Ice processes in Antarctica: identification via multi-wavelength active and passive measurements

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The opportunity: AWARE field campaign

- **unprecedented number of multi-wavelength active and passive systems simultaneously observing the vertical column** (first ever triple-frequency radar & HSRL observation in Antarctica)
- **unique opportunity** of overcoming the scarcity of cloud information at southern high latitudes and **of unravelling processes related to cloud&precipitation physics at high temporal and spatial resolution**.

AMF2 deployment at the CosRay site near McMurdo

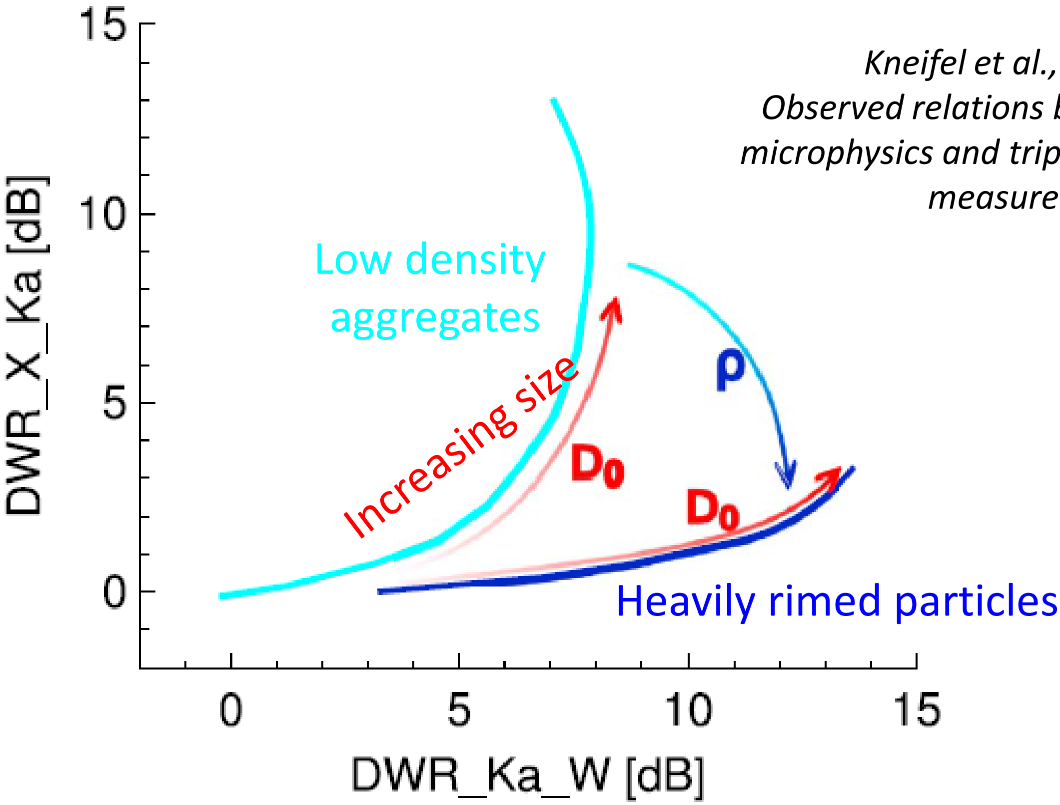
What do we want to do: science goals

1. **To develop a microphysics (D_m and IWC) retrieval for ice and mixed-phase clouds for multi-wavelength radars (X-K_a-W)+HSRL.**

2. **Extract significant observational fingerprints of dominant processes (secondary ice, aggregation, riming) in the Antarctic clouds which can be used to evaluate the various model simulations planned within this project (Ann's talk).**

Key observables:

- Doppler spectra
- DWR signatures
- Polarimetry (?)

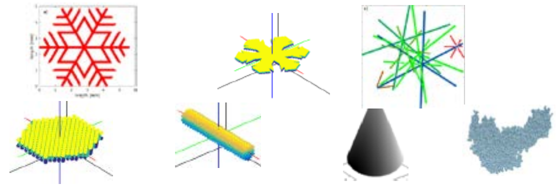


Kneifel et al., JGR 2015: Observed relations between snowfall microphysics and triple-frequency radar measurements

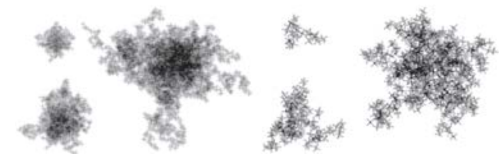
The challenge: ice scattering models

Ice scattering properties are currently computed based on complex single crystals and aggregates

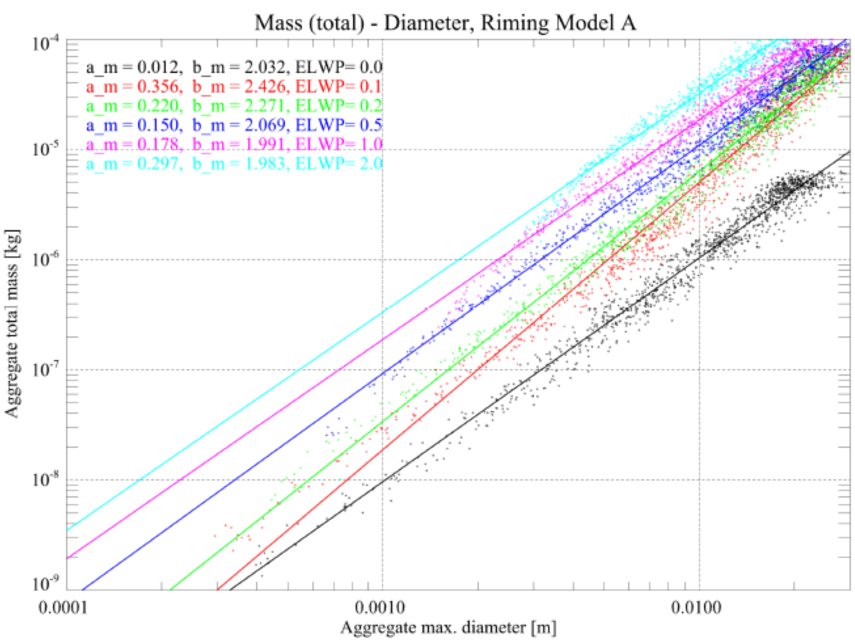
1) Lu et al., (AMT 2016)

