Analysis of NASA GPM Ground Validation Multi-frequency Radar Observations

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Image: Stacy Brodzik

Motivation

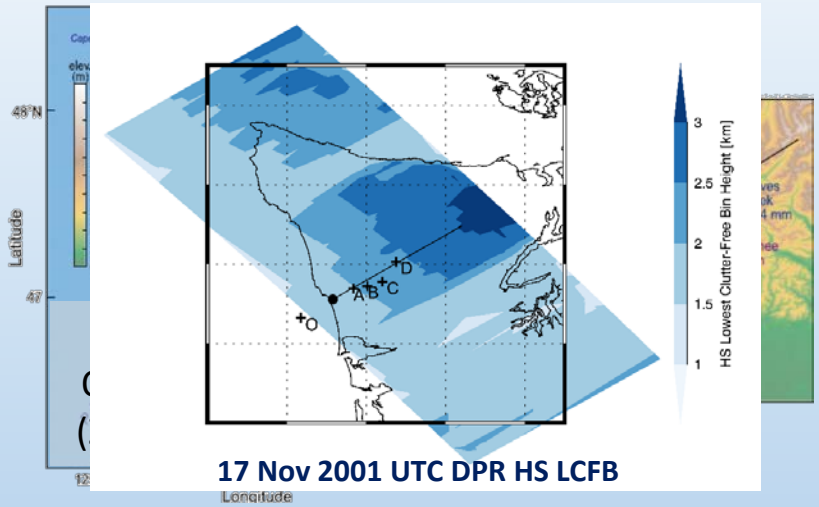
- GPM GV Observation Diversity
  - Core Observatory
  - Constellation Partners
  - Field Campaigns

Goals:

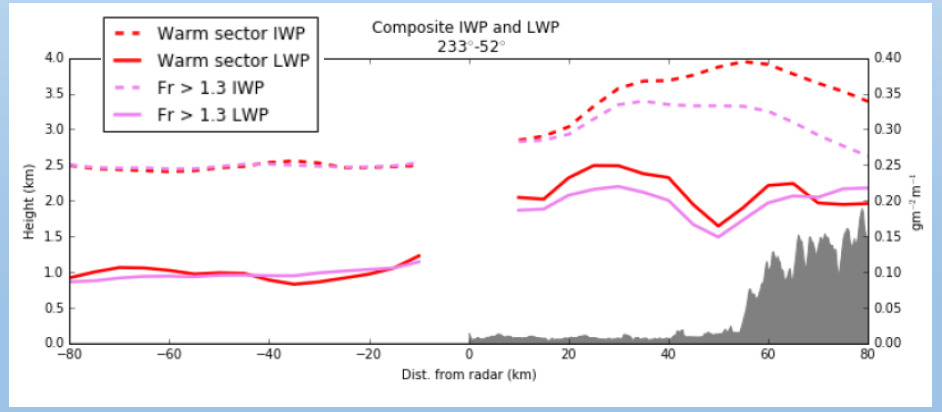
Focus on OLYMPEX Atmospheric River (AR) Events:

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





17 Nov 2001 UTC DPR HS LCFB



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

Methodology

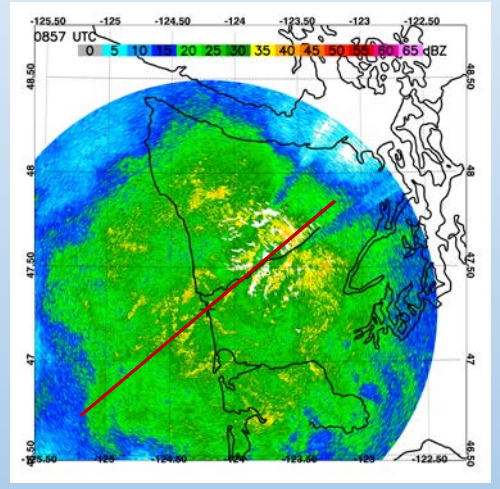
Case Criteria

- 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%)

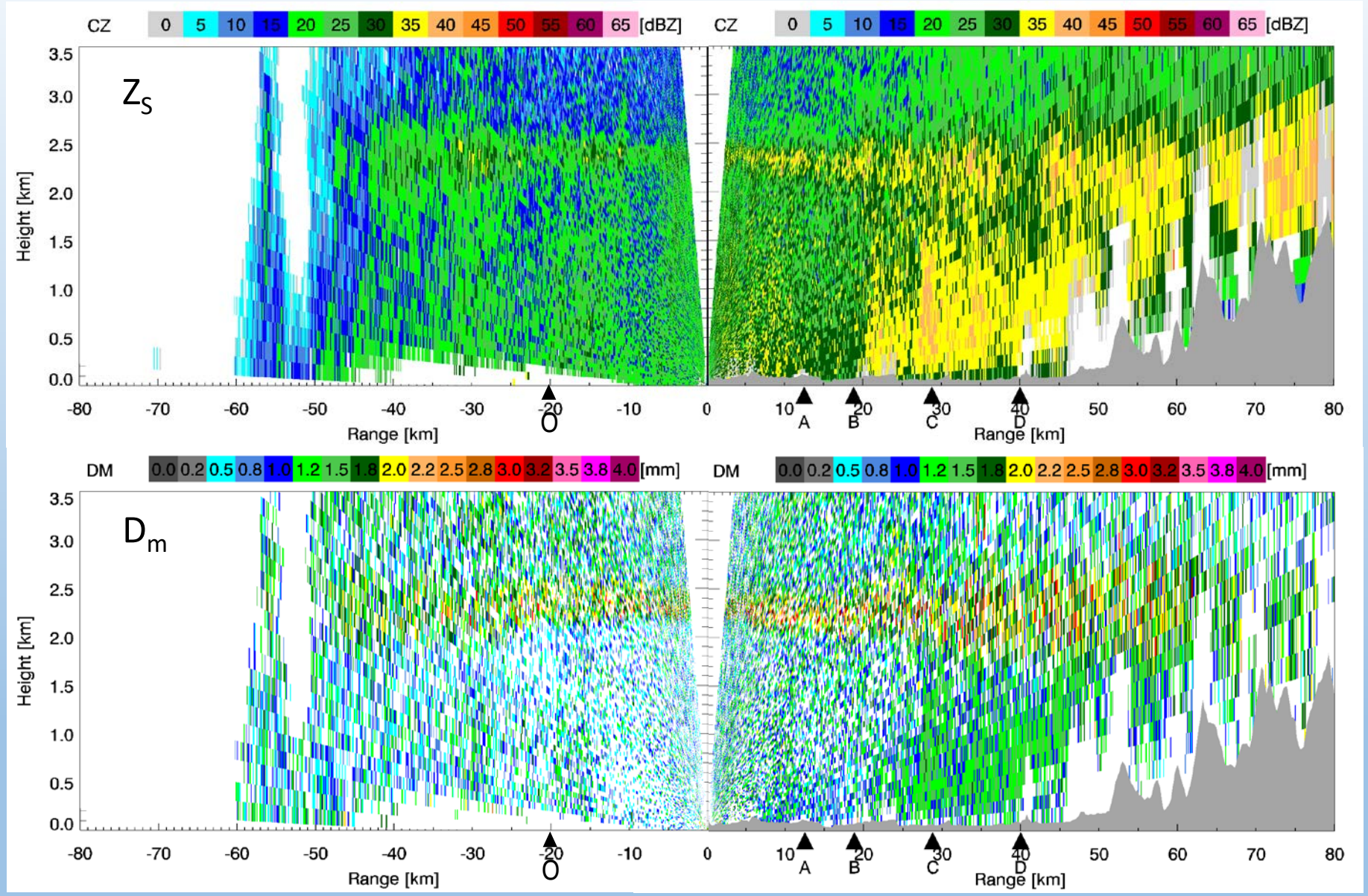
Analysis:

- 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

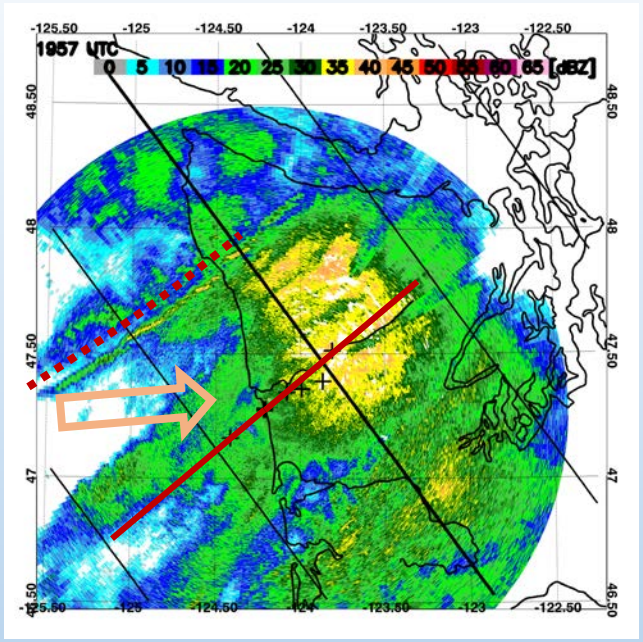


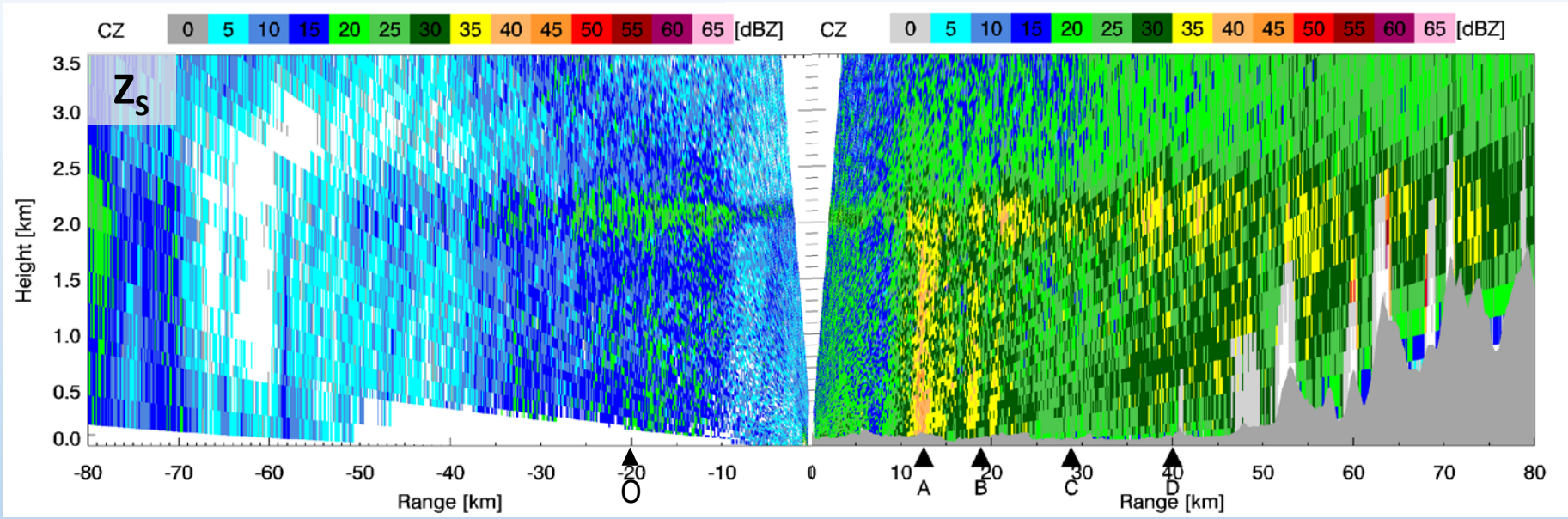
- Along NPOL RHI approaching, through Quinault River Valley
- Terrain, orographic enhancements

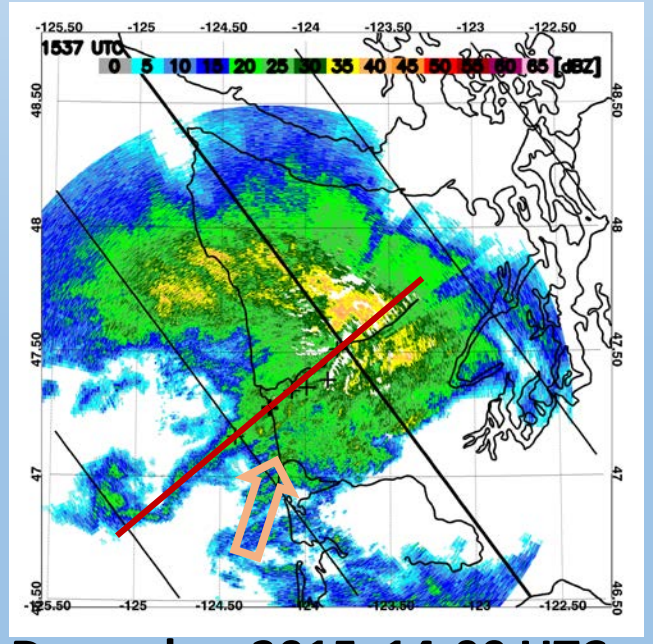


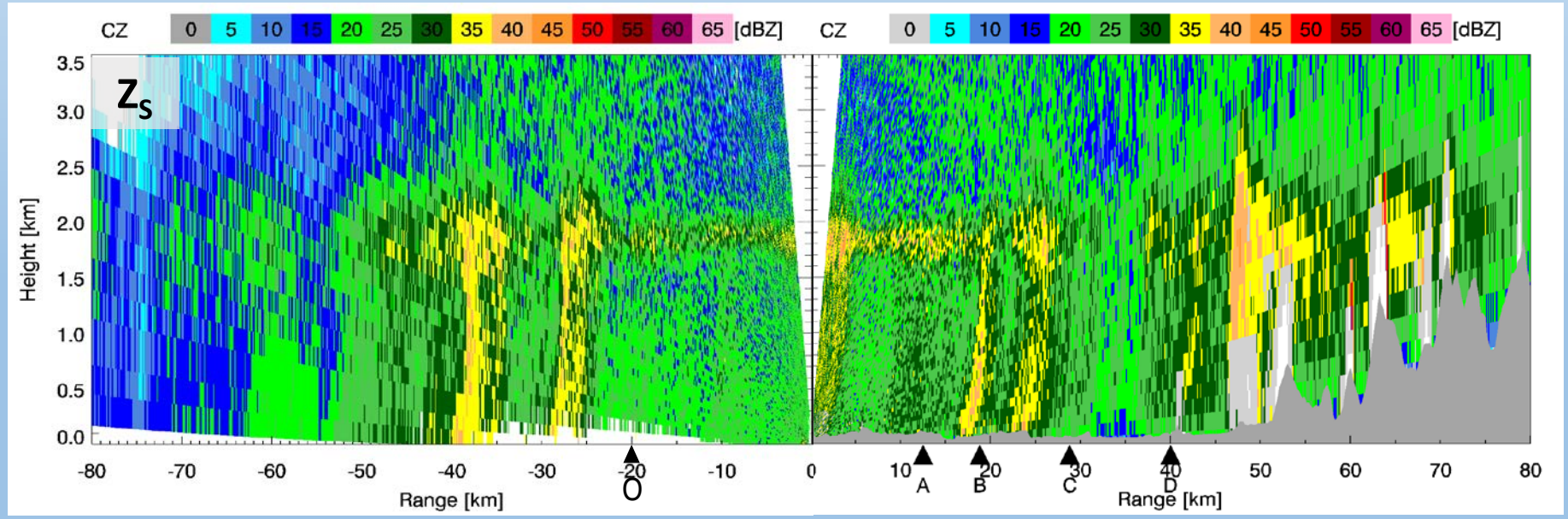
17 November 2015 10-21 UTC

Z_S – NPOL Composites









3 December 2015 14-00 UTC

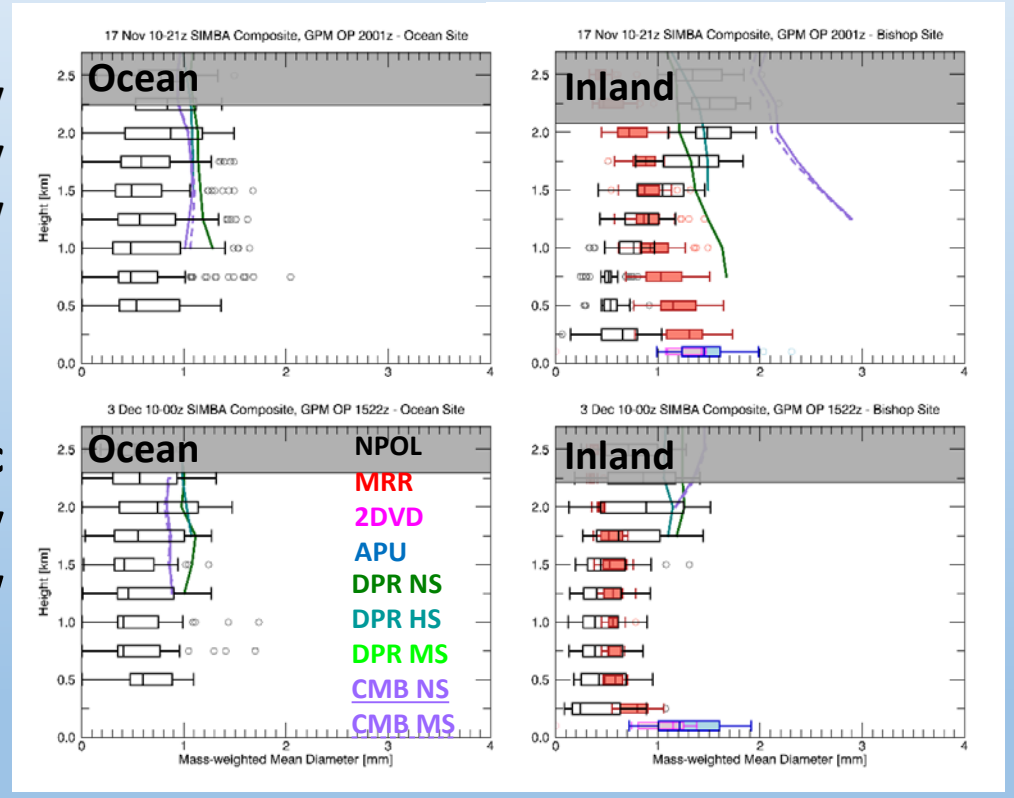
Why Dual-Frequency Ratios for the ARs?

