The Doppler spectra story of a riming event in Finland

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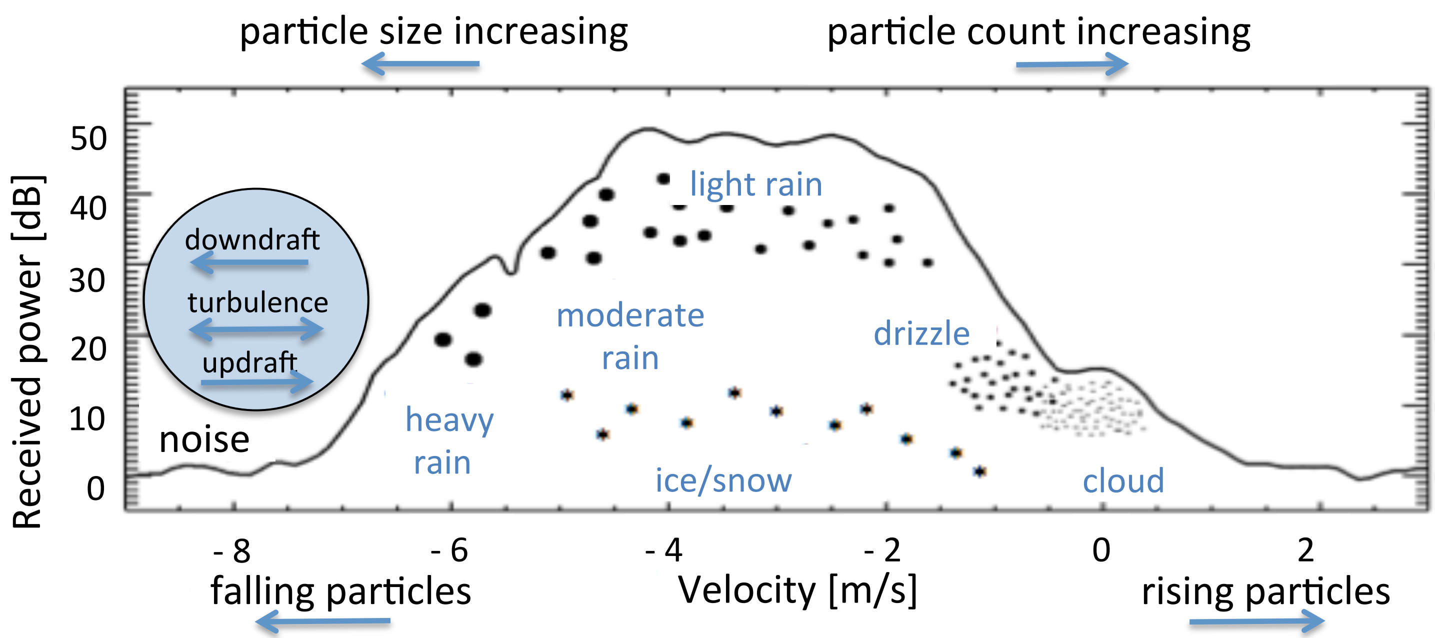
From Doppler radar *moments* to Doppler radar *spectra*

The returned power to the radar represents a combined signal from a variety of targets in the radar pulse volume. The returned power is distributed over a range of Doppler velocities. This is known as the Doppler spectrum.



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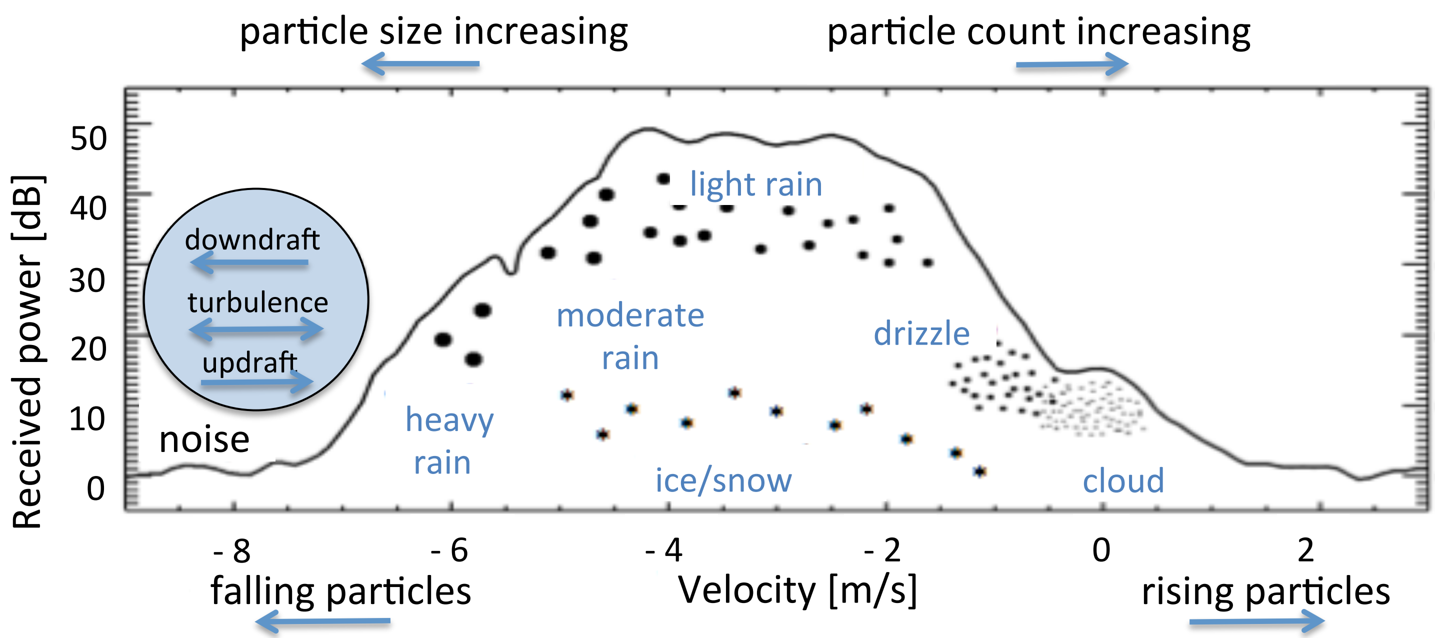

- Historically: storage of first 3 moments of the Doppler spectrum:
  Reflectivity Z_e [dBZ], mean Doppler velocity V_{dop} [m s^{-1}], spectrum width σ [m s^{-1}]
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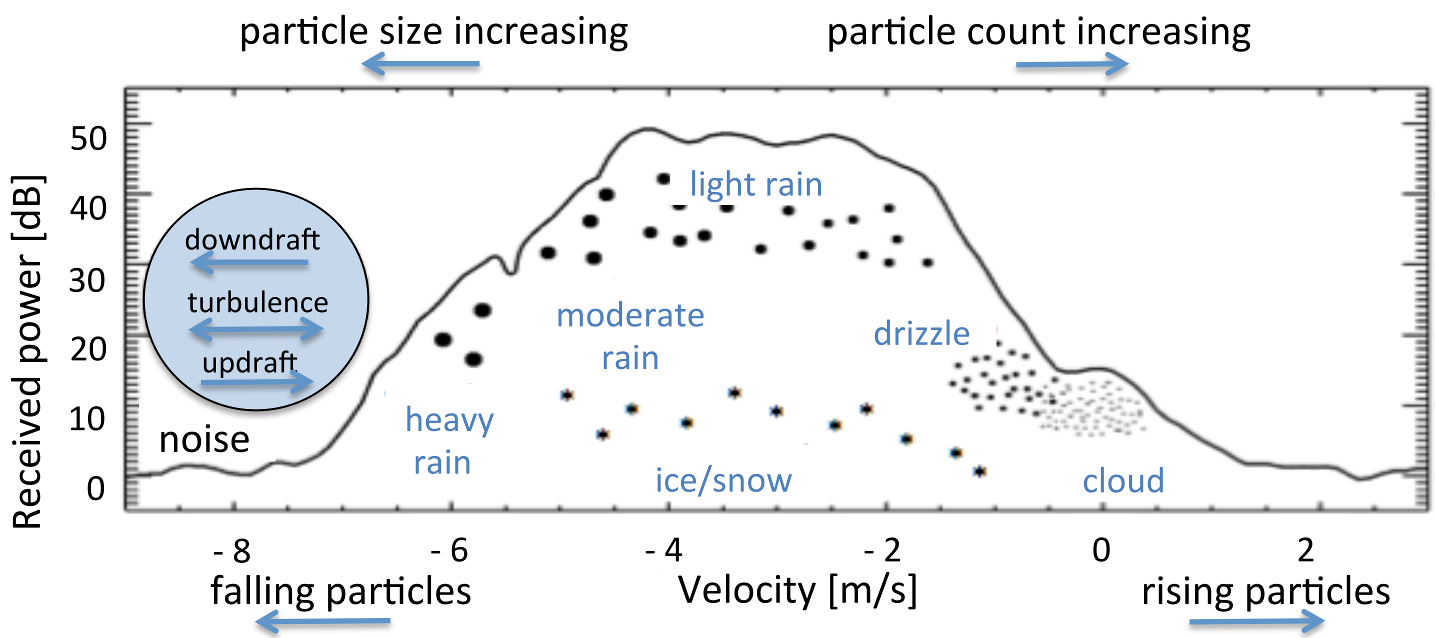

