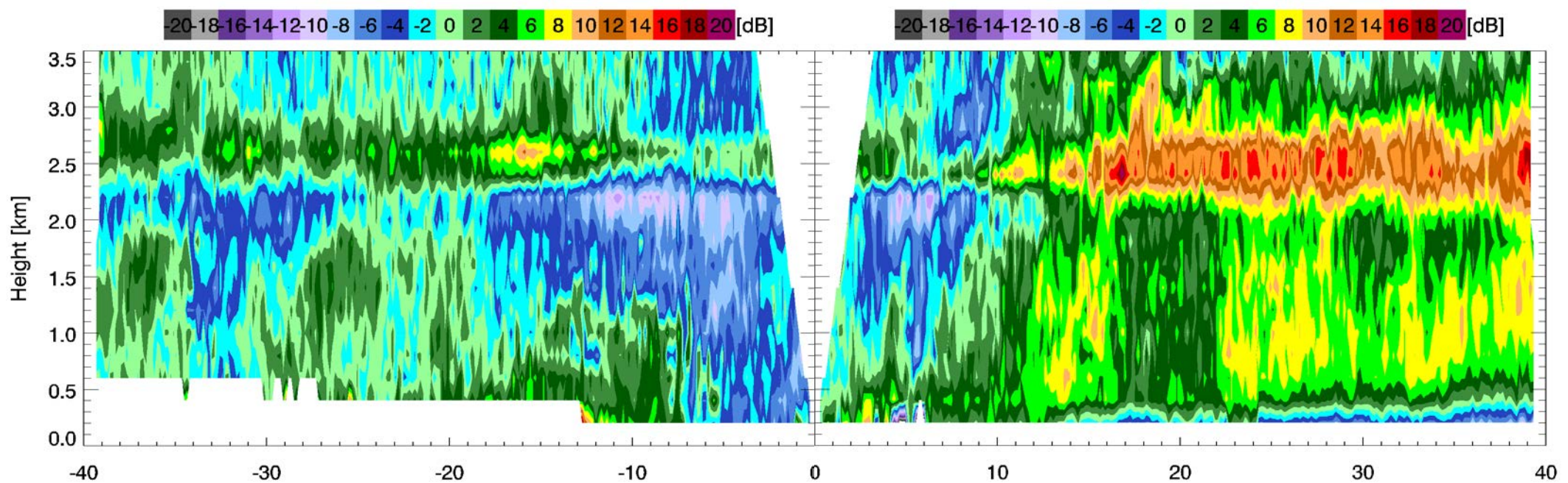
→ Importance of identifying & quantifying **ICE, LIQUID, and MIX** phase hydrometers to better discern processes, improve observing

DFR_{S-Ku} 2 Events

- S-Ku DFR composite, includes all NPOL HID types
- More ocean-side variation in westerly flow case
- DFR layering complexity increases as approach terrain

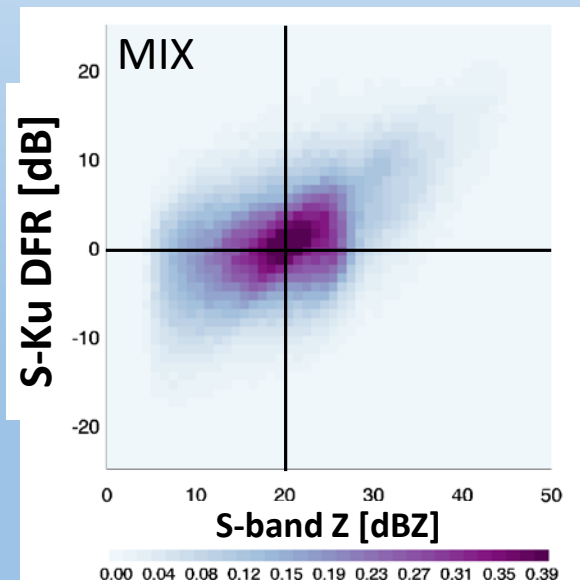
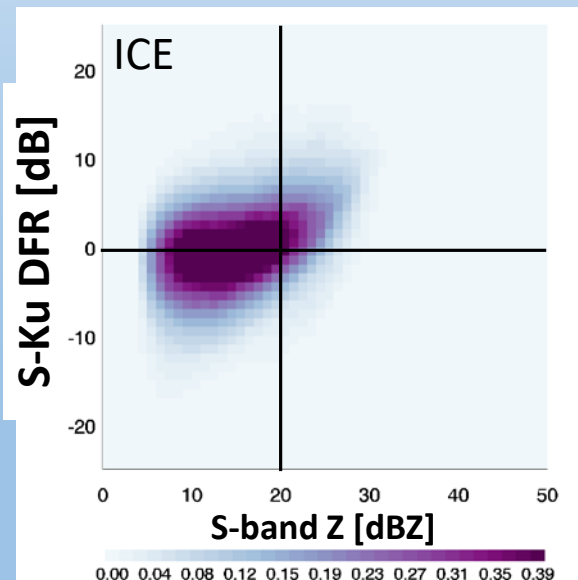
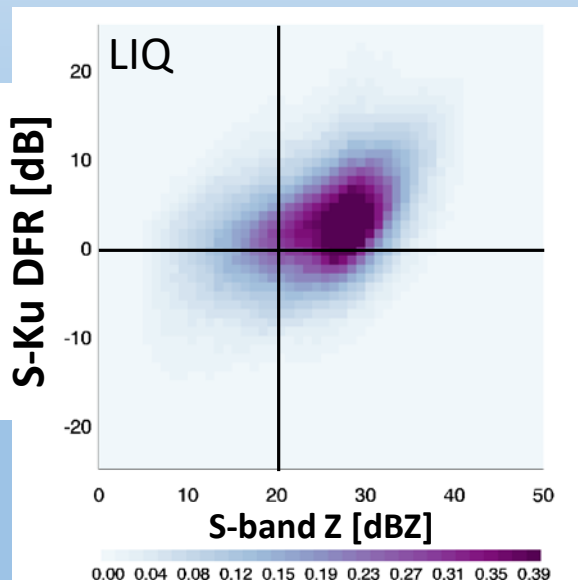
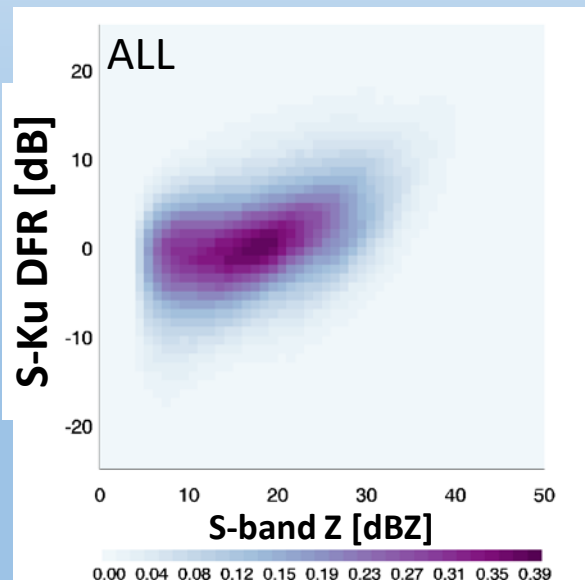
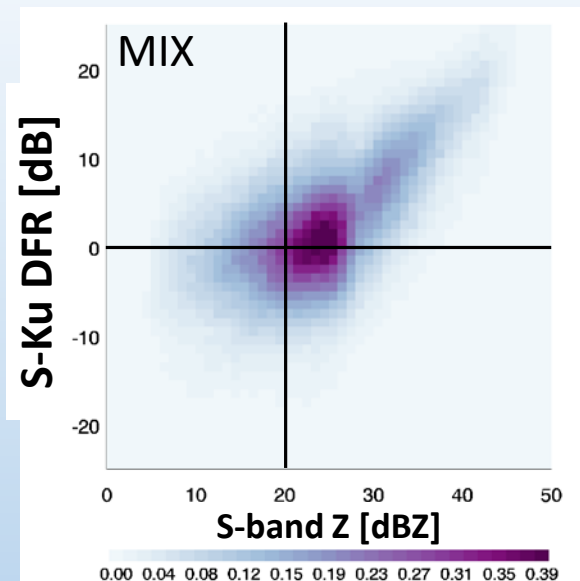
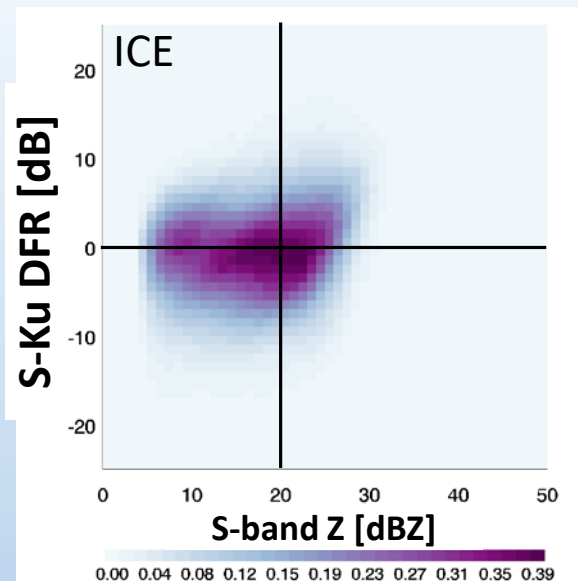
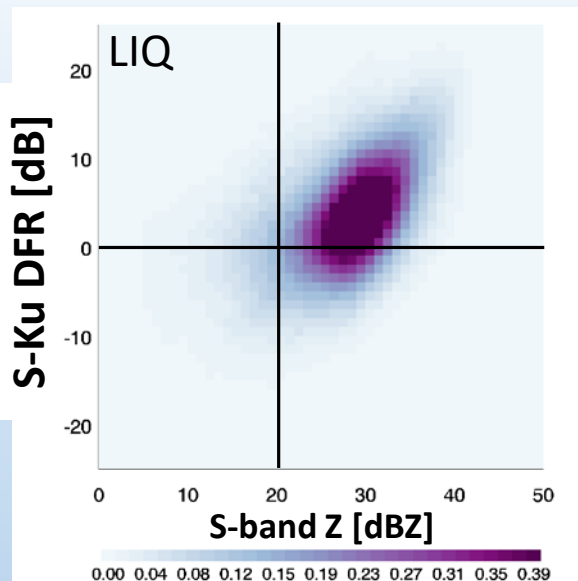
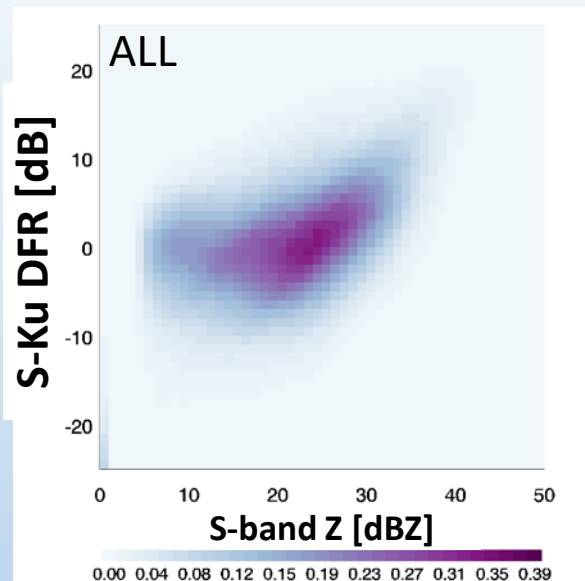


3 December 2015 14-00 UTC – southerly flow



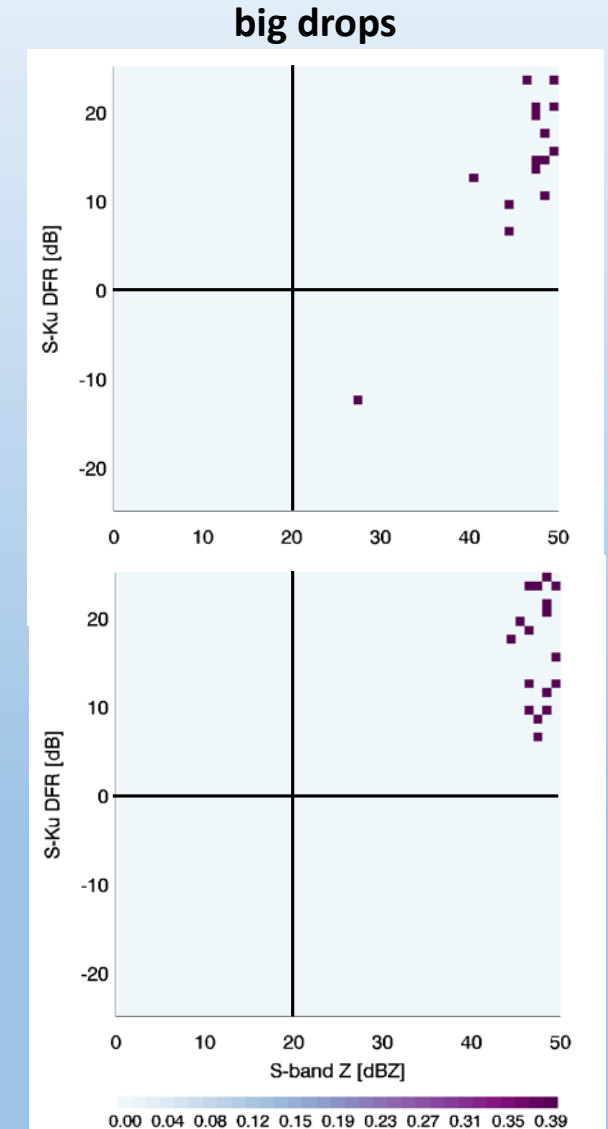
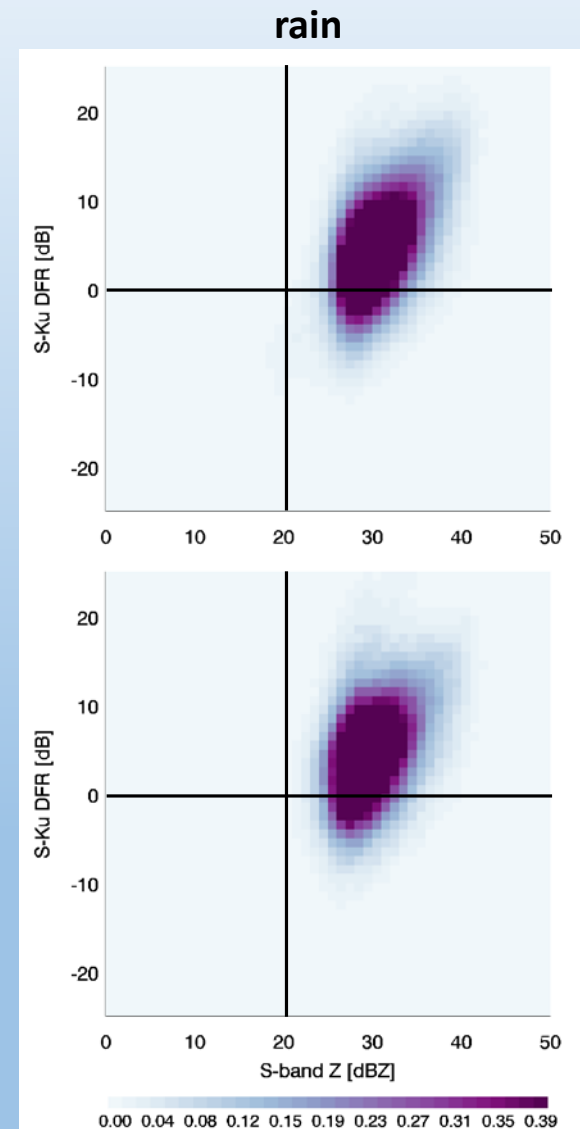
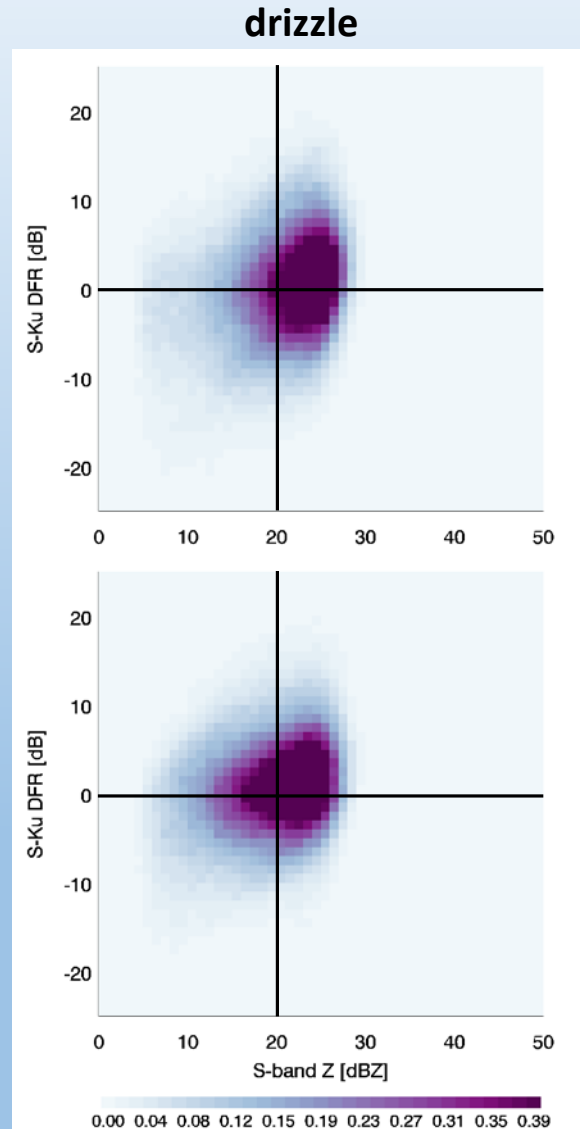
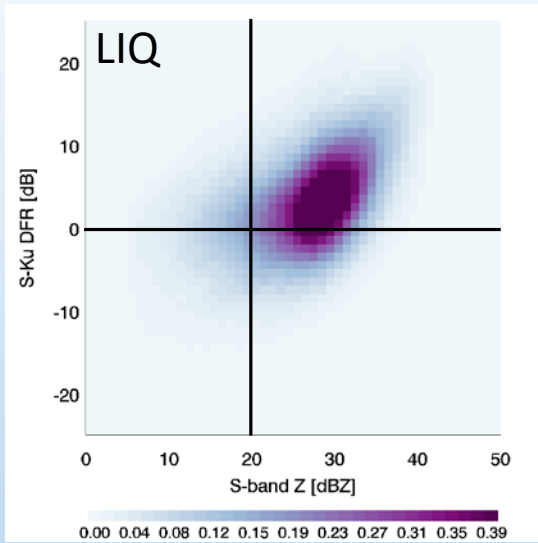
17 November 2015 10-21 UTC – westerly flow