- 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

D_m Composite Profiles

17 Nov Westerly flow

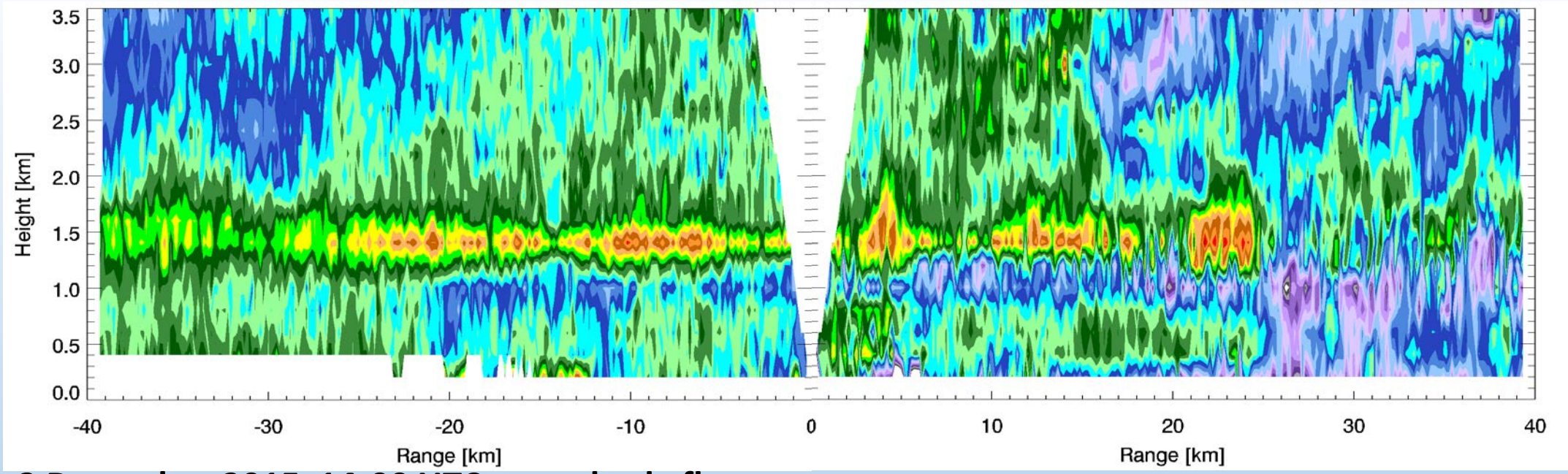
3 Dec Southerly flow



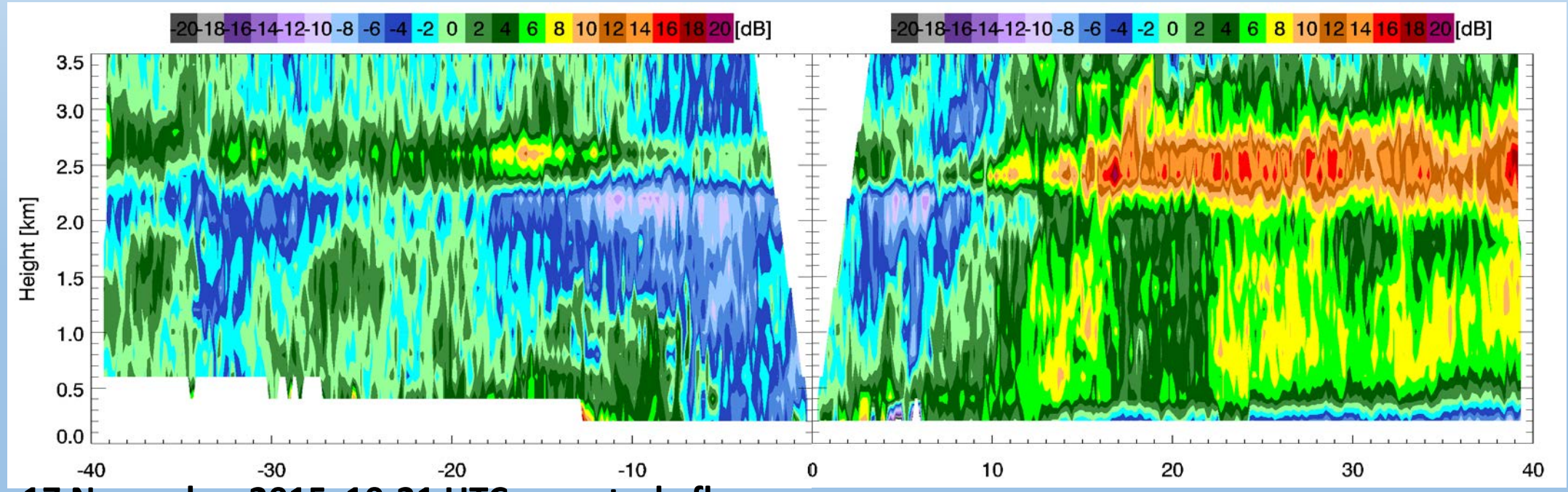
→ Importance of identifying & quantifying **ICE, LIQUID, and MIX** phase hydrometers to better discern processes, improve observing

$DFR_{S\text{-}Ku}$ 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

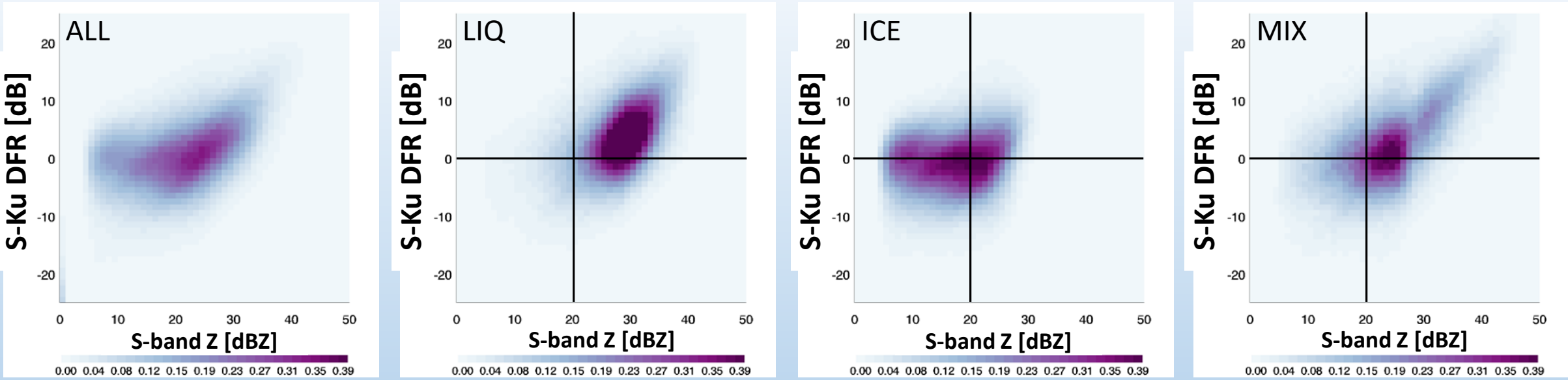


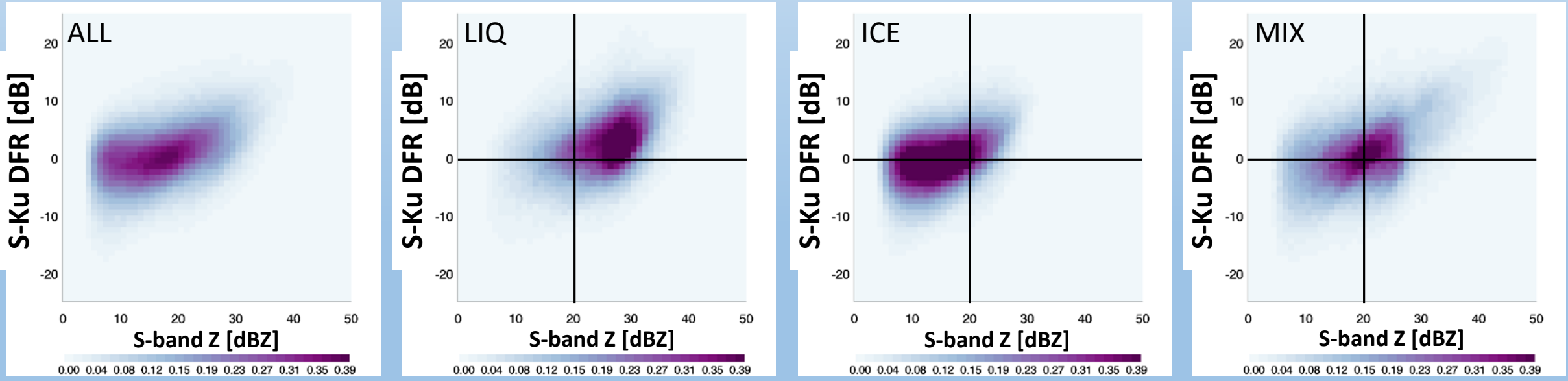
3 December 2015 14-00 UTC – southerly flow



17 November 2015 10-21 UTC – westerly flow

$DFR_{S\text{-}Ku}$ ALL ARs Land Side Scans

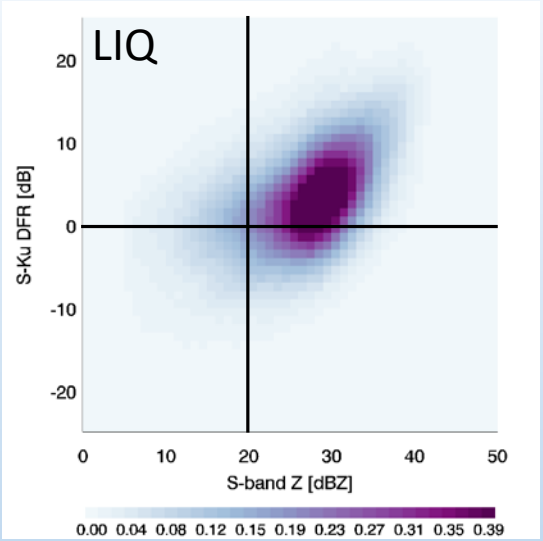




$DFR_{S\text{-}Ku}$ ALL ARs Ocean Side Scans

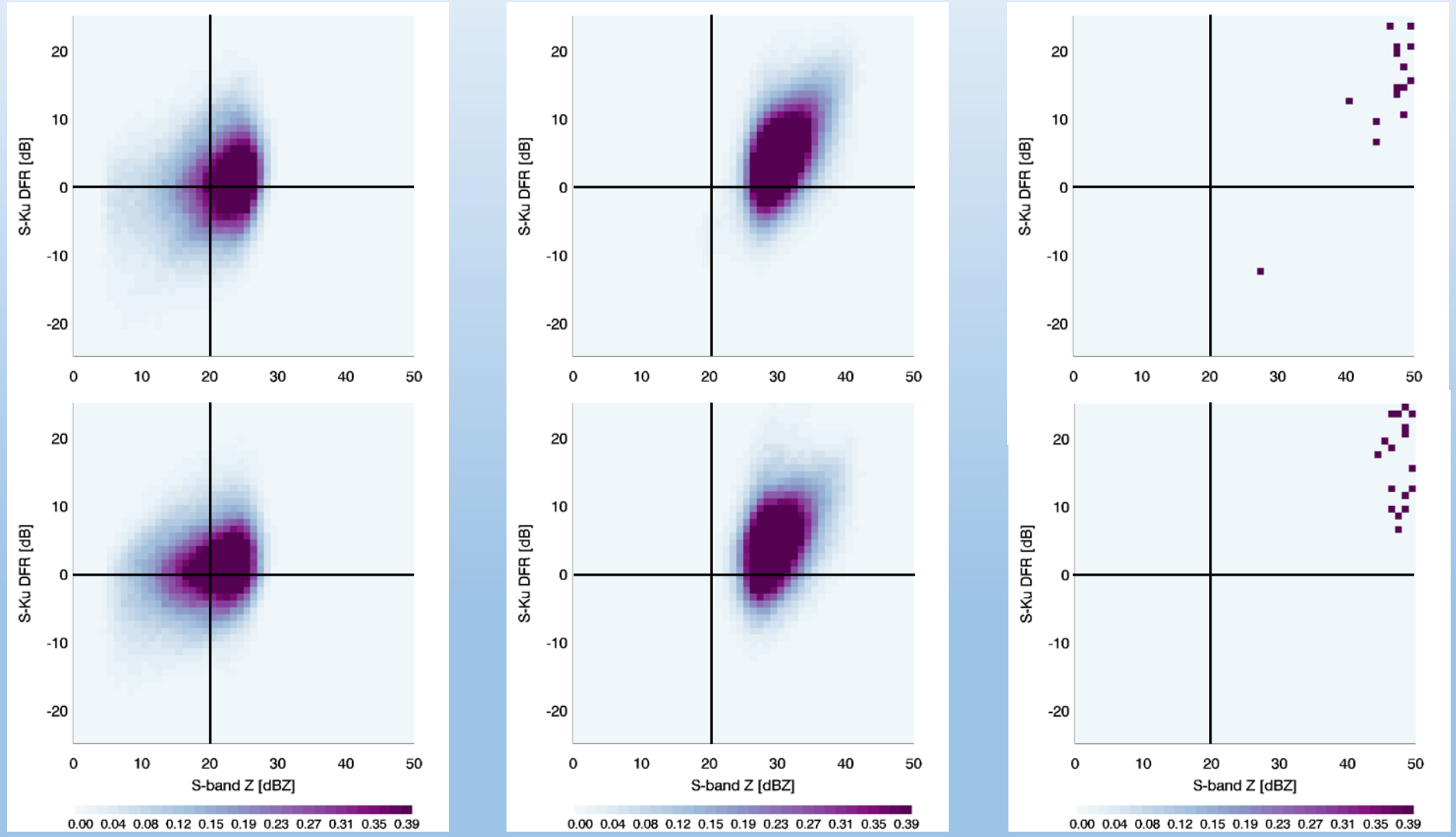
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S-Ku: Liquid phase HID type classes

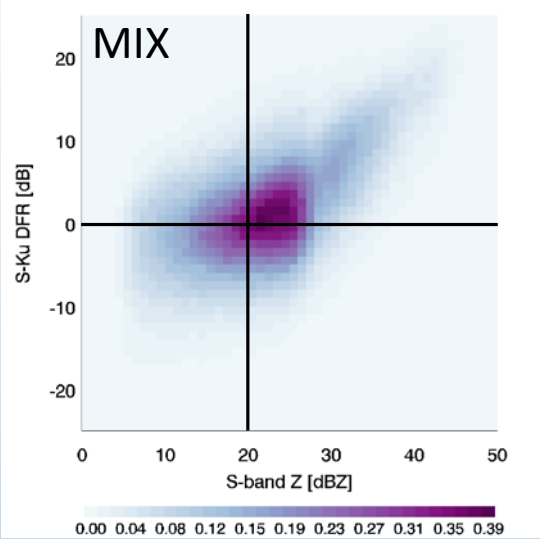


- S-band Z / Rayleigh regime dependence on hydrometeor size evident
- $DFR_{S\text{-}Ku}$ values positive & negative
- OLYMPEX region well known for copious numbers of small drops

drizzle | **rain** | **big drops**

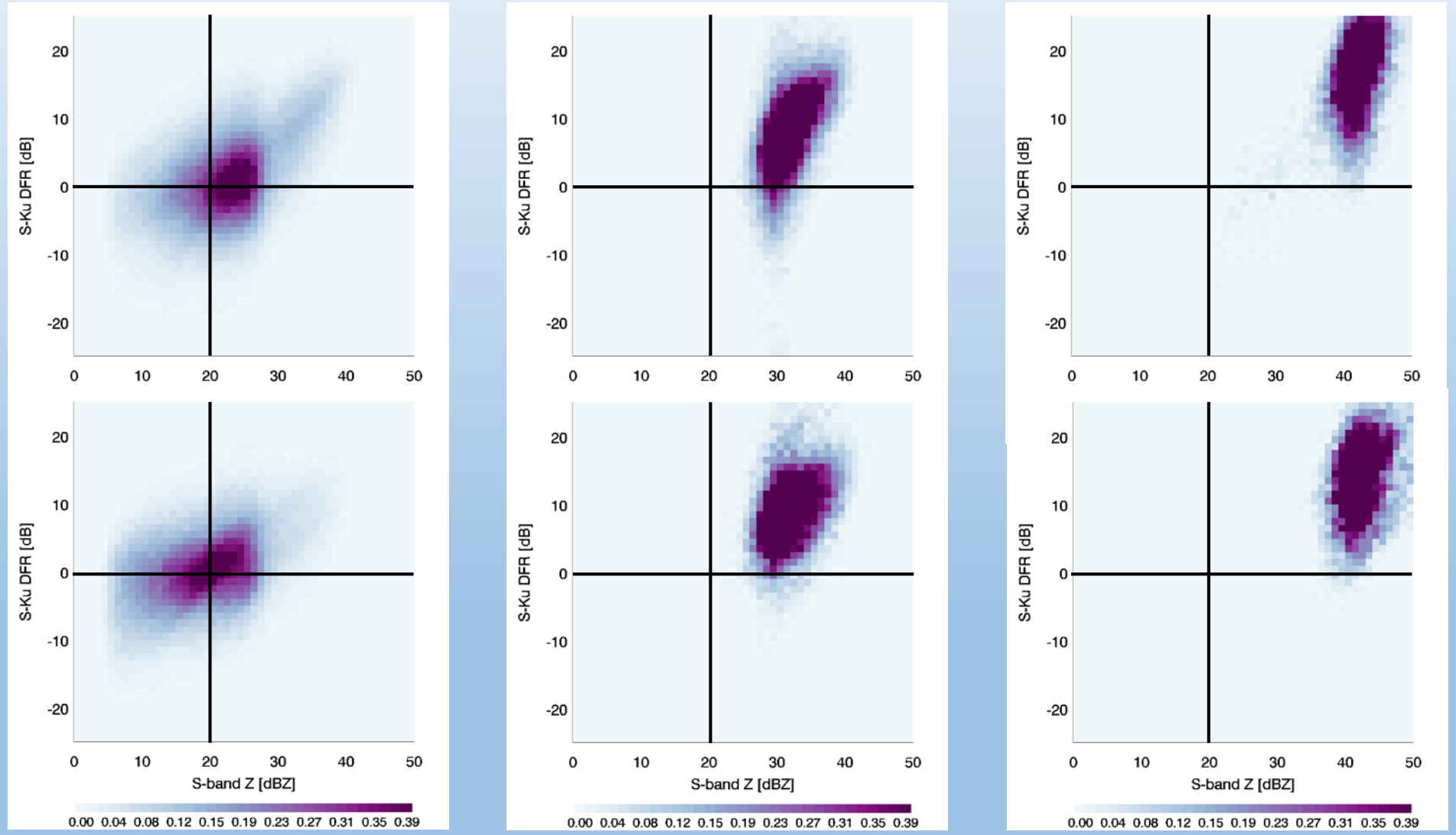


S-Ku: Mix-phase HID type classes

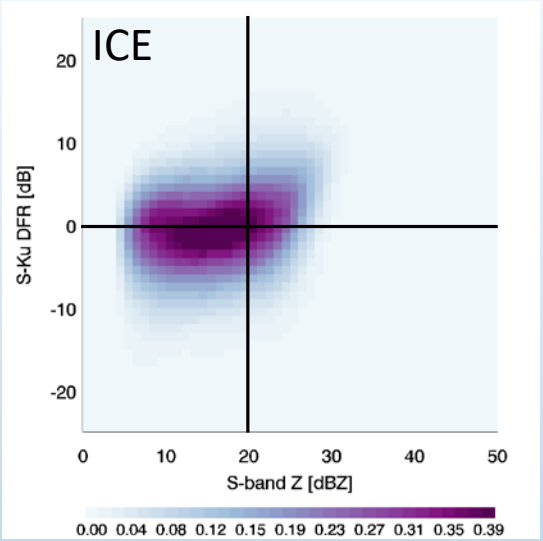


- Wet snow shows most variation, and **more dispersed over ocean**
- Graupel classes more similar to rain, hail; **more dispersed over land**