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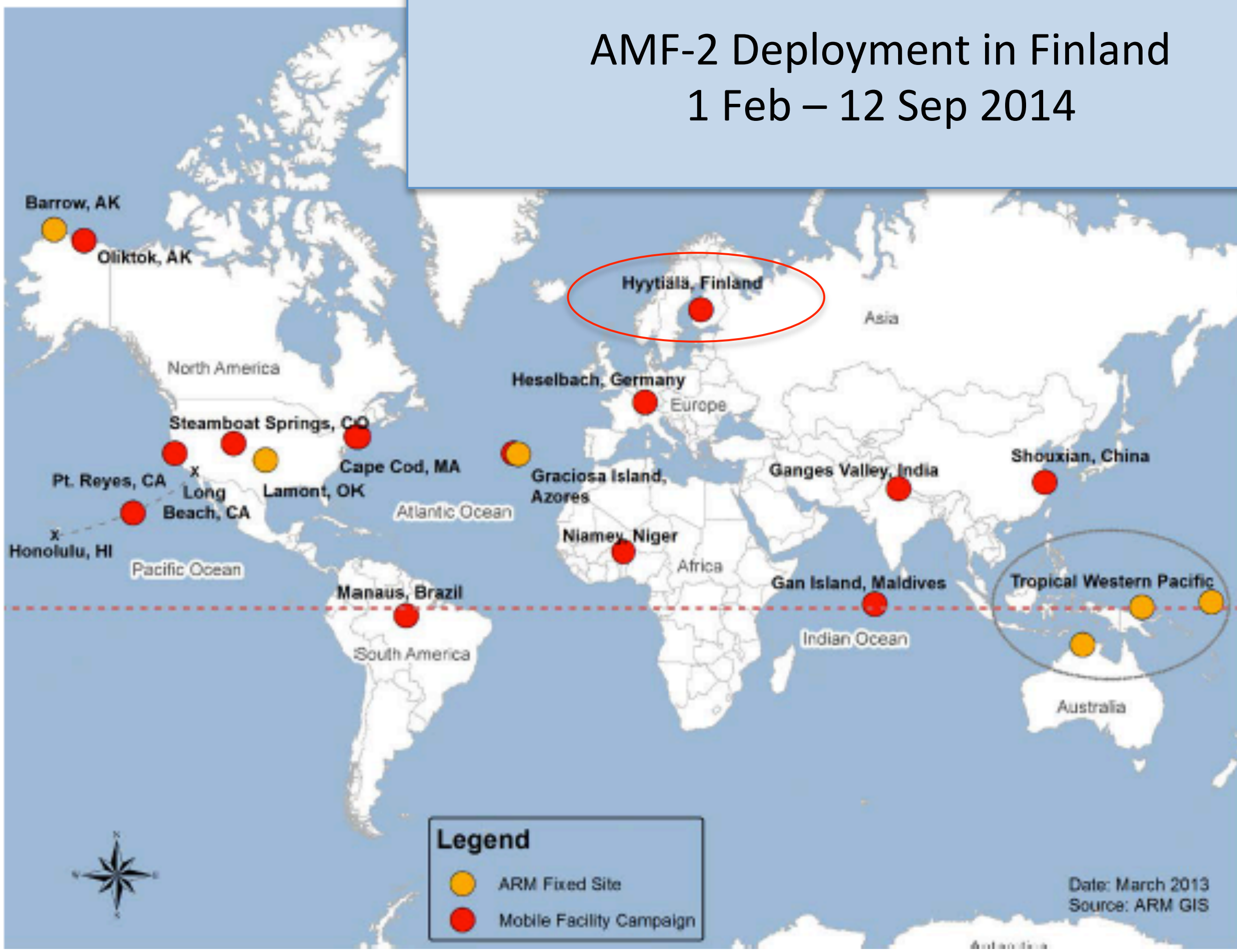
Can we tell the microphysical story of a hydrometeor population in a mixed-phase cloud by observations of cloud radar Doppler spectra?

Outline

1. The BAECC Snowfall Experiment (Finland 2014)
2. Why radar moments sometimes are not enough ...
3. It‘s riming man, hallelujah! (or : Observation of riming in radar Doppler spectra)
4. Vertically or slanted, that is the question!
5. Microphysical evolution of different hydrometeor populations along slanted paths
6. Comparison of observed rimed particle moments with 1D bin model results
7. One peak, two peaks, three peaks, merged peaks ... → Outlook

Atmospheric Radiation Measurement (ARM) Climate Research Facility

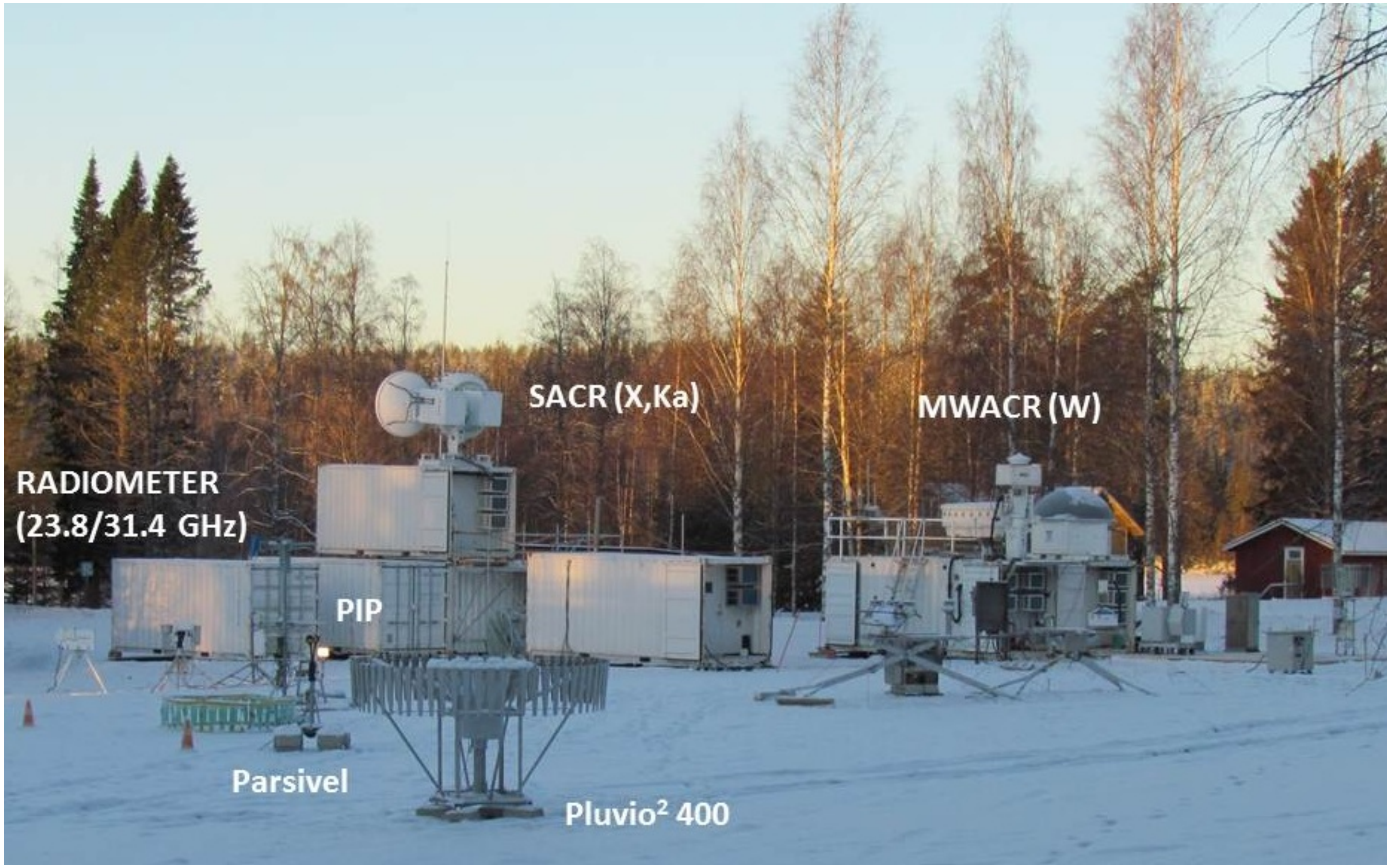
AMF-2 Deployment in Finland
1 Feb – 12 Sep 2014



www.arm.gov

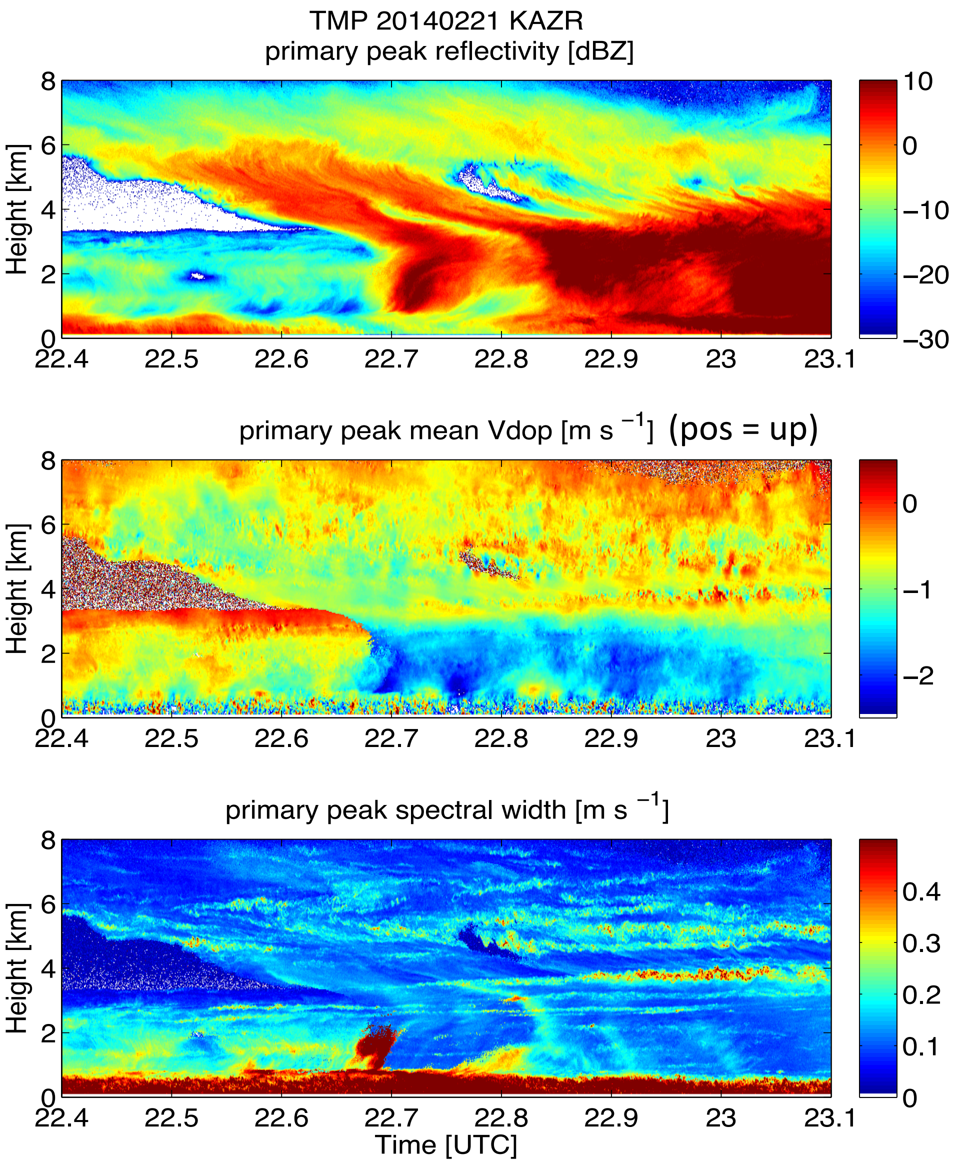
BAECC SNEX IOP 2014, Hyytiälä, Finland (TMP)

- **B**iogenic **A**erosols – **E**ffects on **C**louds and **C**limate **Sn**owfall **Ex**periment (BAECC-SNEX : Feb 1 - April 30)
- Extensive remote-sensing and in-situ instrumentation



(Foto courtesy D. Moisseev & A. von Lerber)

When primary peak moments and vertical profiles are not enough ...