DFR_{S-Ku} ALL ARs Land Side Scans



DFR_{S-Ku} ALL ARs Ocean Side Scans

S-Ku: Liquid phase HID type classes

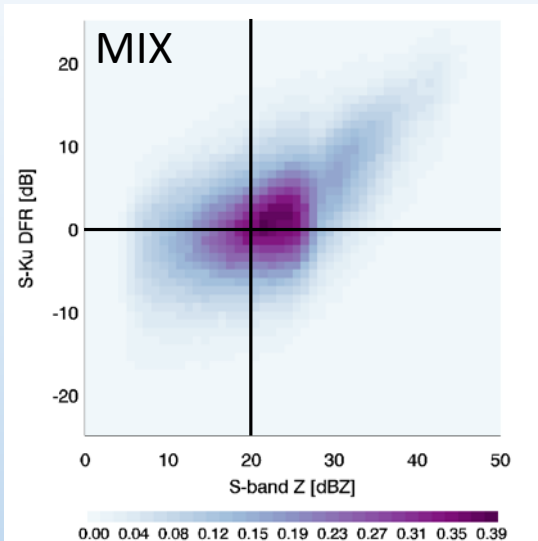


LAND

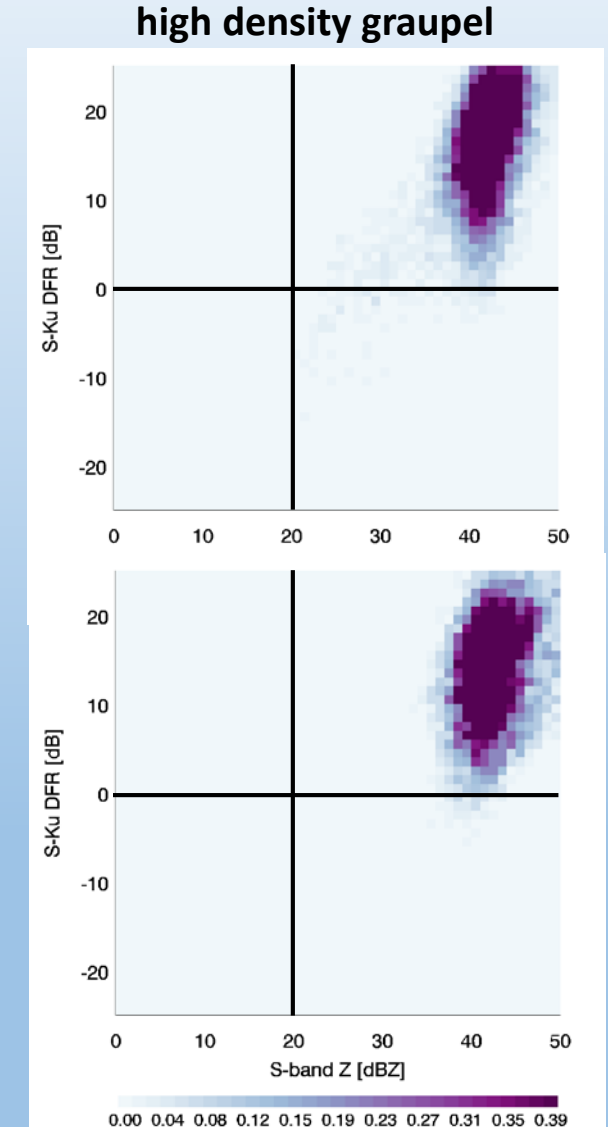
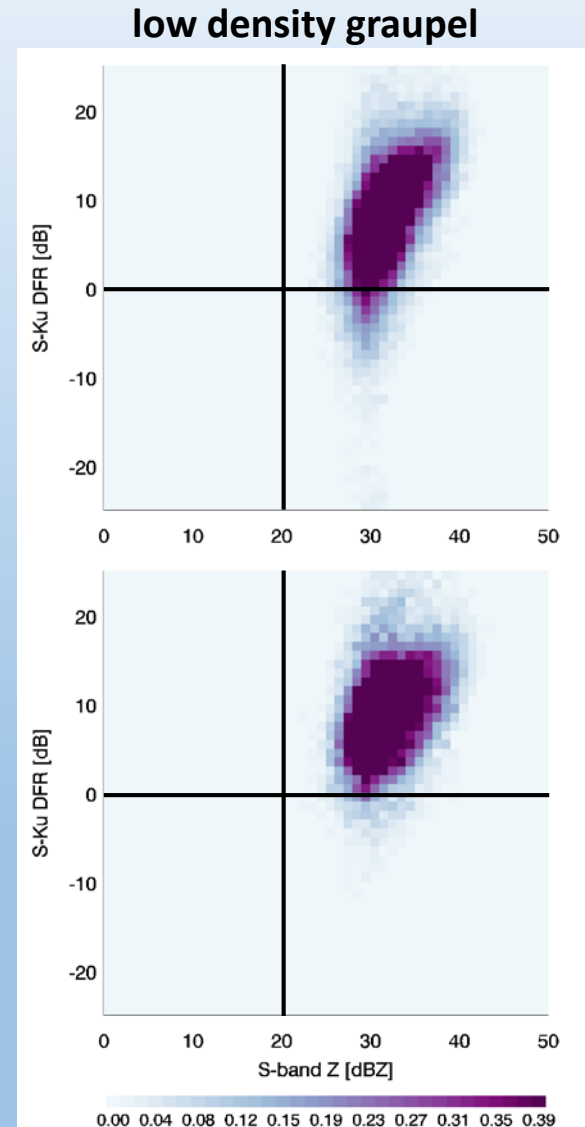
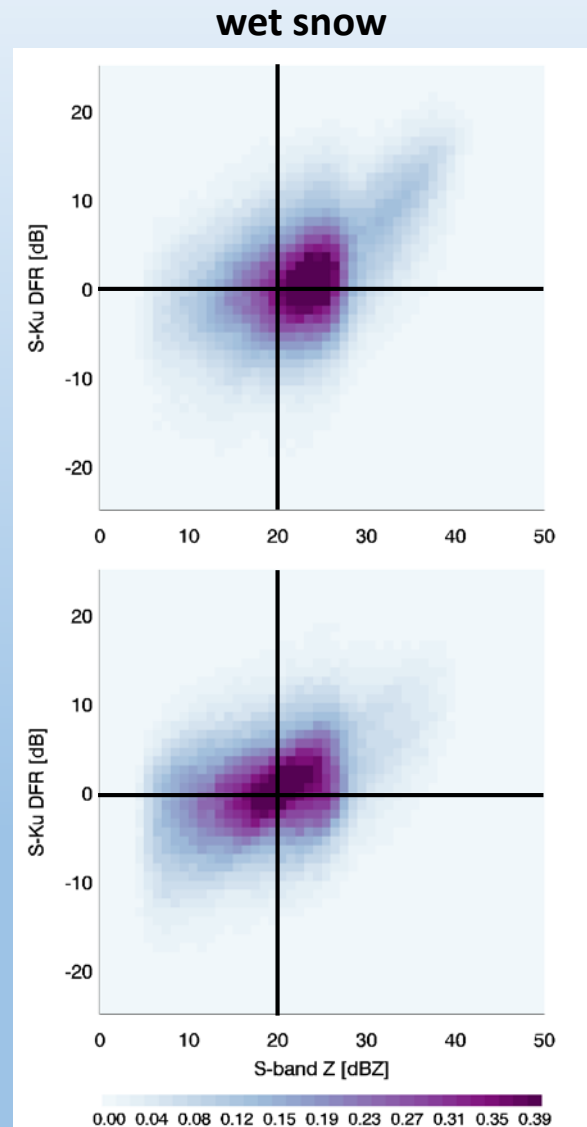
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- S-band Z / Rayleigh regime dependence on hydrometeor size evident
- DFR_{S-Ku} values positive & negative
- OLYMPEX region well known for copious numbers of small drops

S-Ku: Mix-phase HID type classes



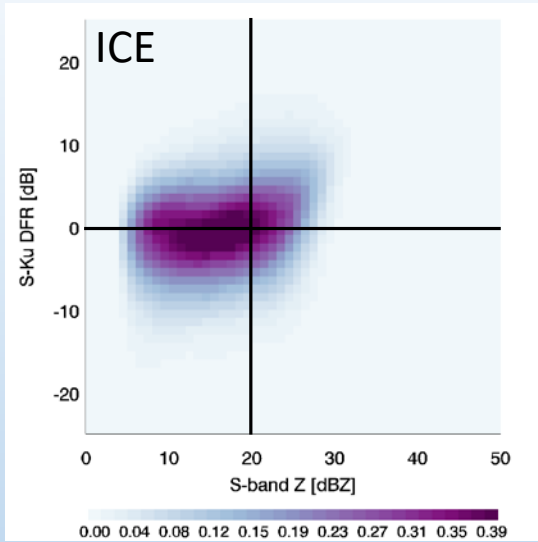
- Wet snow shows most variation, and **more dispersed over ocean**
- Graupel classes more similar to rain, hail; **more dispersed over land**



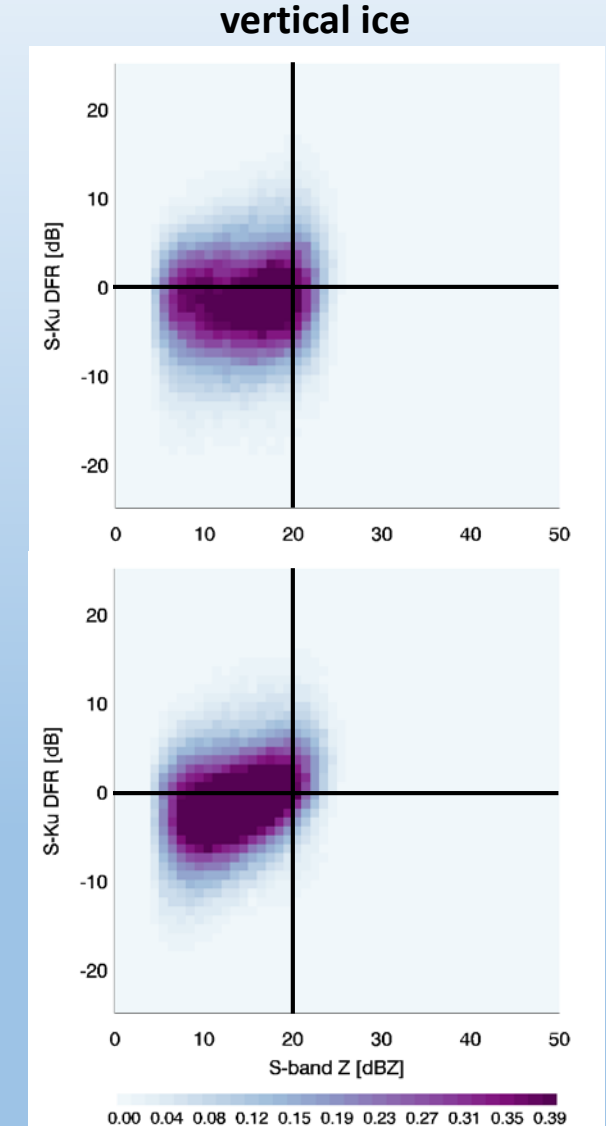
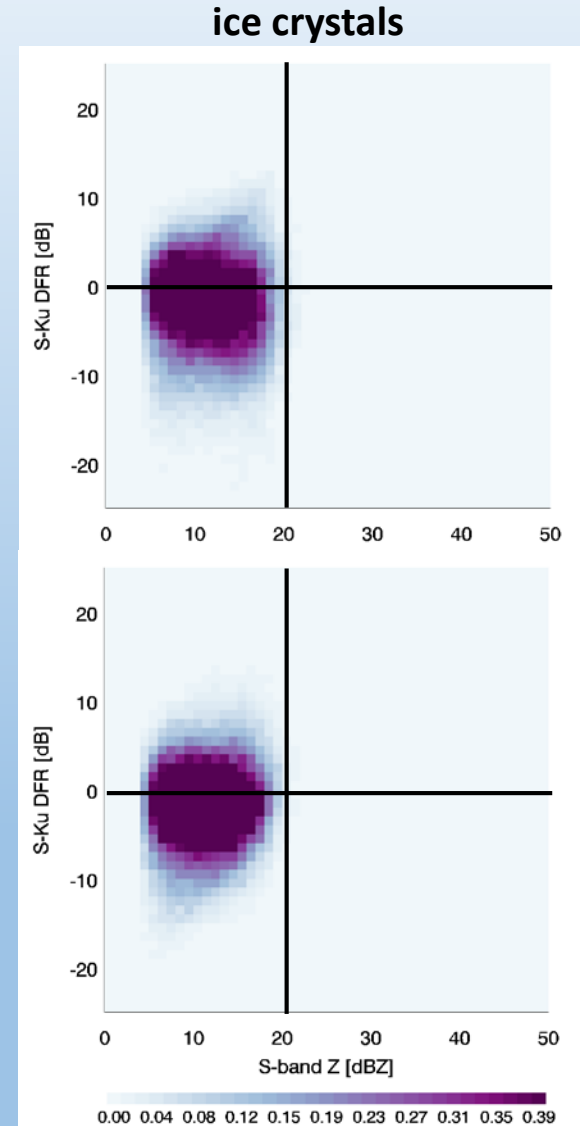
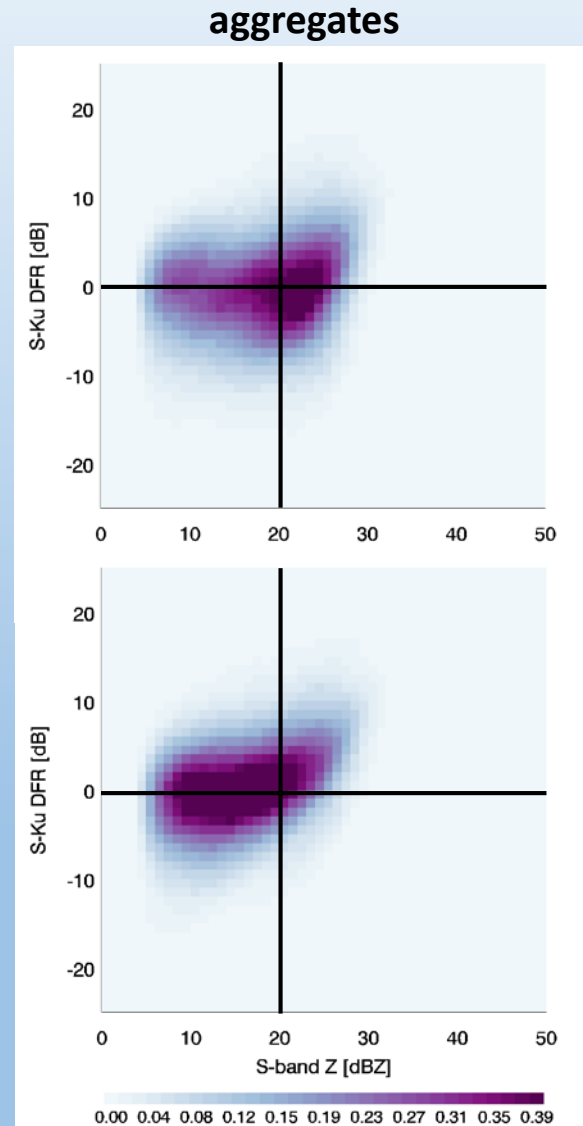
LAND

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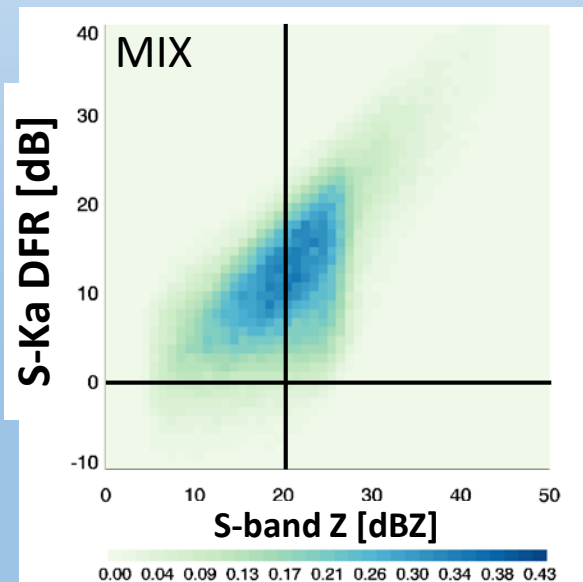
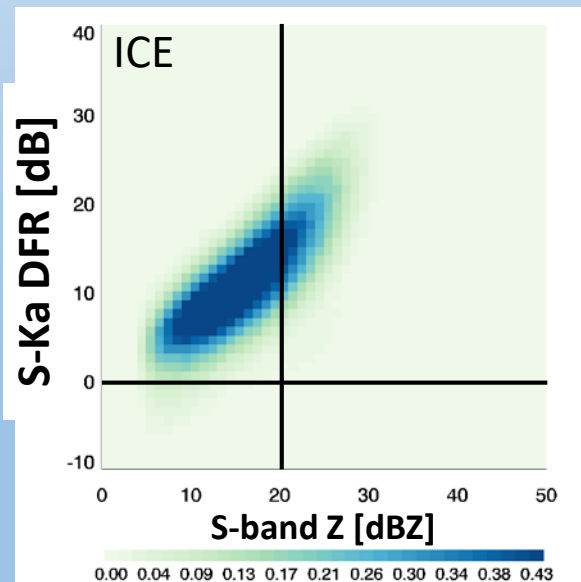
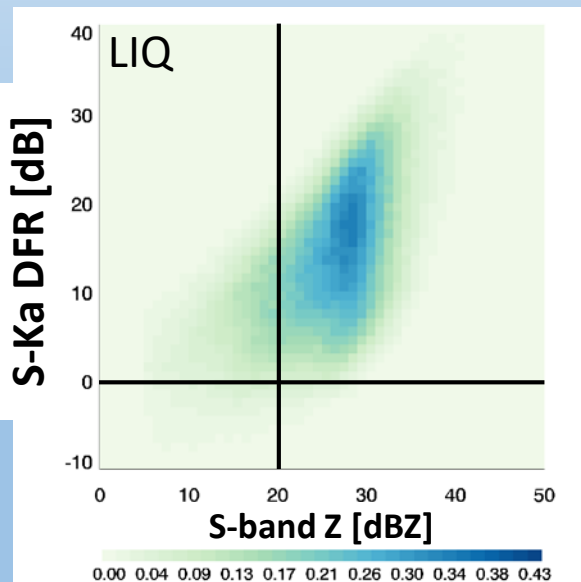
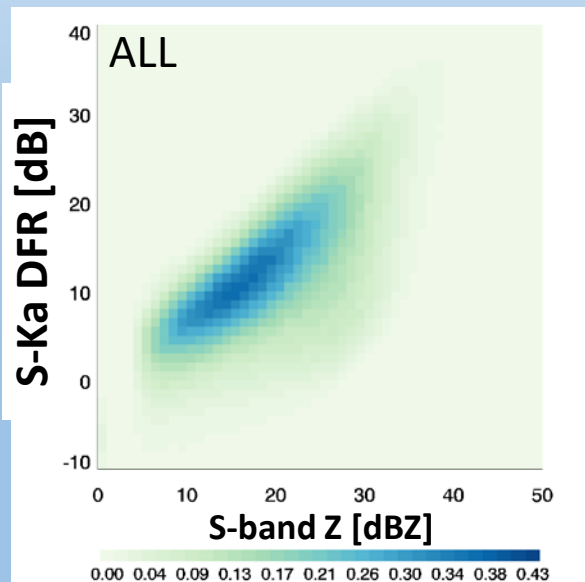
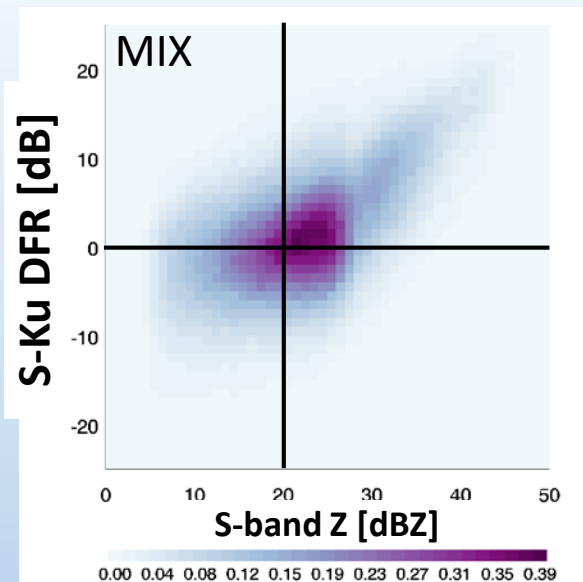
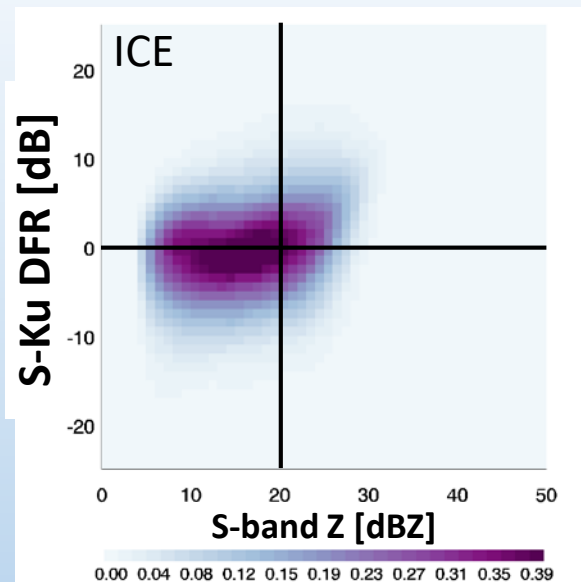
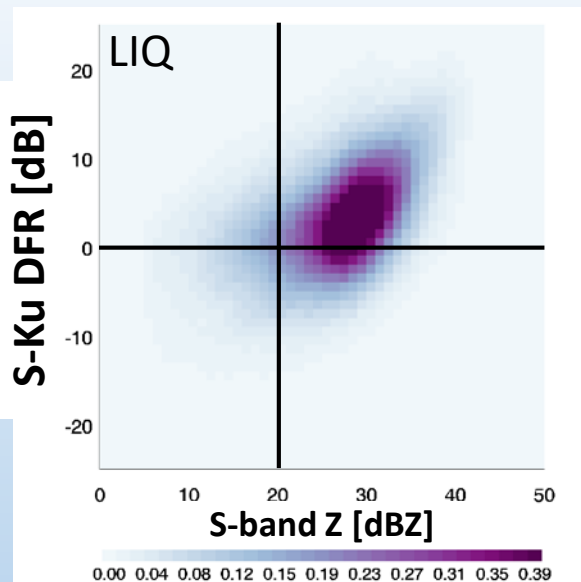
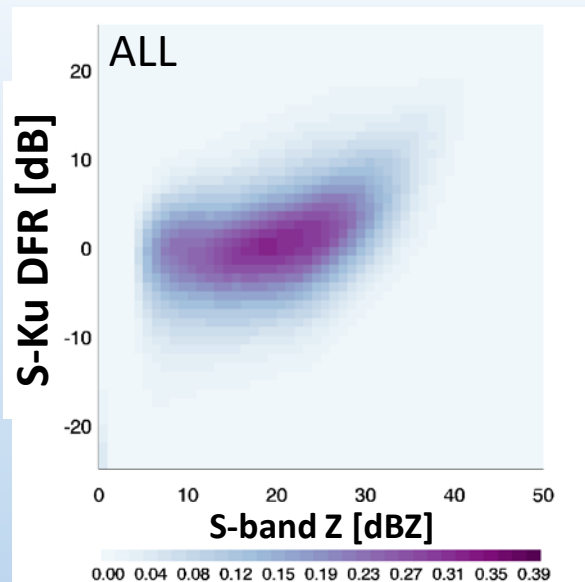
S-Ku: Ice phase HID type classes



- **Aggregates:** different land/ocean modes
- **Ice crystals:** land/ocean similar
- **Vertical ice:** slightly lower DFR