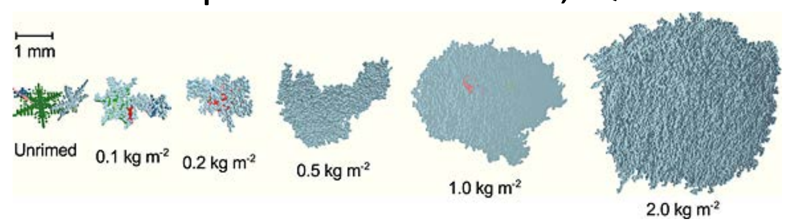


2) Hogan Self-similar Rayleigh-Gans aggregates (JAMC 2017)



3) Leinonen's aggregates and rimed particles (Earth and Space Science 2015, QJRMS 2017)





Particles with different m(D) and A(D) ➔ SSRGA provides good approximation of scat properties (Leinonen et al., QJRMS 2017)

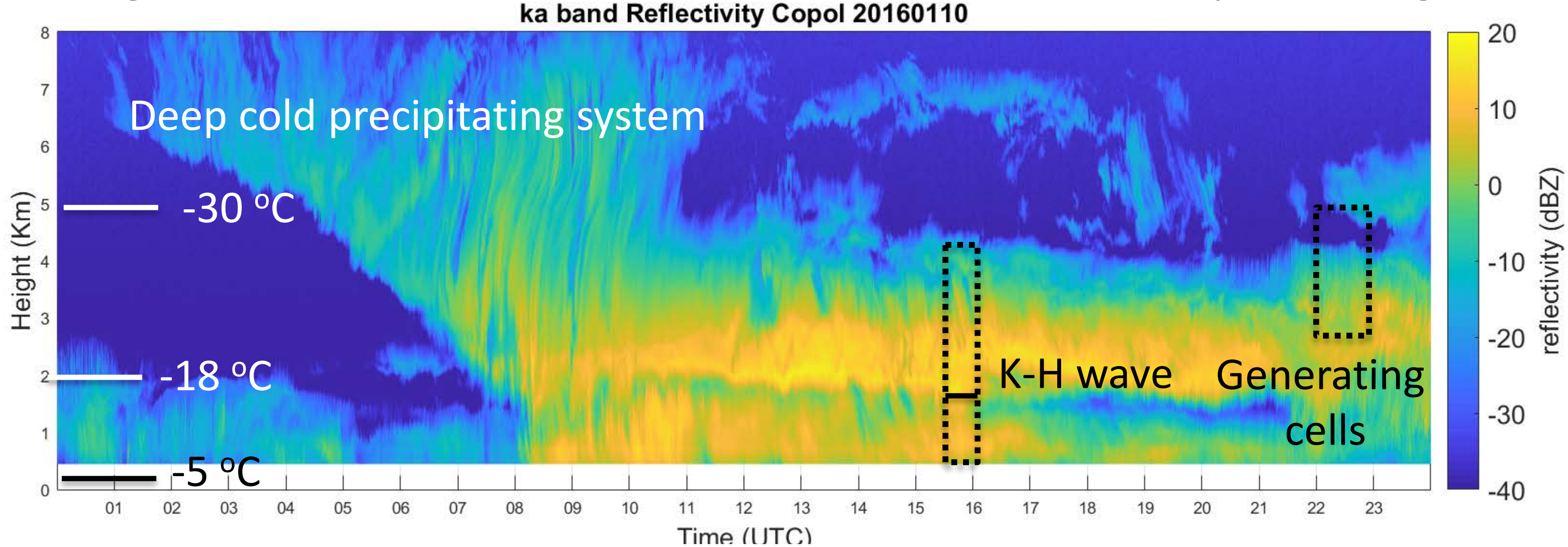
Ice scattering models ⇐⇒ consistent with cloud microphysics as derived by thermodynamic profiles and cloud mask

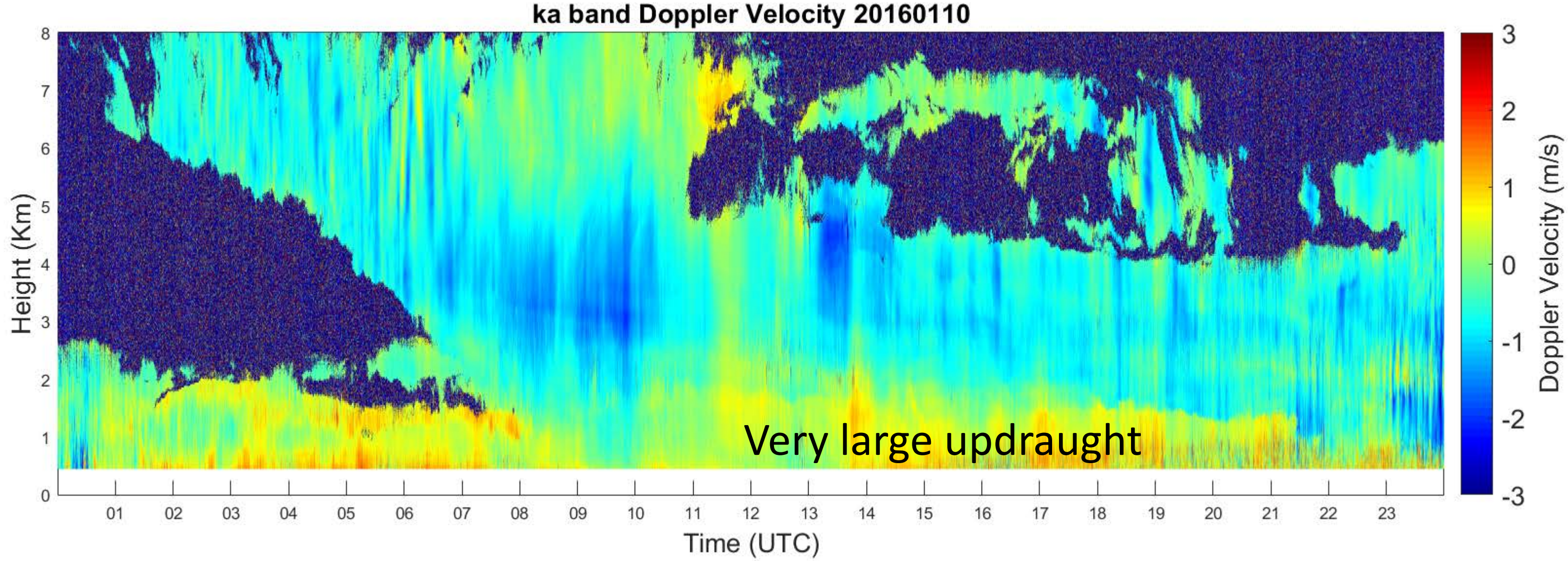
(via polarimetric radar/lidar/Doppler spectra combination, e.g identification of SLWC, dendritic/planar crystal growth layer)