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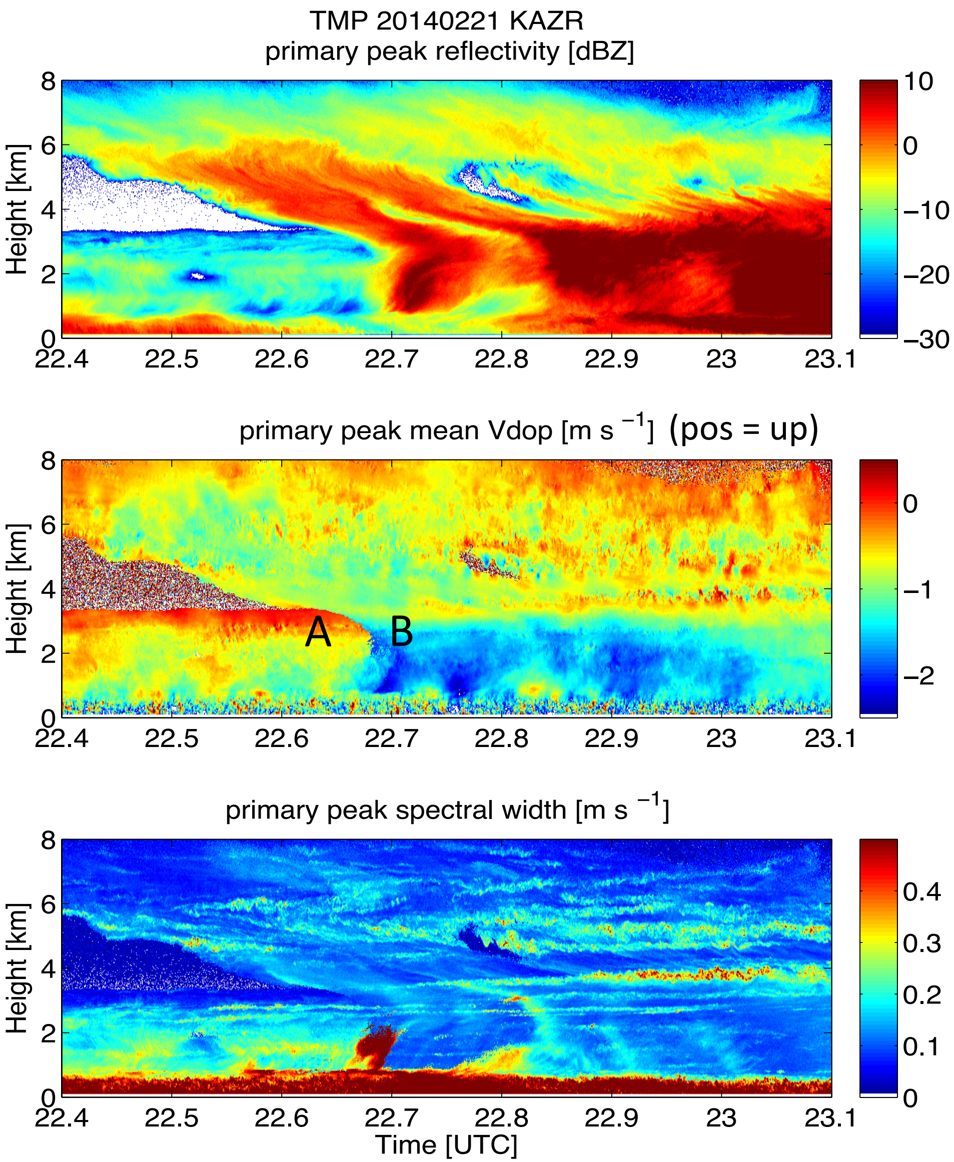

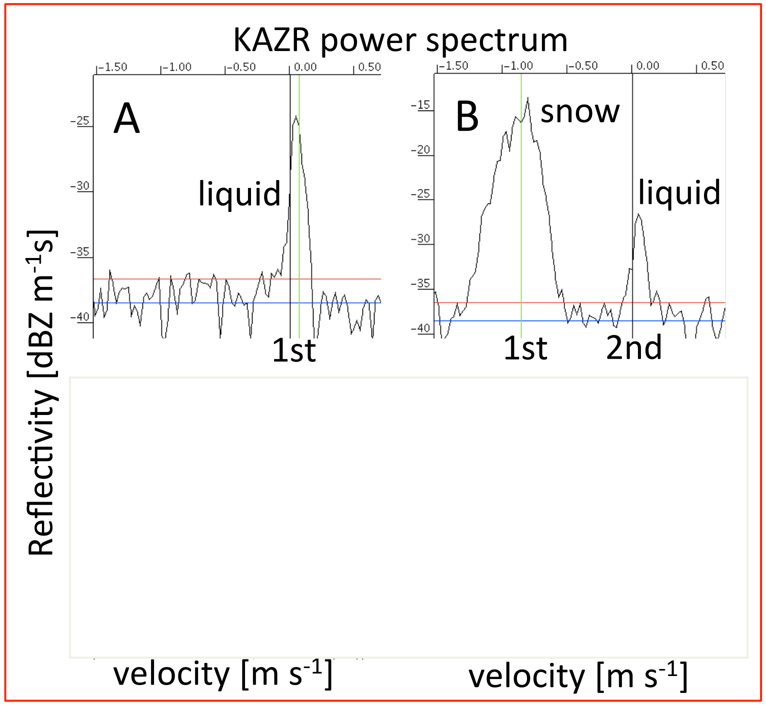

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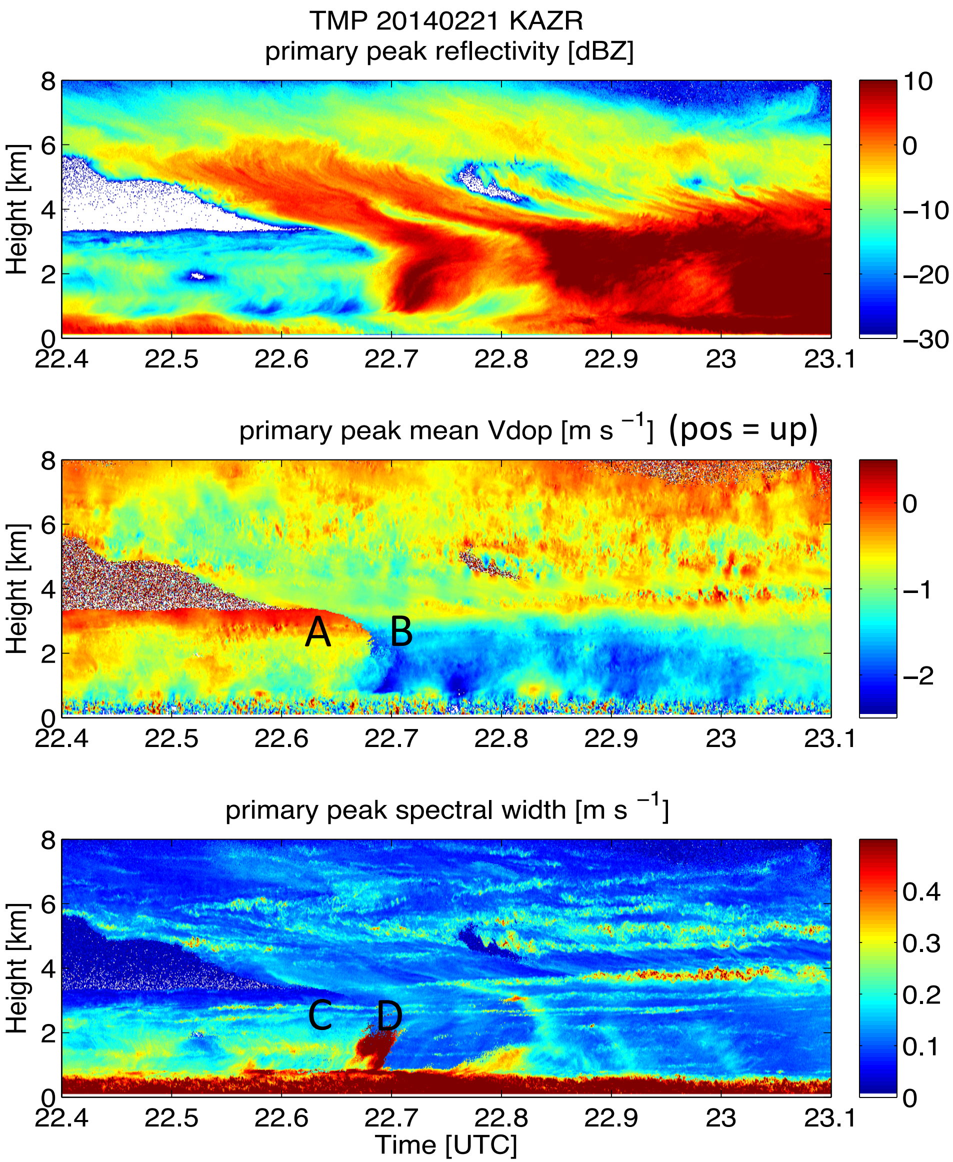