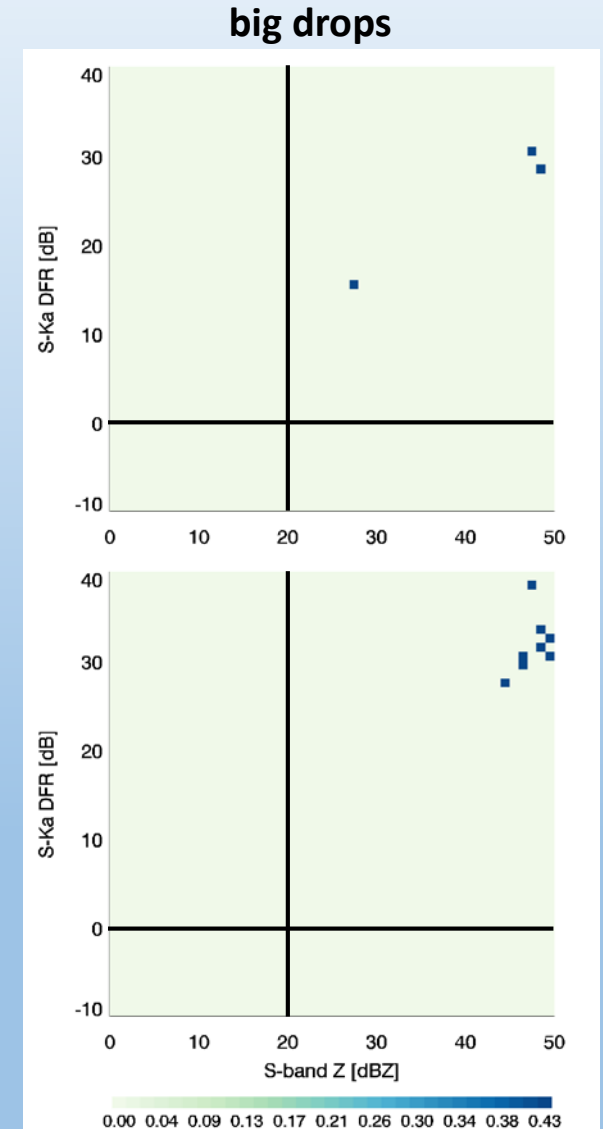
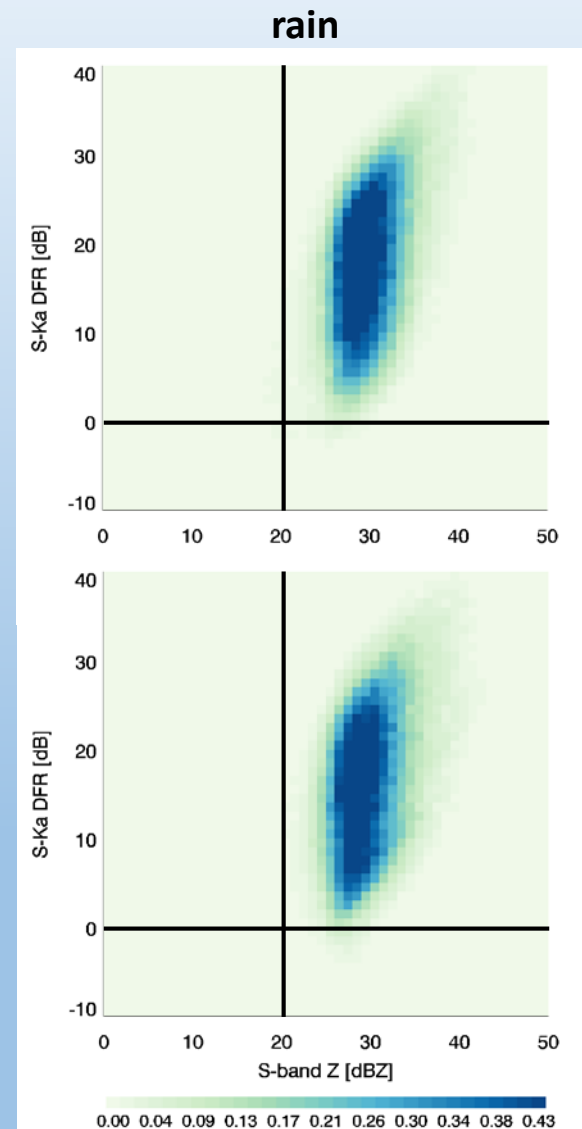
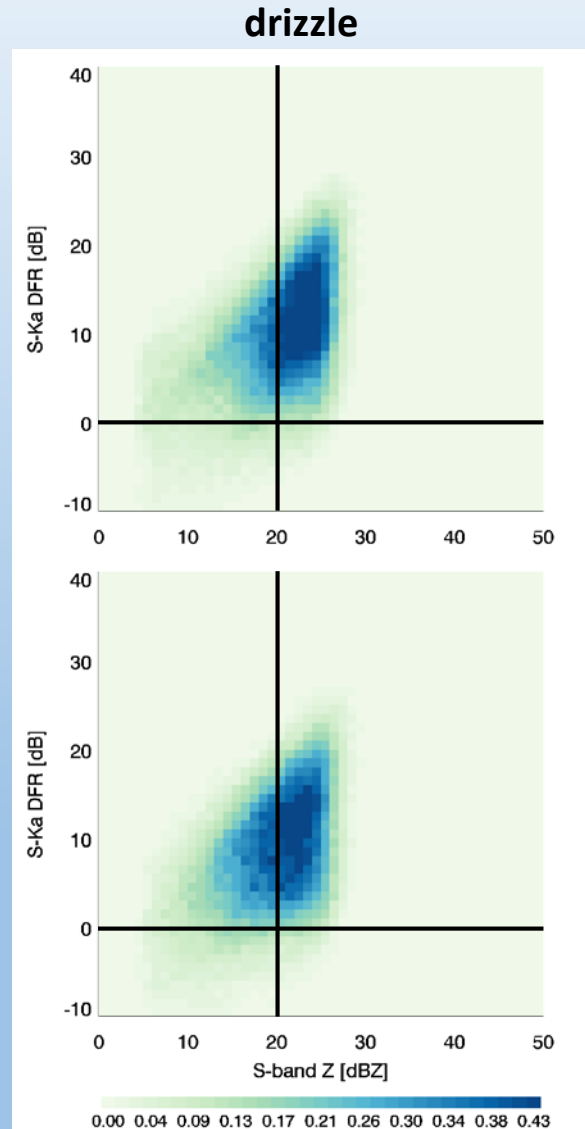
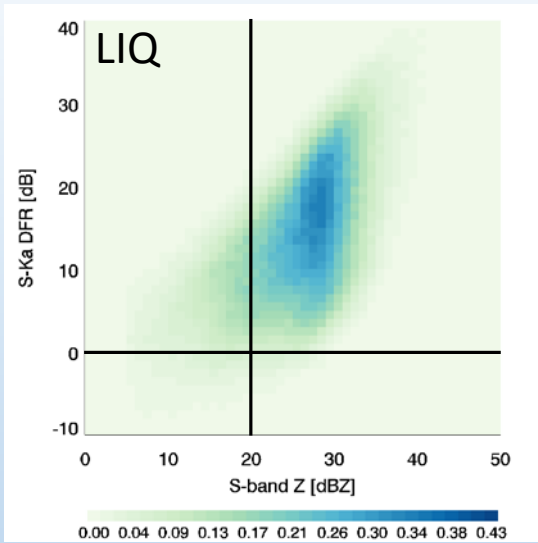


DFR_{S-Ku} ALL ARs Land + Ocean



DFR_{S-Ka} ALL ARs Land + Ocean

S-Ka: Liquid phase HID type classes

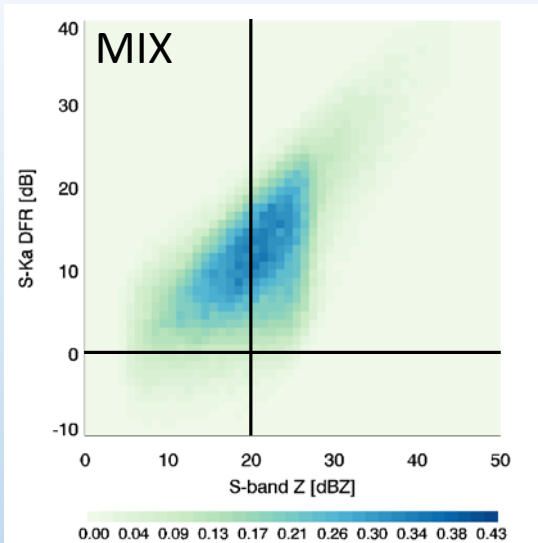


- S-band Z / Rayleigh regime dependence on hydrometeor size evident
- Almost all DFR_{S-Ka} values **positive**

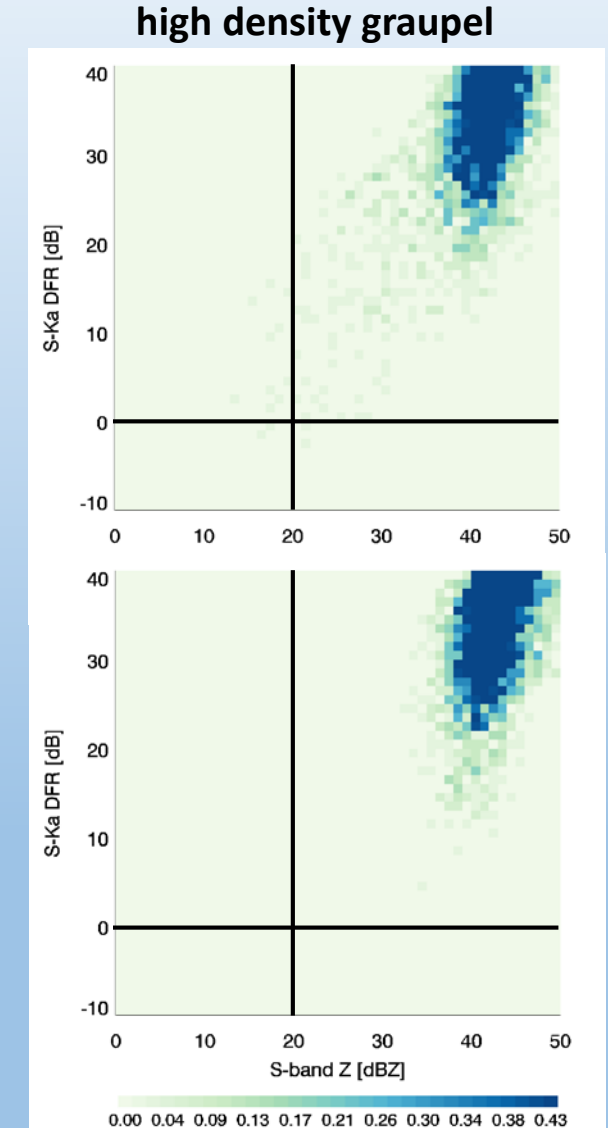
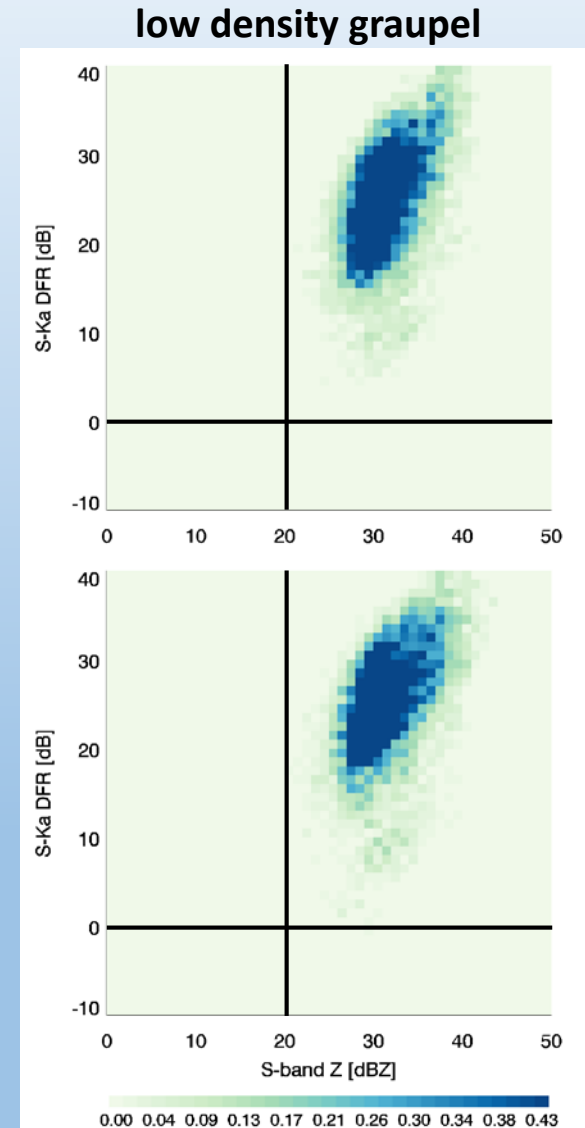
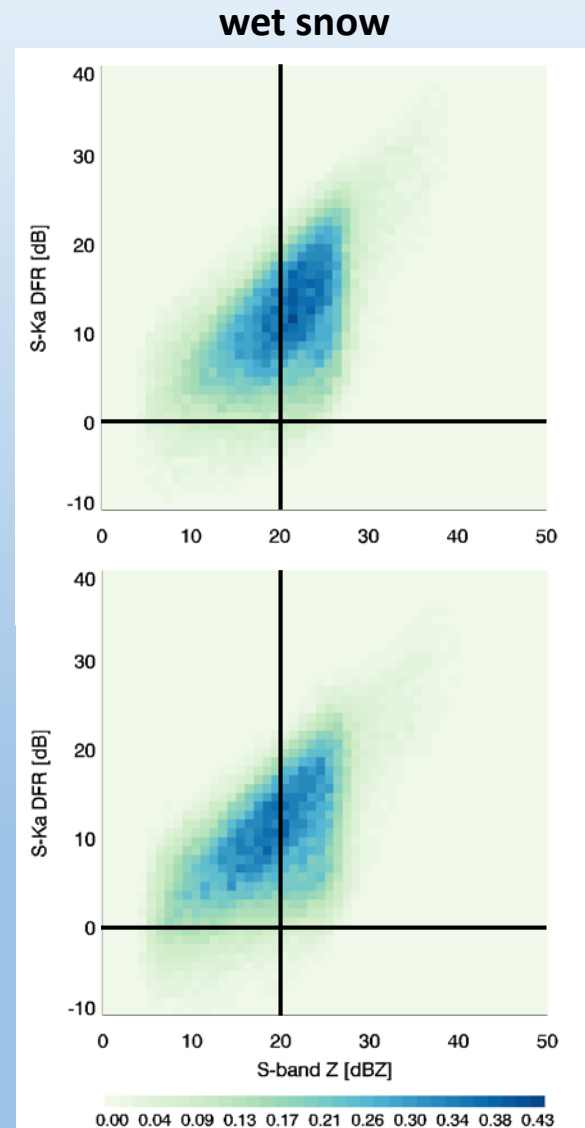
LAND

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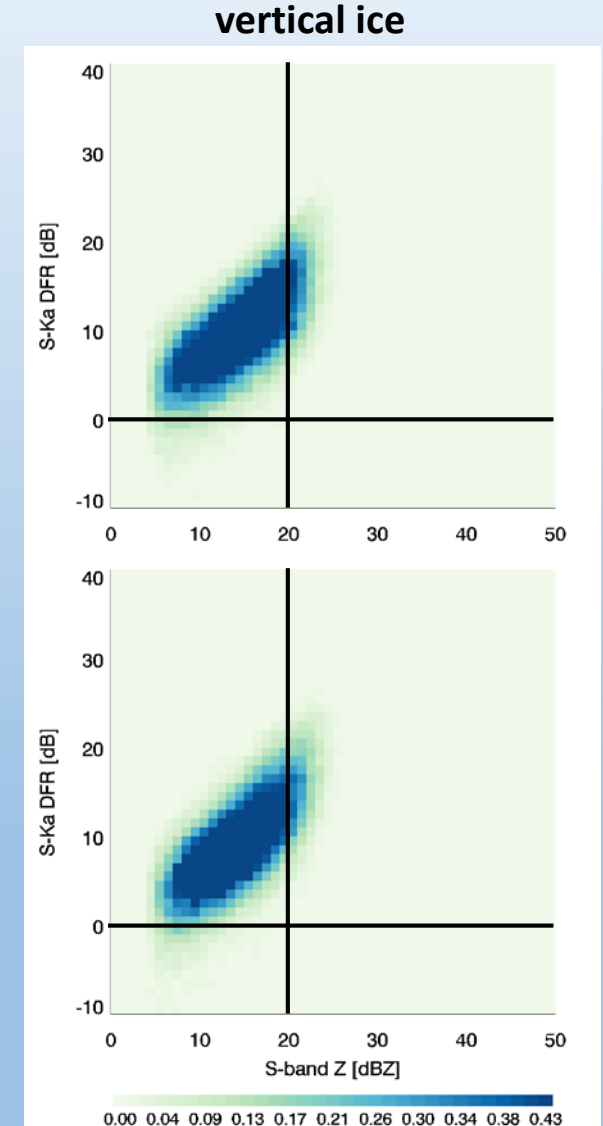
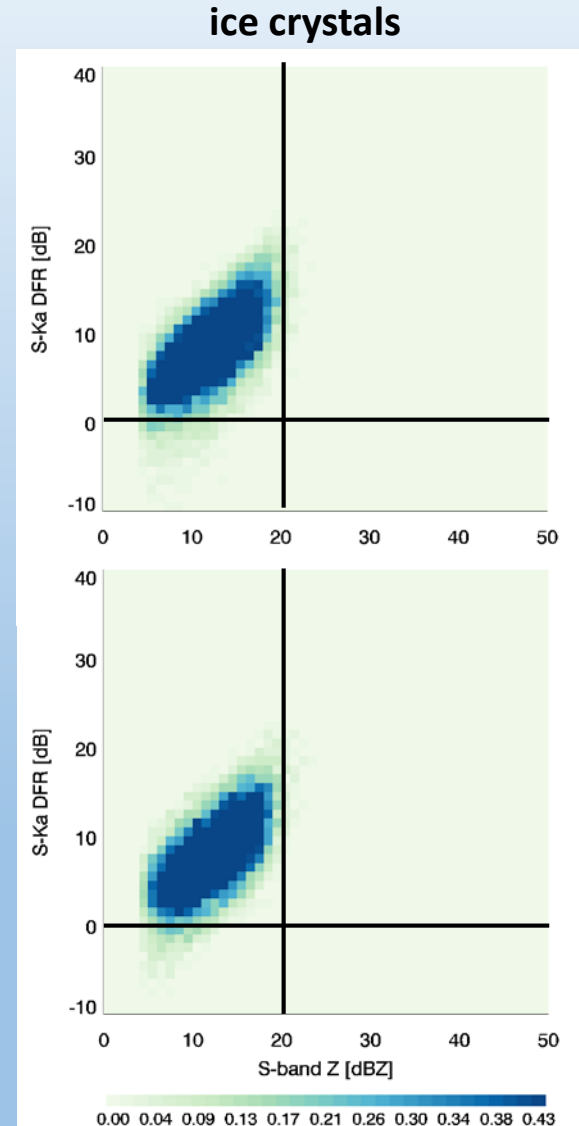
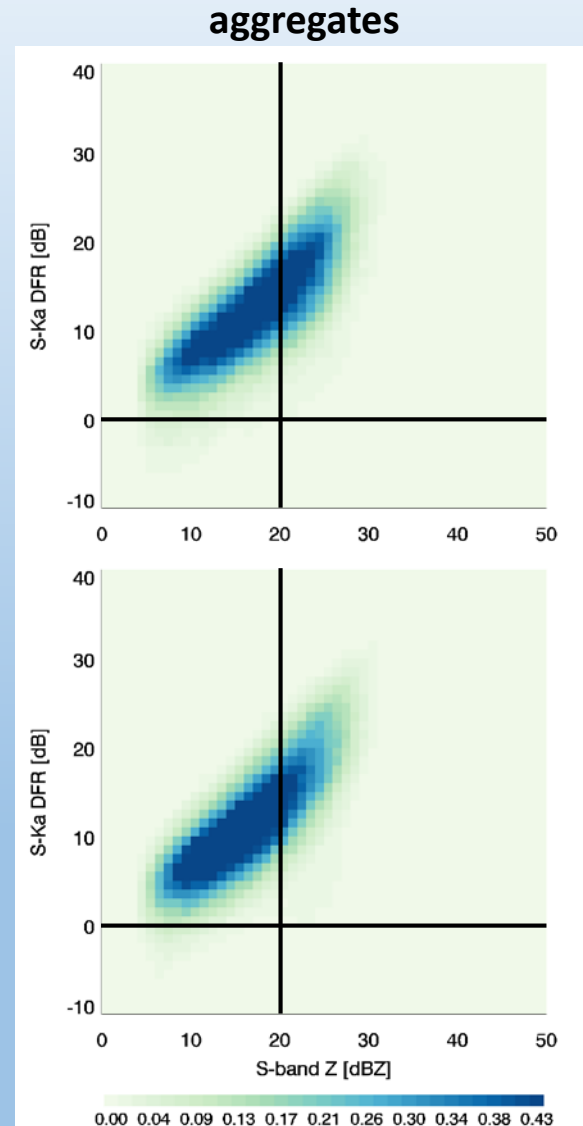
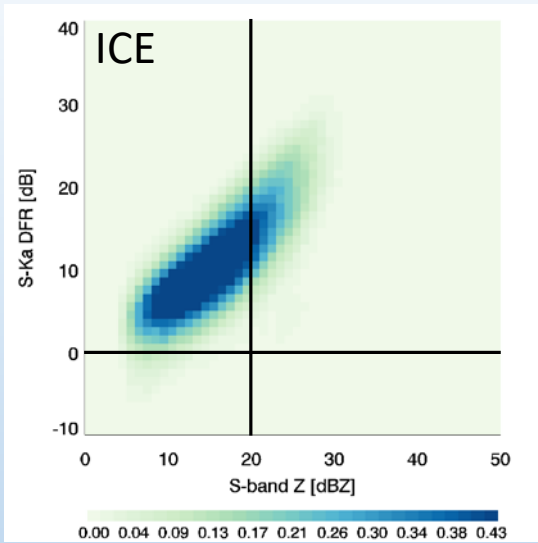
S-Ka: Mix-phase HID type classes