(Kalesse et al., 2016; Luke et al., 2010; Shupe et al., 2004; Verlinde et al., 2013; Oue et al., 2018; Kneifel et al. 2016)

Example of measurements: 10th January 2016

First day of phase 1 of the large melting event over the WAIS (Nicolas et al., 2017).
Linked to strong and sustained advection of warm marine air (favoured by the strong El Nino)

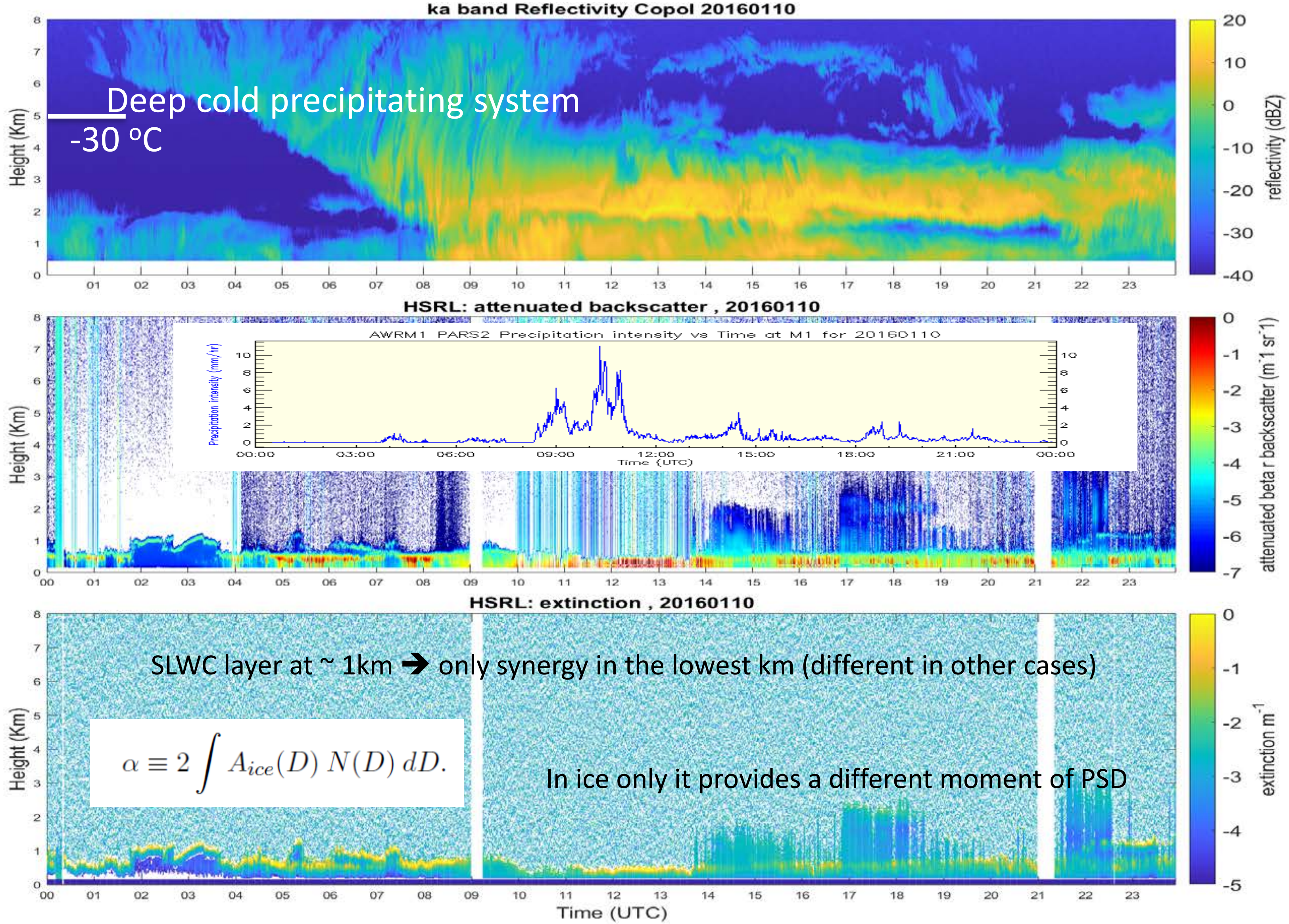




KAZR reflectivity and V_D at 60 m res, beam width is 0.33°. 2s 256-point Doppler spectra with velocity resolution of 0.05m/s