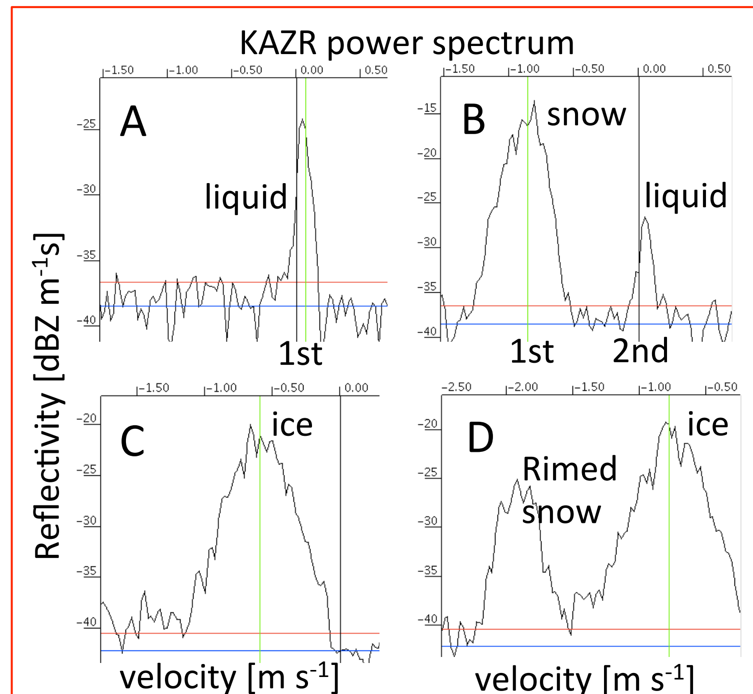

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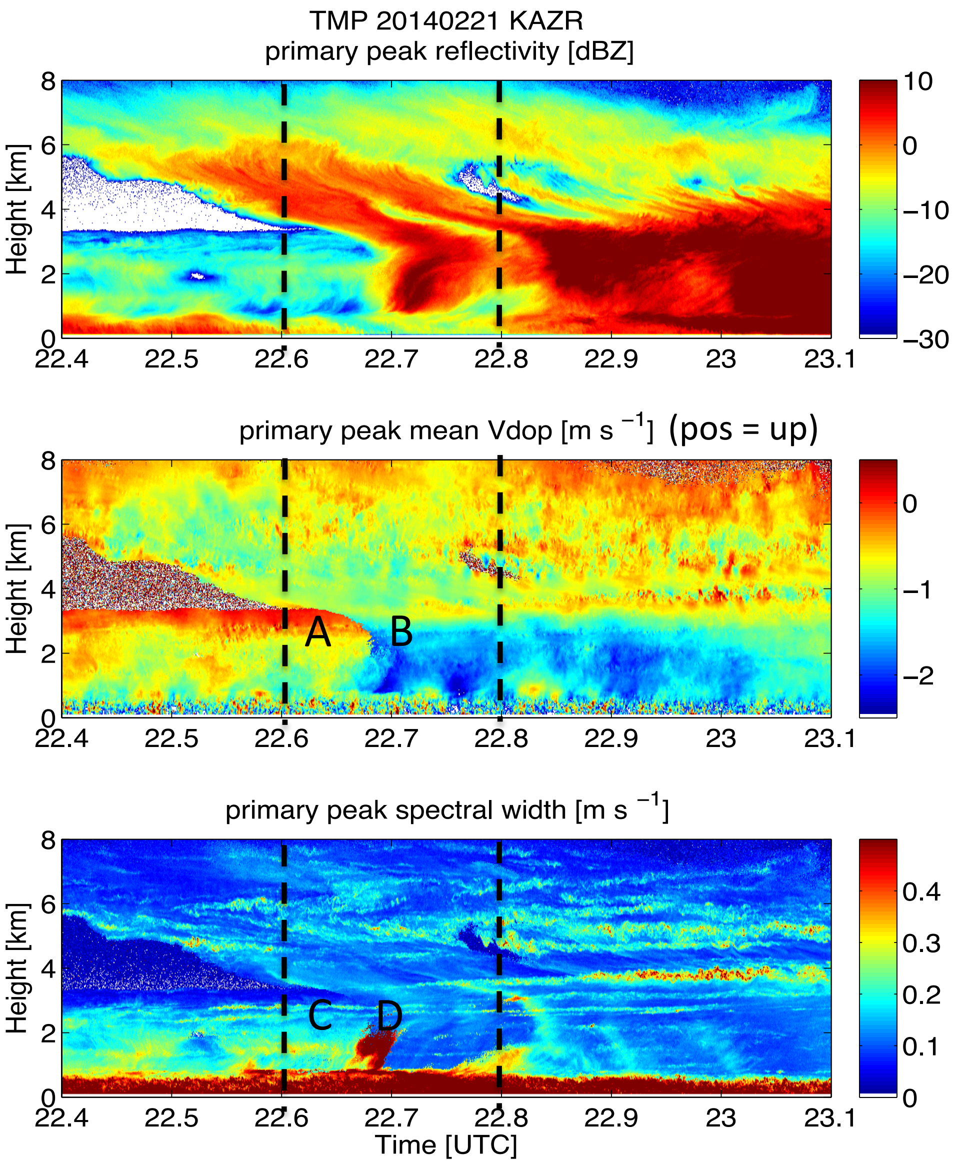

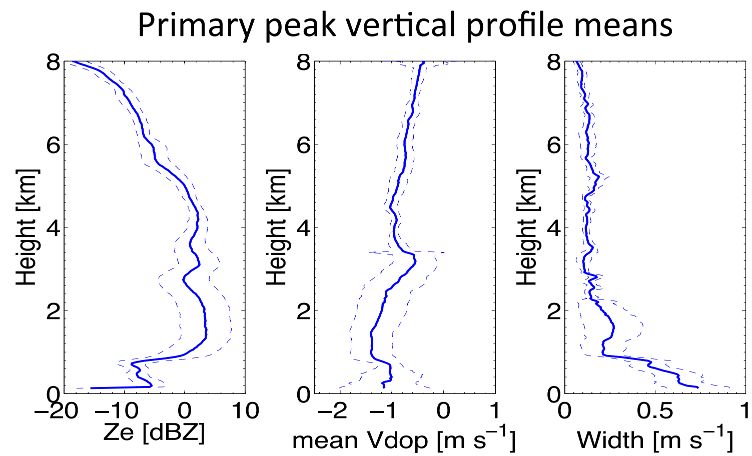

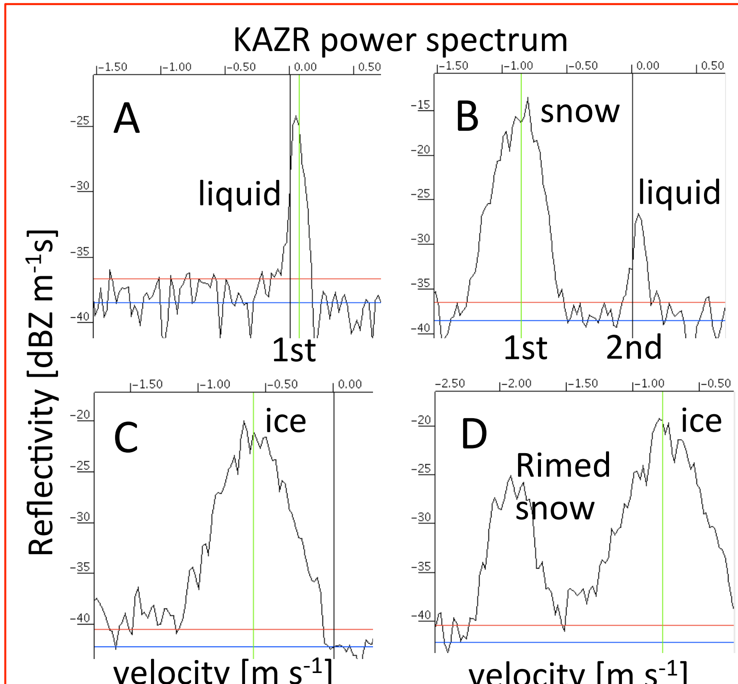

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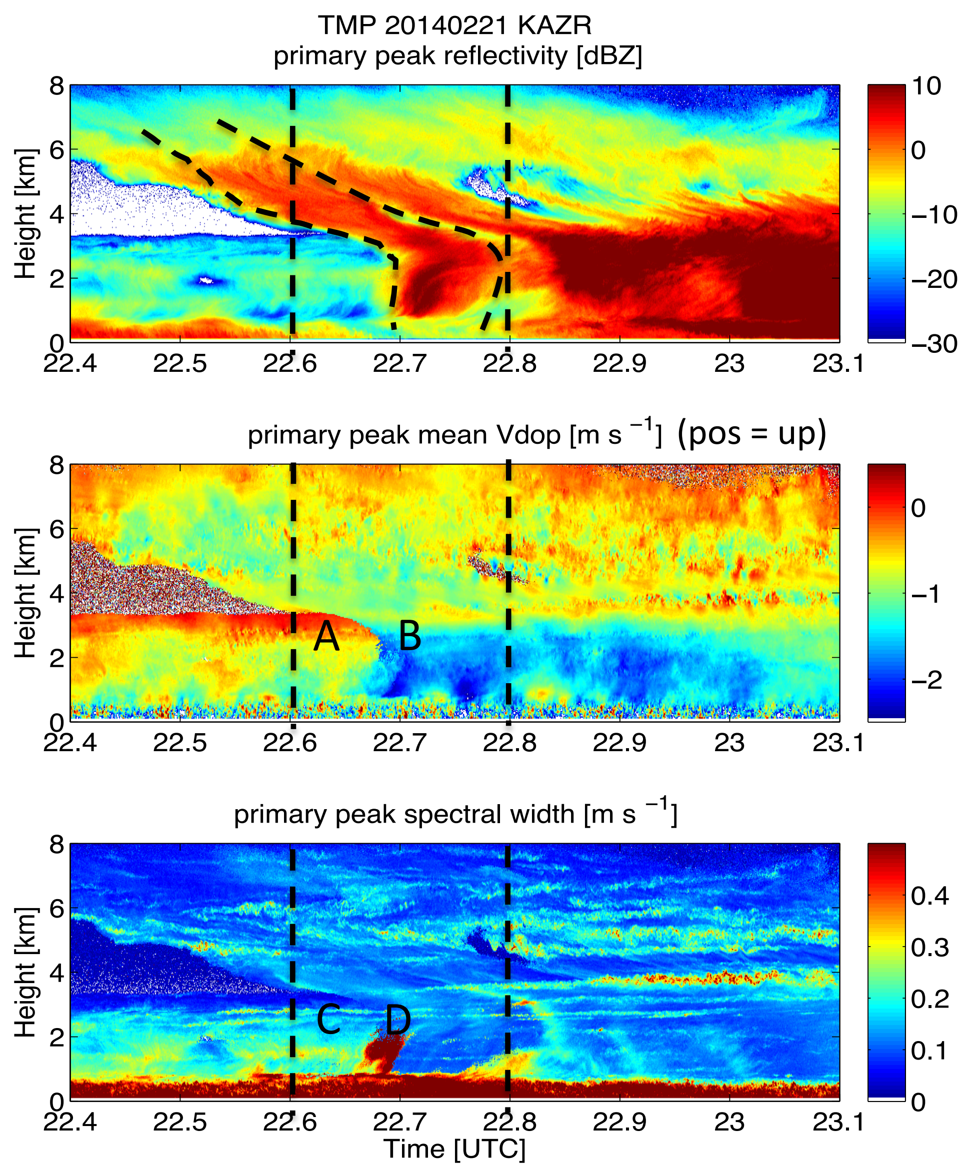
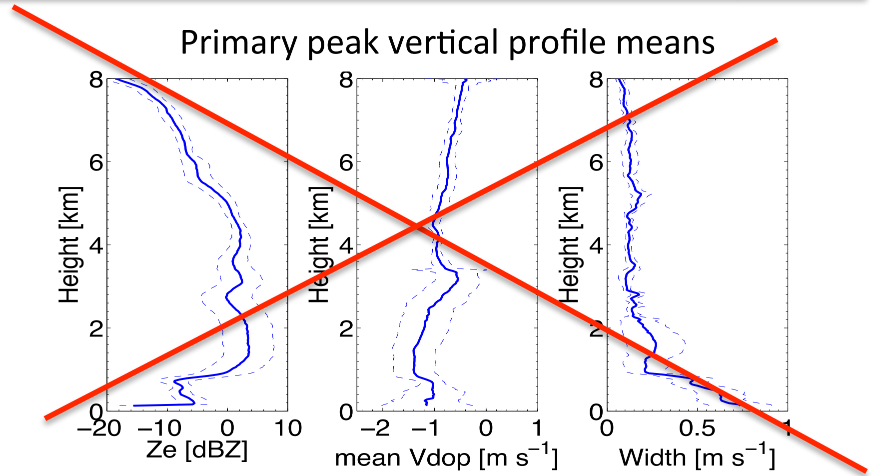
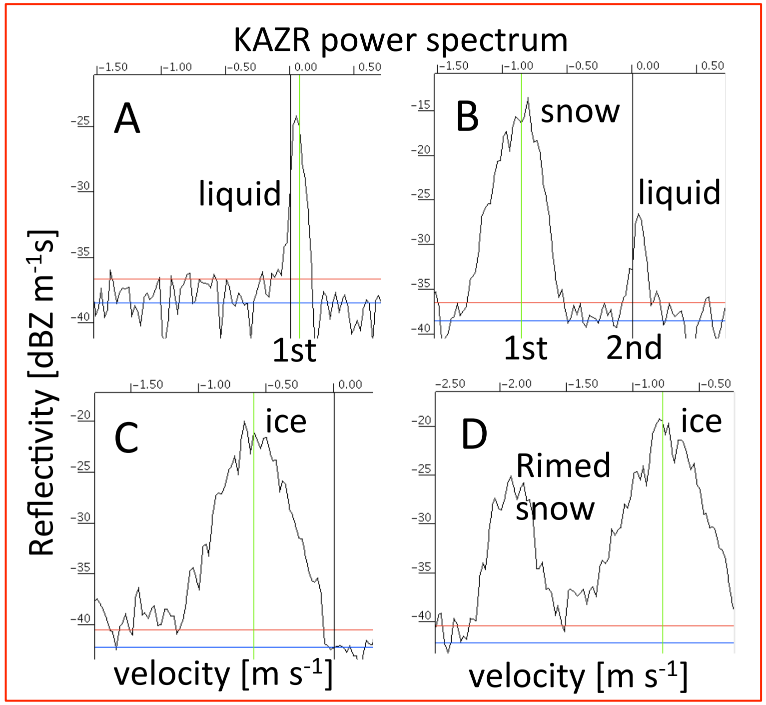
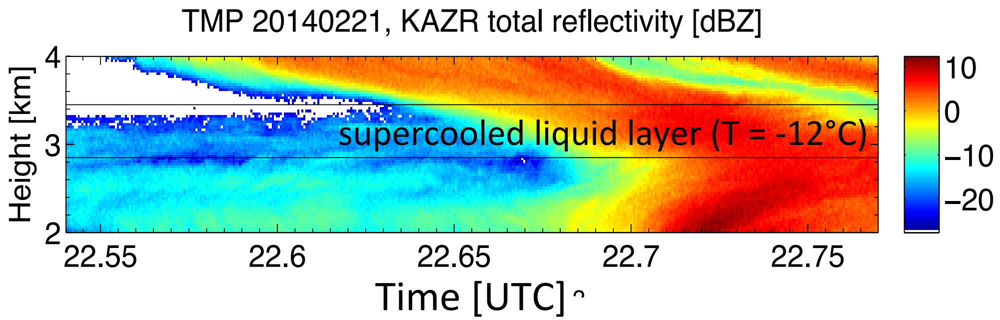
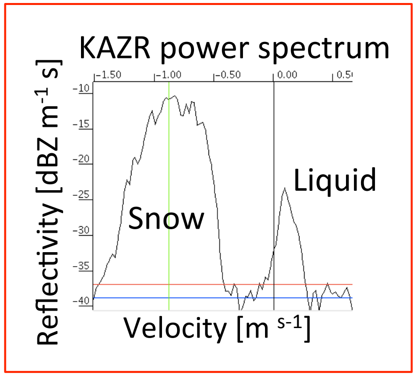