wet snow | **low density graupel** | **high density graupel**

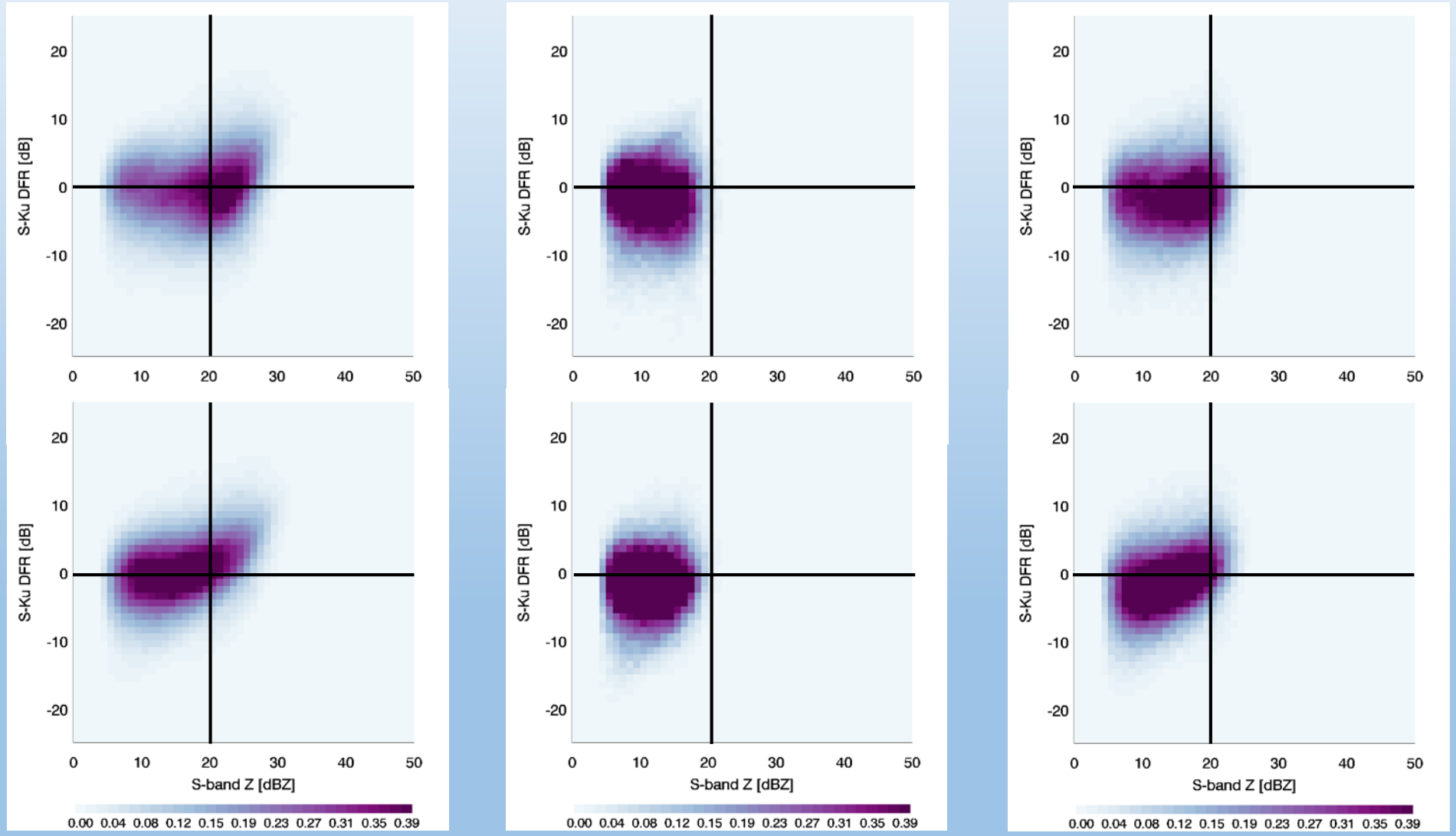


S-Ku: Ice phase HID type classes

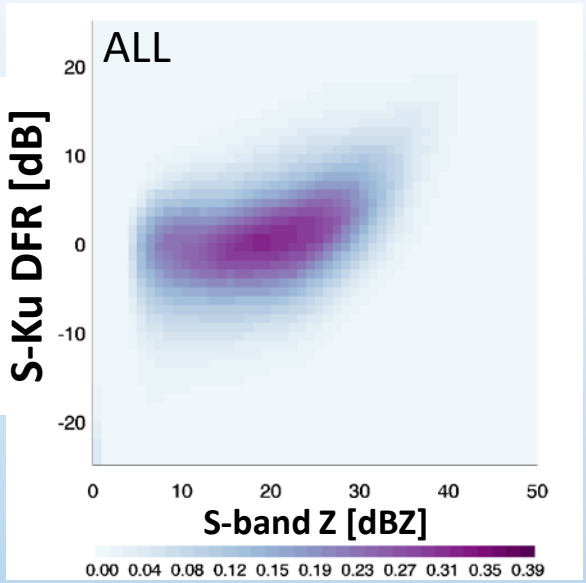


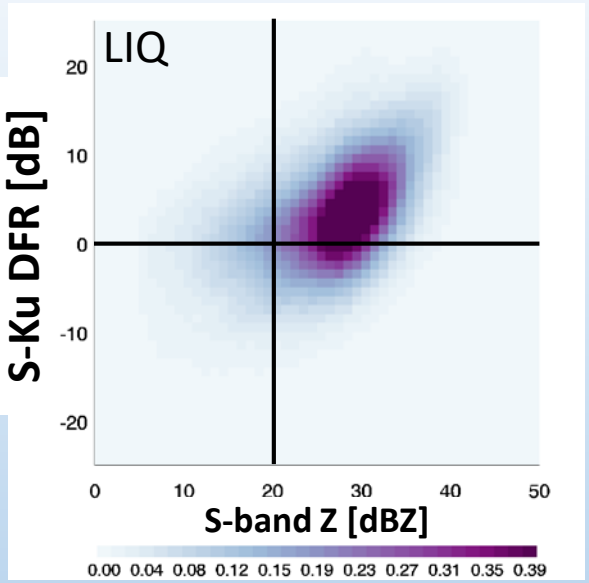
- Aggregates: different land/ ocean modes
- Ice crystals: land/ocean similar
- Vertical ice: slightly lower DFR

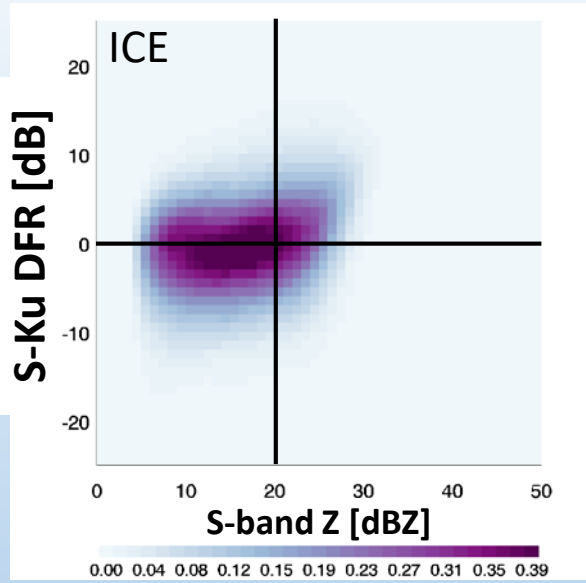
aggregates | **ice crystals** | **vertical ice**