- Wet snow most varied, **more dispersed over ocean**
- Graupel classes more similar to rain, hail; **more dispersed over land**
- Almost all DFR_{S-Ka} values **positive**



S-Ka: Ice phase HID type classes



- Aggregates & ice crystals: slightly more compact over ocean
- Vertical ice: similar to other ICE HID type classes
- Modes more consistent (vs. S-Ku)

LAND

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DFR_{Ku-Ka}: All HID Types – Distribution Space

DFR_{Ku-Ka} vs Ku-band Z:

- Triangular, almost parabolic shape

DFR_{Ku-Ka} vs S-band Z:

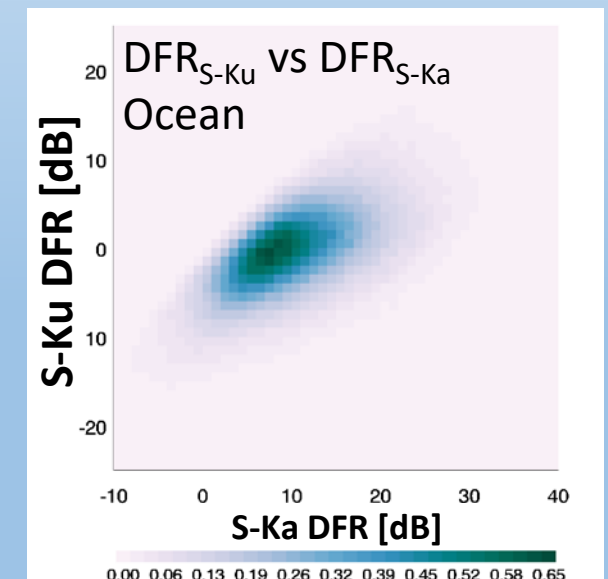
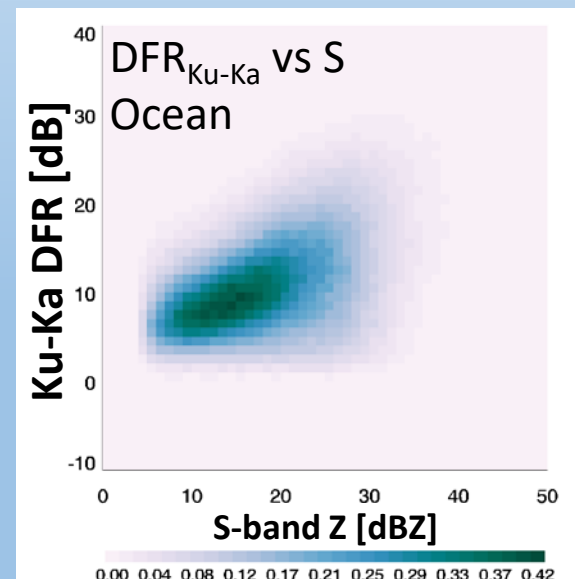
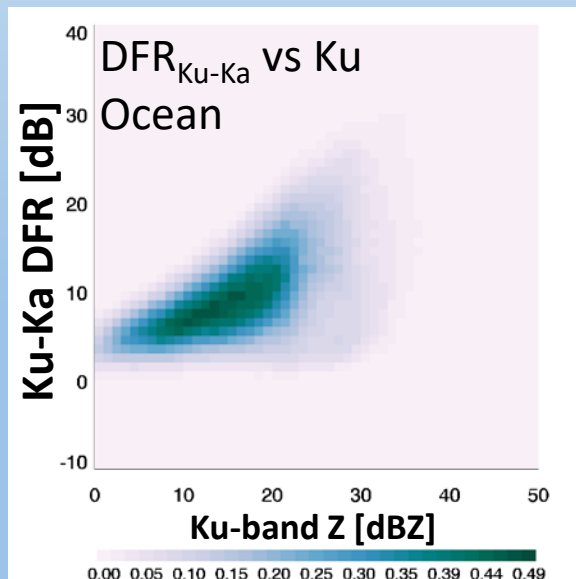
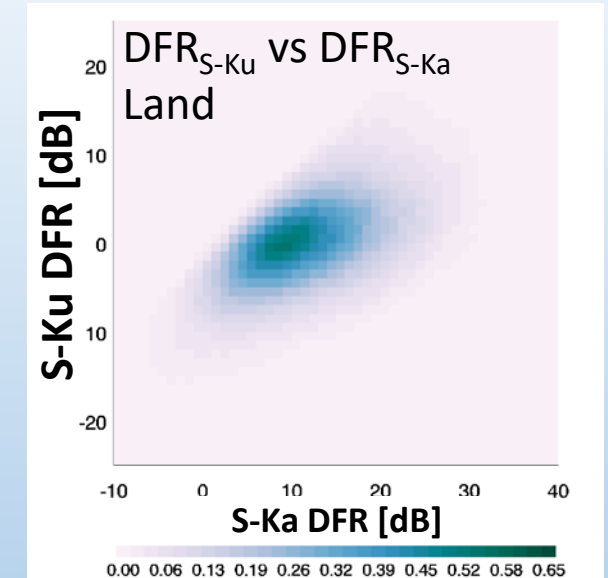
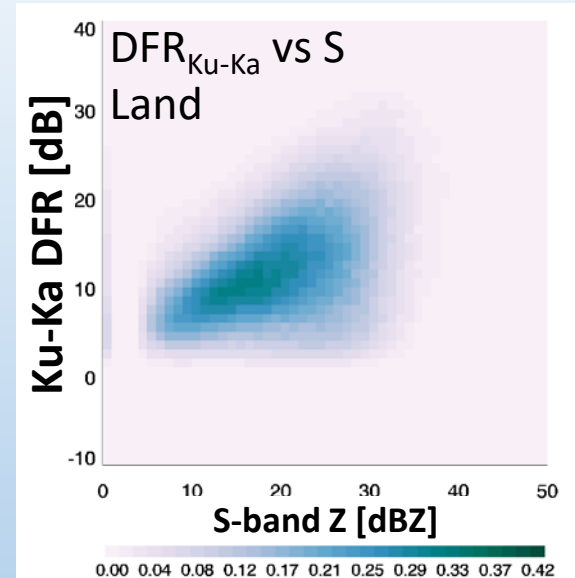
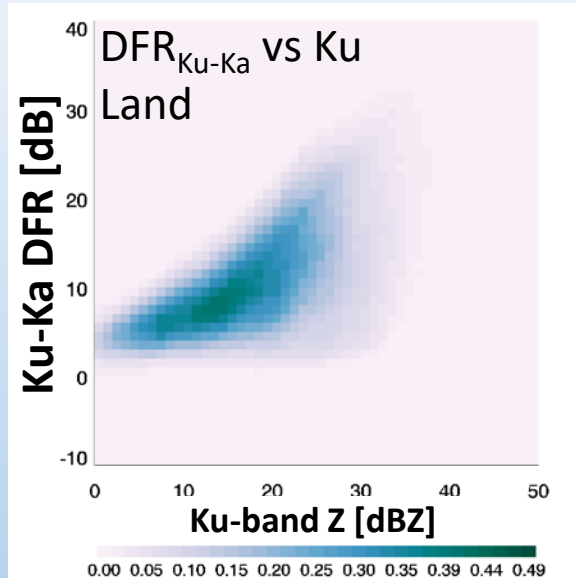
- More broad triangular shape

DFR_{S-Ku} vs DFR_{S-Ka}:

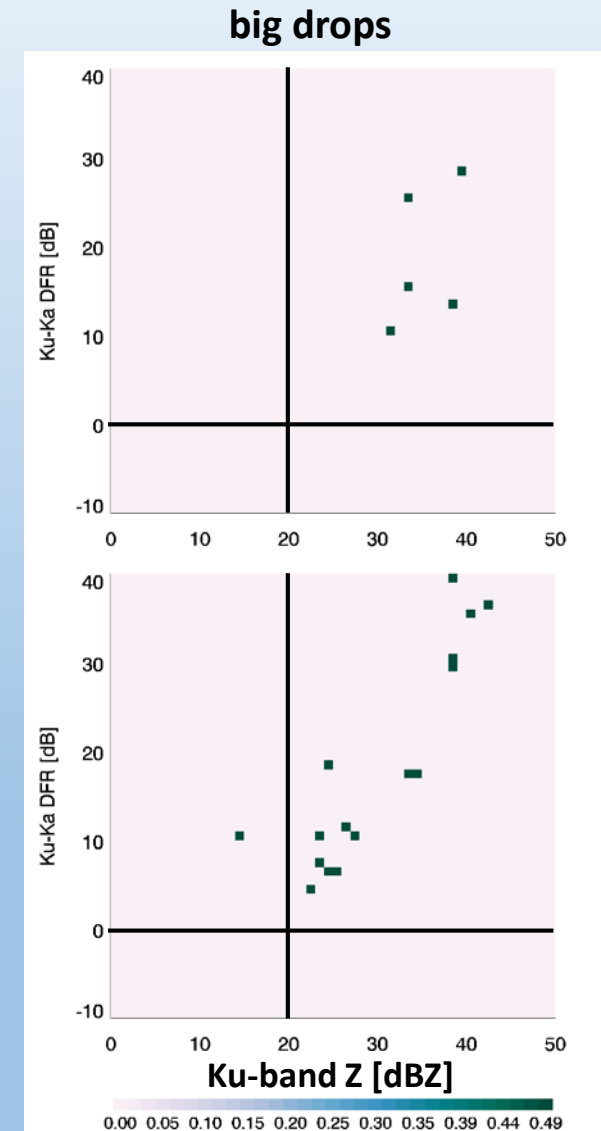
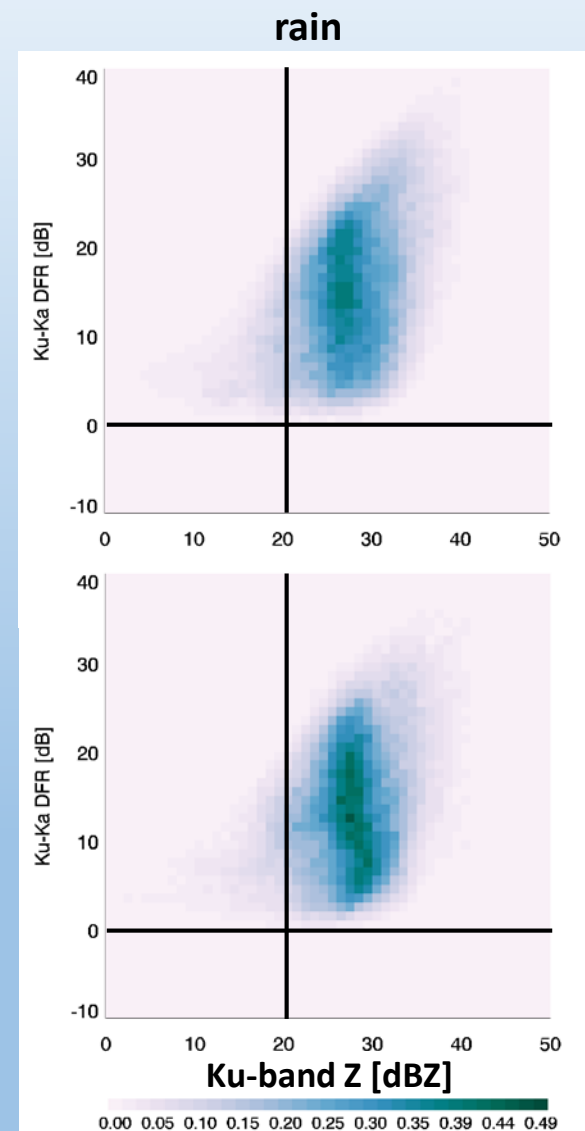
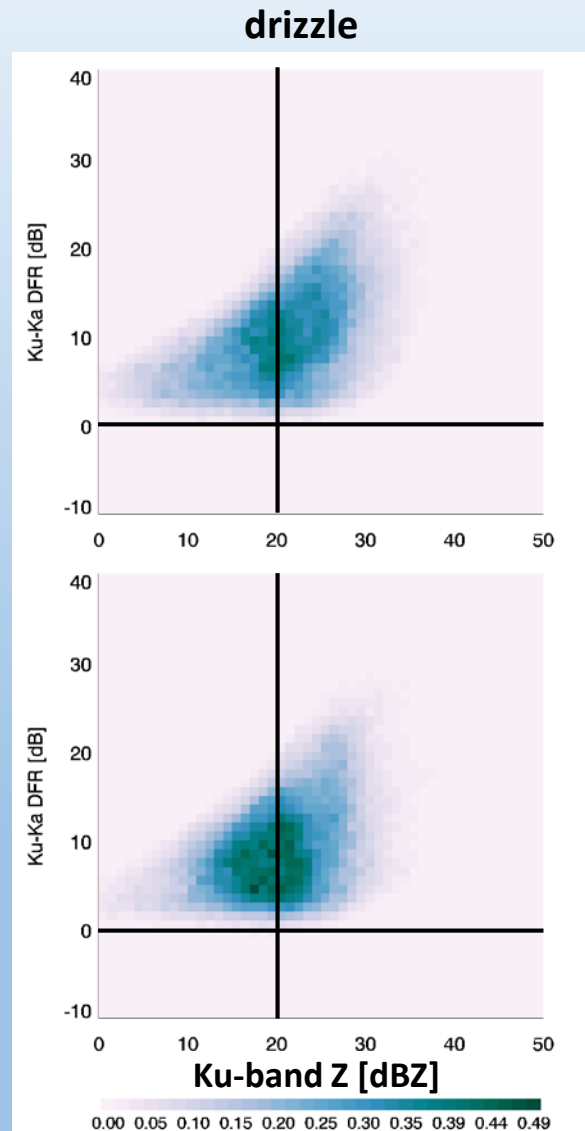
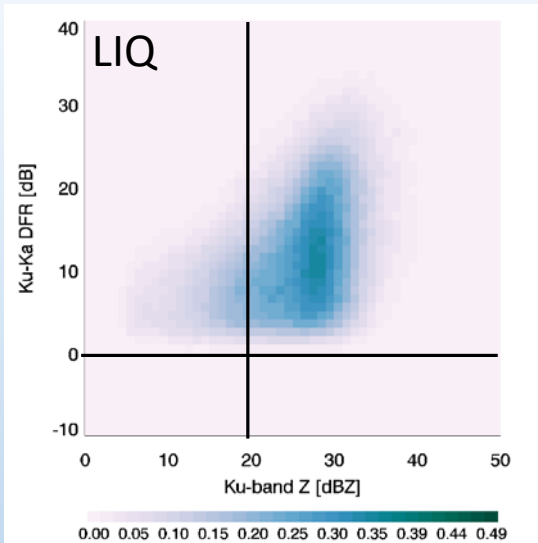
- Most confined distribution

All:

- Ocean distribution more compact than land

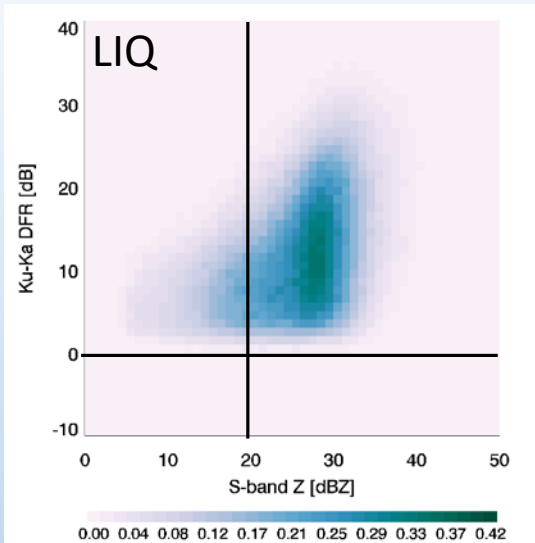


Ku-Ka: Liquid phase HID type classes

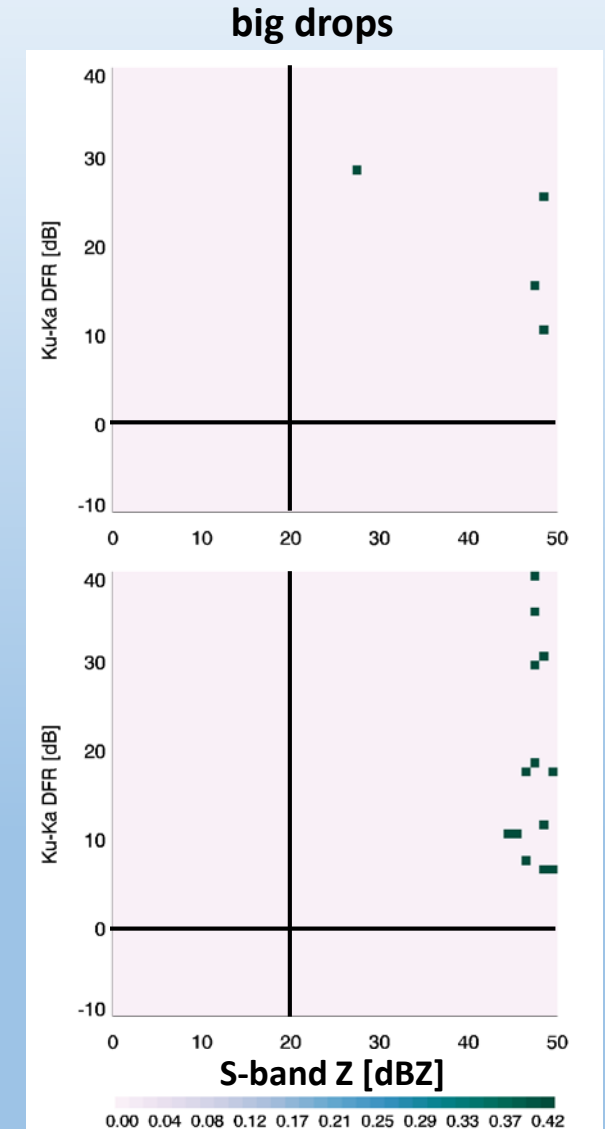
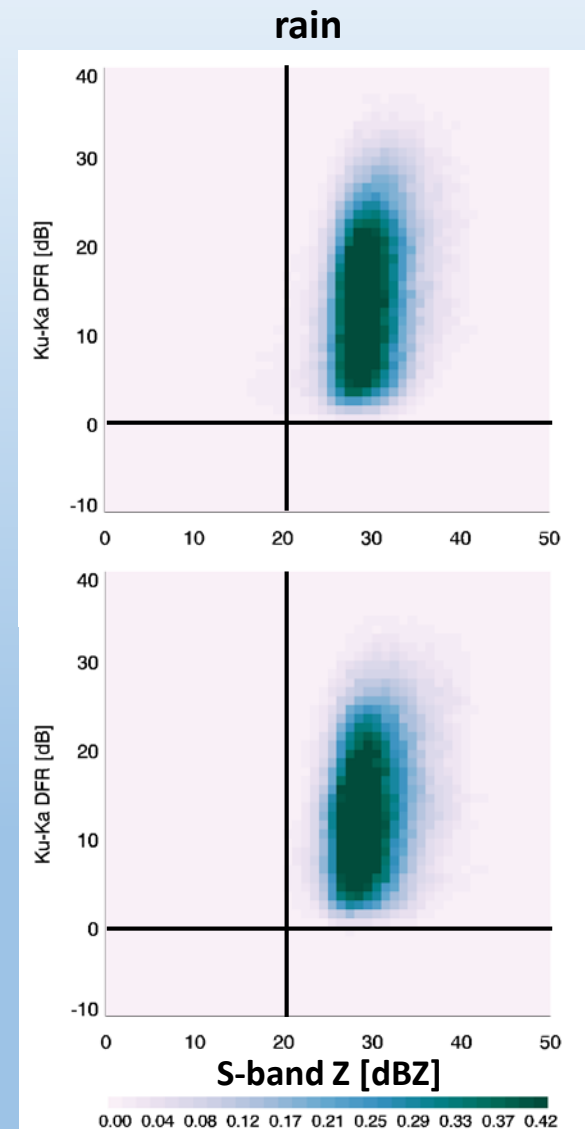
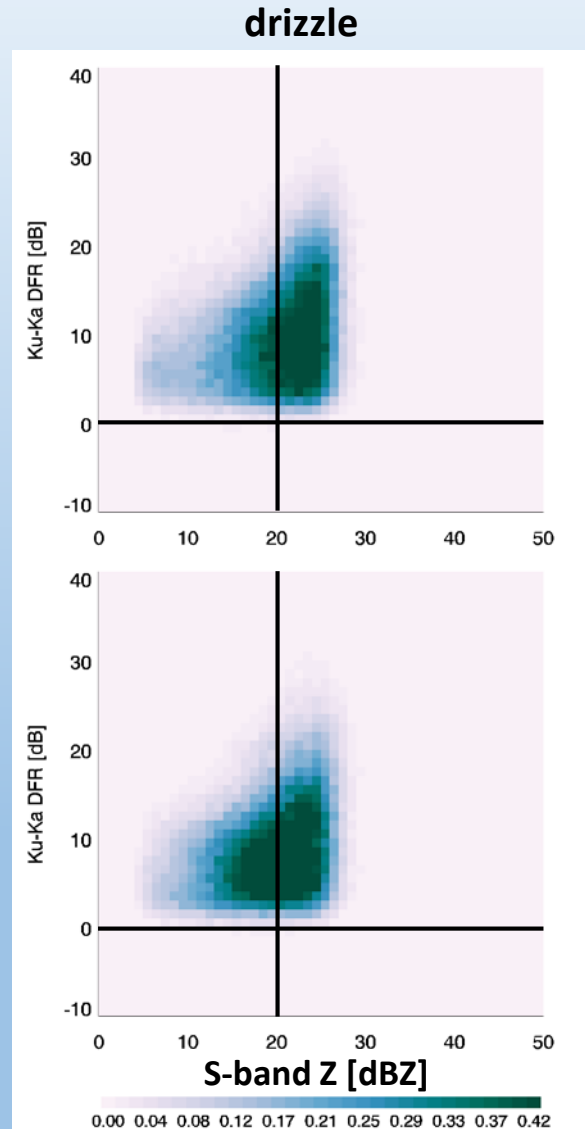