Which observations help in detecting the liquid layers and the riming?





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- KAZR: more liquid layers (0.8-0.9km; 1.5-1.7km)

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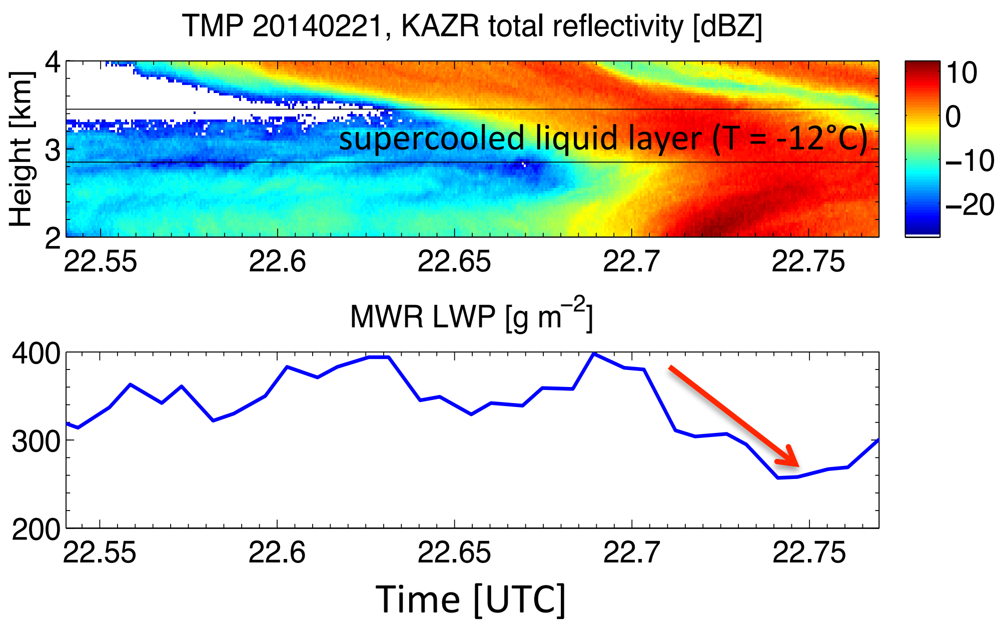

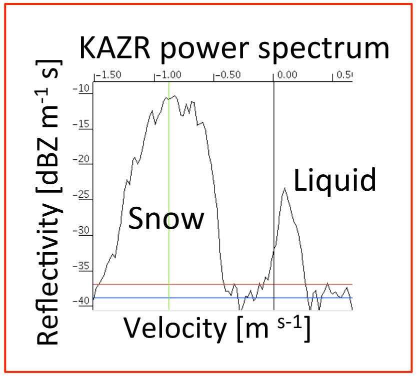

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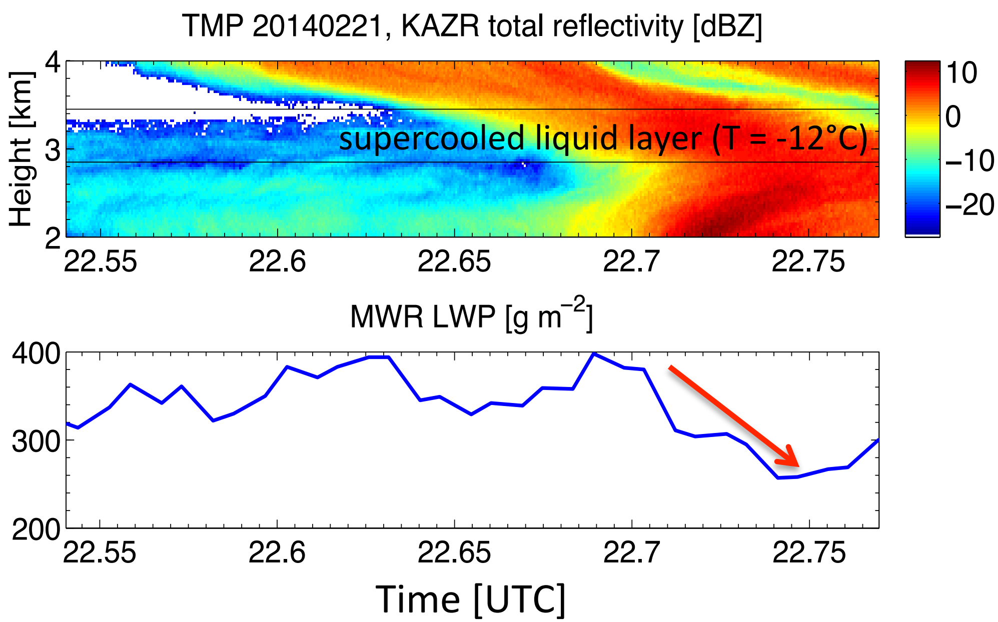

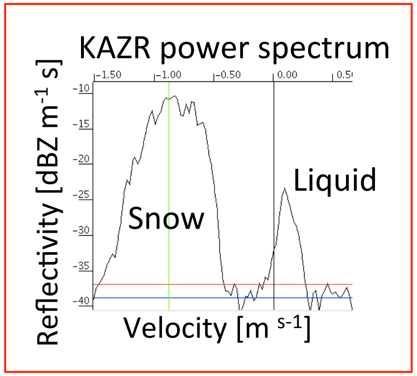

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  - Small+big oriented dendrites, fast roundish particles (rimed)