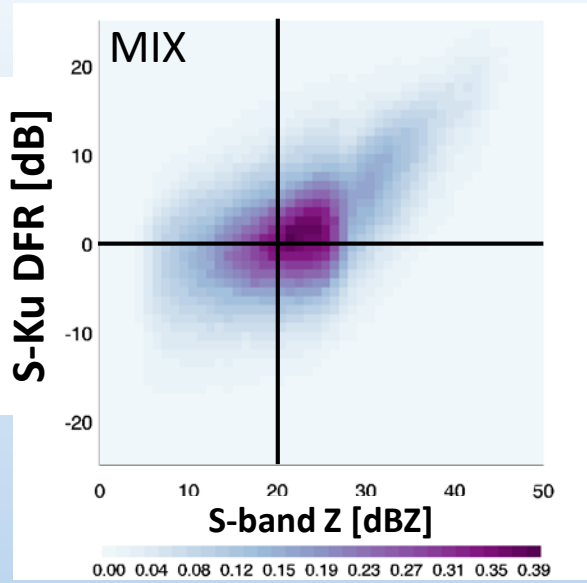


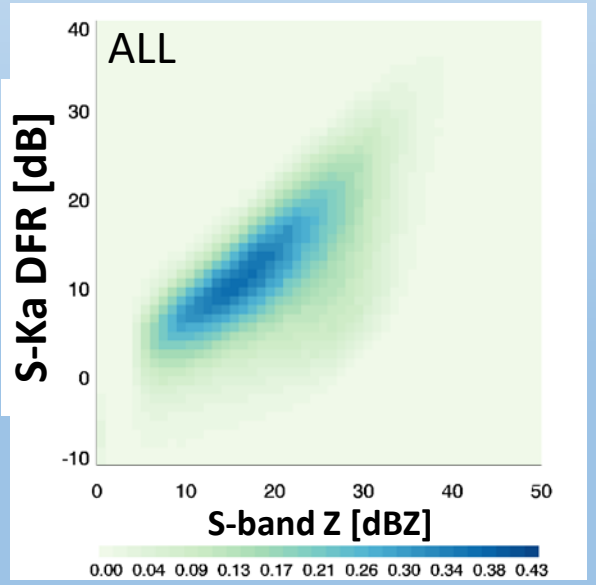
DFR_{S-Ku} ALL ARs Land + Ocean

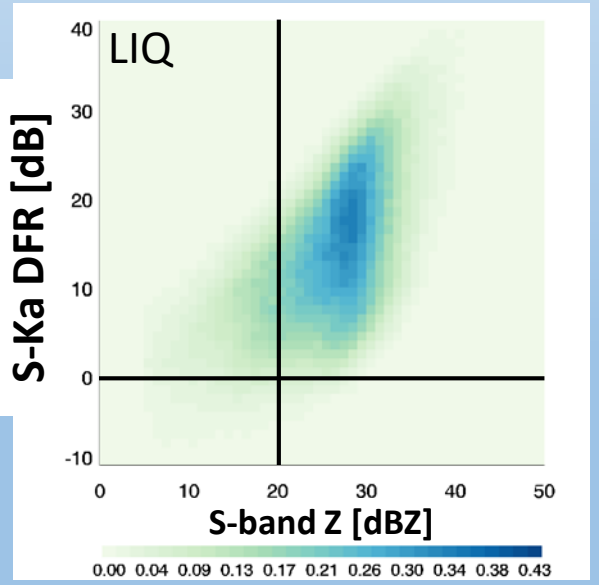


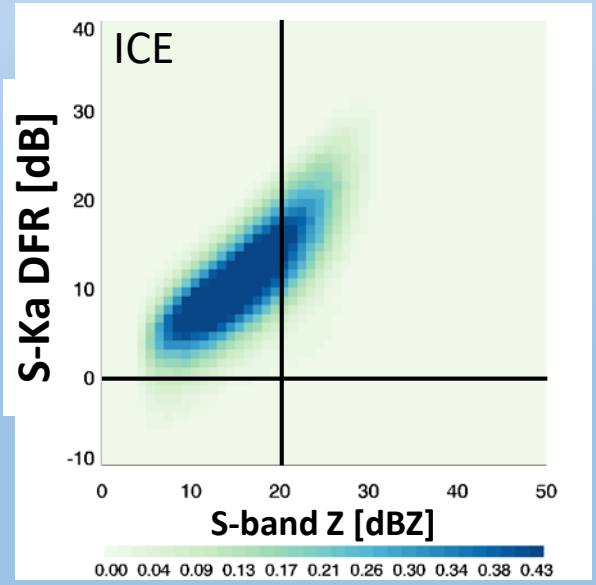


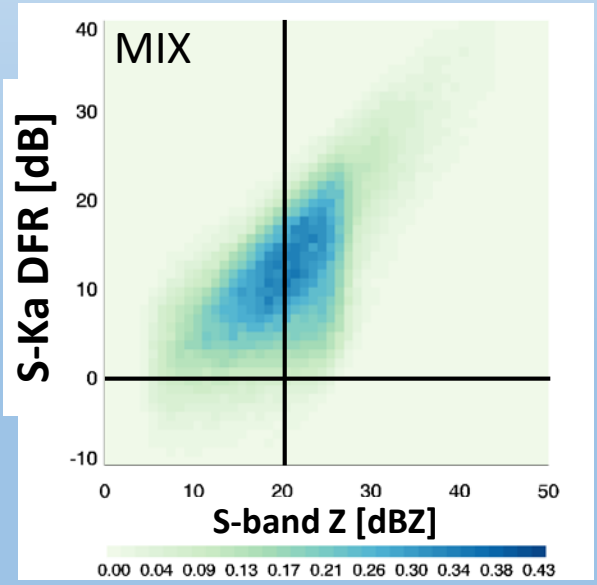






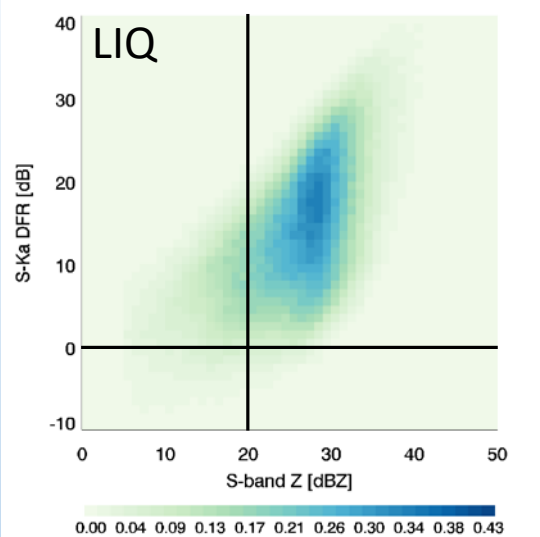






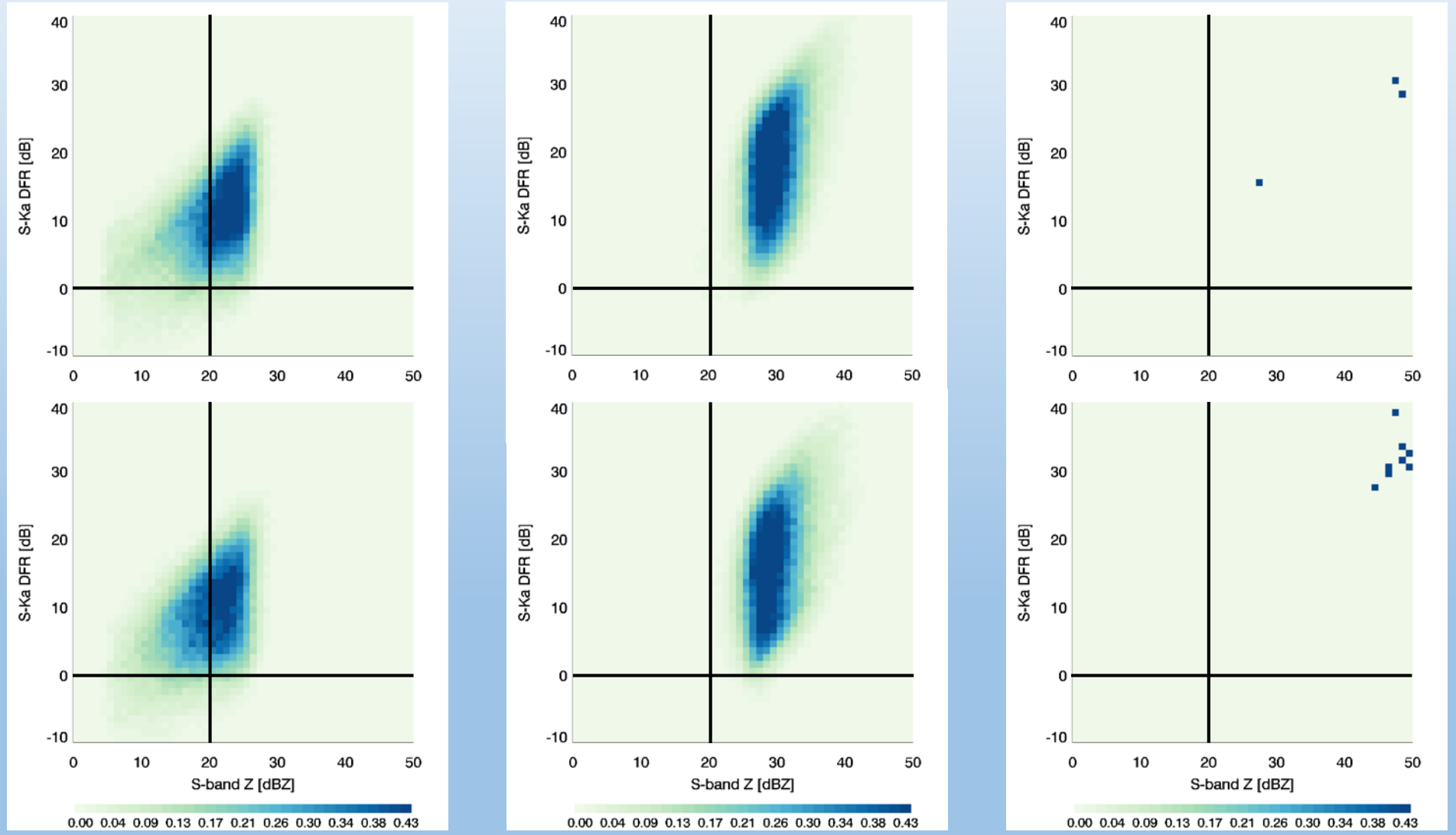
DFR_{S-Ka} ALL ARs Land + Ocean

S-Ka: Liquid phase HID type classes

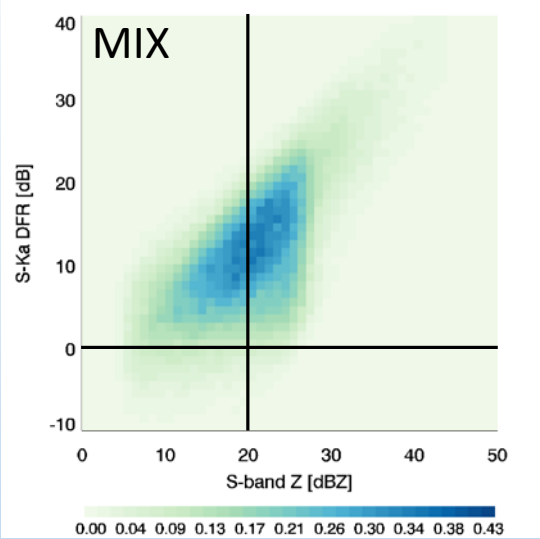


- S-band Z / Rayleigh regime dependence on hydrometeor size evident
- Almost all $DFR_{S\text{-}Ka}$ values **positive**

drizzle | **rain** | **big drops**

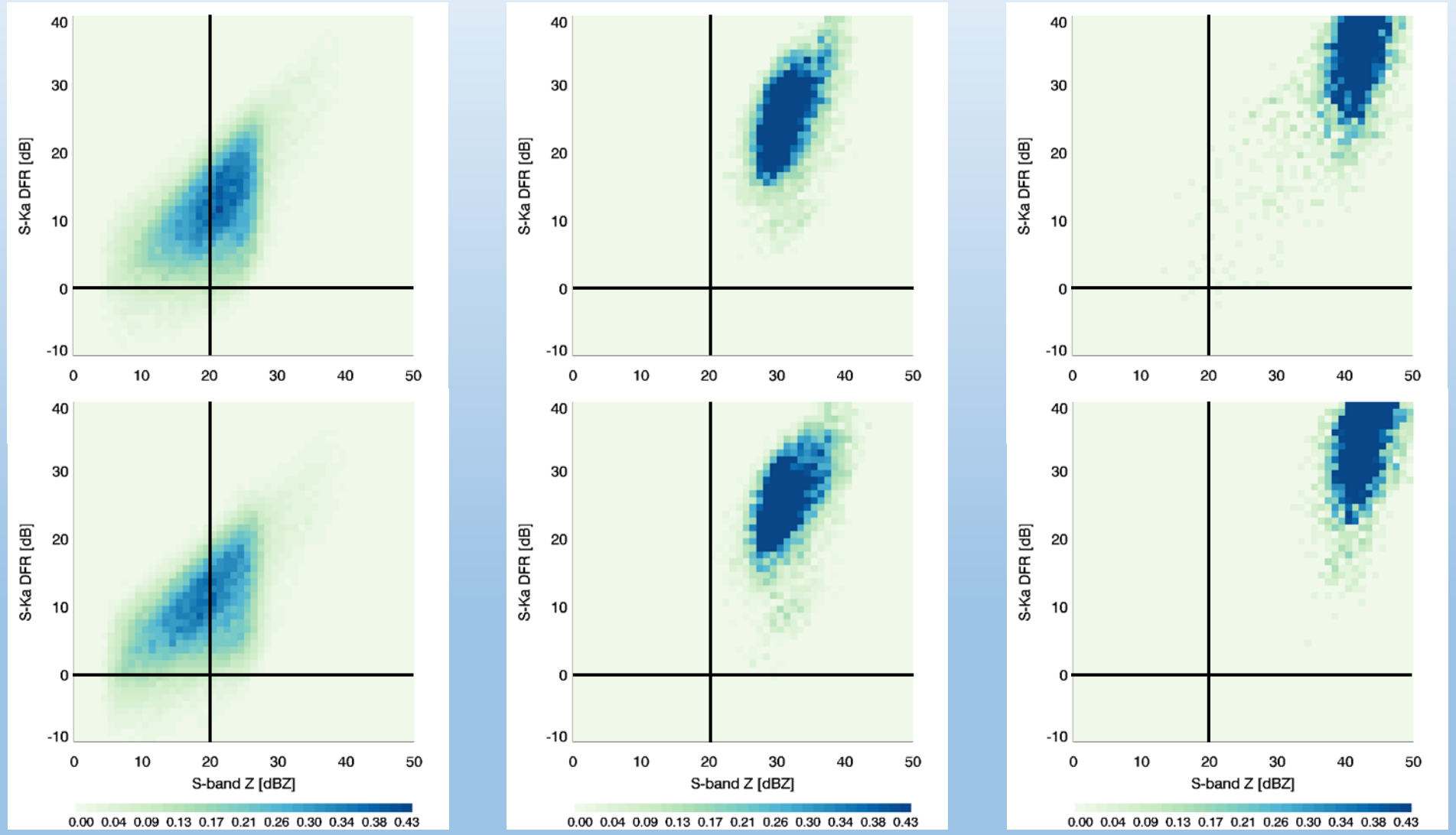


S-Ka: Mix-phase HID type classes

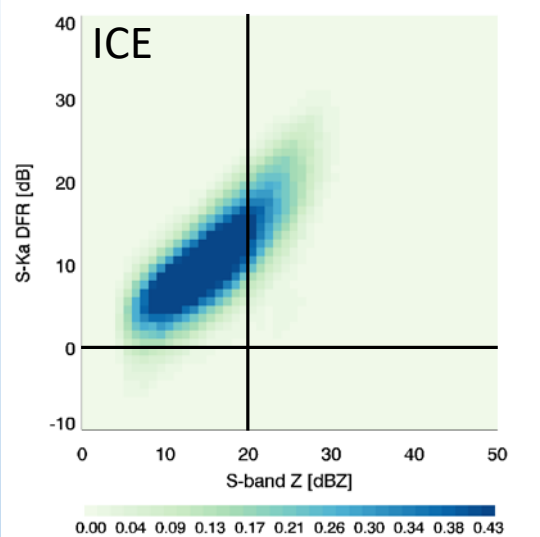


- Wet snow most varied, **more dispersed over ocean**
- Graupel classes more similar to rain, hail; **more dispersed over land**
- Almost all $DFR_{S\text{-}Ka}$ values **positive**

wet snow | **low density graupel** | **high density graupel**

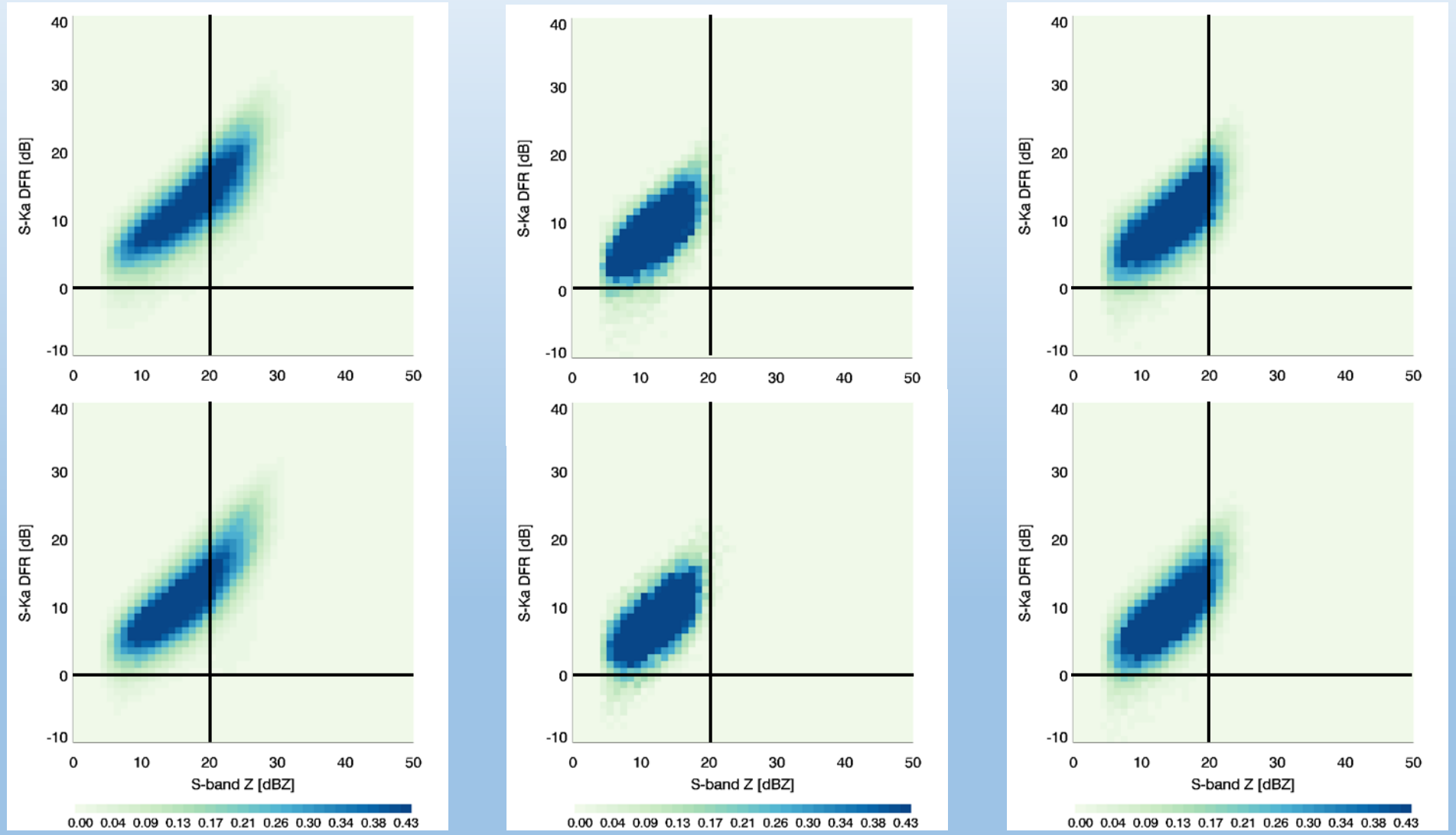


S-Ka: Ice phase HID type classes



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

aggregates | **ice crystals** | **vertical ice**



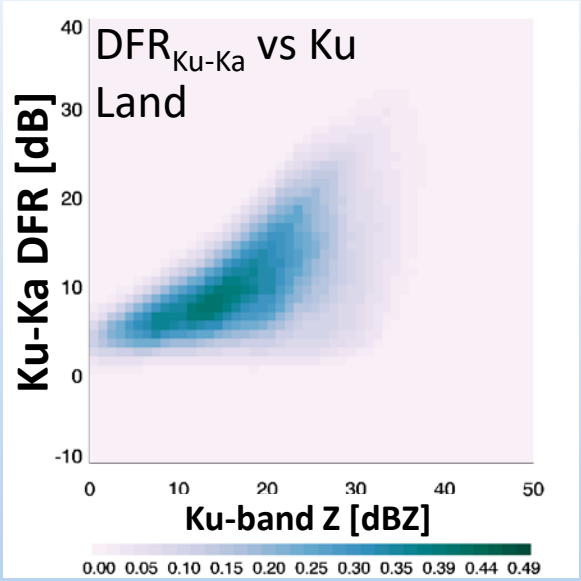
DFR_{Ku-Ka}: All HID Types – Distribution Space

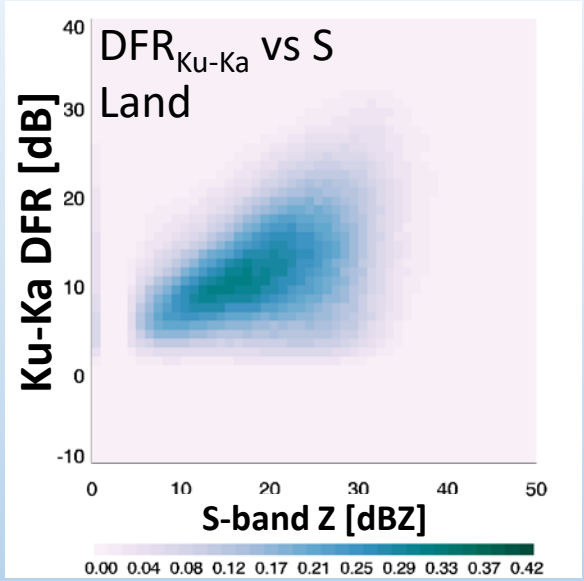
DFR_{Ku-Ka} vs Ku-band Z:
- Triangular, almost parabolic shape

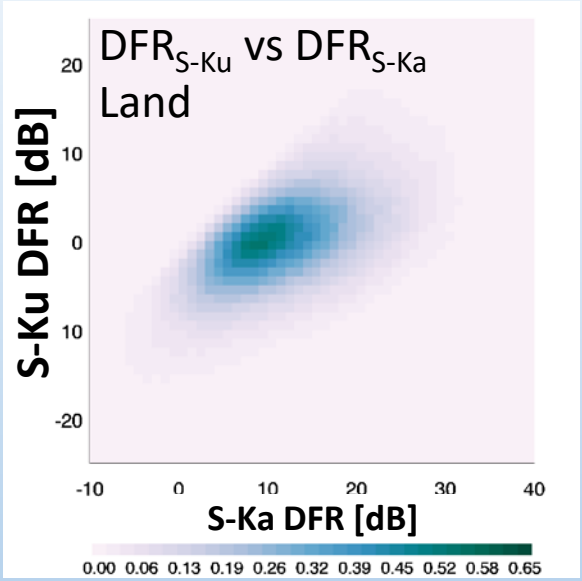
DFR_{Ku-Ka} vs S-band Z:
- More broad triangular shape

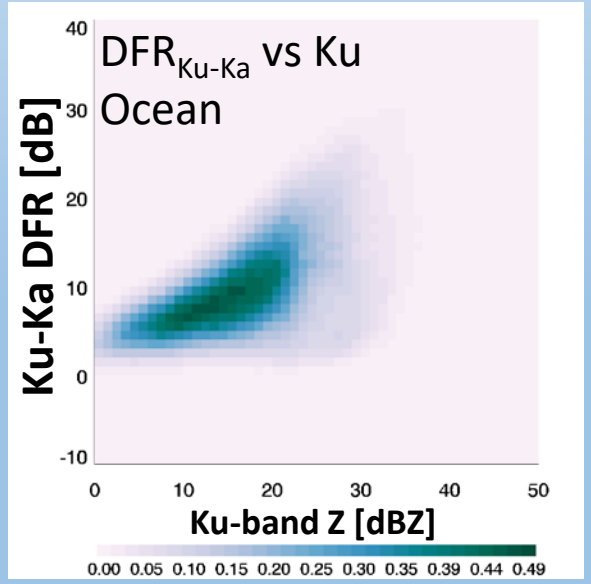
DFR_{S-Ku} vs DFR_{S-Ka}:
- Most confined distribution

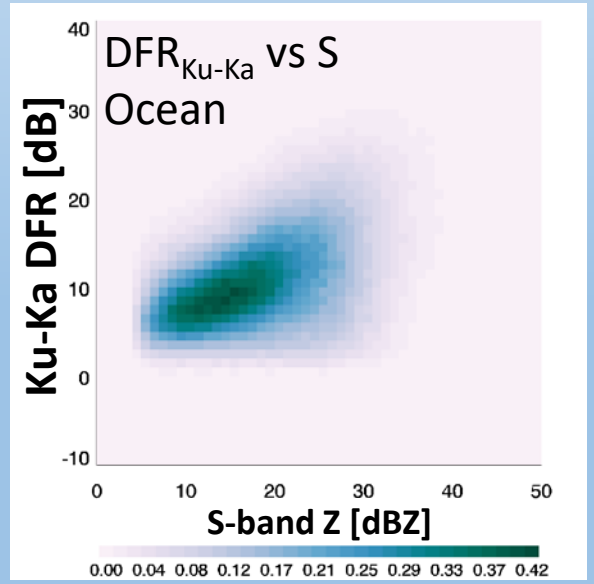
All:
- Ocean distribution more compact than land