- No negative DFR_{Ku-Ka} values
- Ocean distributions more compact
- Modes & size separation more pronounced in S-band space

Ku-Ka: Liquid phase HID type classes



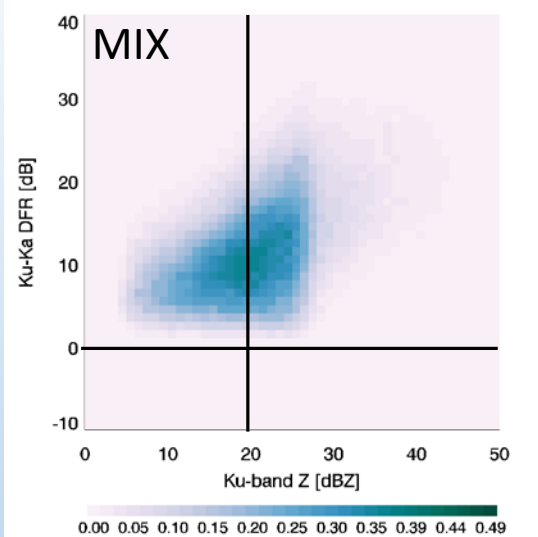
- No negative DFR_{Ku-Ka} values
- Ocean distributions more compact
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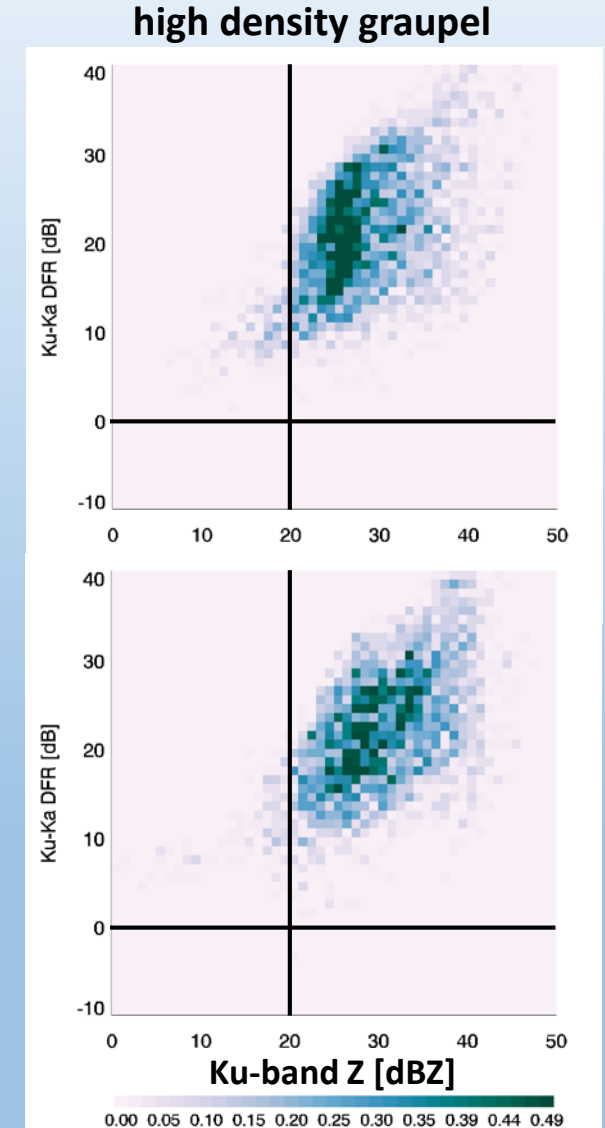
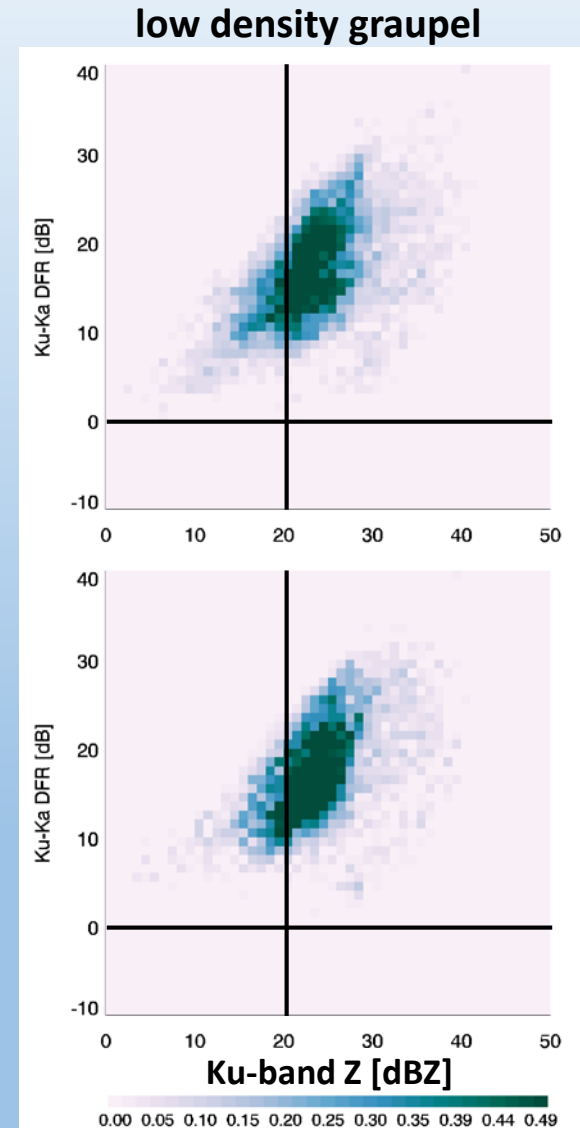
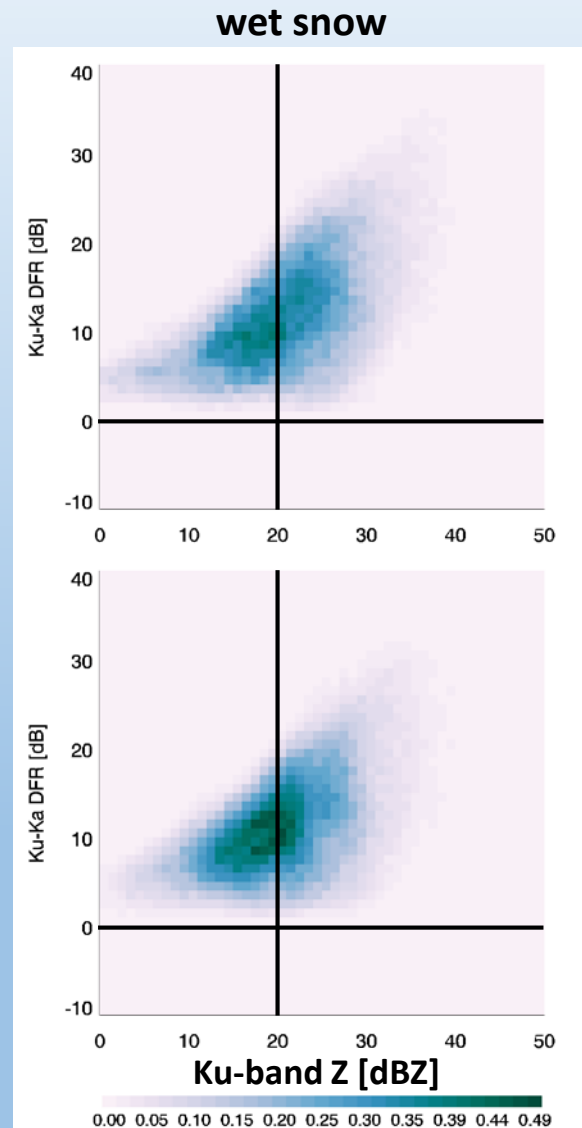
LAND

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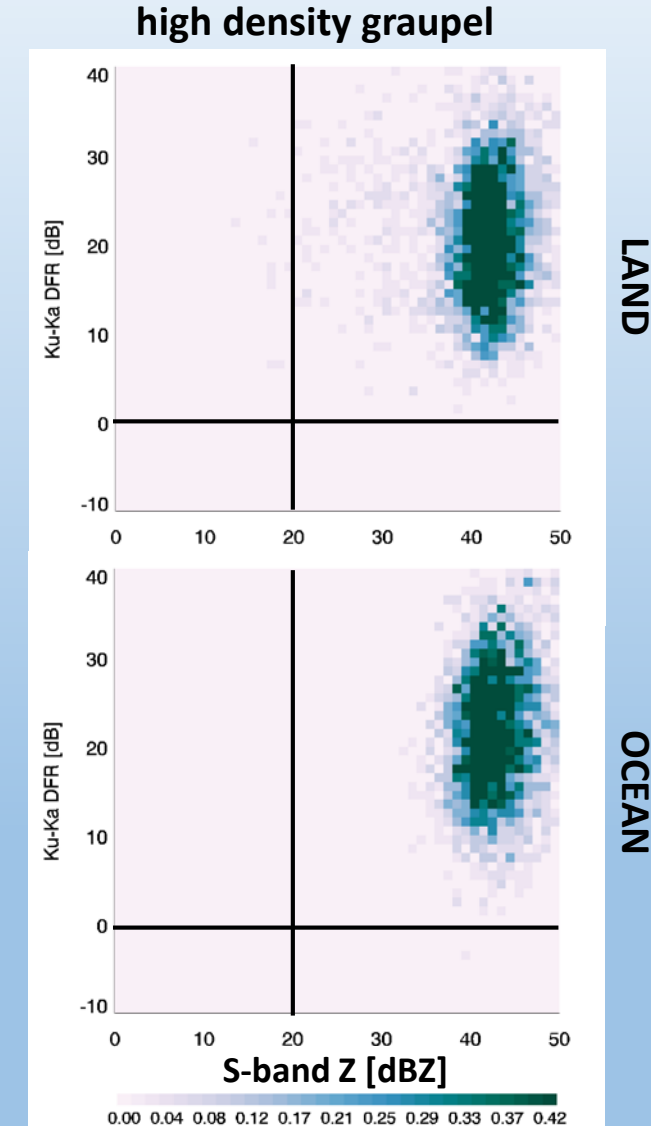
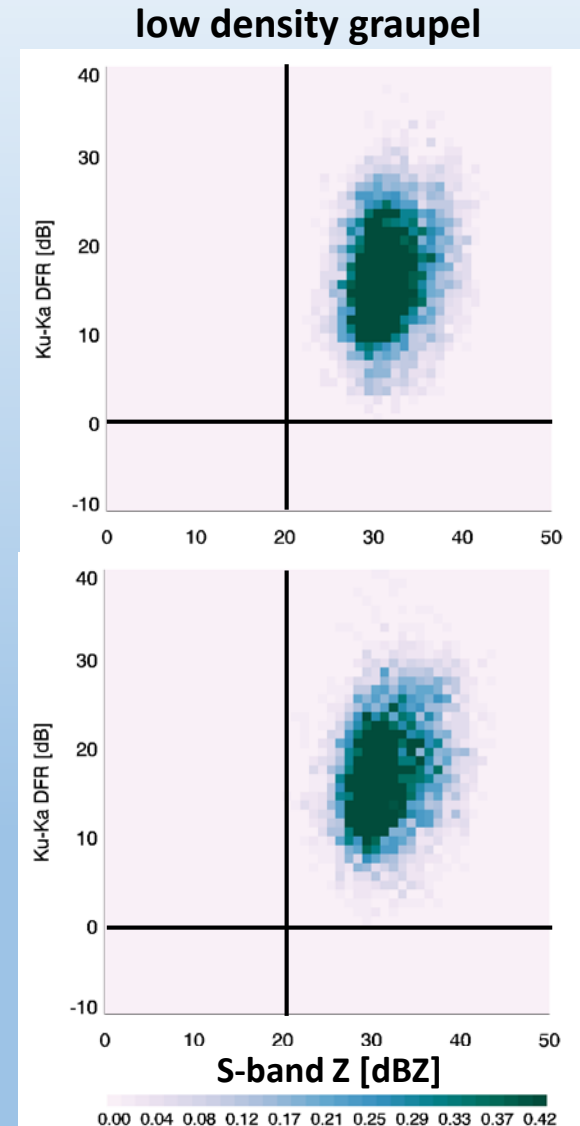
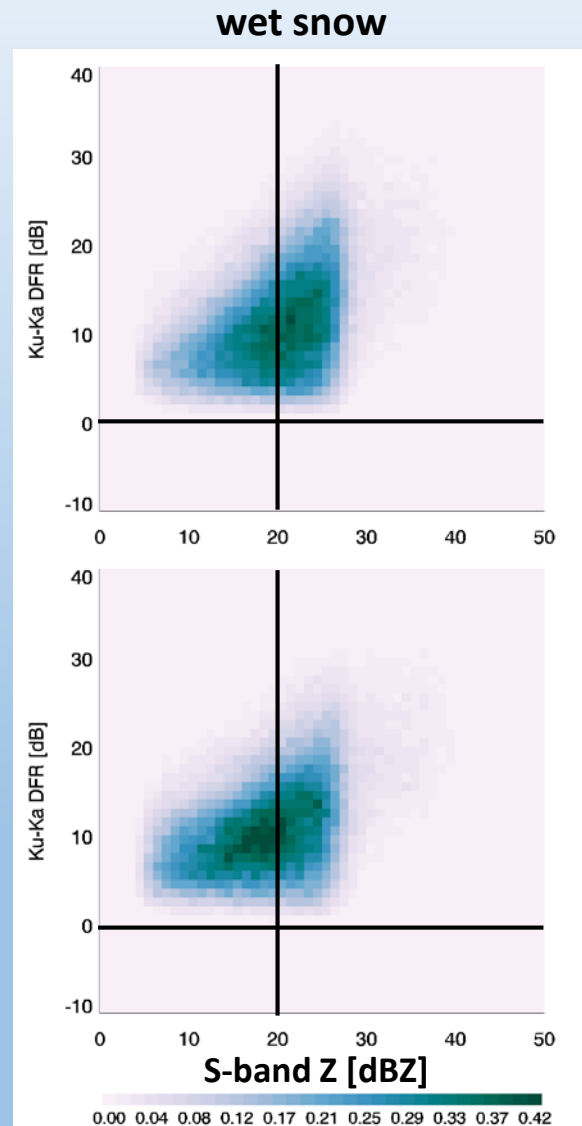
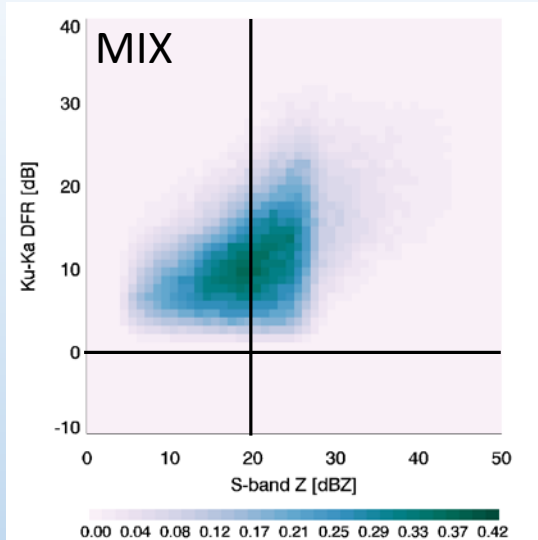
Ku-Ka: Mix-phase HID type classes



- Wet snow: **more compact over ocean**
- Graupel: more compact over land (vs. Ku-band Z)
- Modes & size separation more pronounced in S-band space

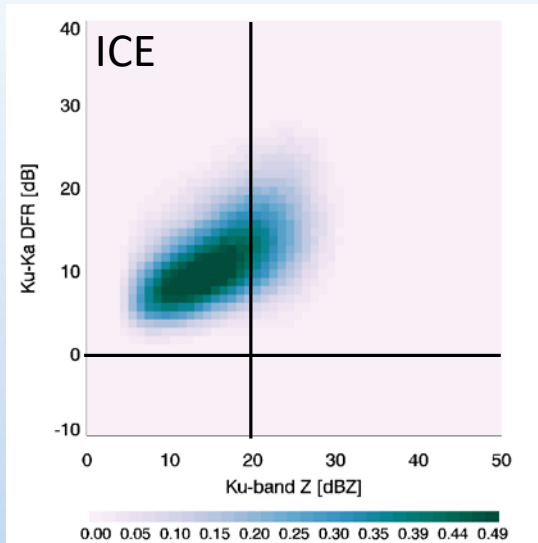


Ku-Ka: Mix-phase HID type classes

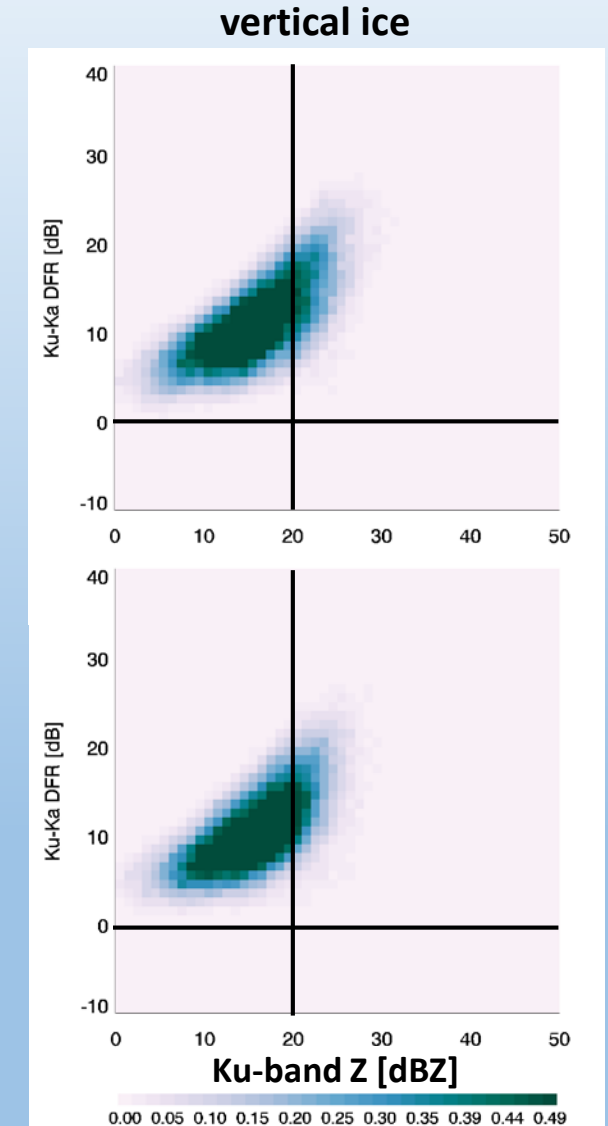
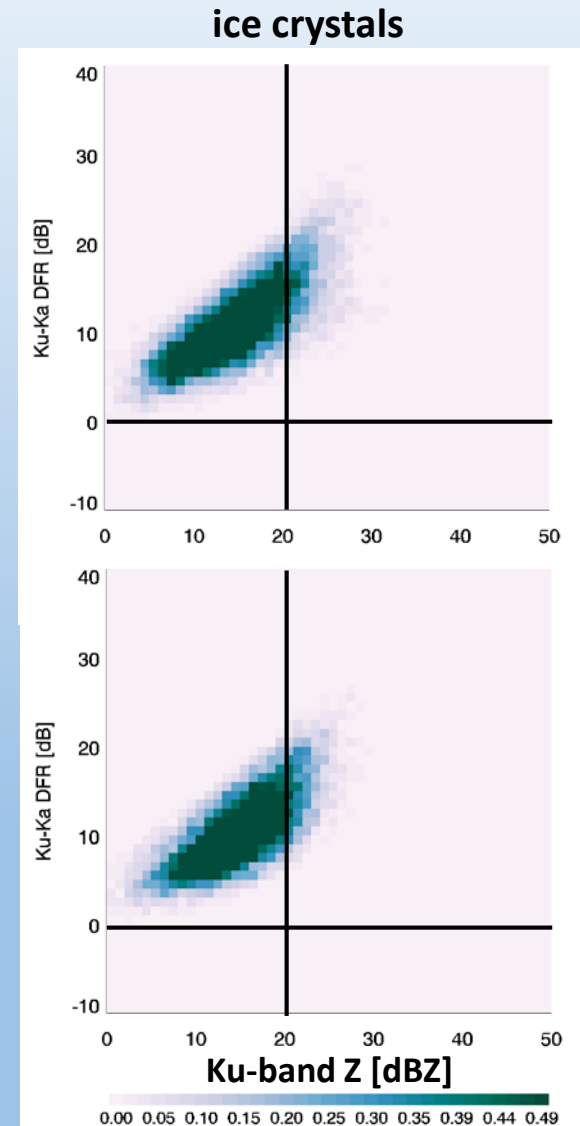
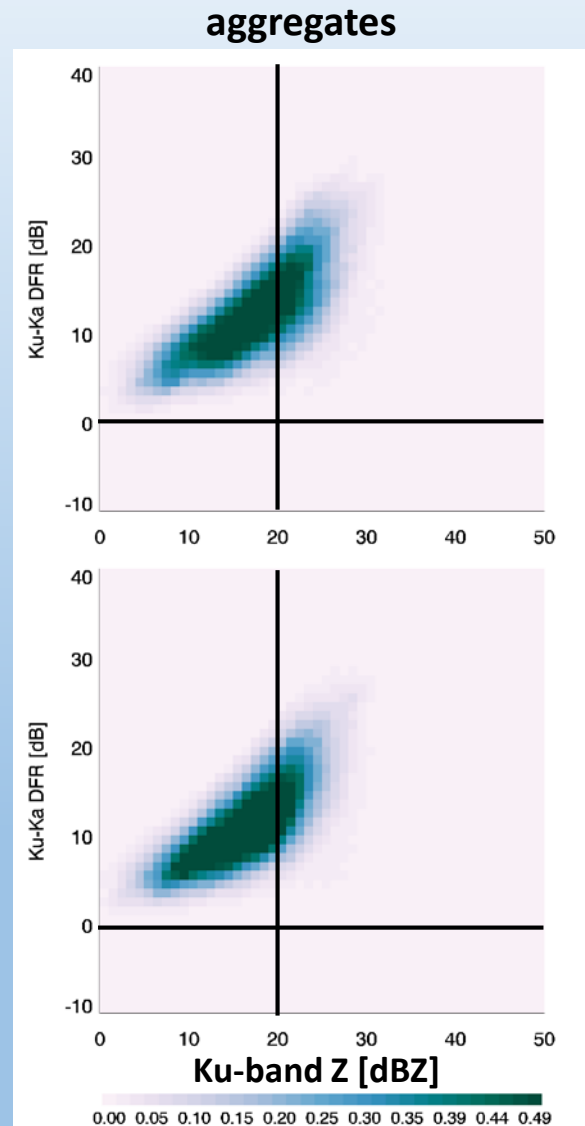