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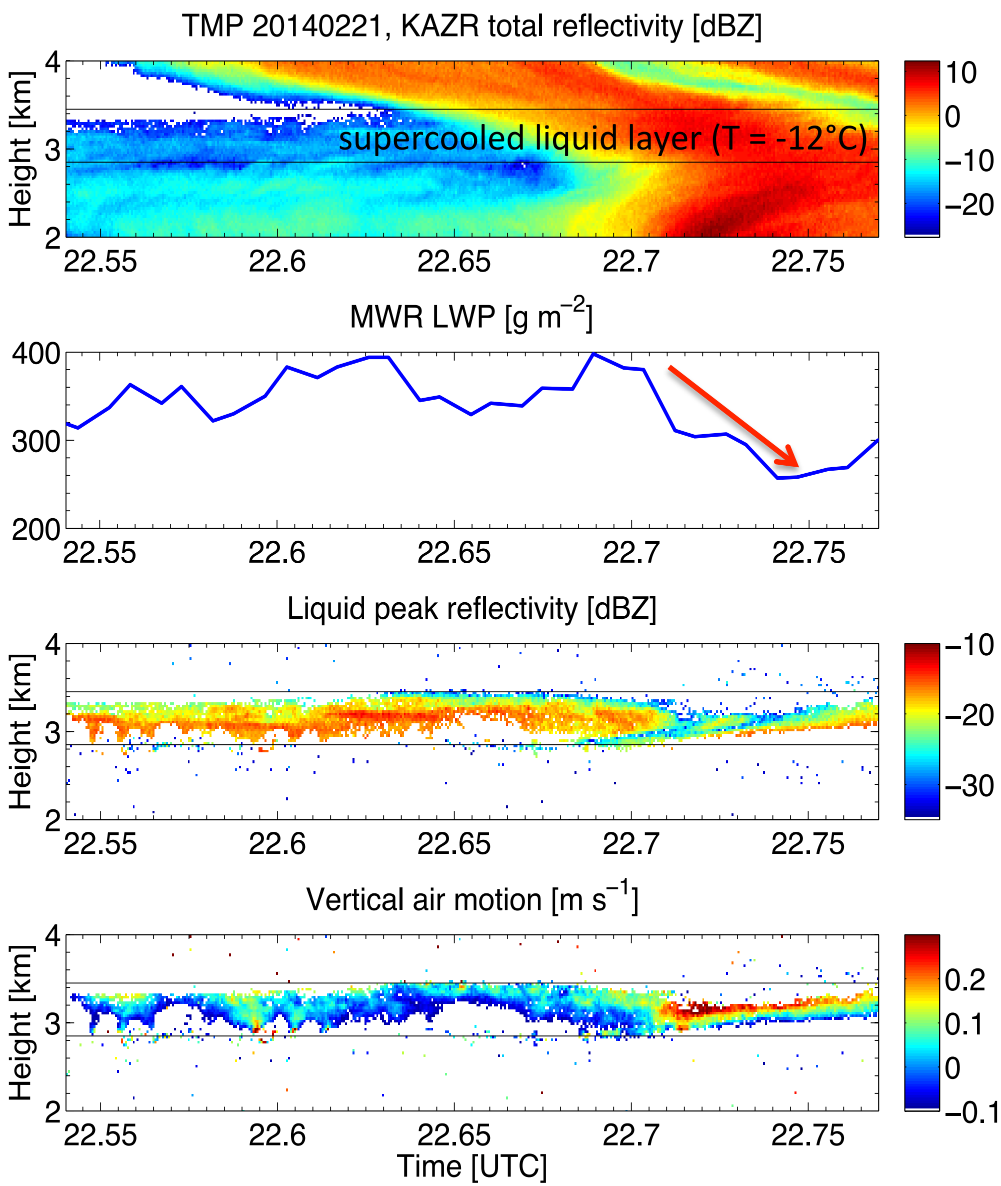

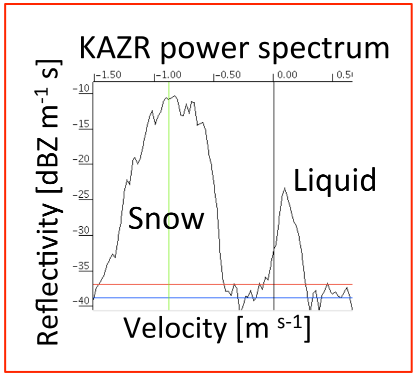

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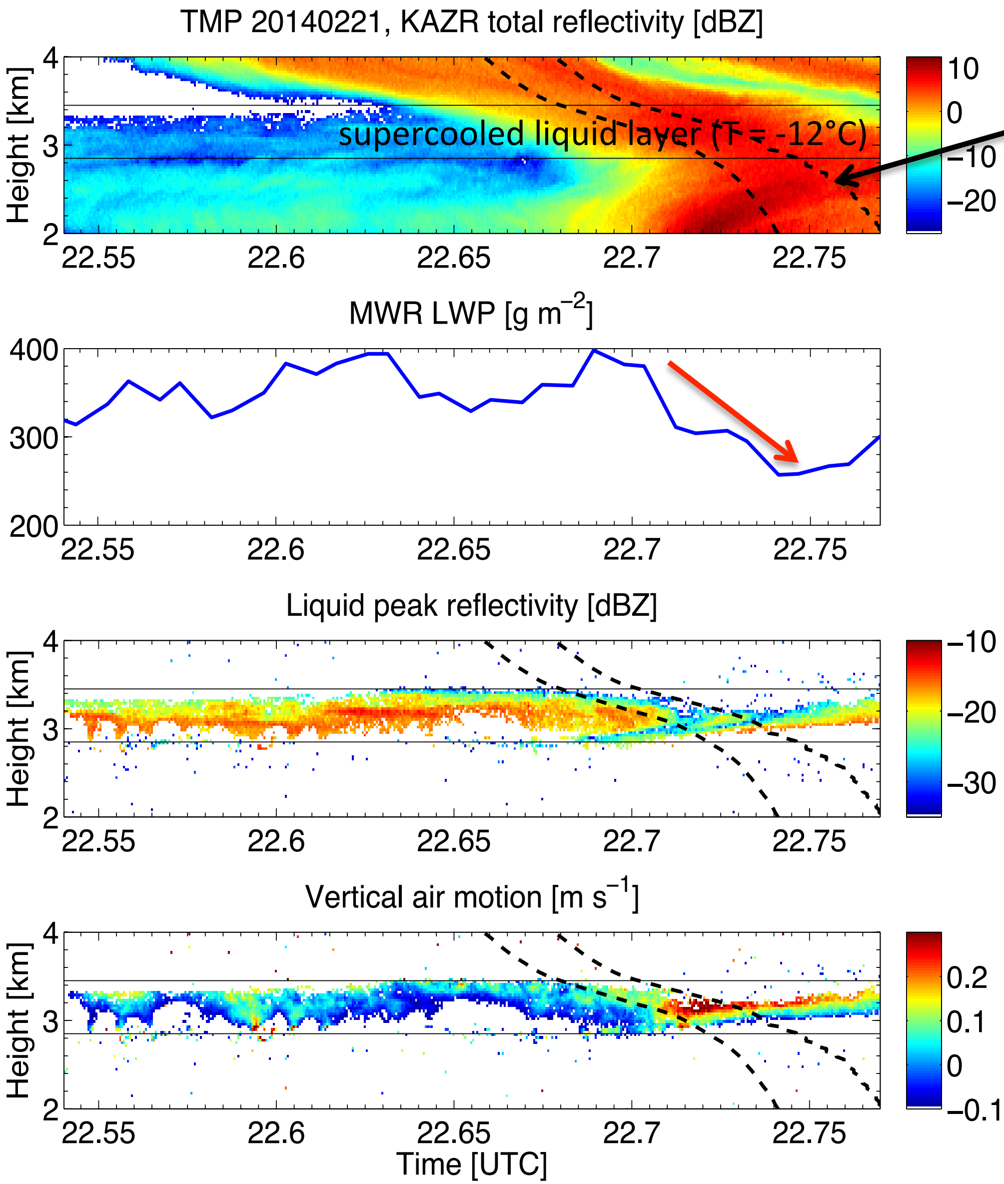
- Liquid mode reflectivity (N, sigma) → LWC
- Liquid mode mean Doppler velocity → Vair

How do we determine the slanted fall streaks ?



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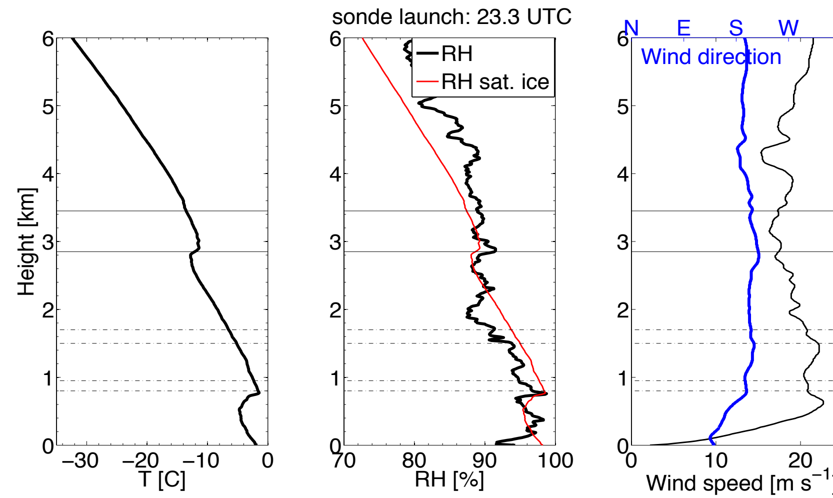

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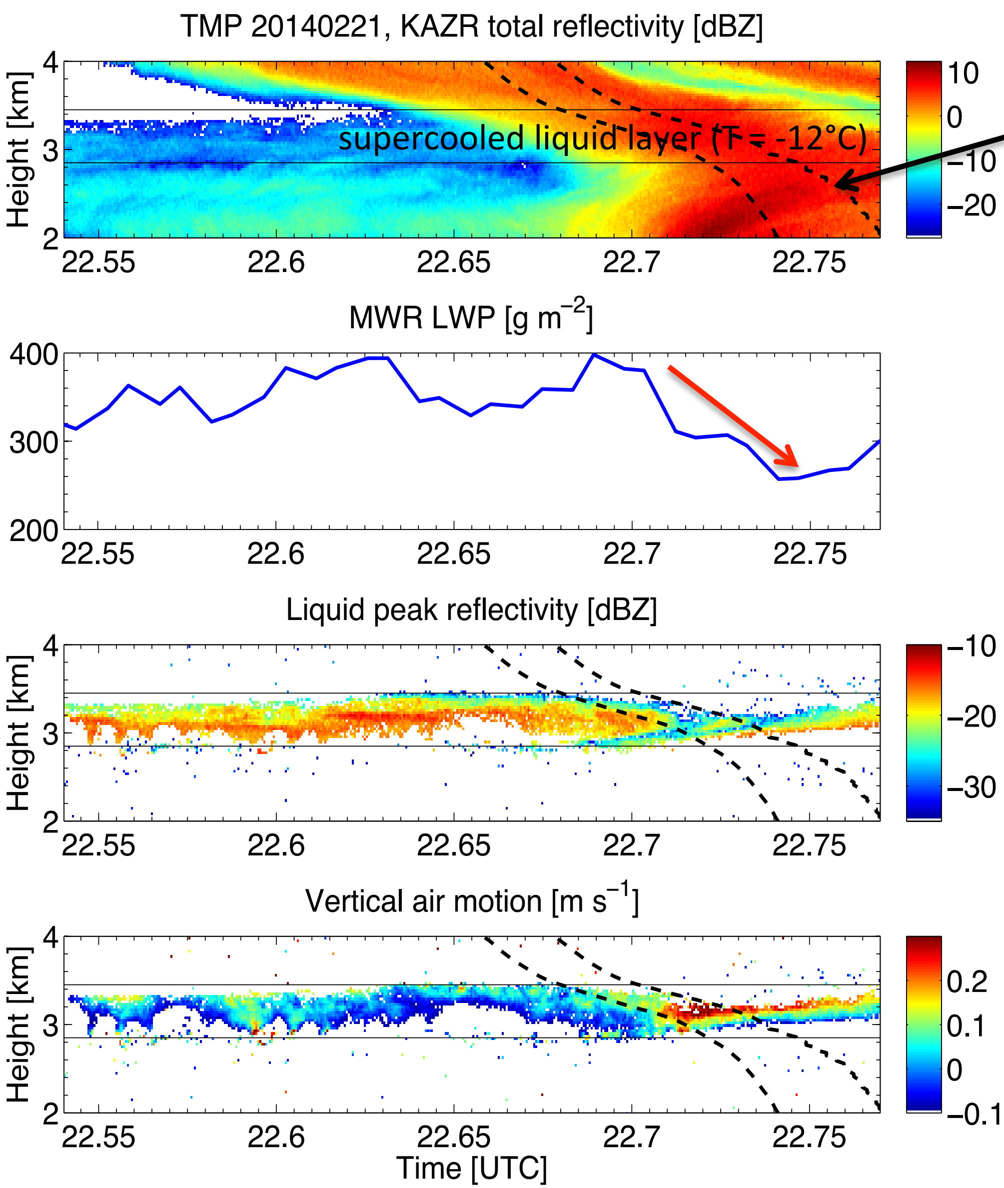