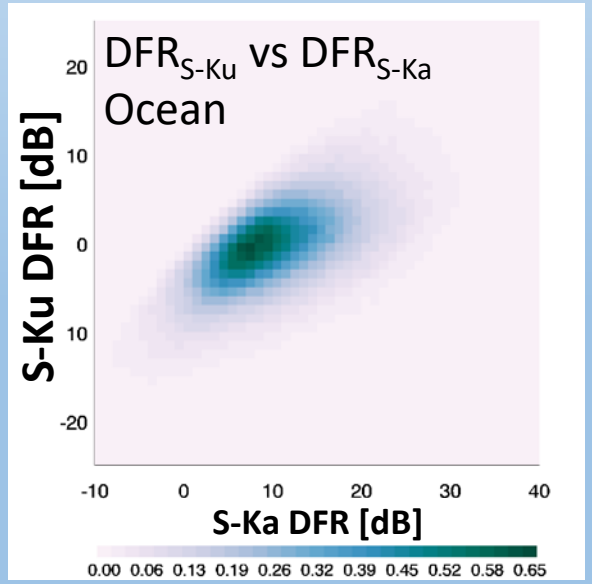




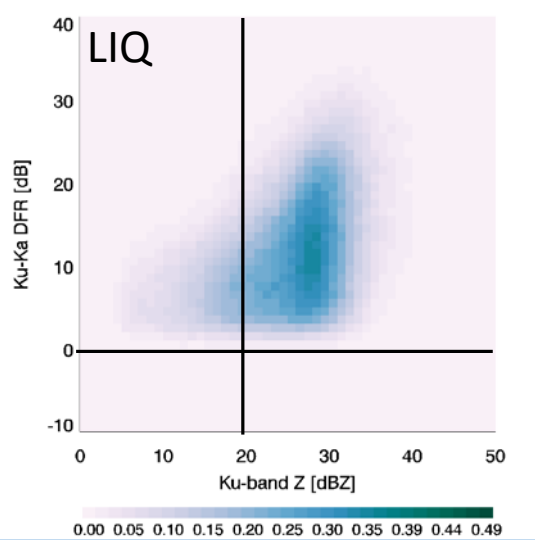




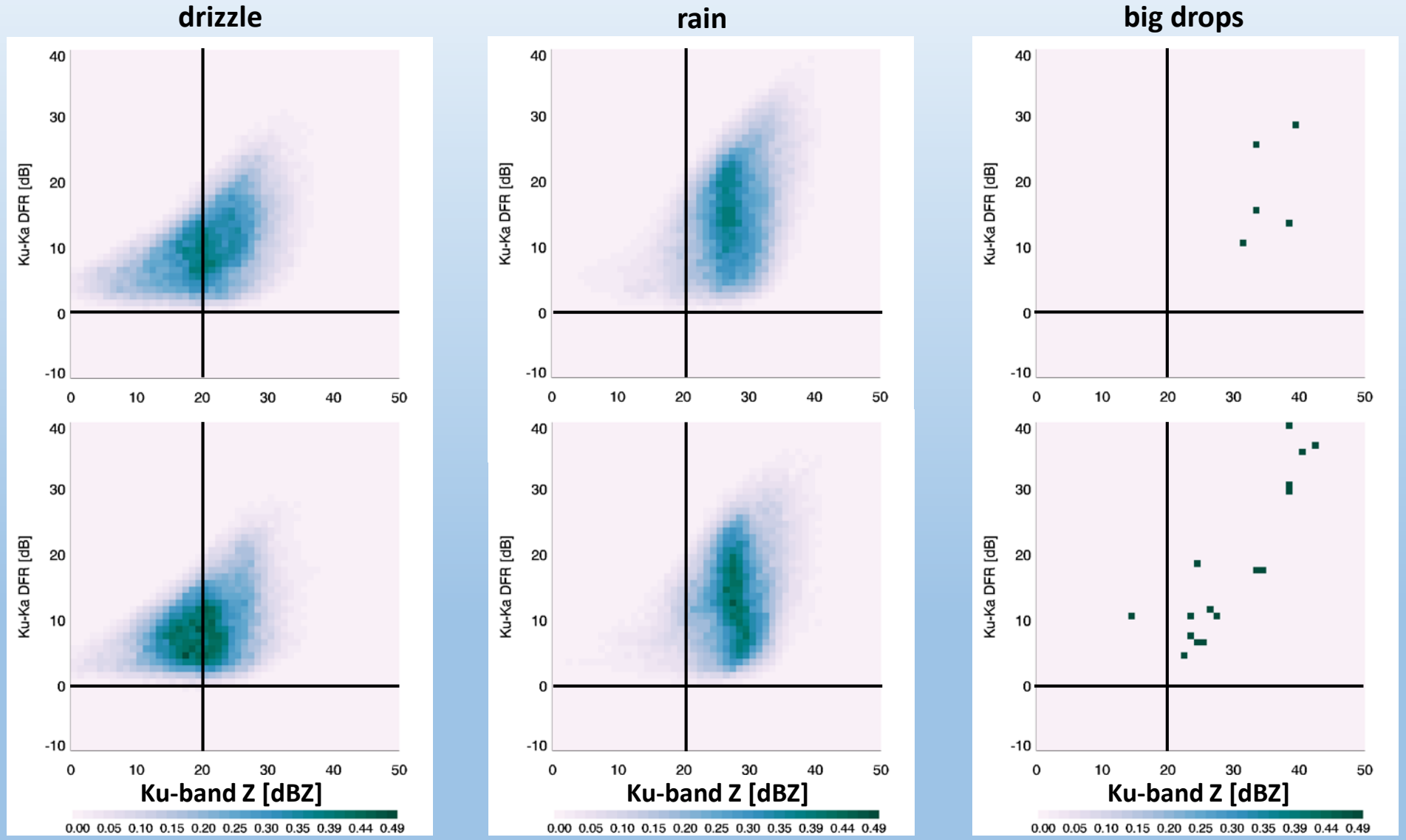




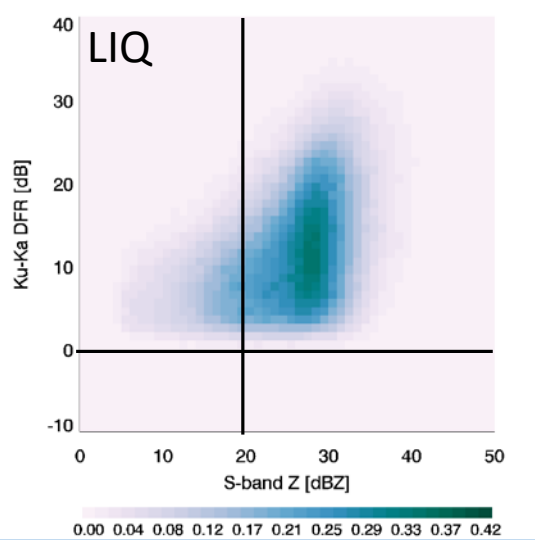
Ku-Ka: Liquid phase HID type classes



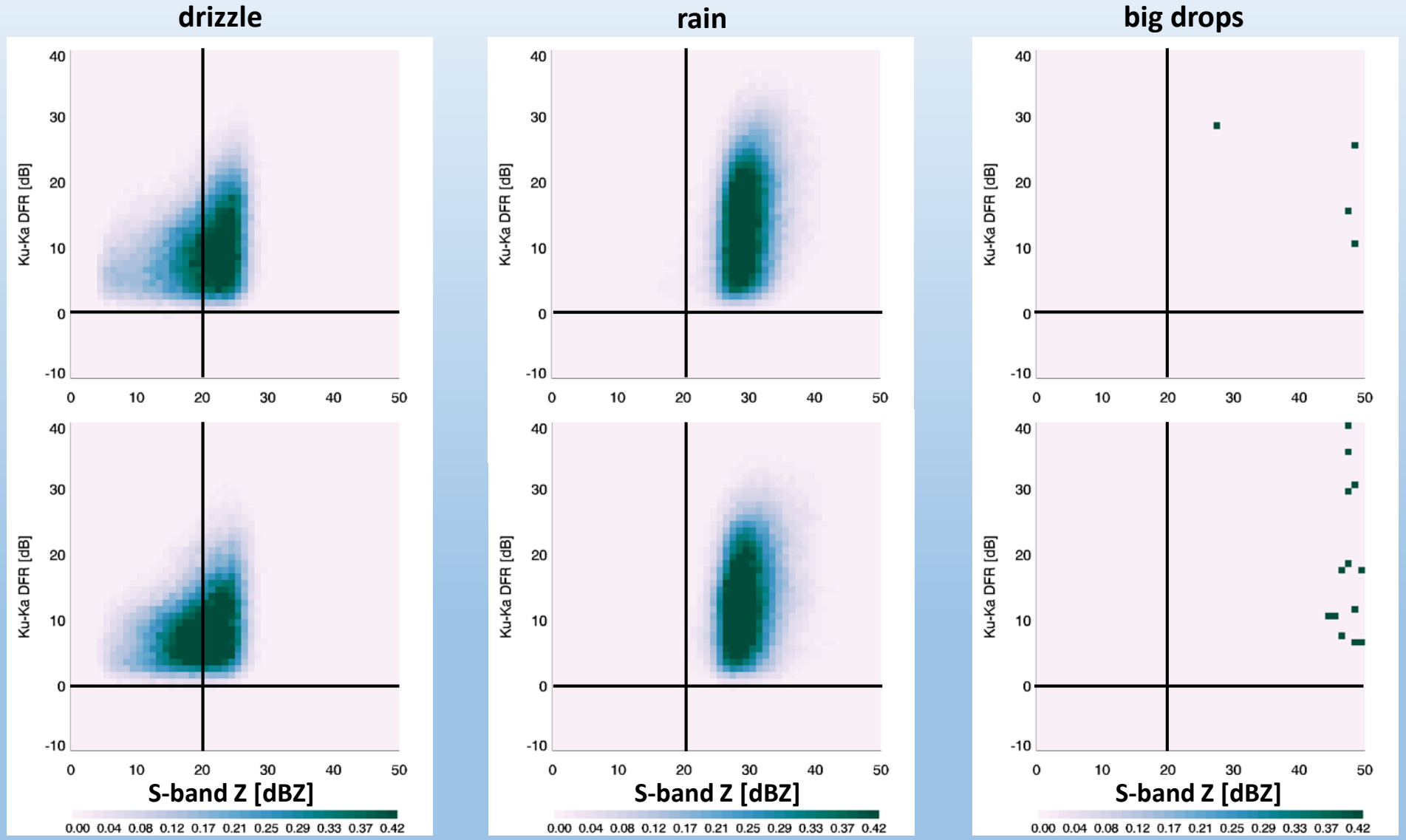
- No negative $DFR_{Ku\text{-}Ka}$ values
- Ocean distributions more compact
- Modes & size separation more pronounced in S-band space



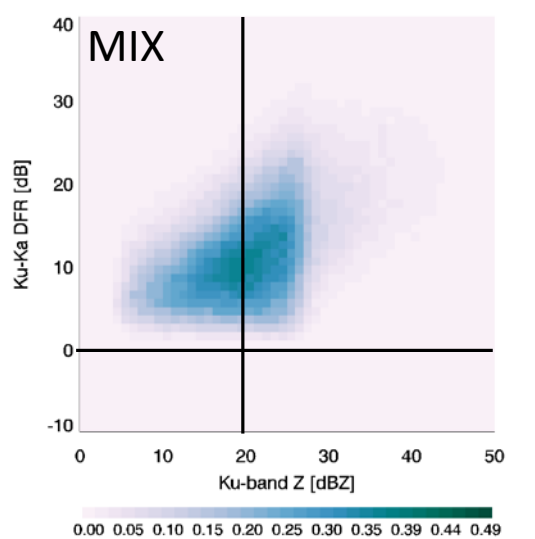
Ku-Ka: Liquid phase HID type classes



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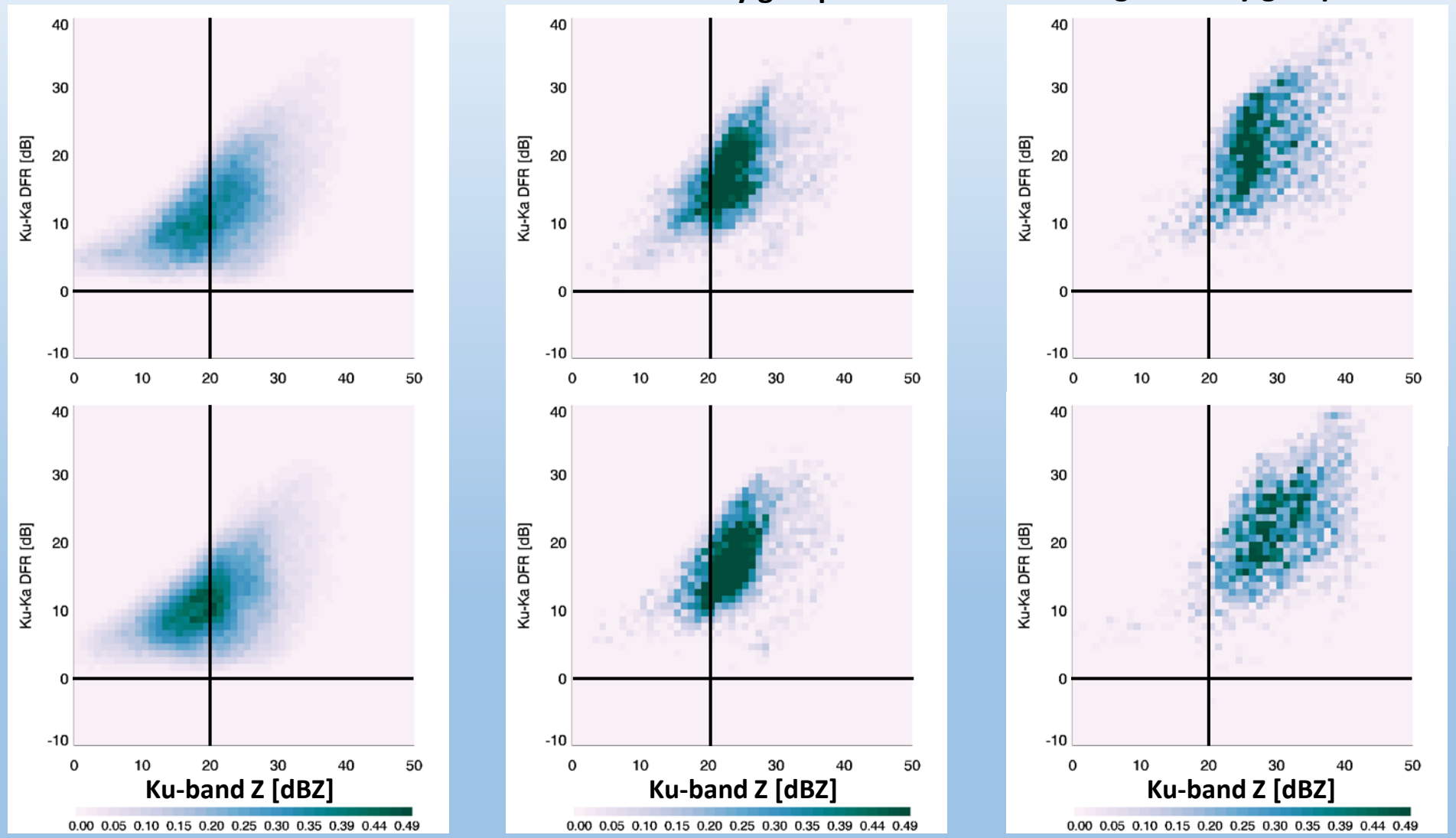