- Wet snow: **more compact over ocean**
- Graupel: more compact over land (vs. Ku-band Z)
- Modes & size separation more pronounced in S-band space

Ku-Ka: Ice phase HID type classes



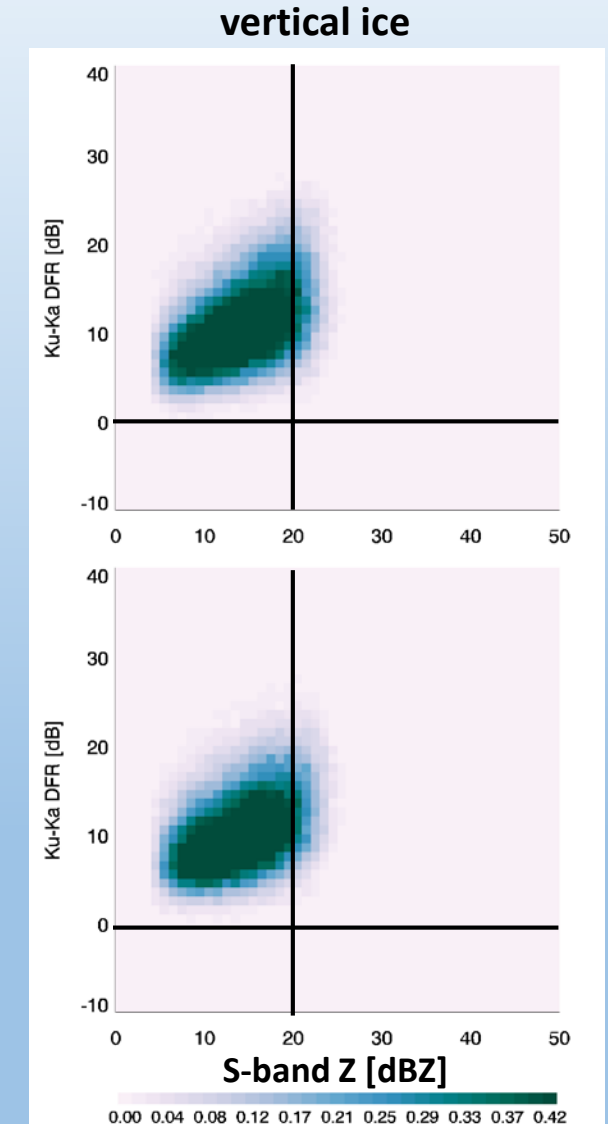
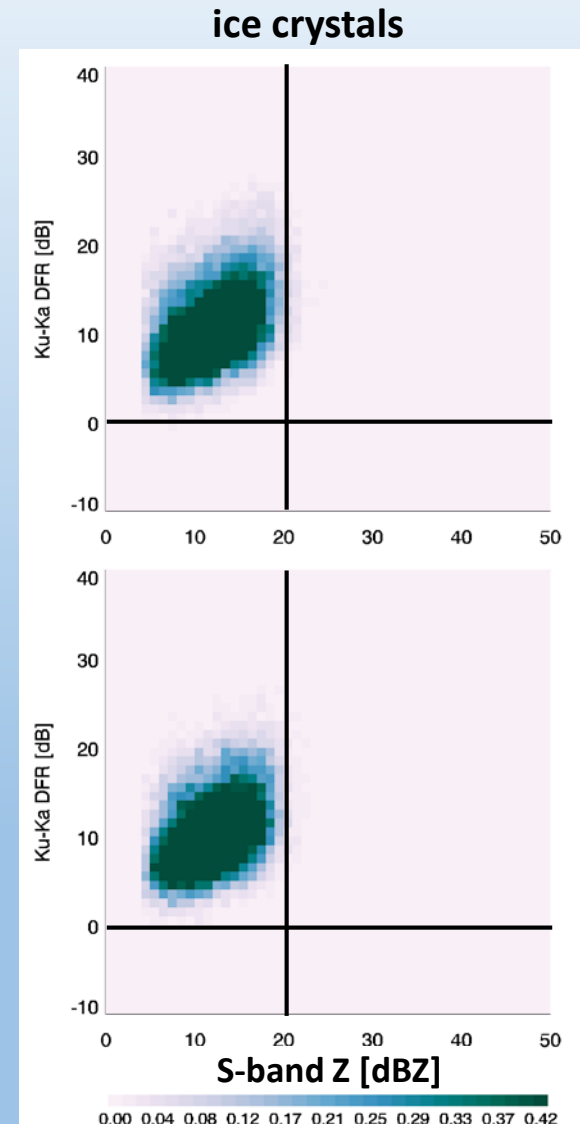
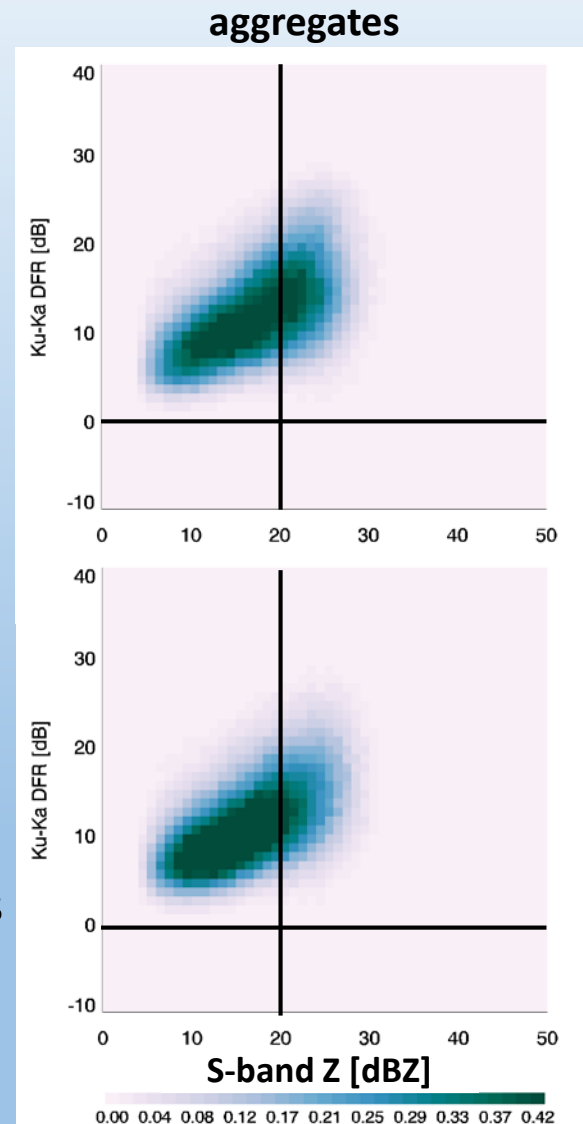
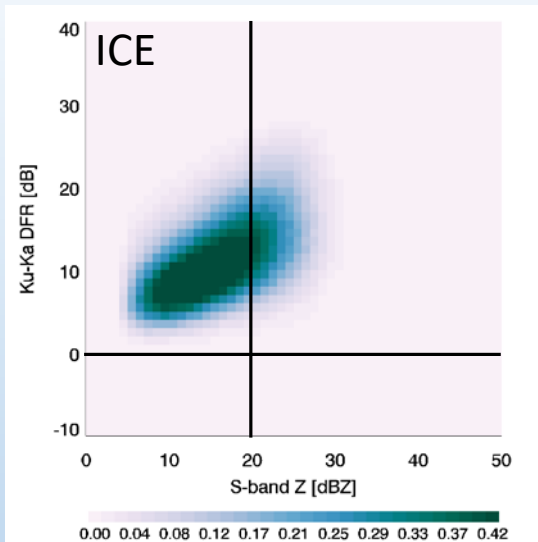
- Ku-band:
 - more consistent distribution shape among all ice types (but hail – not shown)
- S-band:
 - all ice: slightly broader distributions
 - Size separation more pronounced
 - Less linear



LAND

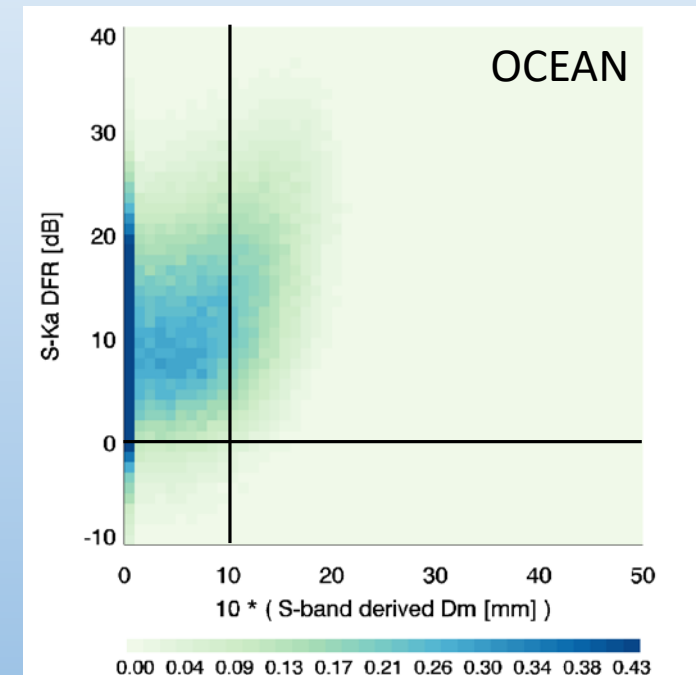
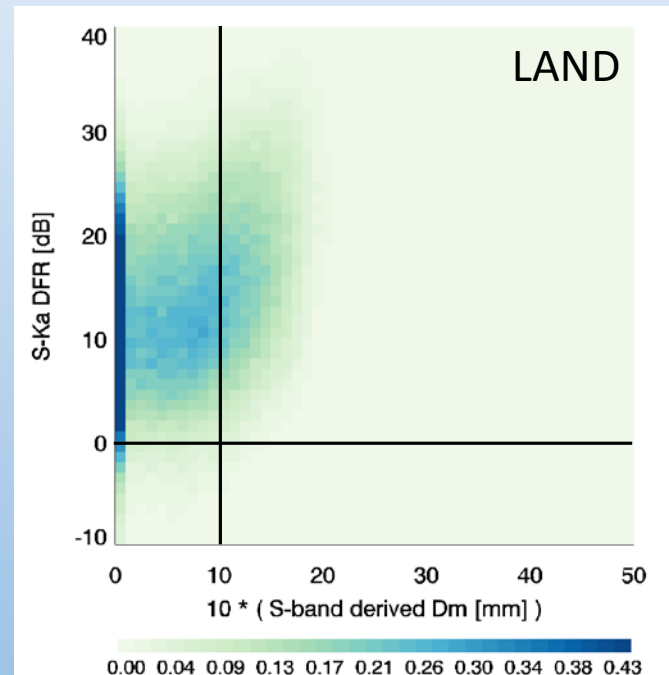
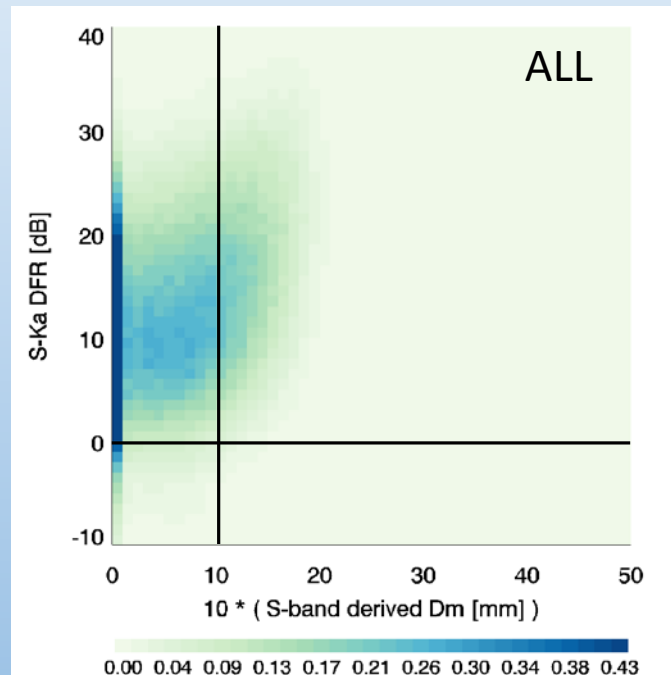
OCEAN

Ku-Ka: Ice phase HID type classes



- Ku-band:
 - more consistent distribution shape among all ice types (but hail – not shown)
- S-band:
 - all ice: slightly broader distributions
 - Some size separation
 - Less linear

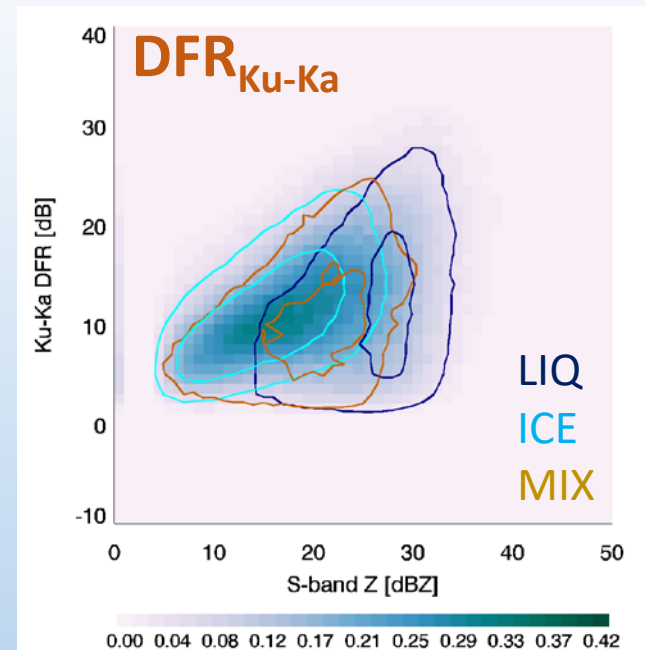
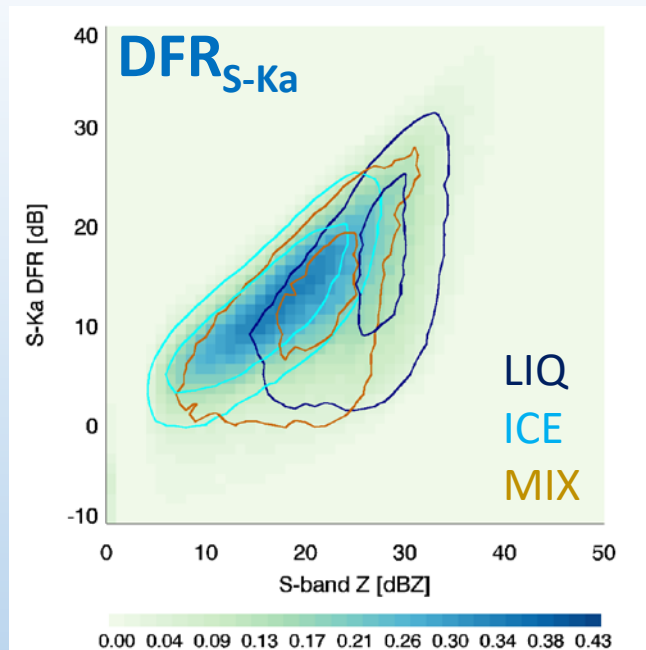
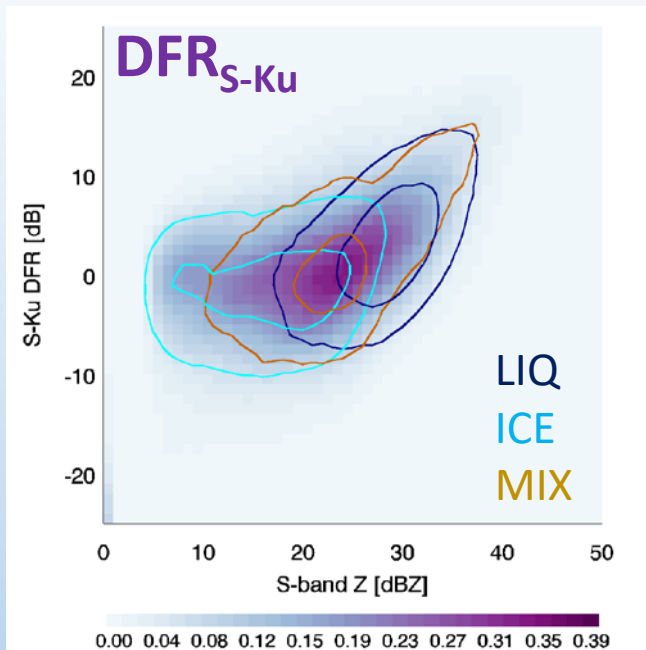
Only LIQ HID Types: DFR_{S-Ka} vs. $10 * D_m$



- Little trend, somewhat more compact over ocean
- Many very small drops

DFRs All ARs

S-Ku
S-Ka
Ku-Ka
(vs. Z_S)

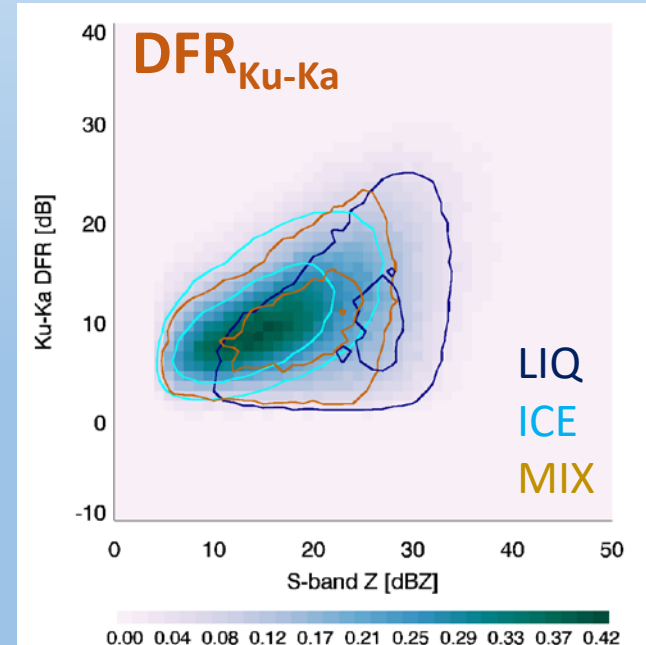
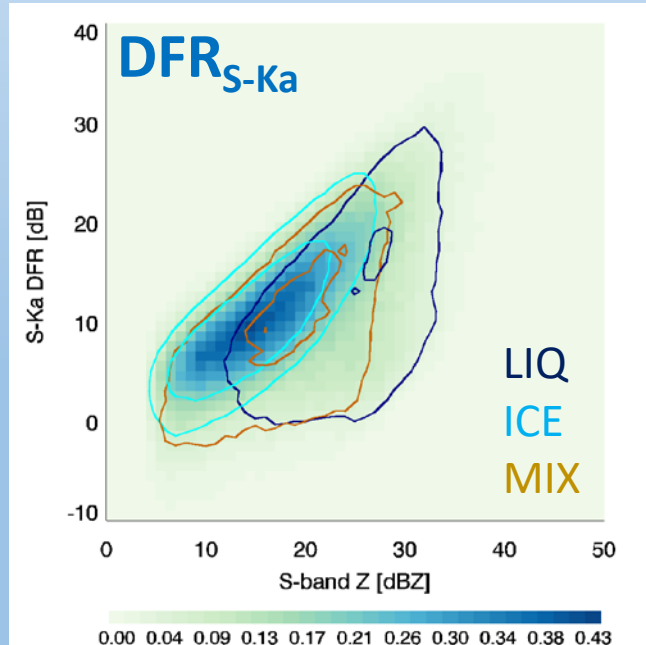
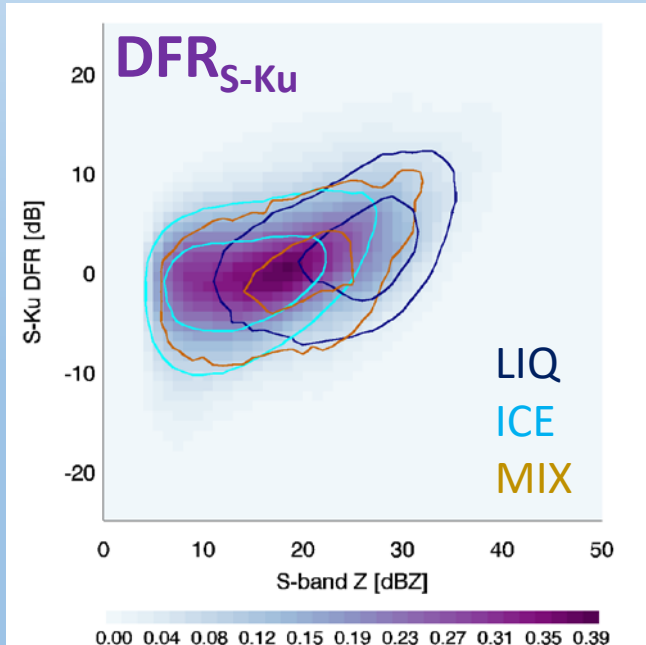