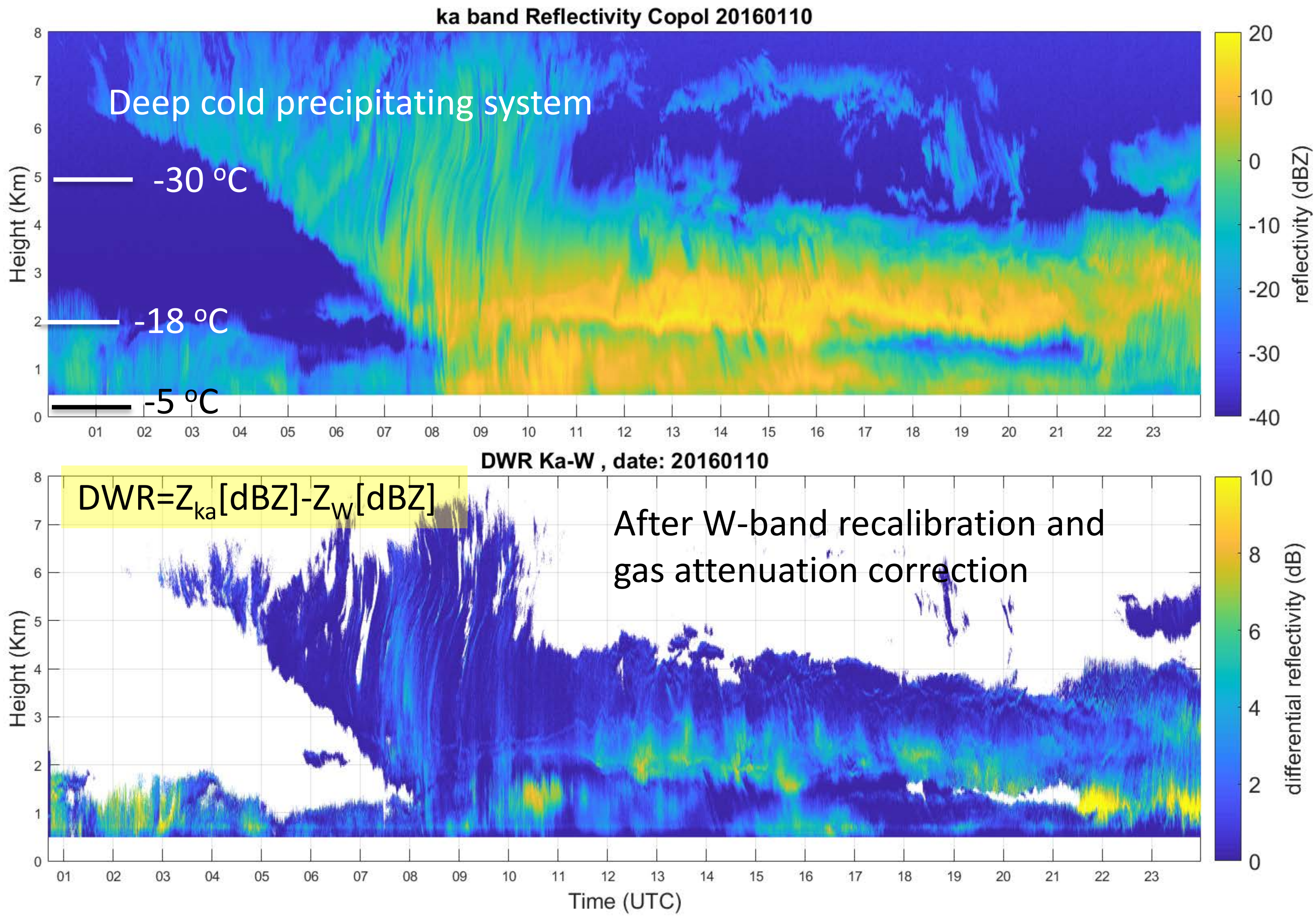
10th January 2016: HSRL

Complementary and synergistic role of HSRL (courtesy from Ed Eloranta, hsrl.ssec.wisc.edu)



10th January 2016: Ka-W DWR

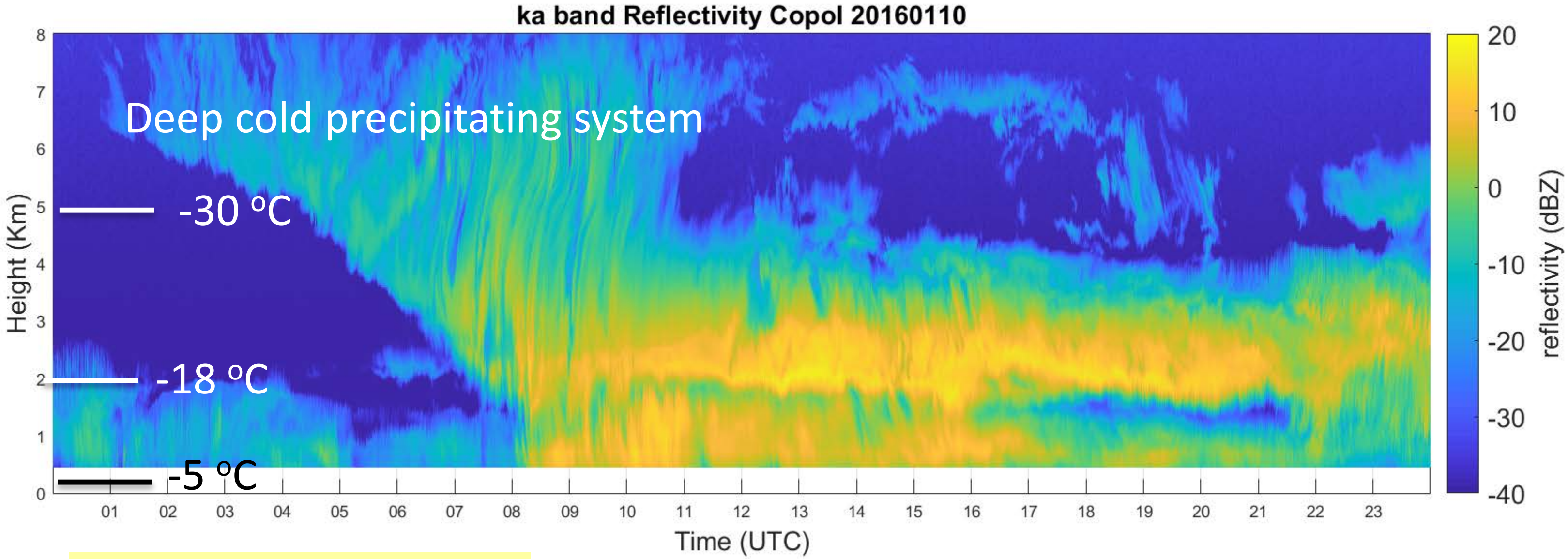
MWACR reflectivity and V_D at 60 m res, beam width is 0.38°.