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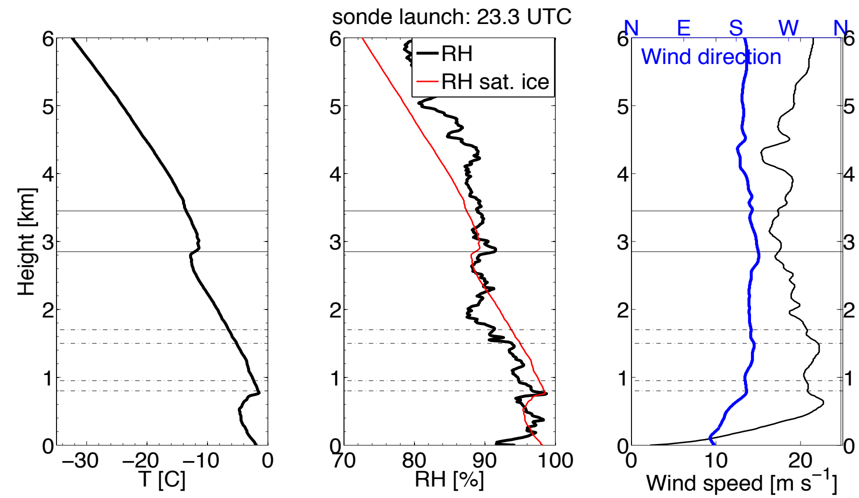
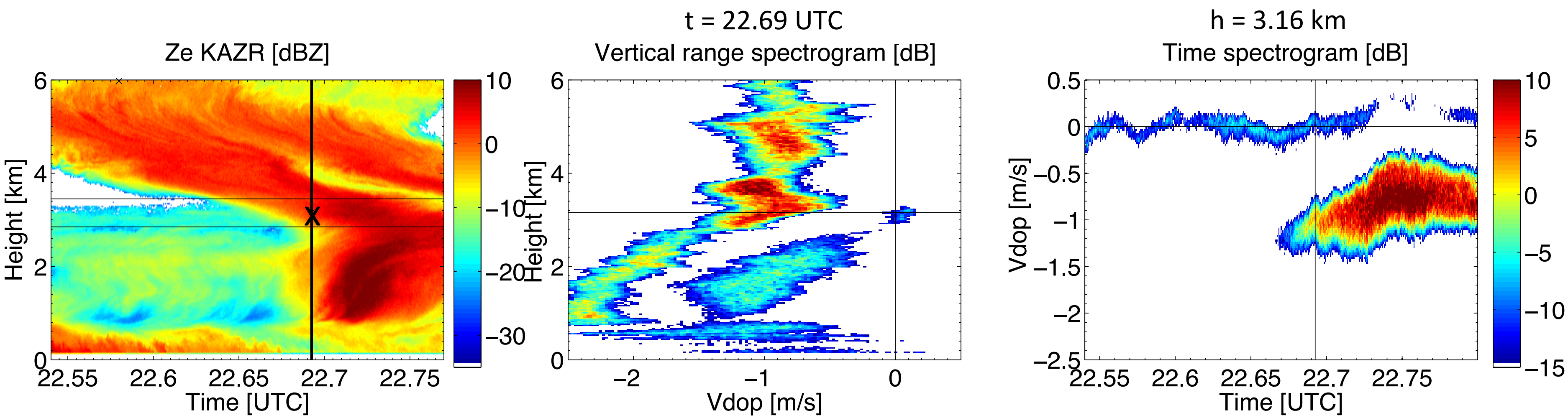


$$\frac{dz}{dt_{rad}} = \frac{v_{dop}(z) \cdot u(z_{gen})}{u(z) - u(z_{gen})}$$

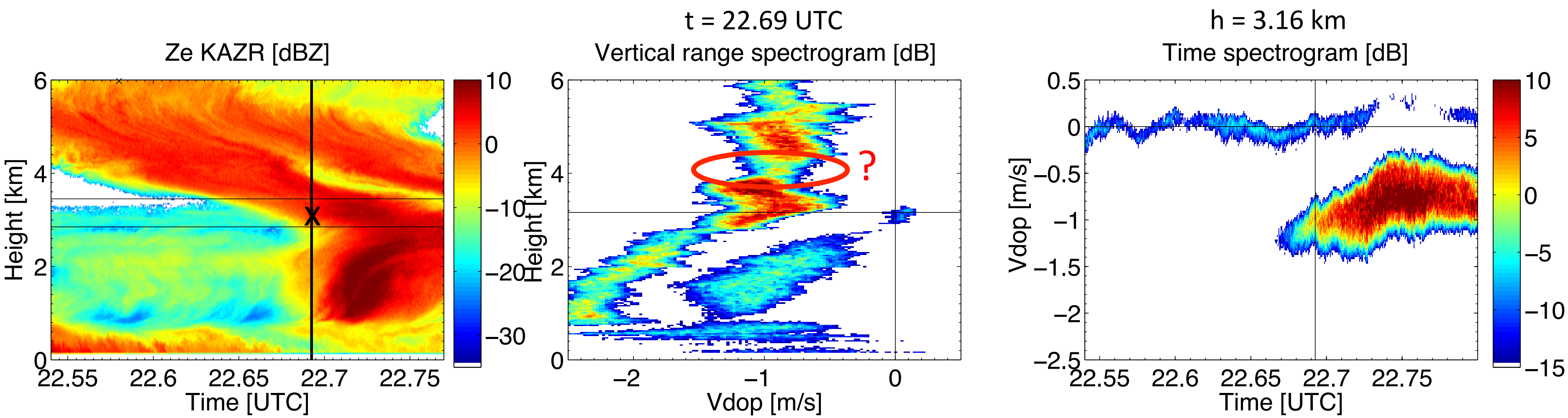
Marshall, 1953; Marshall & Gunn, 1954

t_{rad} : Radar time (x-axis in vpt. mode)
$v_{dop}(z)$: Doppler velocity of the particle(s)
$u(z)$: Horizontal wind
$u(z_{gen})$: Horizontal wind at generating level z_{gen}

Vertical vs slanted Doppler spectrum profiles – an example



Vertical vs slanted Doppler spectrum profiles – an example



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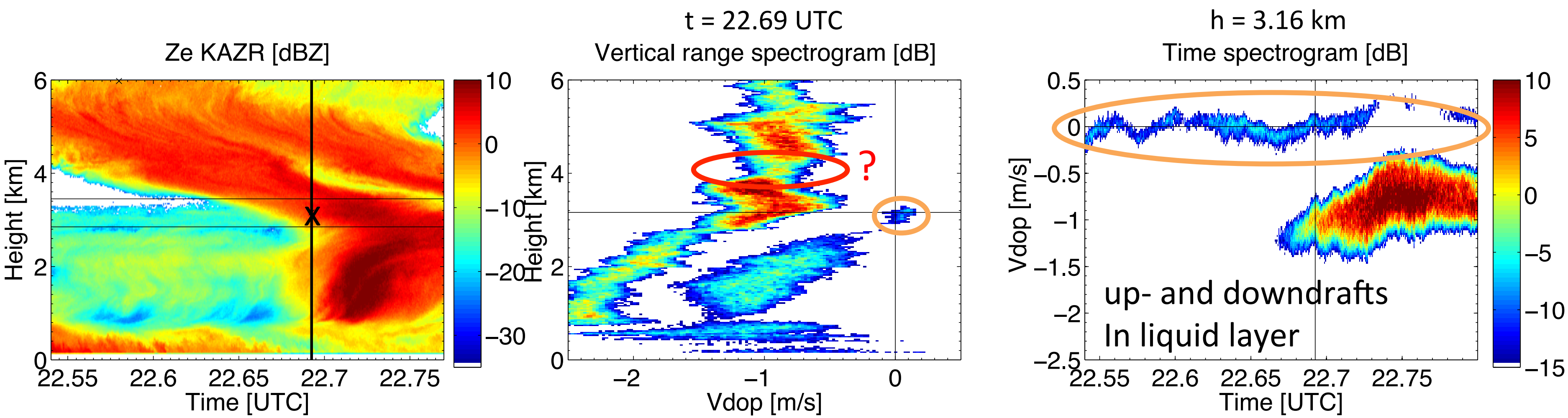

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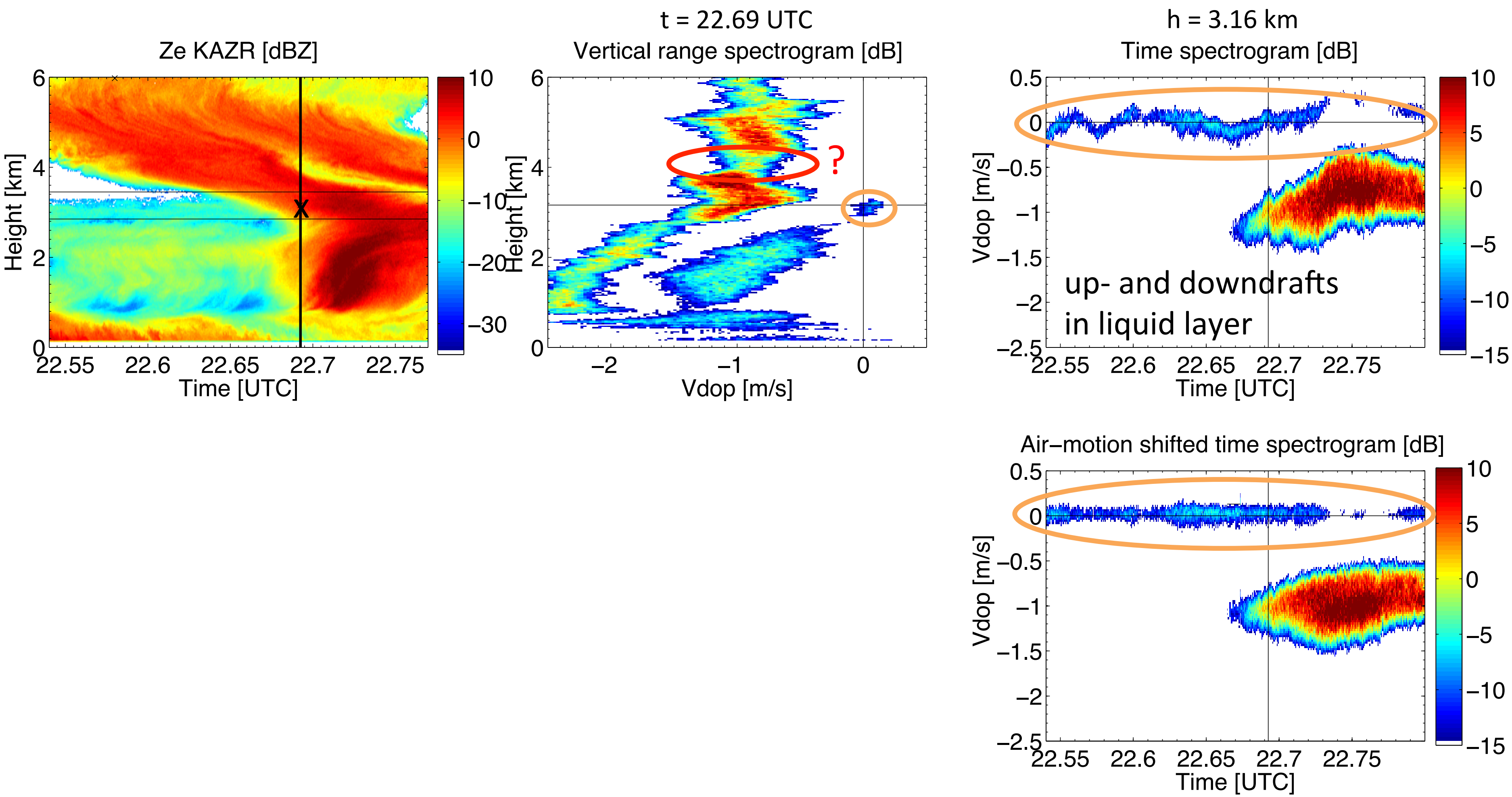