Ku-Ka: Mix-phase HID type classes

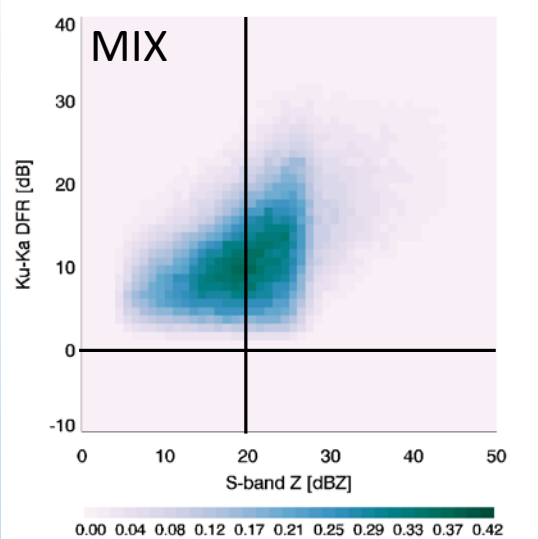


- Wet snow: **more compact over ocean**
- Graupel: more compact over land (vs. Ku-band Z)
- Modes & size separation more pronounced in S-band space

wet snow | **low density graupel** | **high density graupel**

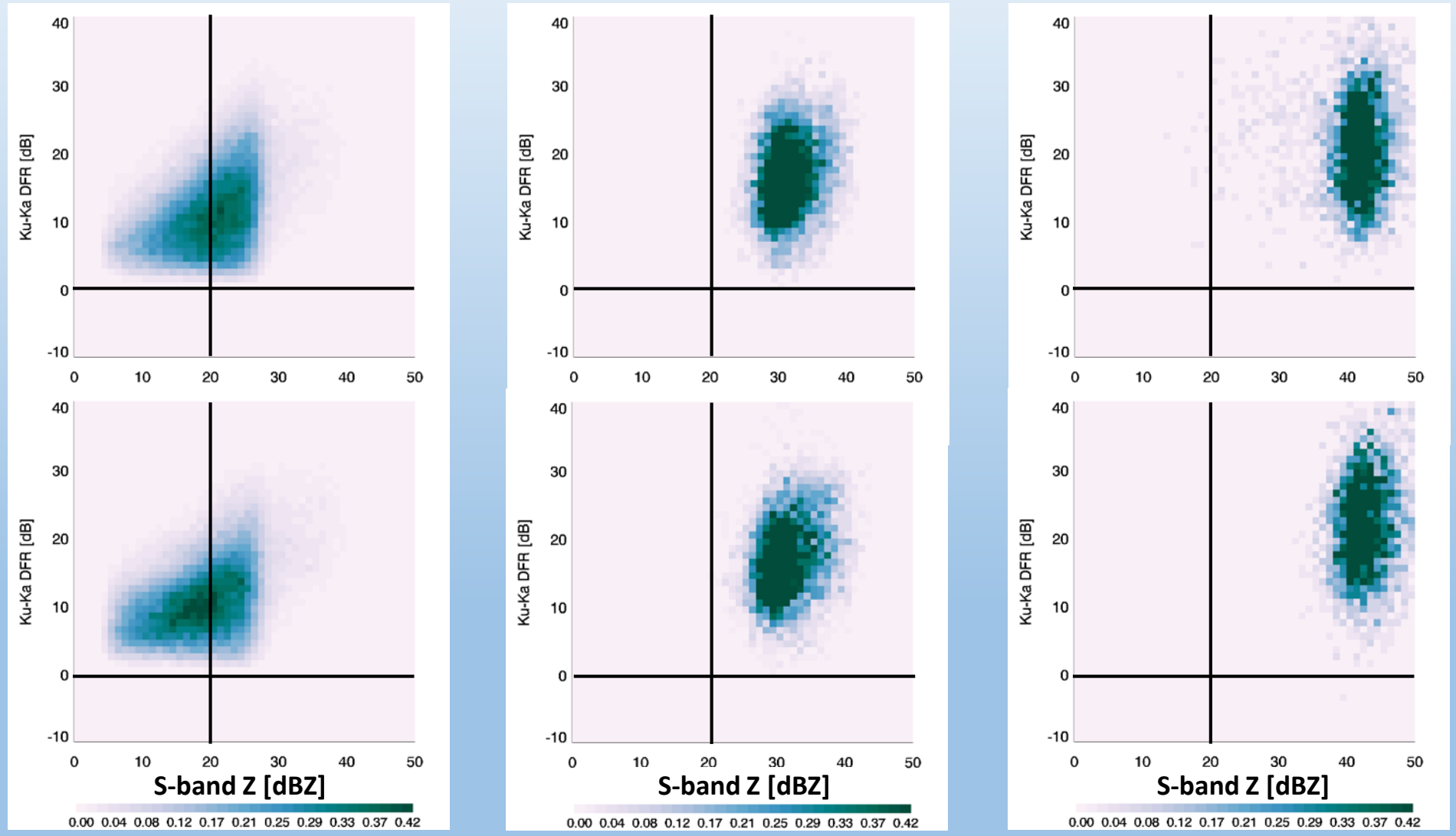


Ku-Ka: Mix-phase HID type classes

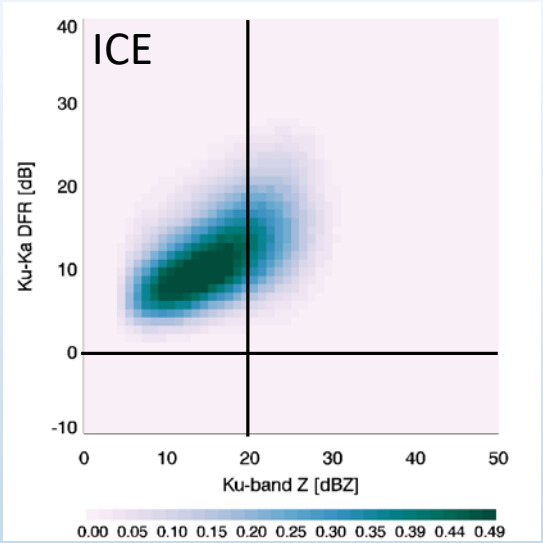


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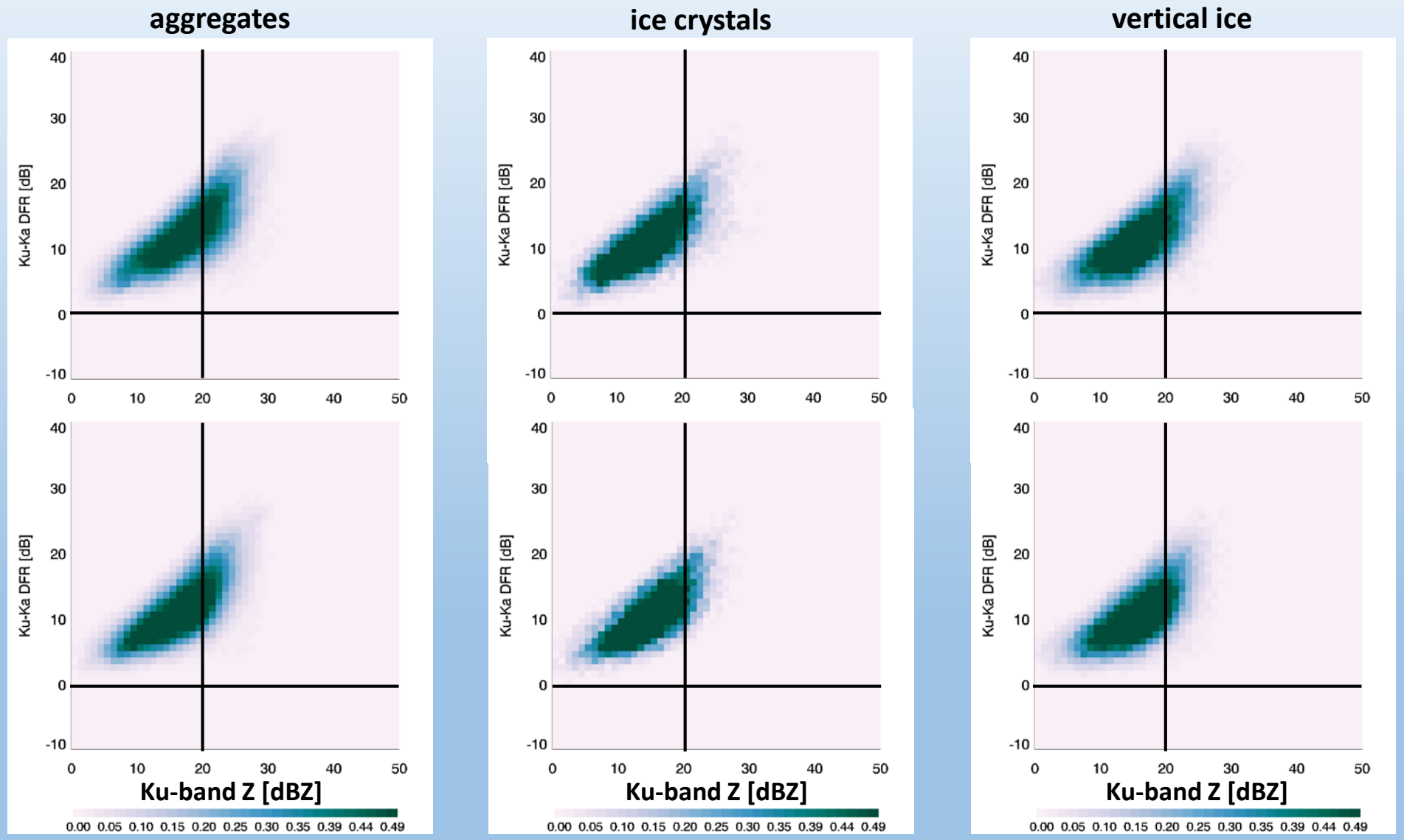
wet snow | **low density graupel** | **high density graupel**



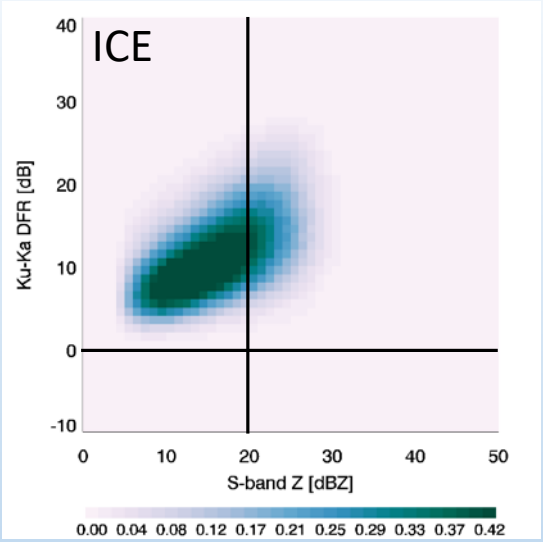
Ku-Ka: Ice phase HID type classes



- 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

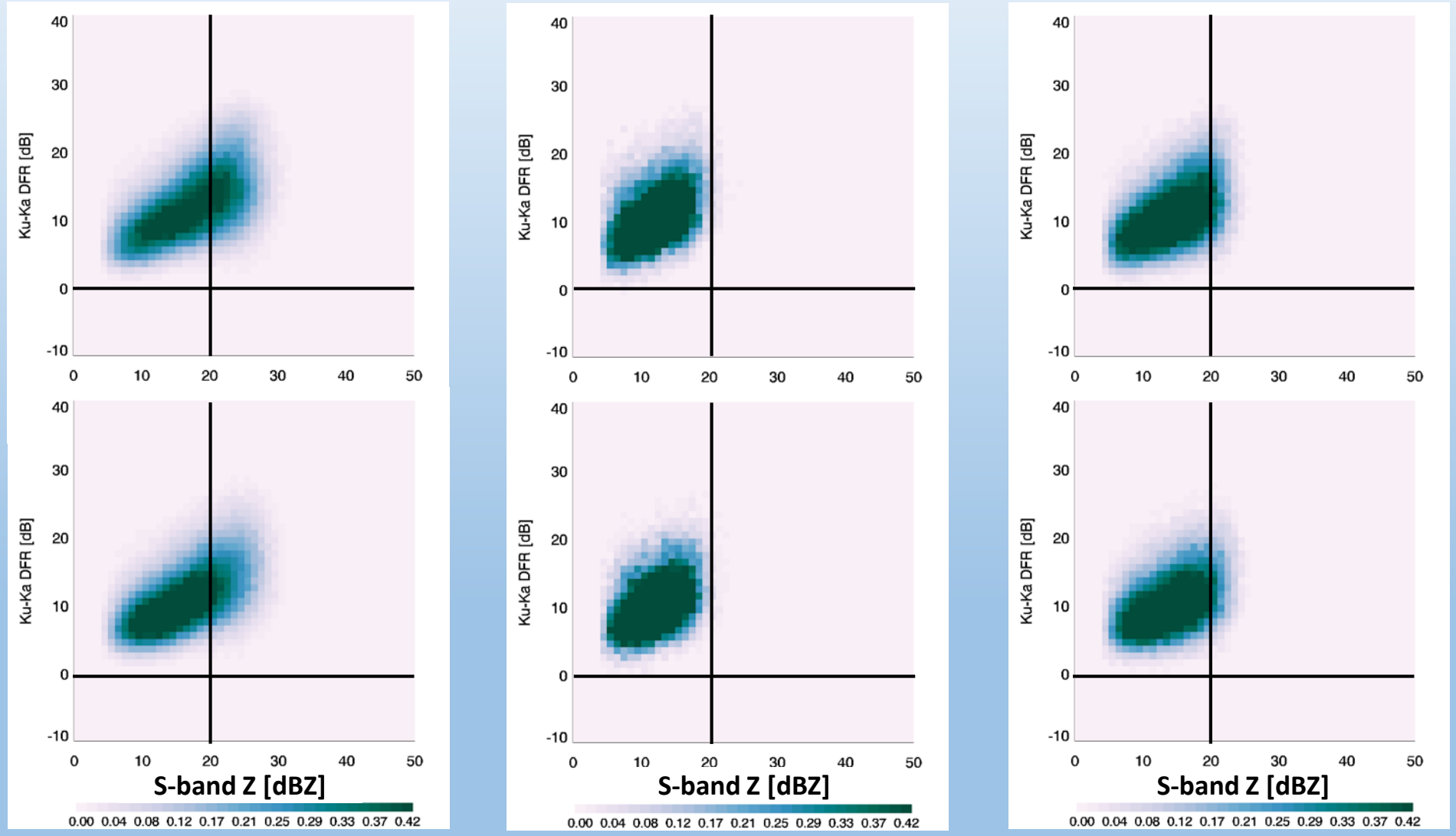


Ku-Ka: Ice phase HID type classes

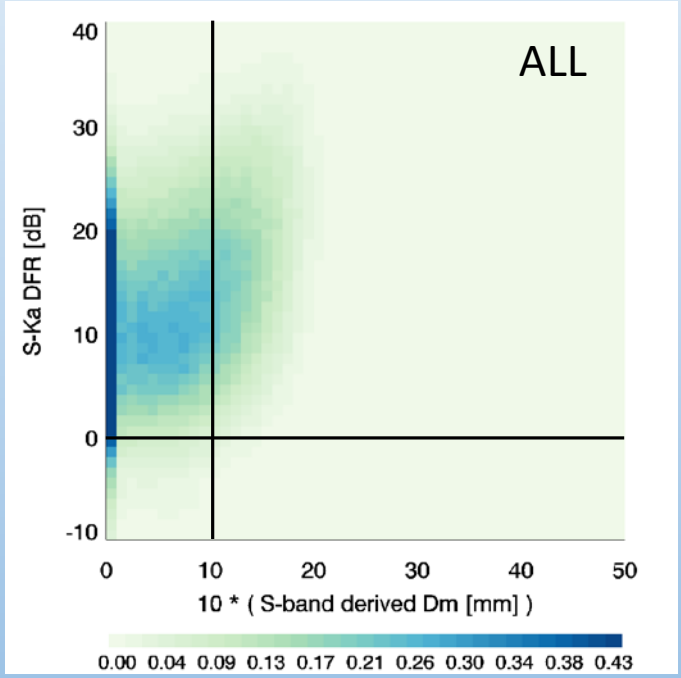


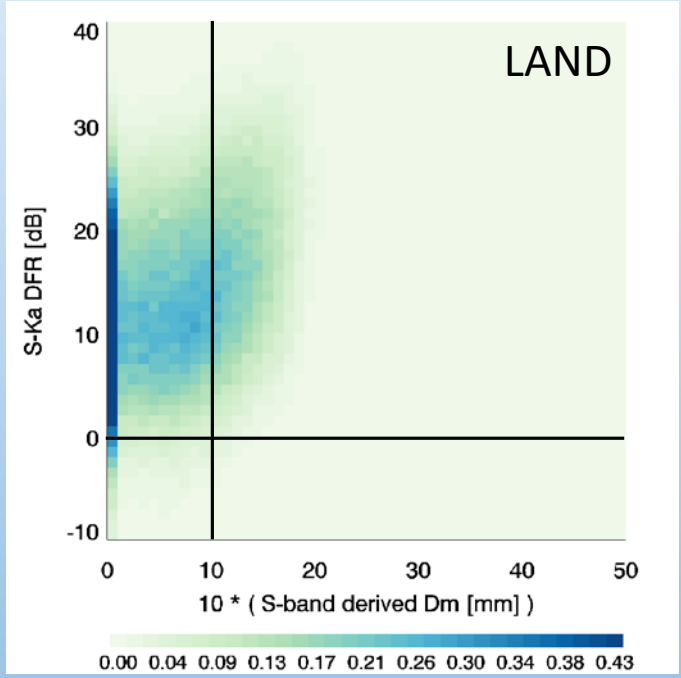
- Ku-band:
  - more consistent distribution shape among all ice types (but hail – not shown)
- S-band:
  - all ice: slightly broader distributions
  - Some size separation
  - Less linear

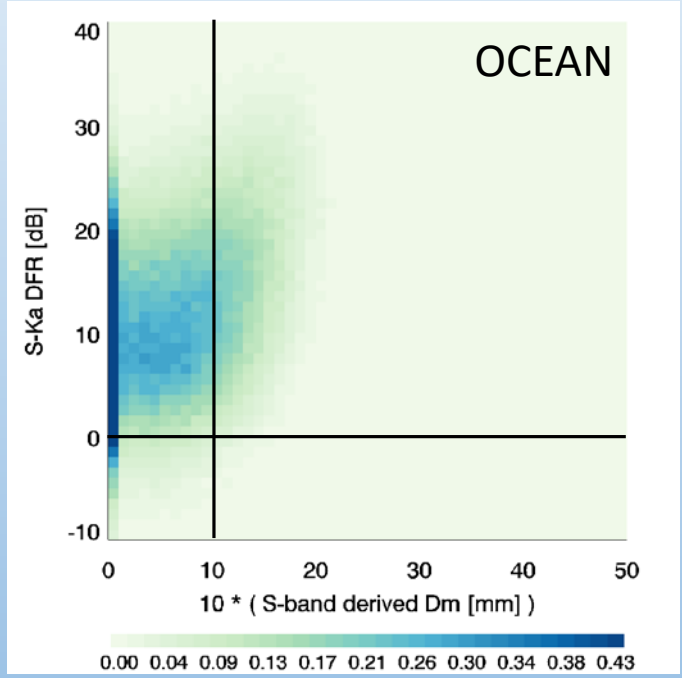
aggregates | **ice crystals** | **vertical ice**