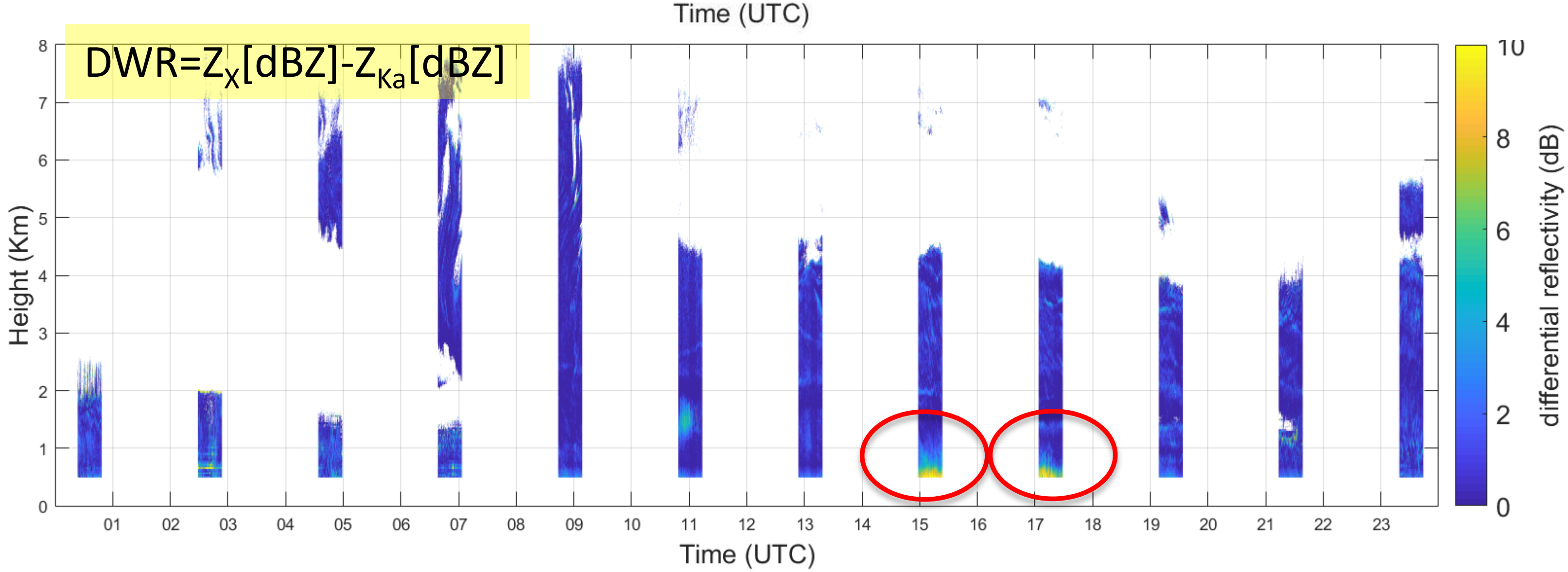


Regions of large DWR corresponding to large particles (➔ non-Rayleigh scatterers at W)

10^{th} January 2016: Ka-W DWR

XSACR reflectivity and V_D at XX m, beam width is 1.27°, radar is scanning only pointing at nadir 30 minutes every two hours

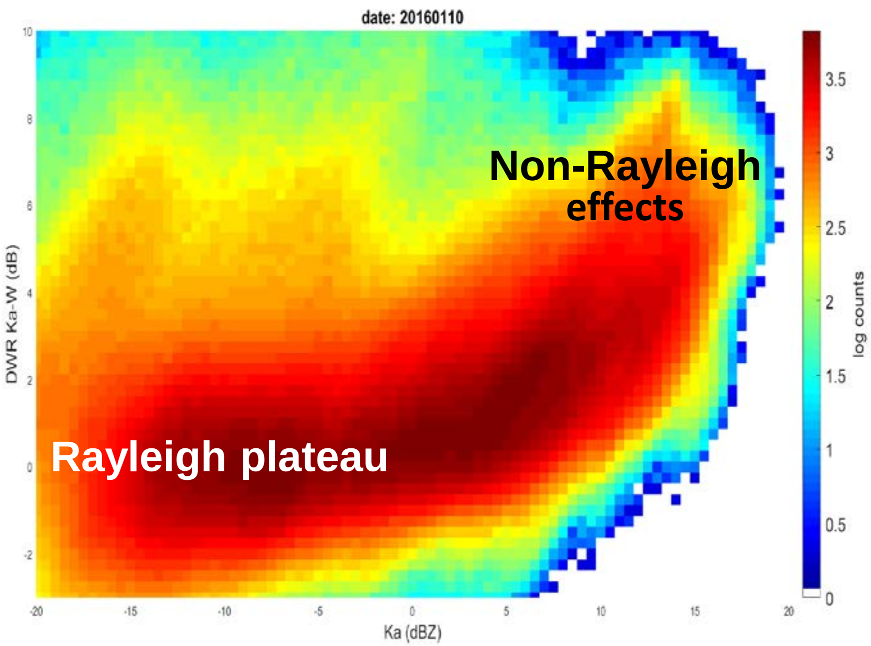




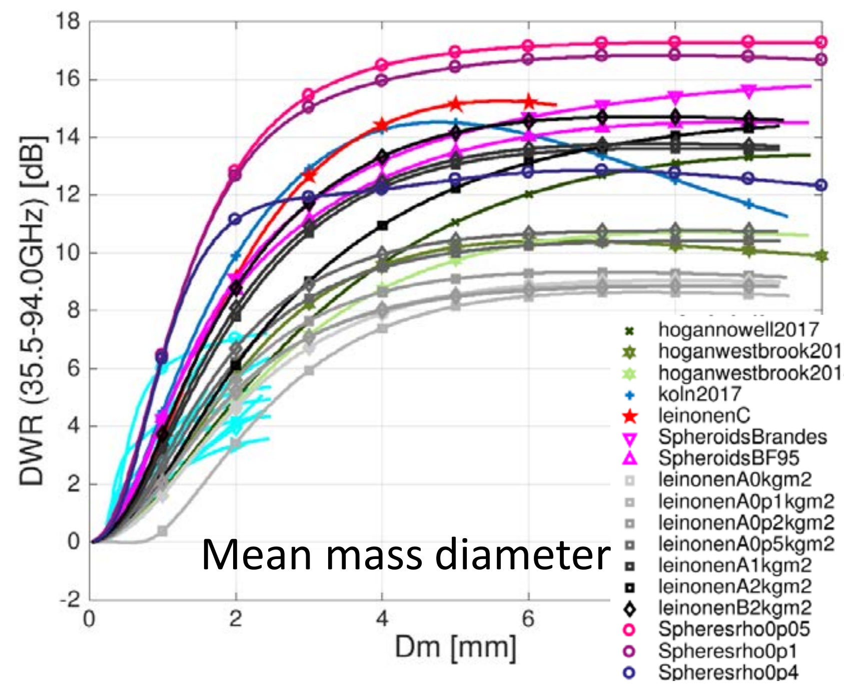
Regions of large DWR corresponding to very large particles (➔ non-Rayleigh scatterers at Ka)