Land Scans

- S-Ku DFR has largest LIQ and ICE overlap
- MIX overlaps in all 3 spaces
- Ocean regime is slightly more compact

*Histograms include all HID phases

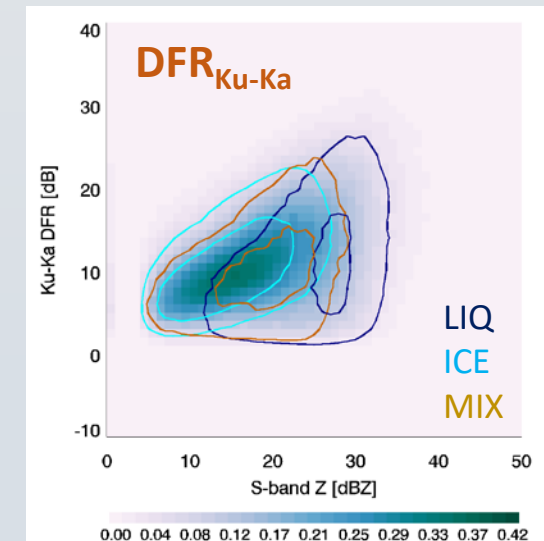
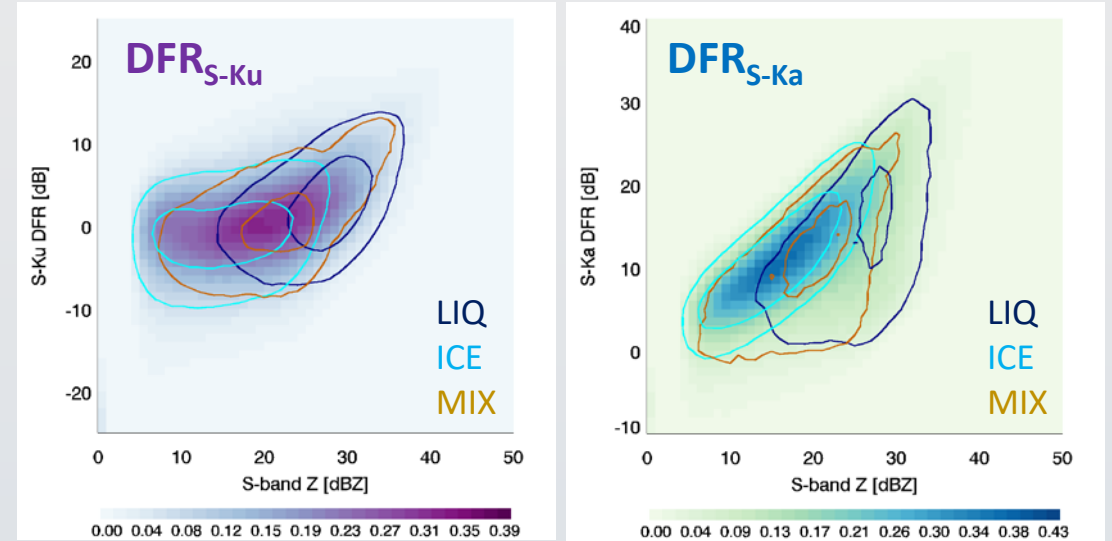
*Contours at densities of 0.1, 0.3 for each HID phase



Ocean Scans

Summary

- OLYMPEX AR composite RHIs show enhancement as approach terrain, mean flow orientation control
- *DFR layering* consistent with terrain complexity
 - Magnitude of terrain-normal flow influences DFR enhancement location, severity
- DFR_{S-Ka} shows most difference among HID phases
- DFR_{Ku-Ka} vs *S-band Z* gives most space for comparing individual HID type classes
- Ocean DFR distributions in general are slightly more compact
 - Indicates more complex processes over land
 - But there are exceptions: wet snow (S-Ku, S-Ka), graupel (Ku-Ka vs. Ku-band Z)
- Inexact beam matching
- *Implications for future spaceborne radar concepts*

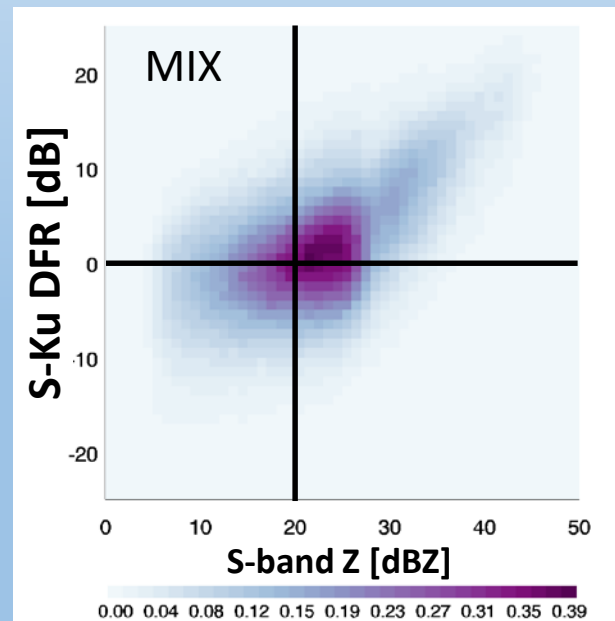
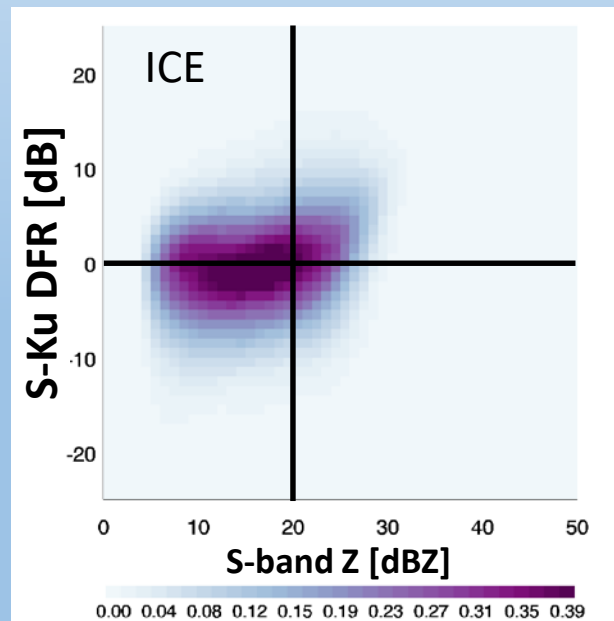
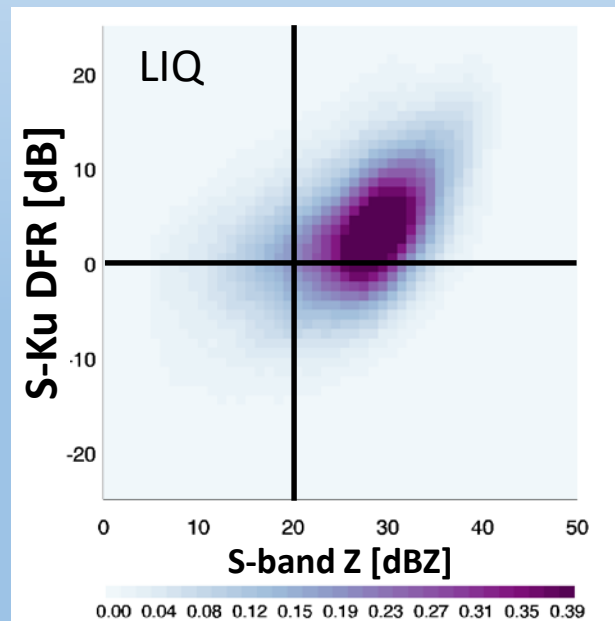
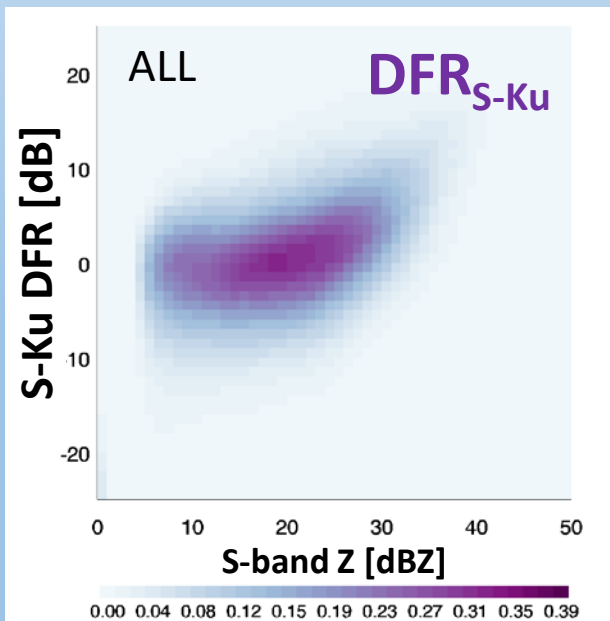
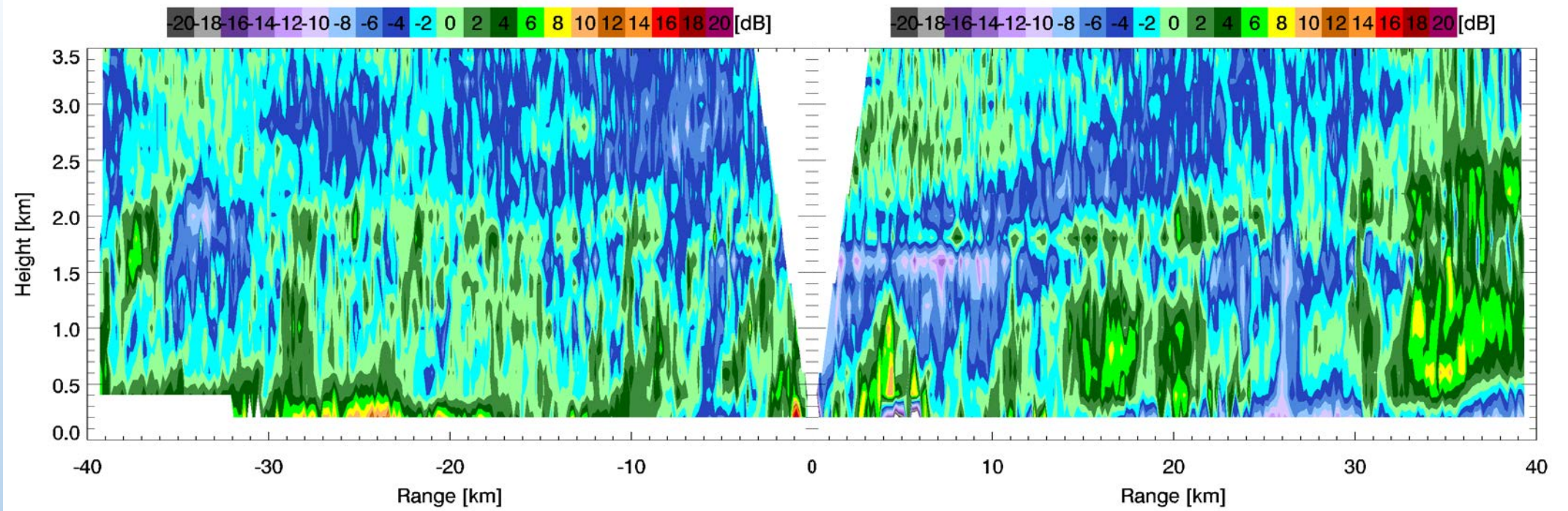


*Histograms include all HID phases

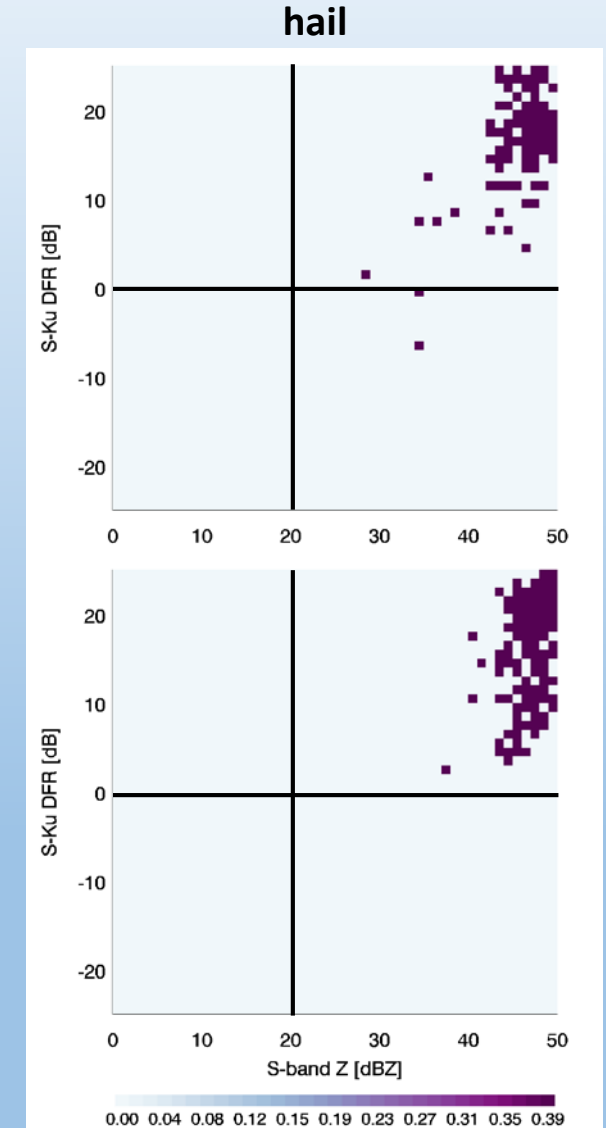
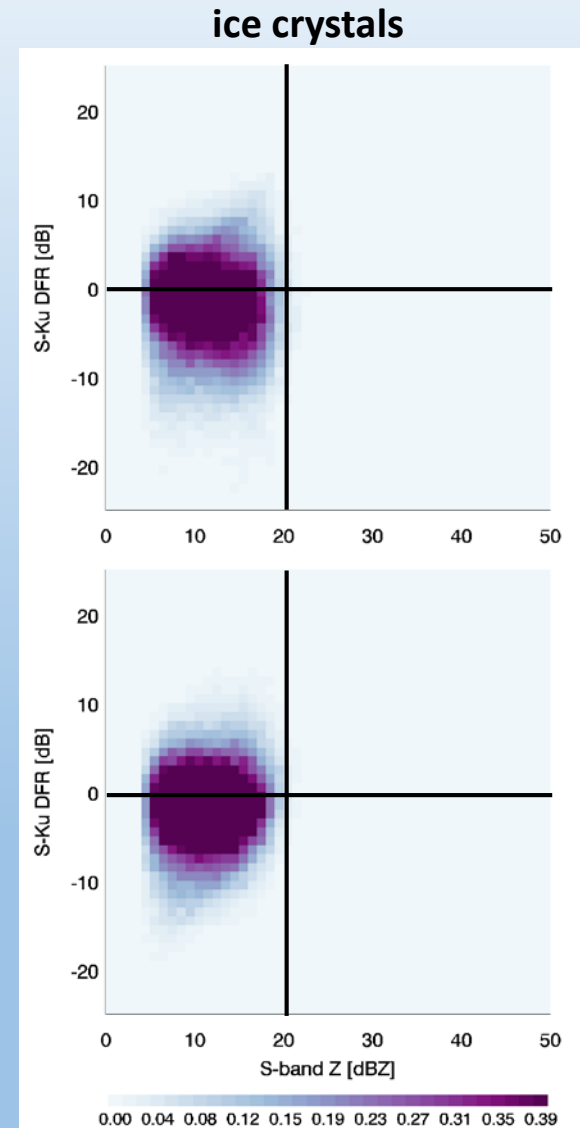
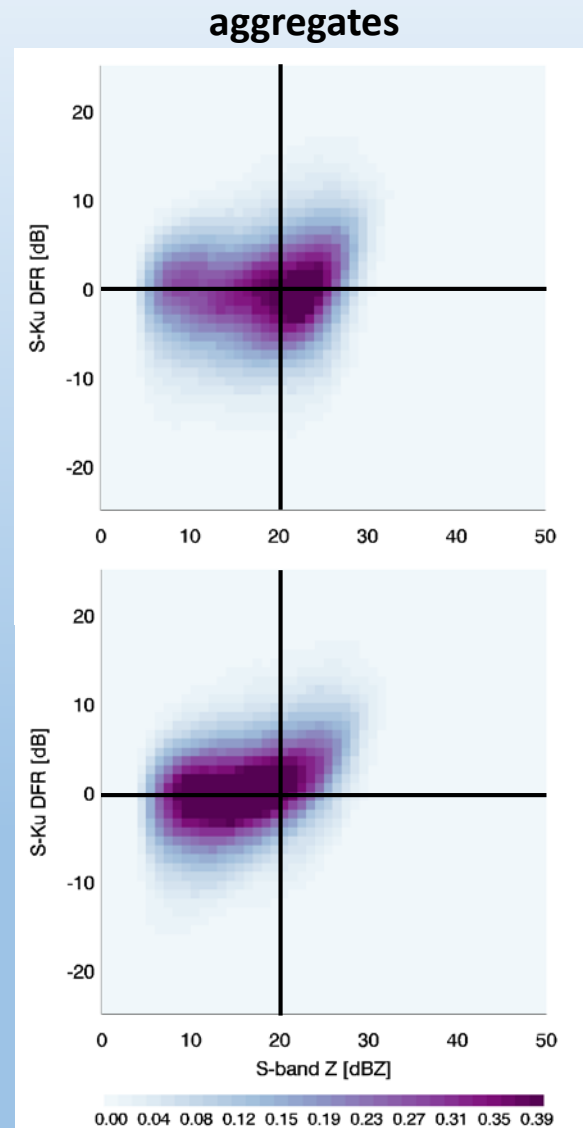
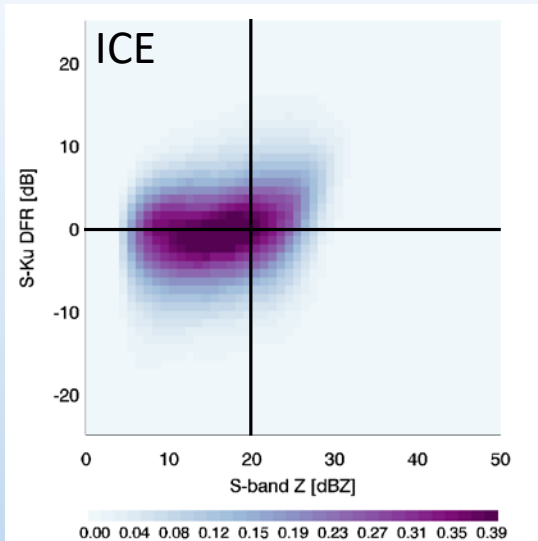
*Contours at densities of 0.1, 0.3 for each HID phase

DFR_{S-Ku} All ARs

- S-Ku DFR composite, includes all NPOL HID types
- Histograms: land + ocean



S-Ku: Ice phase HID type classes

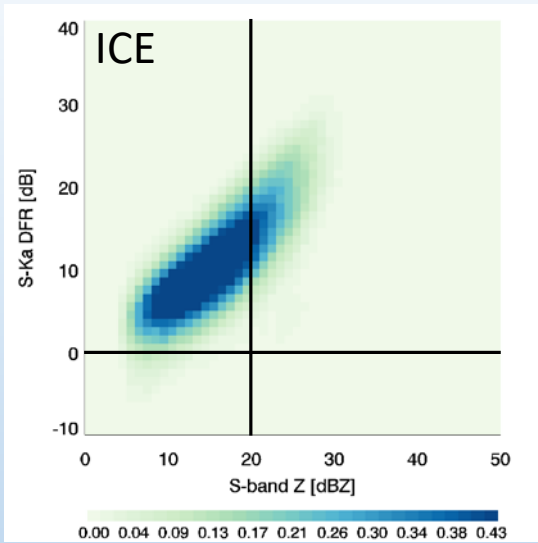


- Aggregates: different land/ocean modes
- Ice crystals: land/ocean similar
- Hail: see Rayleigh dependence
- Vertical ice: slightly lower DFR