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







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

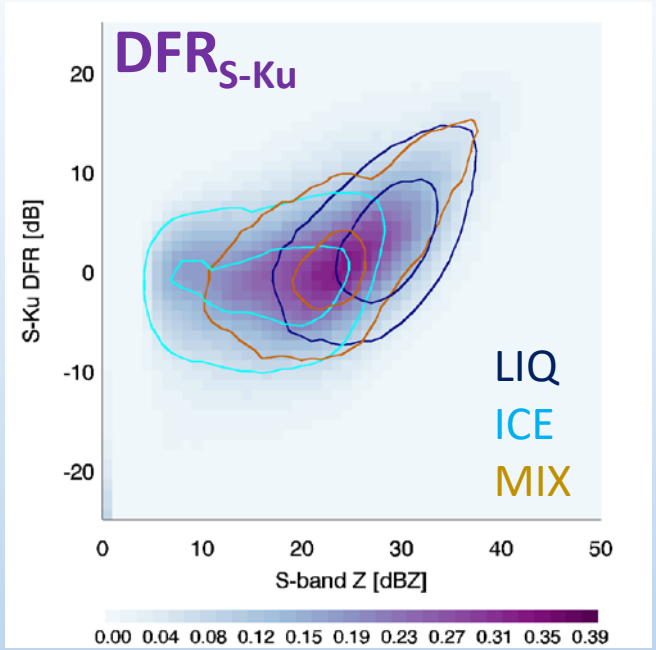
DFRs All ARs

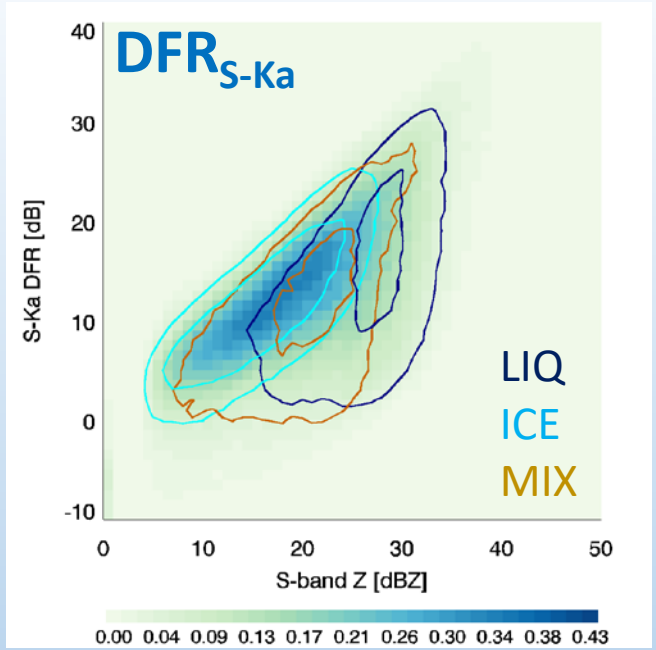
S-Ku
S-Ka
Ku-Ka
(vs. Z_S)

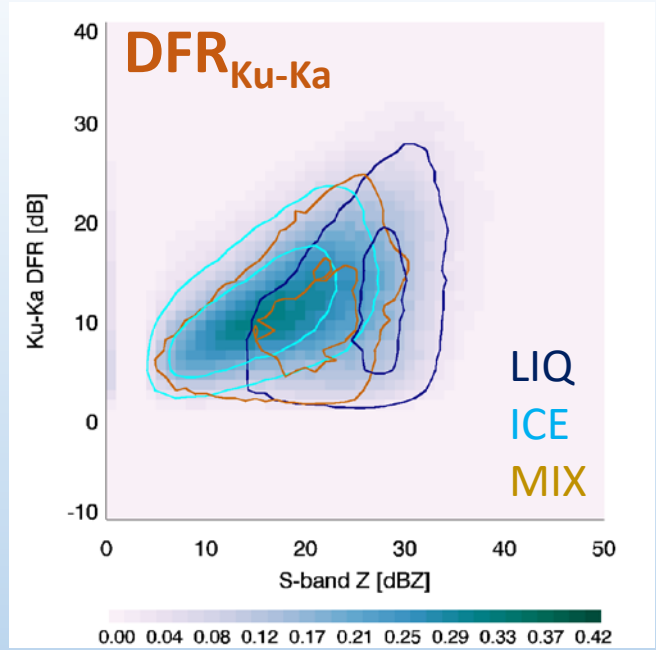
- S-Ku DFR has largest LIQ and ICE overlap
- MIX overlaps in all 3 spaces
- Ocean regime is slightly more compact

*Histograms include all HID phases

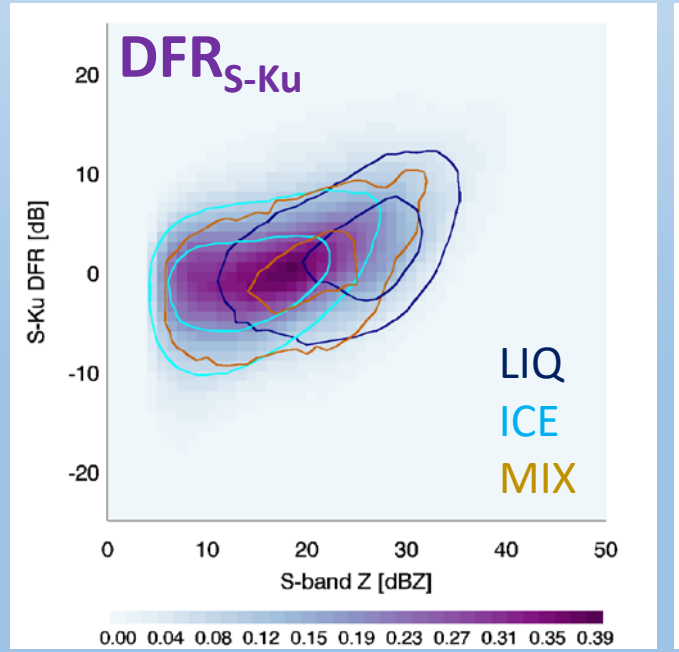
*Contours at densities of 0.1, 0.3 for each HID phase

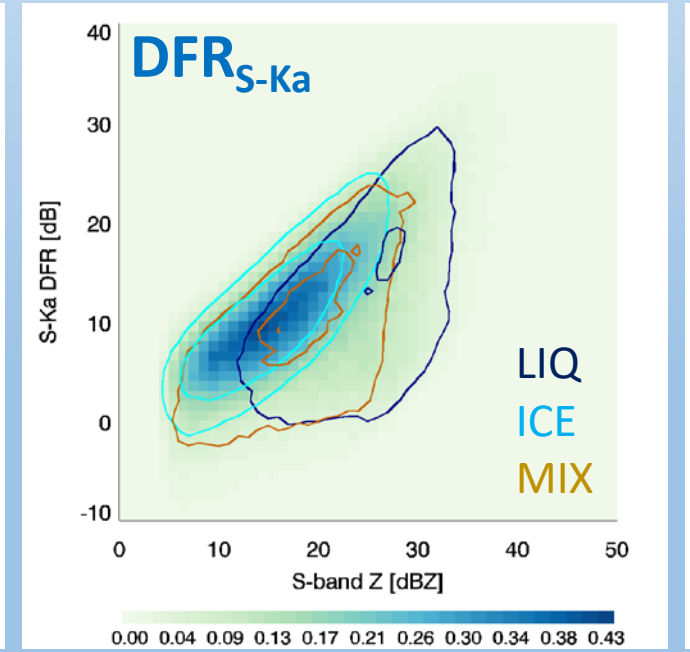


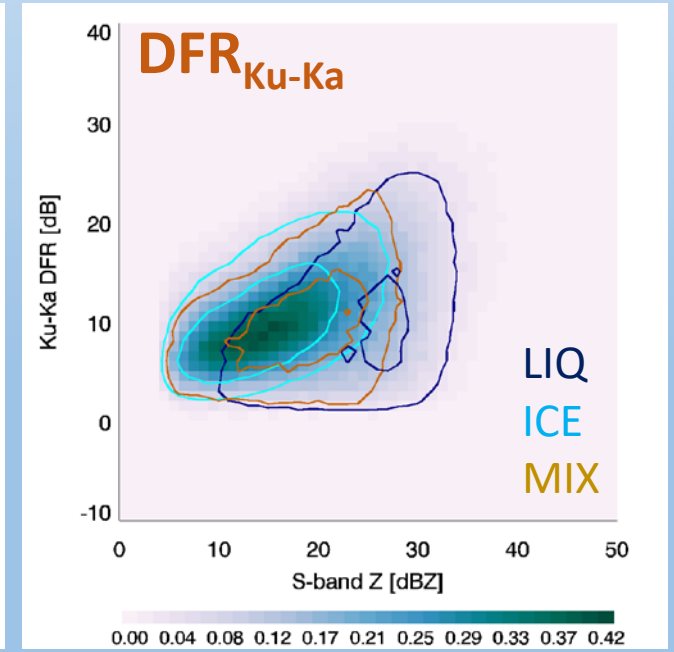




Land Scans



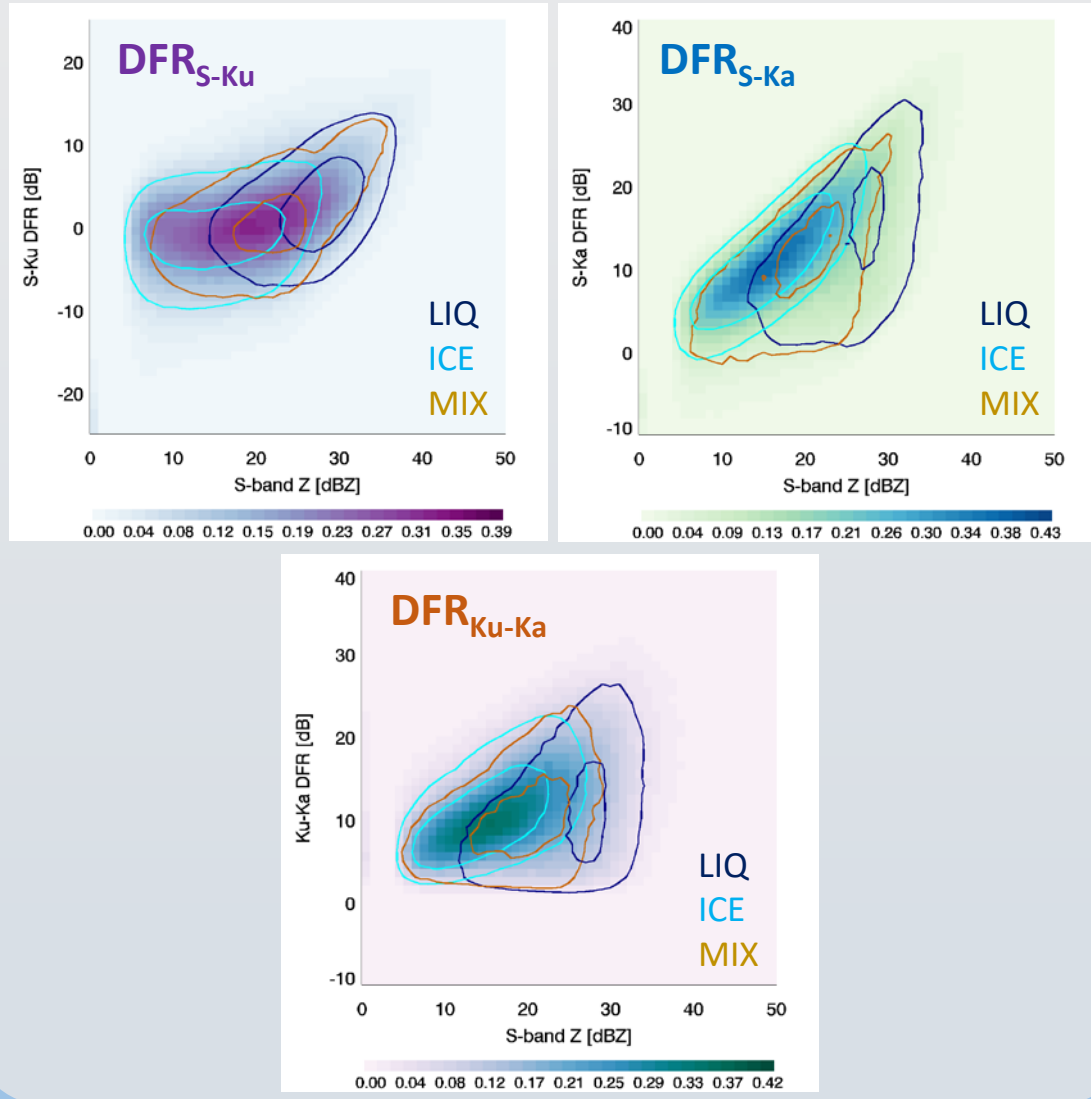




Ocean Scans

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
- *$DFR_{S\text{-}Ka}$ shows most difference among HID phases*
- *$DFR_{Ku\text{-}Ka}$ 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*

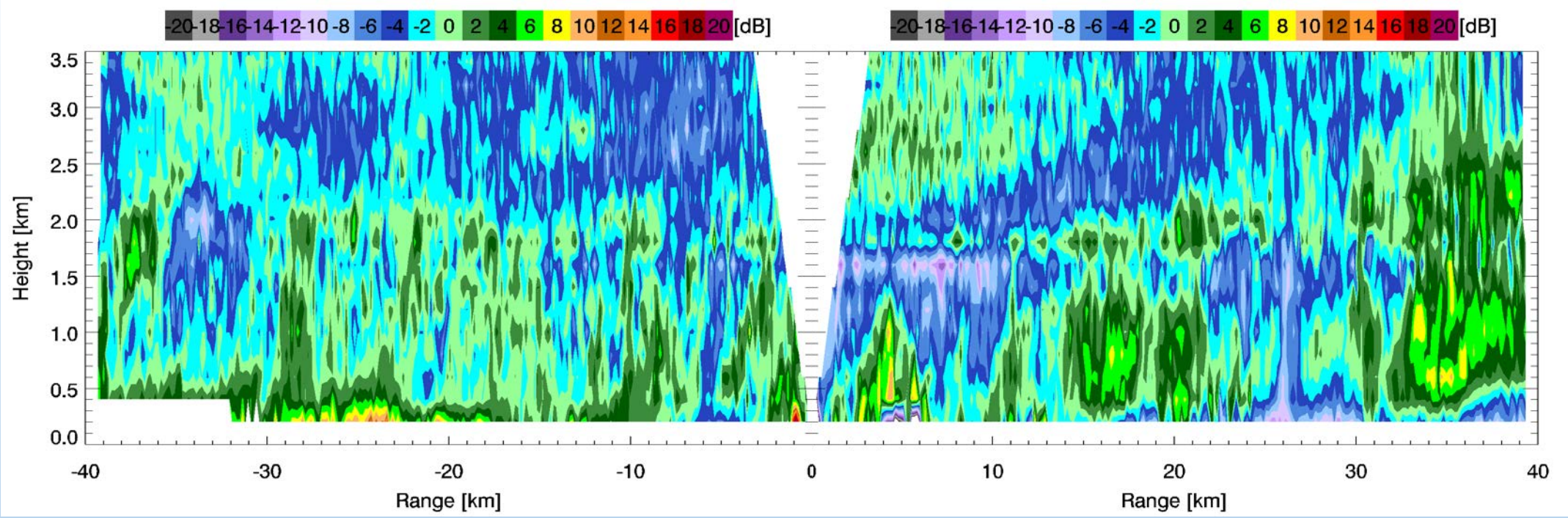


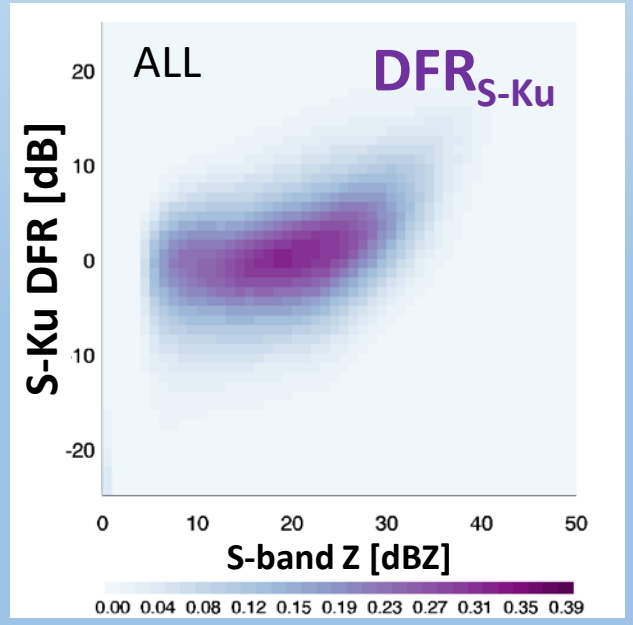
*Histograms include all HID phases
*Contours at densities of 0.1, 0.3 for each HID phase

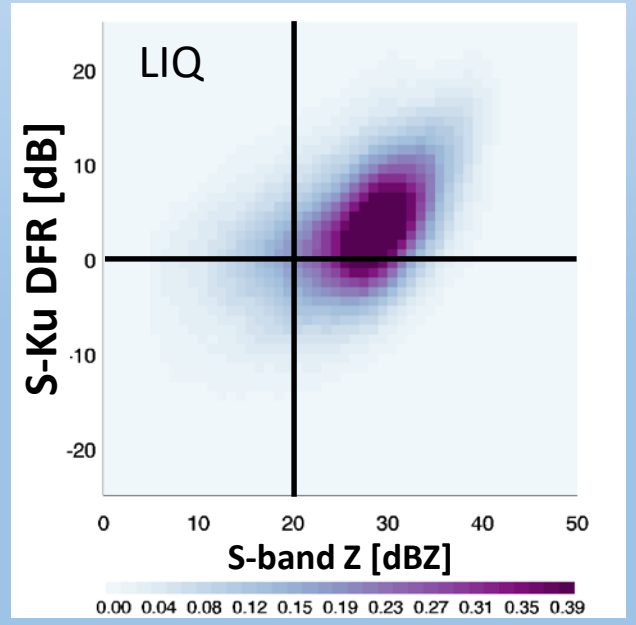
This work was partially supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Universities Space Research Association through a contract with NASA.