Ice crystal sizing capabilities

Measurements 10-1-16



Model theoretical curves



Good sizing capability up to ~2-3 mm

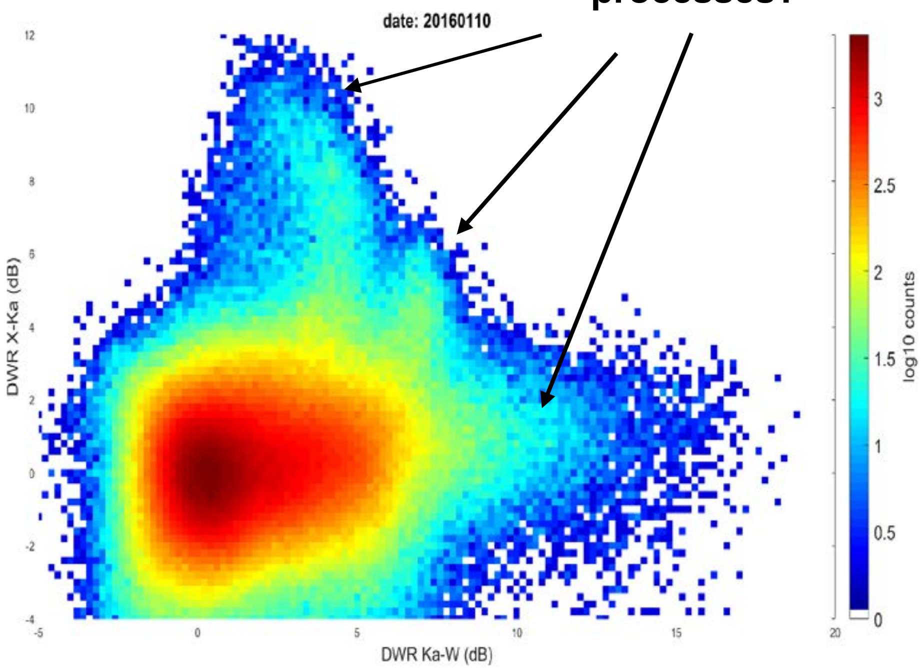
X-Ka covers up to ~8-10 mm

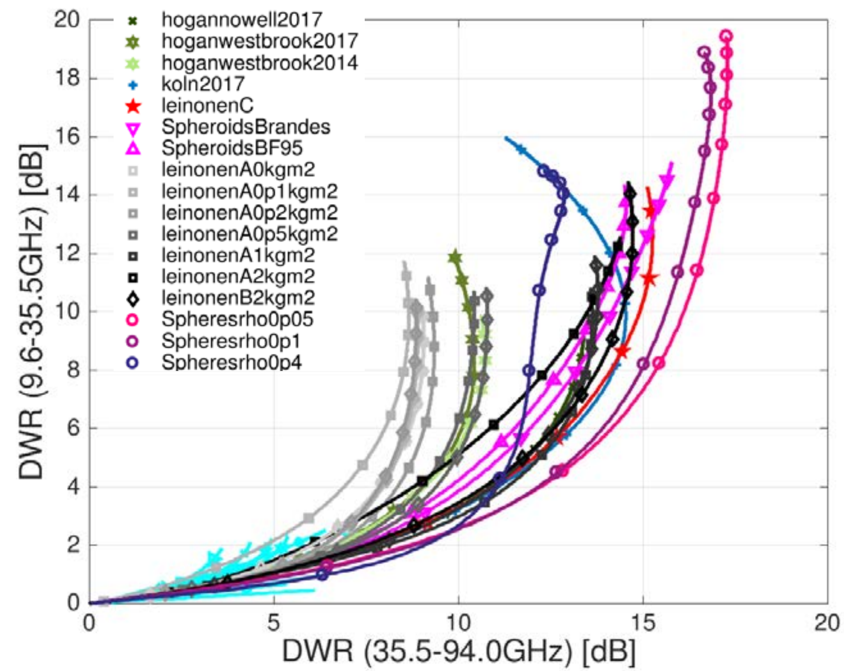
Ice crystal sizing capabilities

Measurements 10-1-16

Model theoretical curves

3 different modes
➔different principal microphysical processes?





Optimal estimation of ice microphysics properties

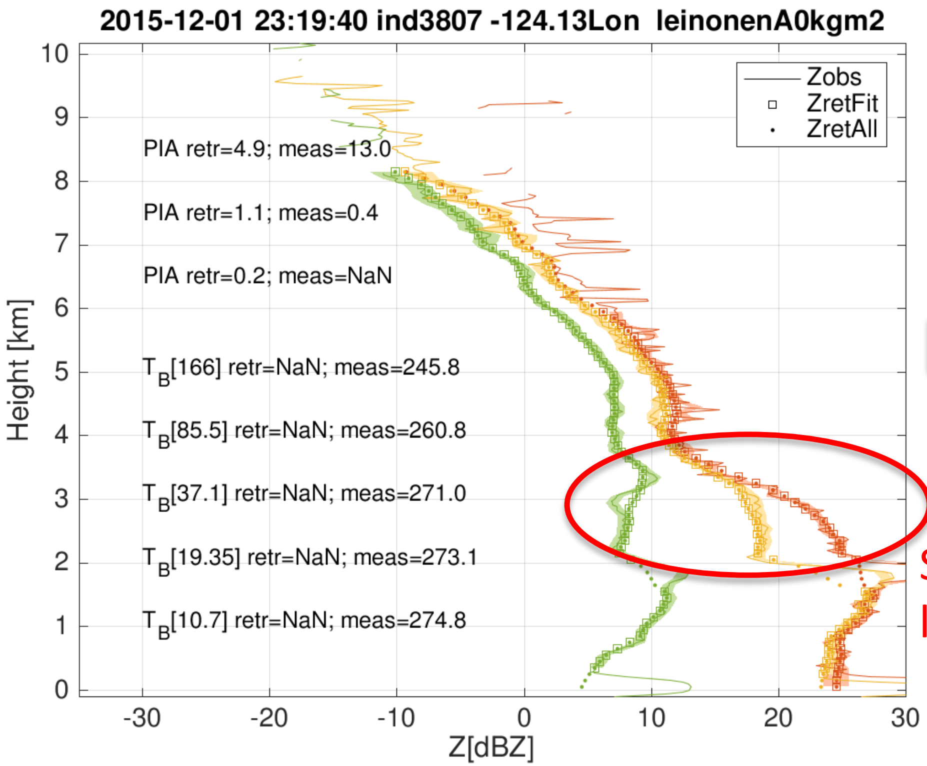
Measurement vector:

$$y = [Z_1 \dots Z_n, k_1 \dots k_n, T_B]$$

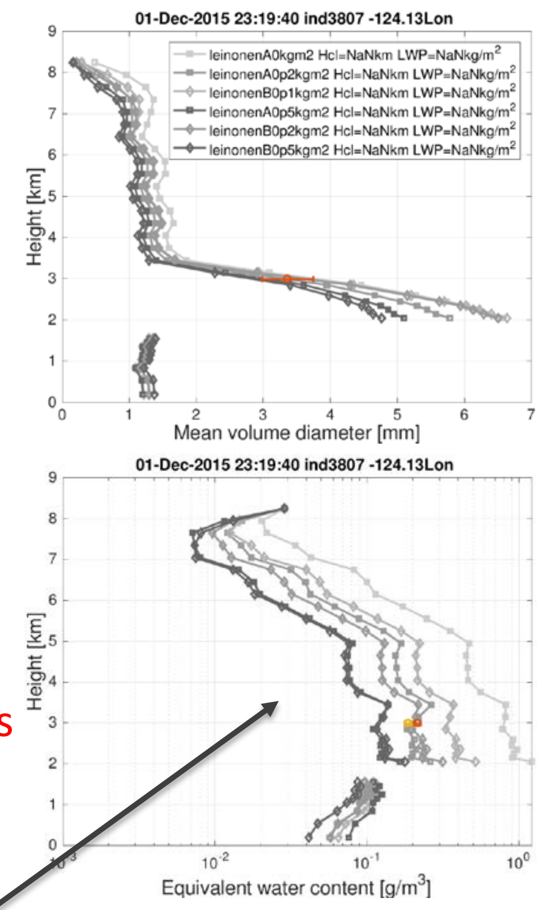
Unknown vector:

$$x = [D_{m,1} \dots D_{m,n}, IWC_1 \dots IWC_n]$$

Example from the OLYMPEX field campaign:
(in situ measurements available for validation)