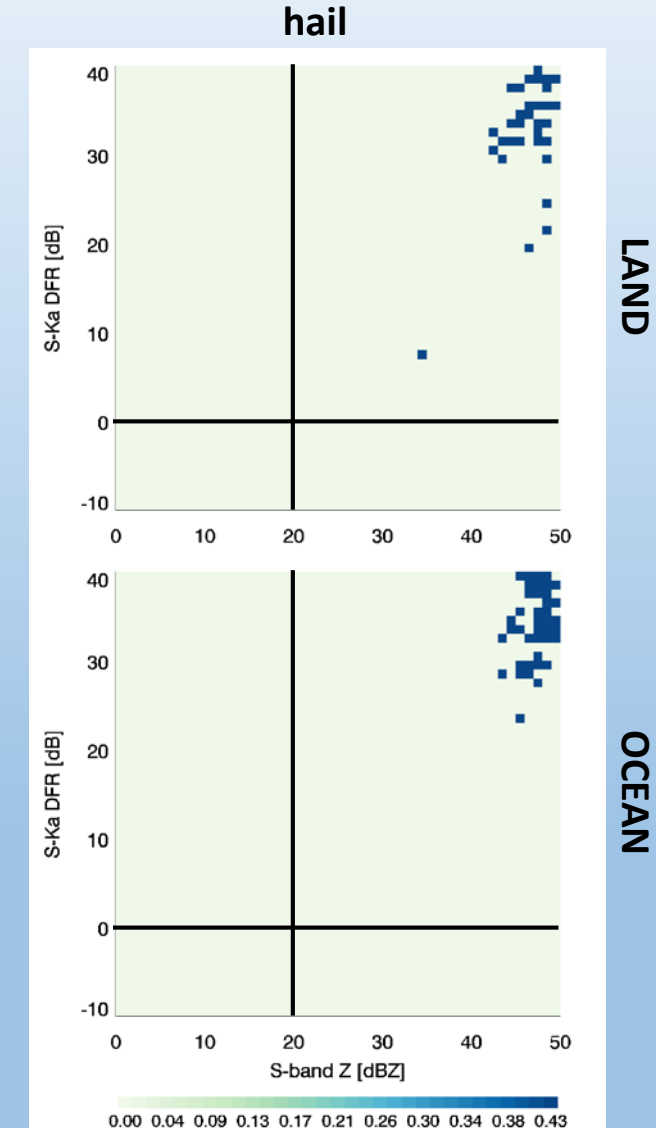
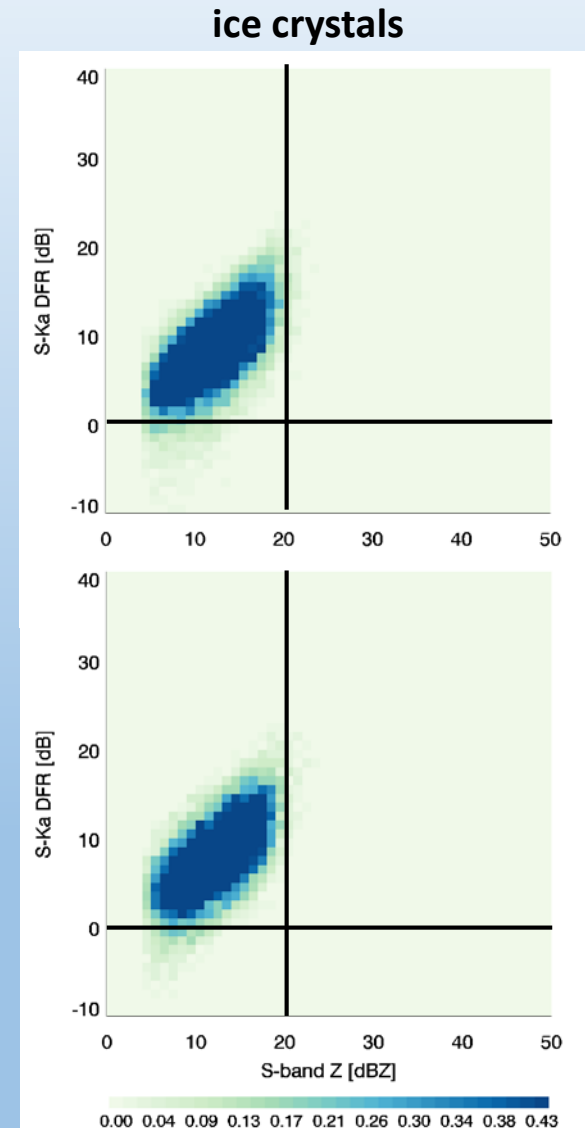
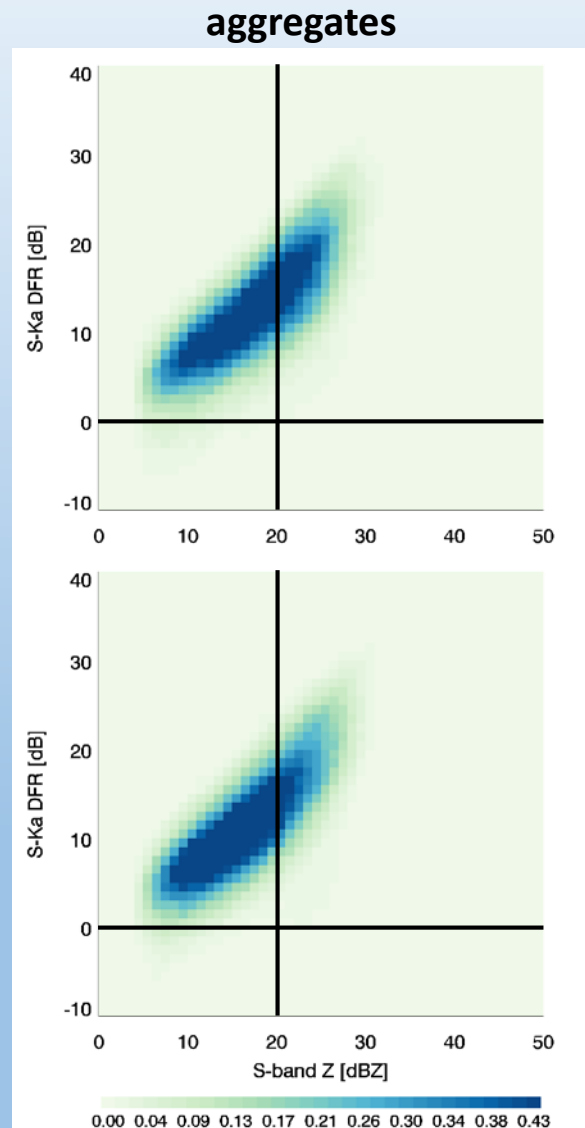
LAND

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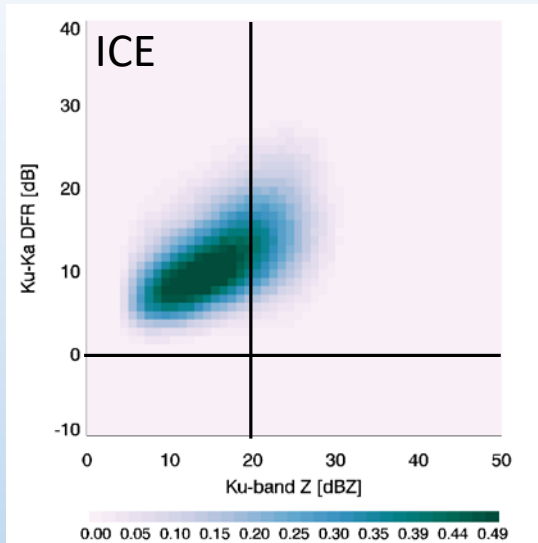
S-Ka: Ice phase HID type classes



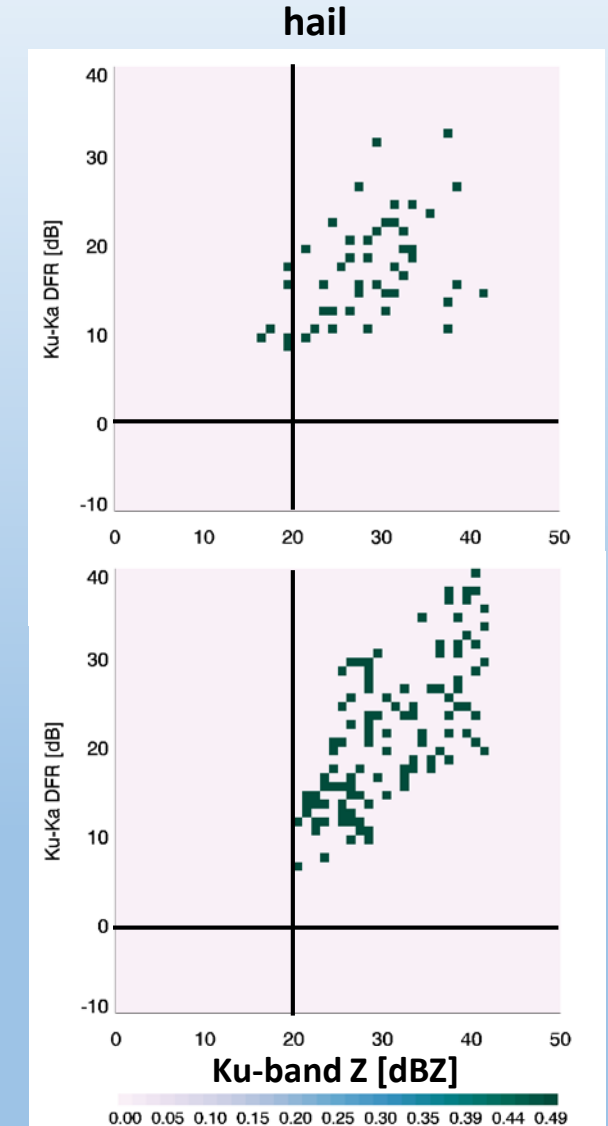
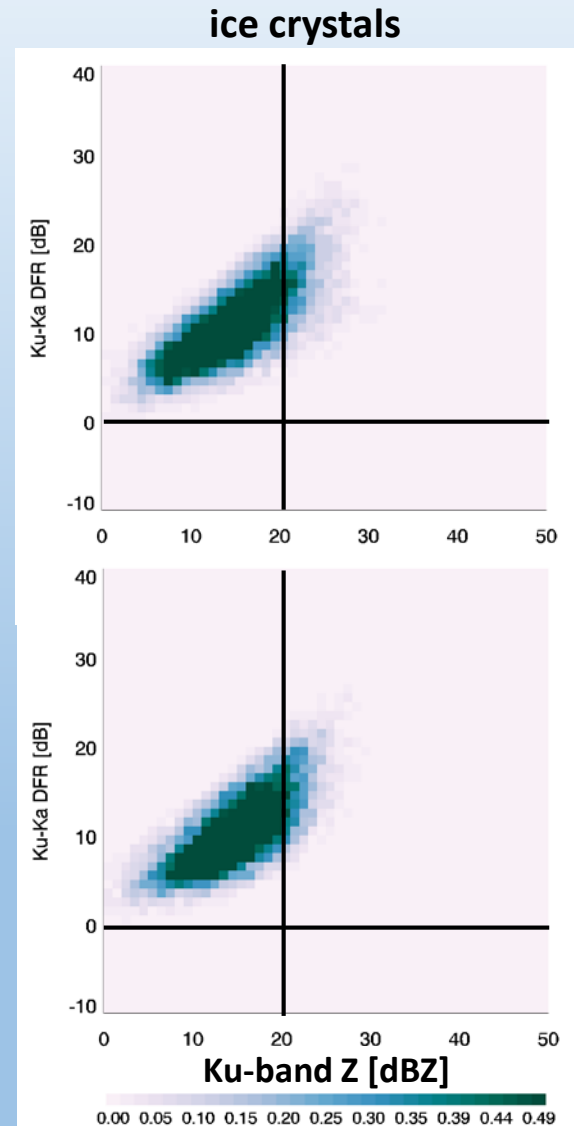
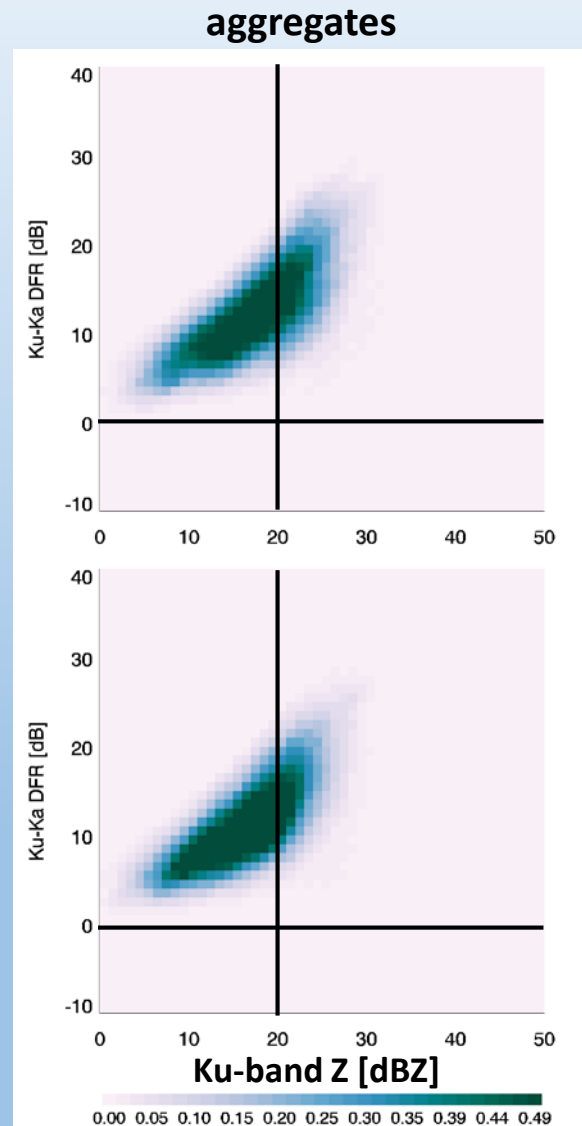
- Aggregates & ice crystals: slightly more compact over ocean
- Vertical ice: behavior in this space very similar to other ICE HID type classes



Ku-Ka: Ice phase HID type classes



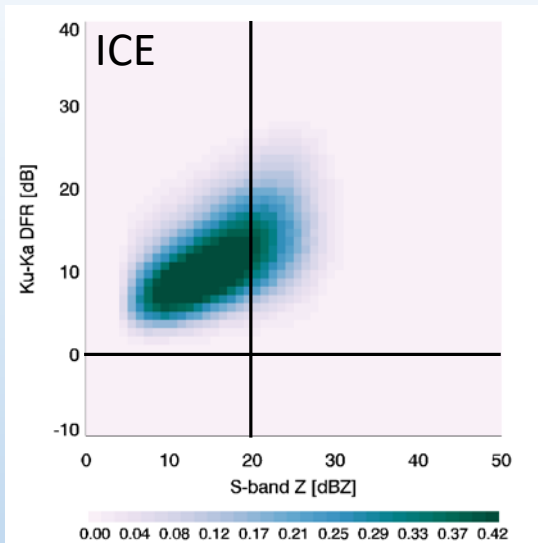
- Ku-band:
 - more consistent distribution shape among all ice types (but hail)
- S-band:
 - all ice more dispersed
 - Size separation more pronounced
 - Less linear



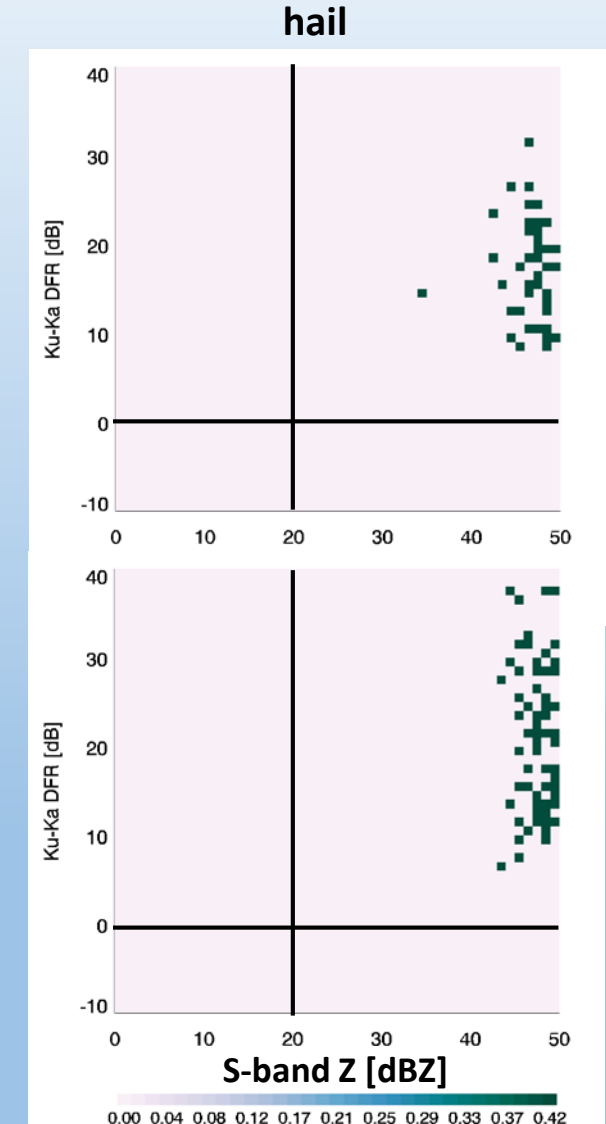
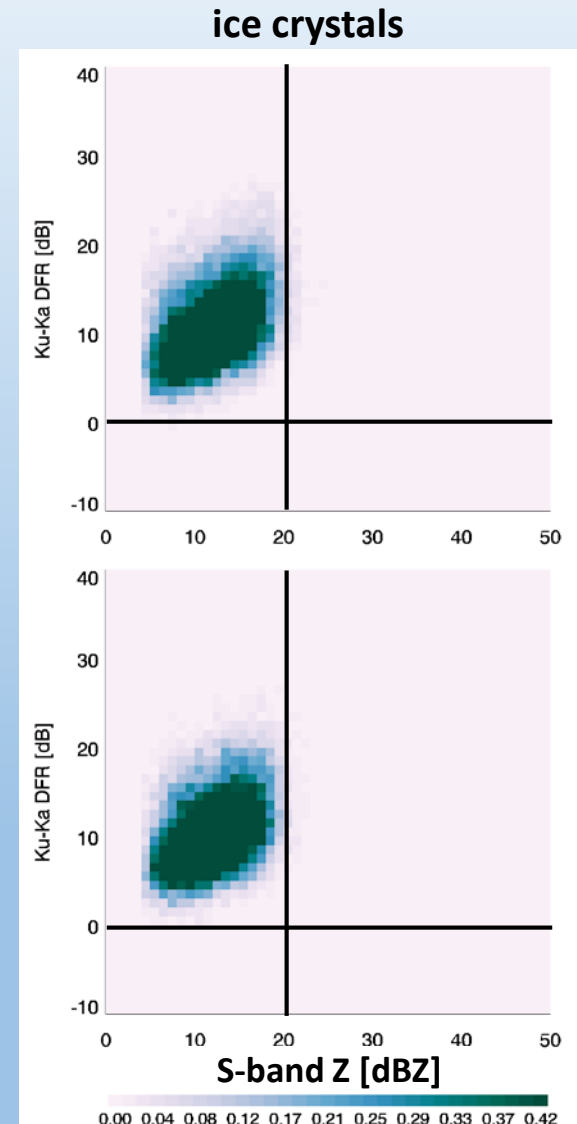
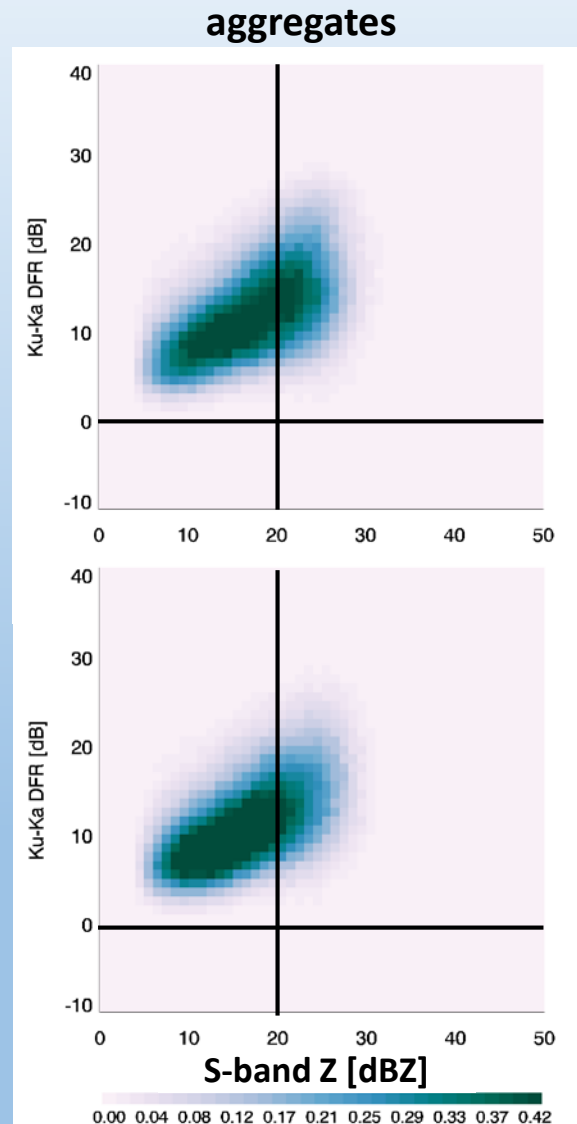
LAND

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Ku-Ka: Ice phase HID type classes



- Ku-band:
 - more consistent distribution shape among all ice types (but hail)
- S-band:
 - all ice more dispersed
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LAND

OCEAN