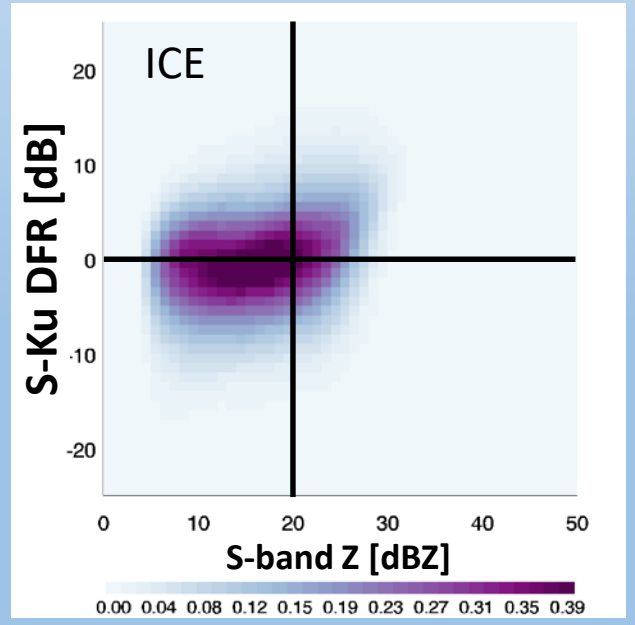
$DFR_{S\text{-}Ku}$ All ARs

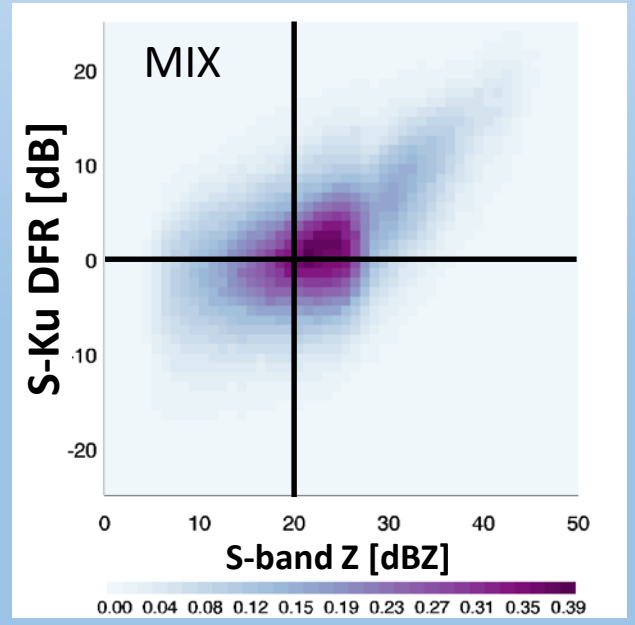
- S-Ku DFR composite, includes all NPOL HID types
- Histograms: land + ocean



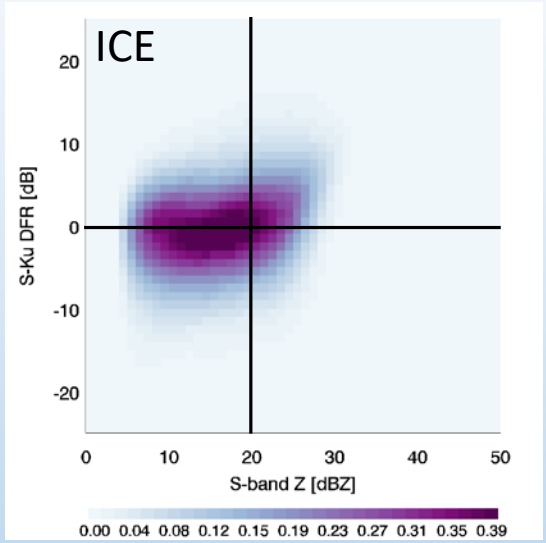






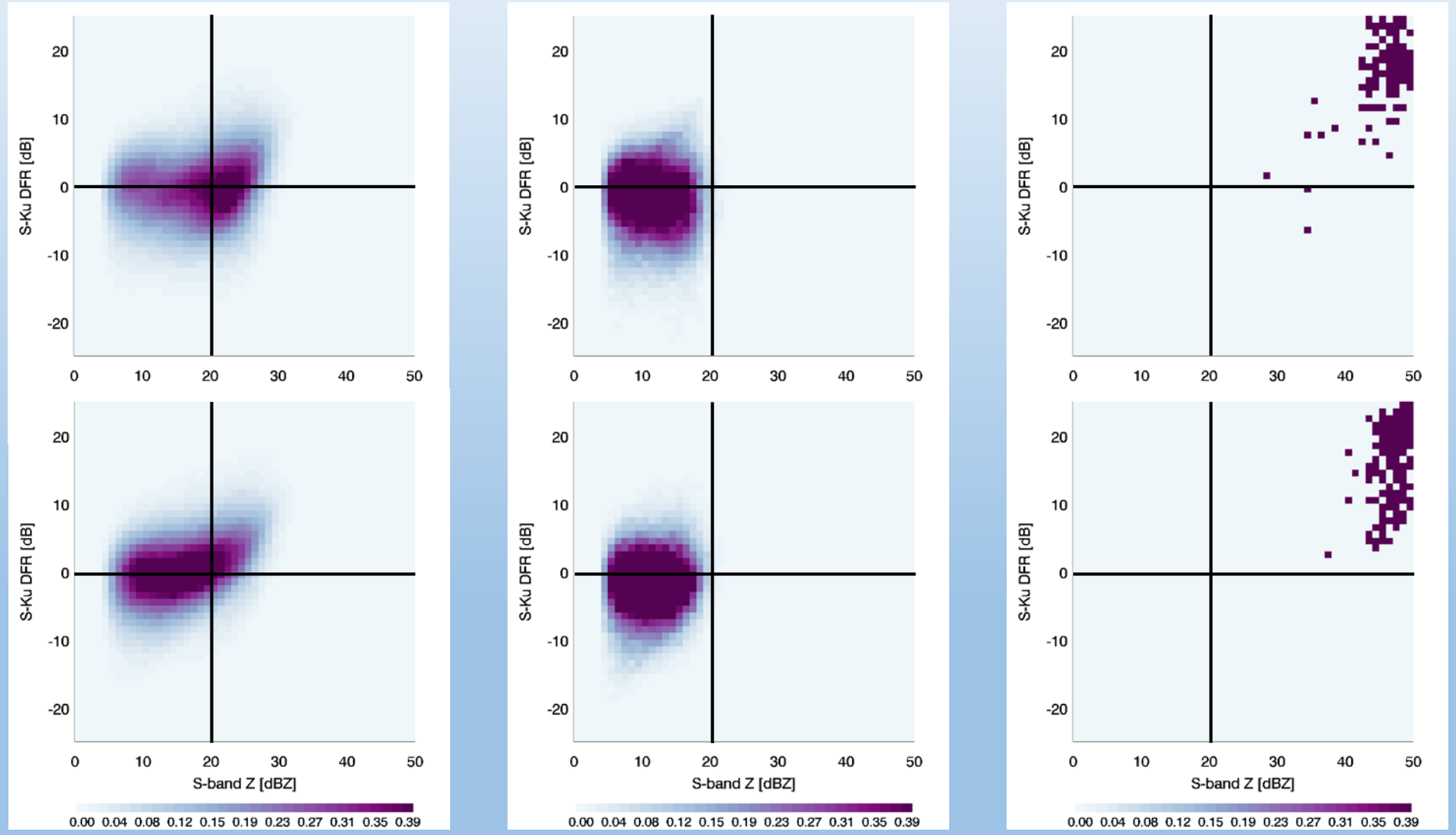


S-Ku: Ice phase HID type classes

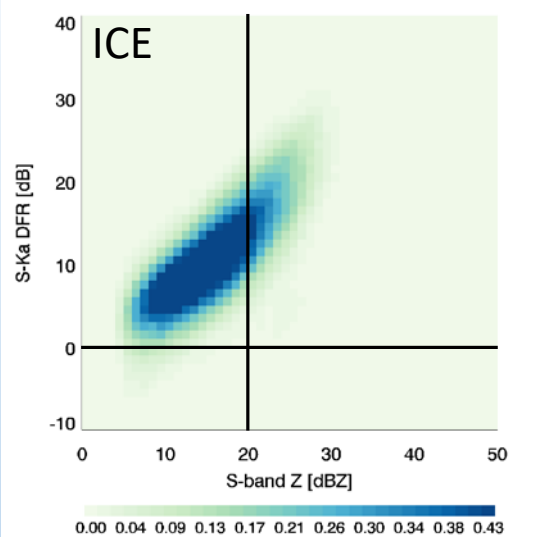


- Aggregates: different land/ ocean modes
- Ice crystals: land/ocean similar
- Hail: see Rayleigh dependence
- Vertical ice: slightly lower DFR

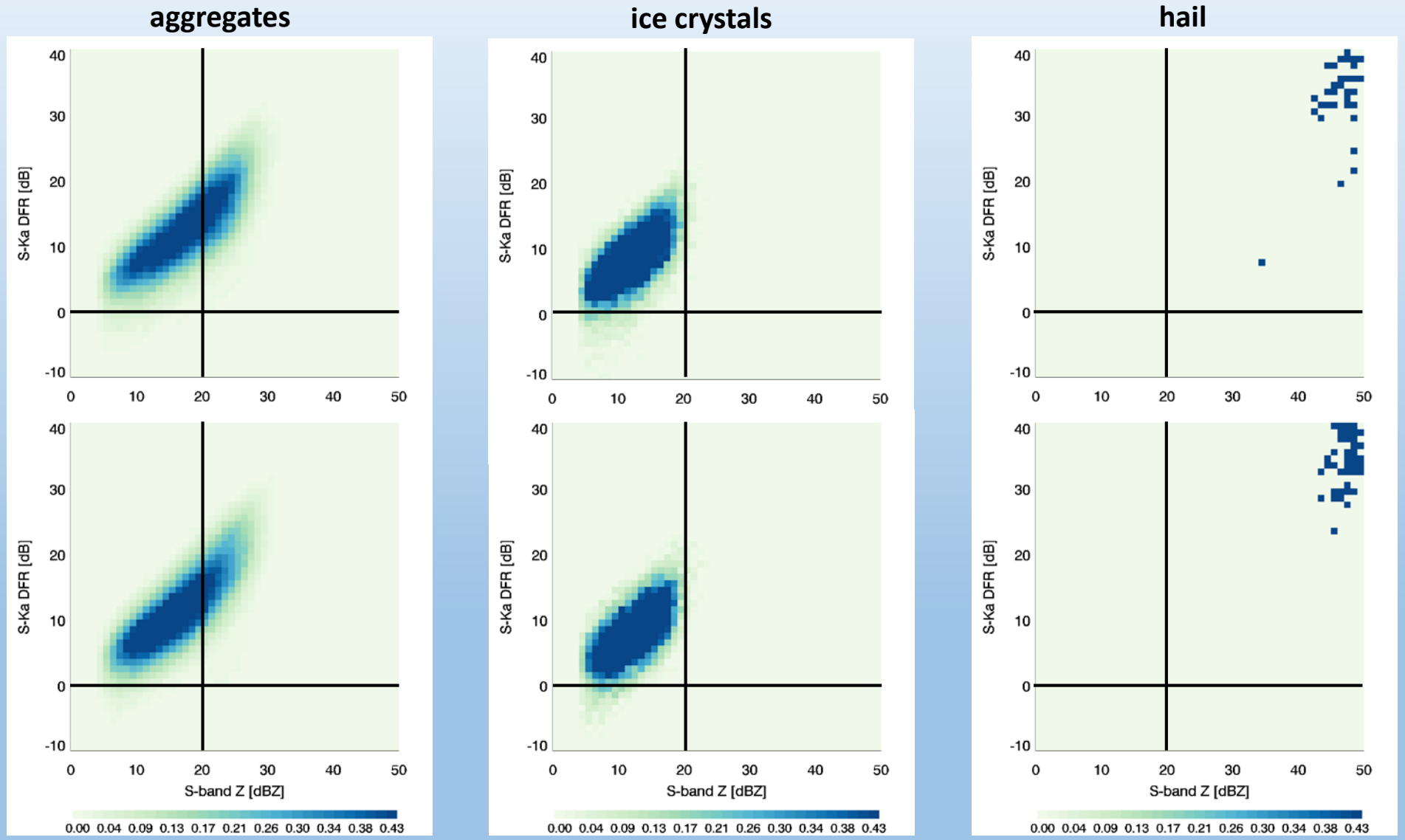
aggregates | **ice crystals** | **hail**



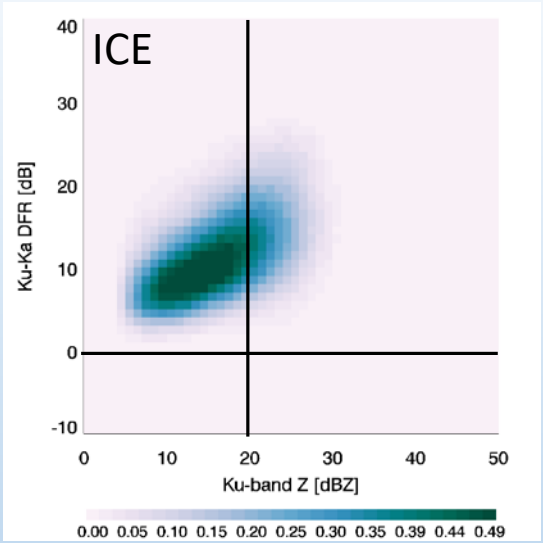
S-Ka: Ice phase HID type classes



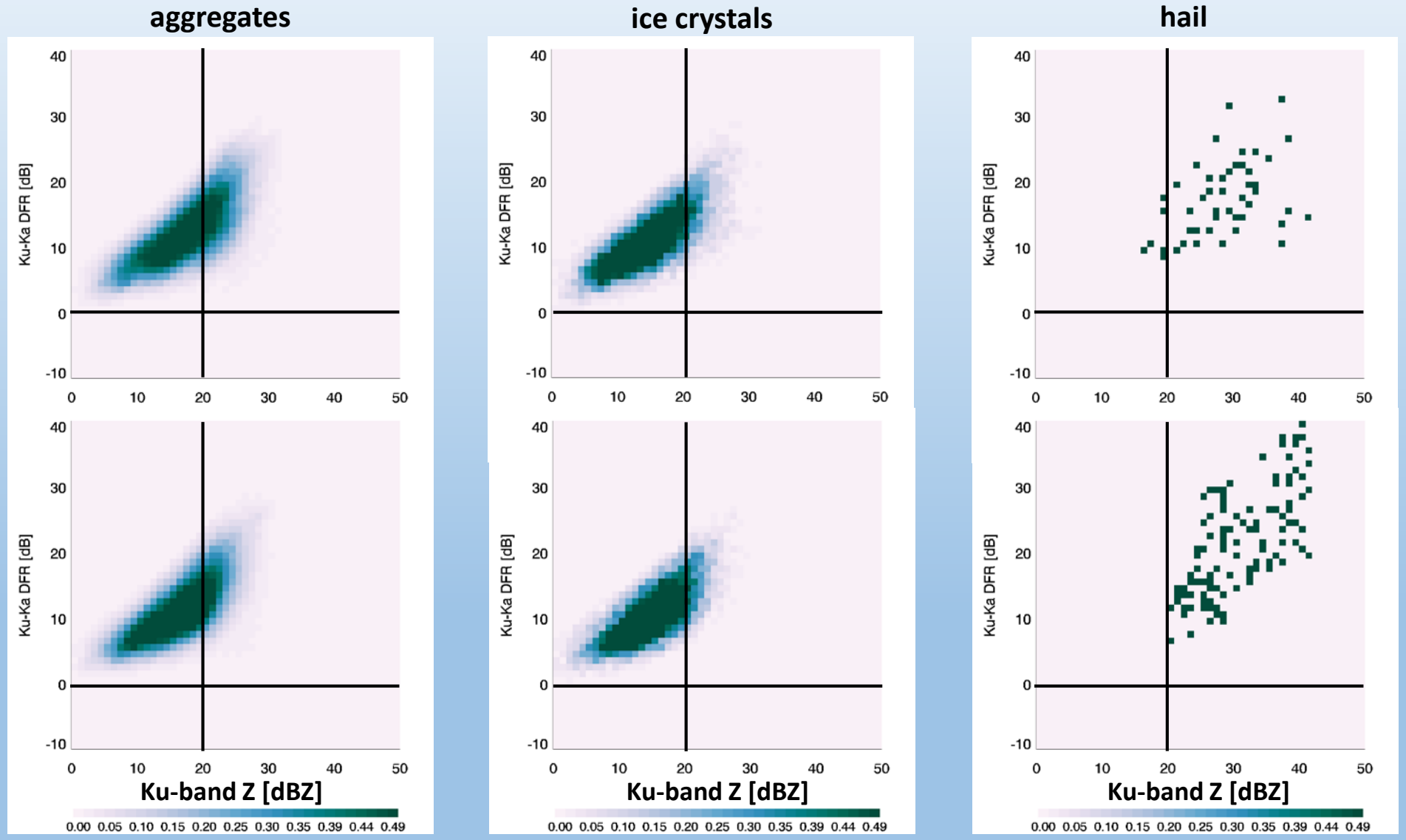
- Aggregates & ice crystals: slightly more compact over ocean
- Vertical ice: behavior in this space very similar to other ICE HID type classes



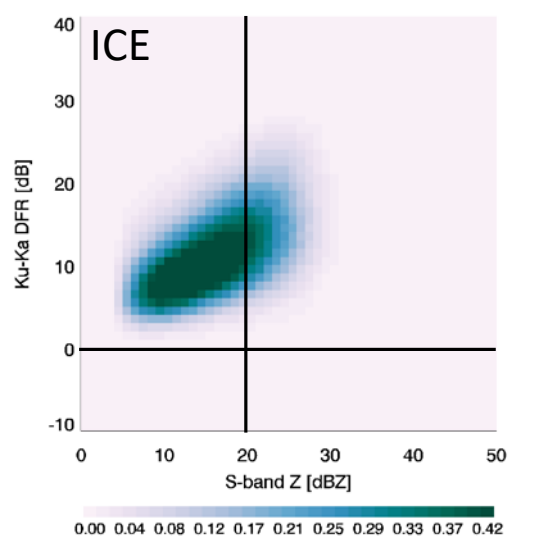
Ku-Ka: Ice phase HID type classes



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Ku-Ka: Ice phase HID type classes



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aggregates | **ice crystals** | **hail**