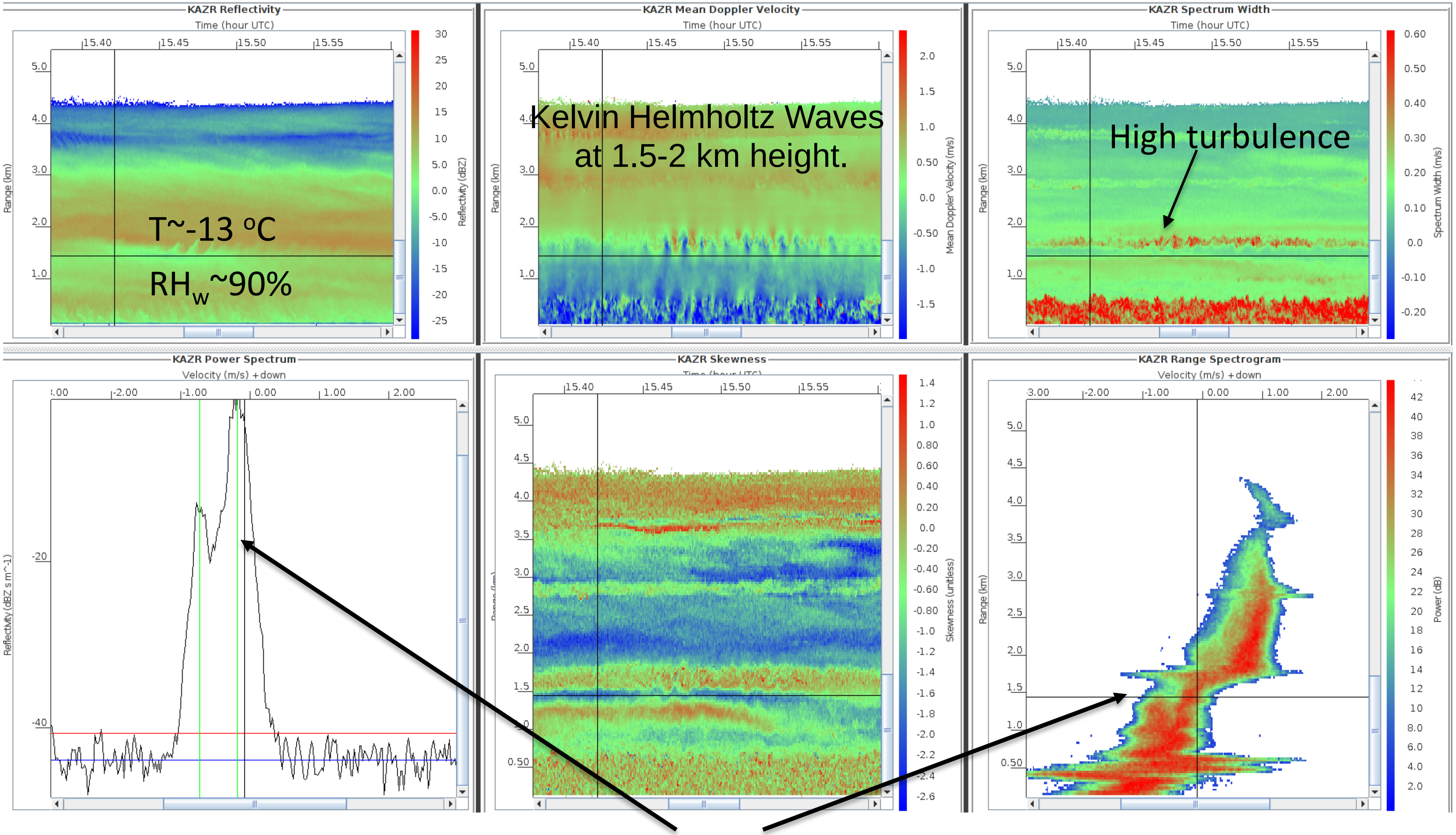


Signature of large aggregates



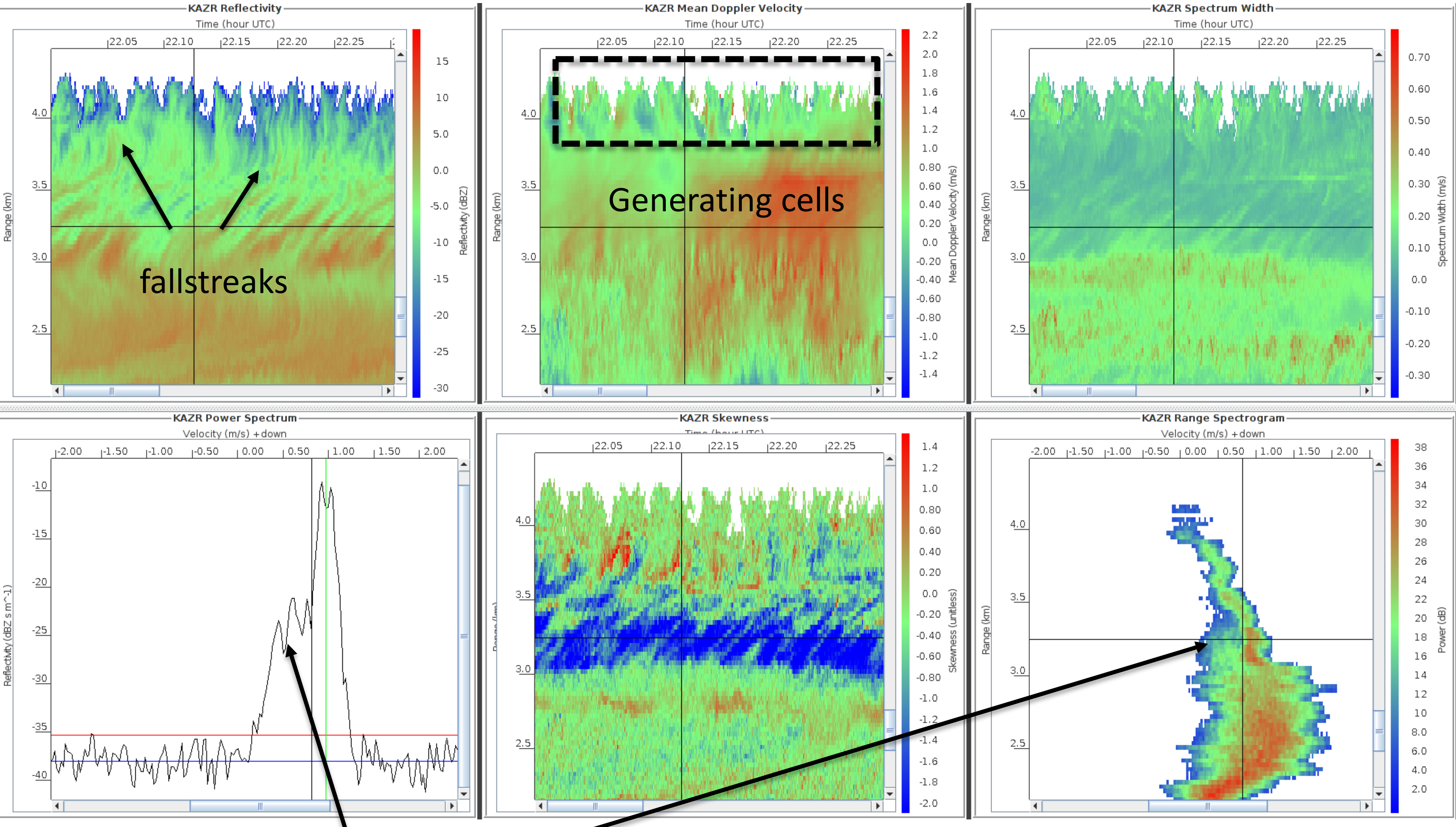
The use of the lidar extinction can help to reduce the range of possible solutions

Doppler spectra bimodality below K-H waves: nucleation or SIP?



Just below the KH feature, the Doppler spectra show bi-modality (indicated also by negative skewness band). Does turbulence induce nucleation or secondary ice? The temperature region (-10…-15°C) would favor ice-fragmentation.

Doppler spectra in generating cells at cloud top



Below the generating cell layer, one finds strongly negative skewness caused by additional smaller/slower particles. It is unclear what is responsible for this secondary mode, but one can see it very persistent over the entire hour!

Data availability and project roadmap

	2015		2016											
	N	D	J	F	M	A	M	J	J	A	S	O	N	D
ceil	19													31
hsrl	29													31
kasacr		2							2 7				6	
kazr	17													31
mpl	19											7 12		31
mwacr	29			19										
mwr		7	17 29							2 5				31
pars2	19													31
xsacr		7							2 7 15					

Due to contract issues work on project started only in 2018 (not yet at full steam)

	Description	Responsible person	Months 1--6	7--12	13-18	19--24	25--30	31--36
SO1.1	Quality control of AWARE dataset	PI & Tridon						
SO1.2	Implementation of the enhanced cloud mask	PI & Tridon						
SO1.3	Development and test of the OE profiling retrieval algorithm	PI&Kneifel& Tridon						
SO1.4	Complete data analysis for the AWARE dataset	PI& Tridon						
SO2.1	Identification of case studies dominated by a specific process	Kneifel						
SO2.2	Forward simulation of observations from LES case study simulations	Kneifel & Fridlind						
SO2.3	Use of forward simulation results to evaluate process observability	Kneifel						
SO3.1	Comparison of observations and ModelE simulations by CVS weather state	PI&Fridlind						
SO3.2	Selection and set-up of case studies for LES and SCM simulations	Fridlind & Ackerman						
SO3.3	ModelE SCM and GCM performance improvement	Ackerman & Fridlind						
D1	PI data product for AWARE field campaign	PI & Tridon				x		
D2	Algorithm theoretical basis description and code for OE algorithm	Tridon				x		
D3	Case study specifications for LES and SCM, GISS simulation results	Fridlind				x		
D4	Improvement of GCM schemes through SCM case studies and full GCM	Ackerman & Fridlind						x
D5	Recommendations for future process retrieval development	PI&Kneifel & Tridon						x
D6	Annual reports	PI & all co-Is			x	x		x

Conclusions and future work

- Modular optimal estimation retrieval for multi-wavelength active and passive observations under development with state-of-the-art scattering properties LUT for ice.

- Snow microphysics still challenging even with multi-frequency observations → multiple solutions with different scattering models compatible with observations. Clever selection of scattering model needed (cloud mask and process identification via spectra/polarimetry).

- Key challenges:

1) Identify dominating ice processes (riming vs aggregation vs sublimation/deposition).

2) Can we say something about secondary ice? (e.g. triggers, occurrences vs T/RH/wind shear/cloud structure?)

Thanks for your attention

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Atmospheric System Research