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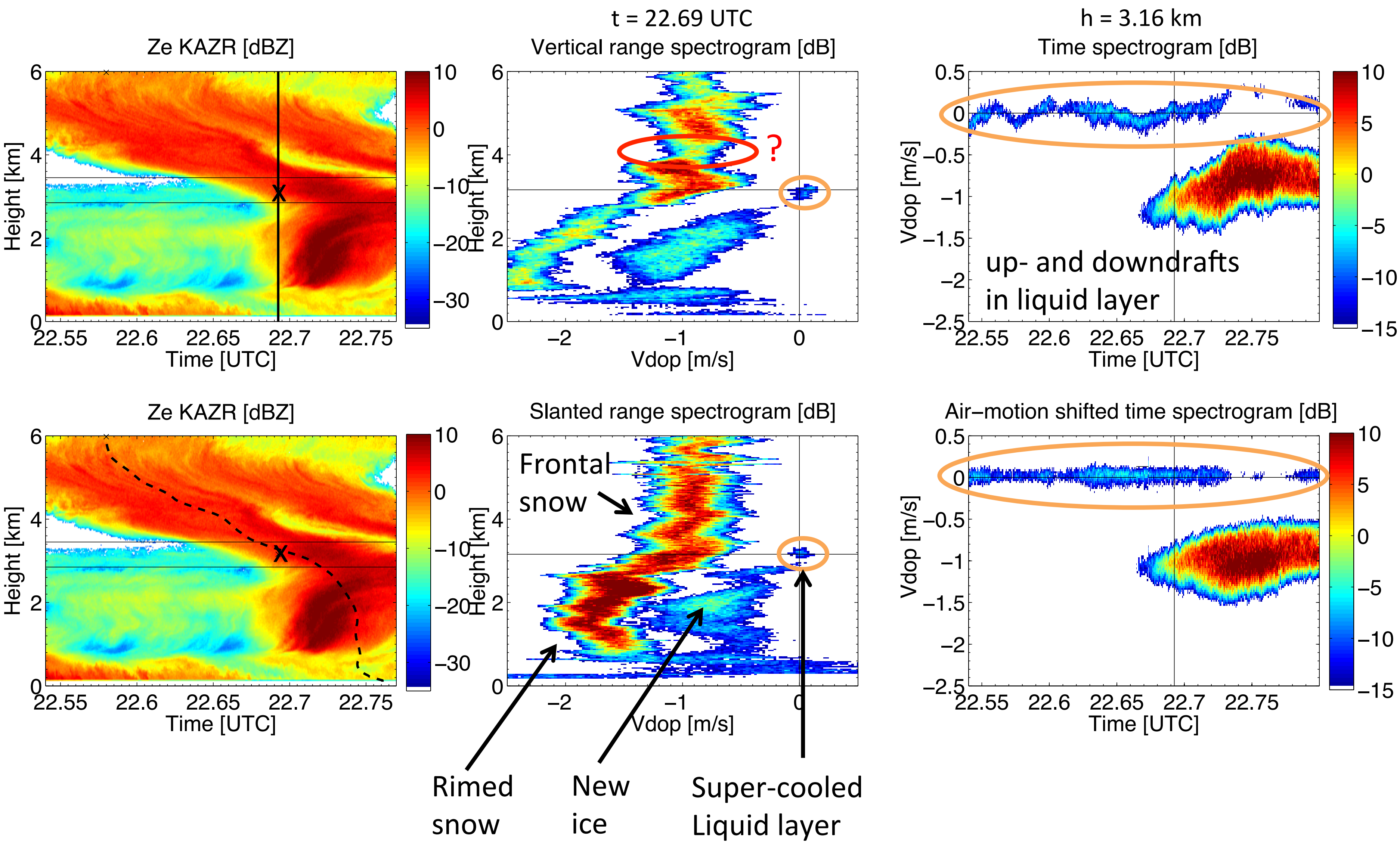

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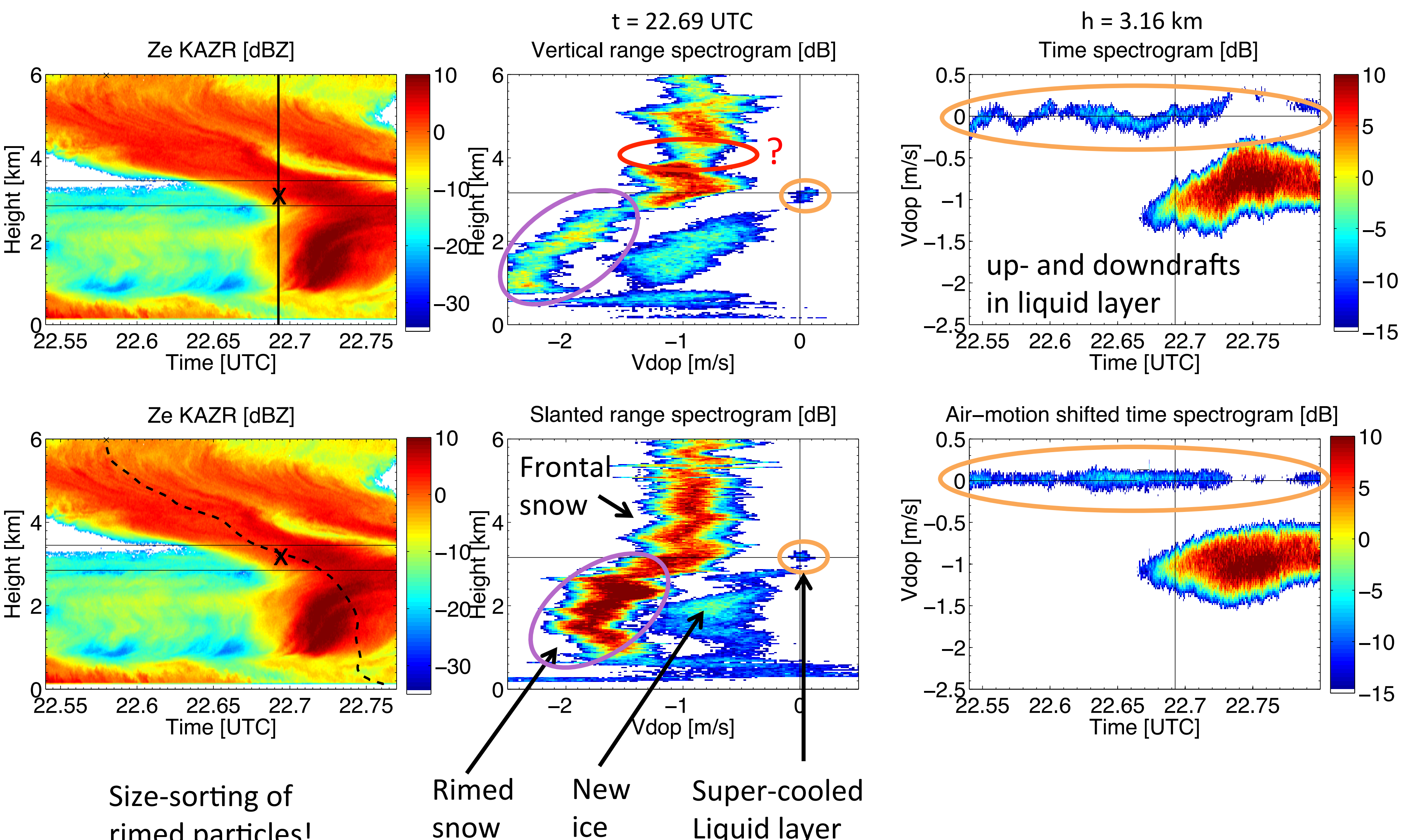
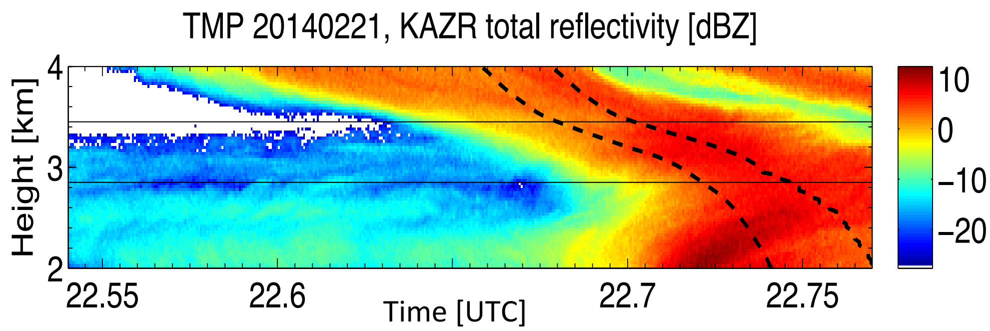
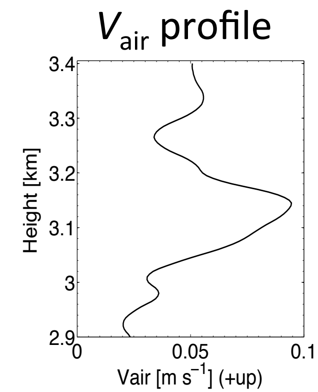
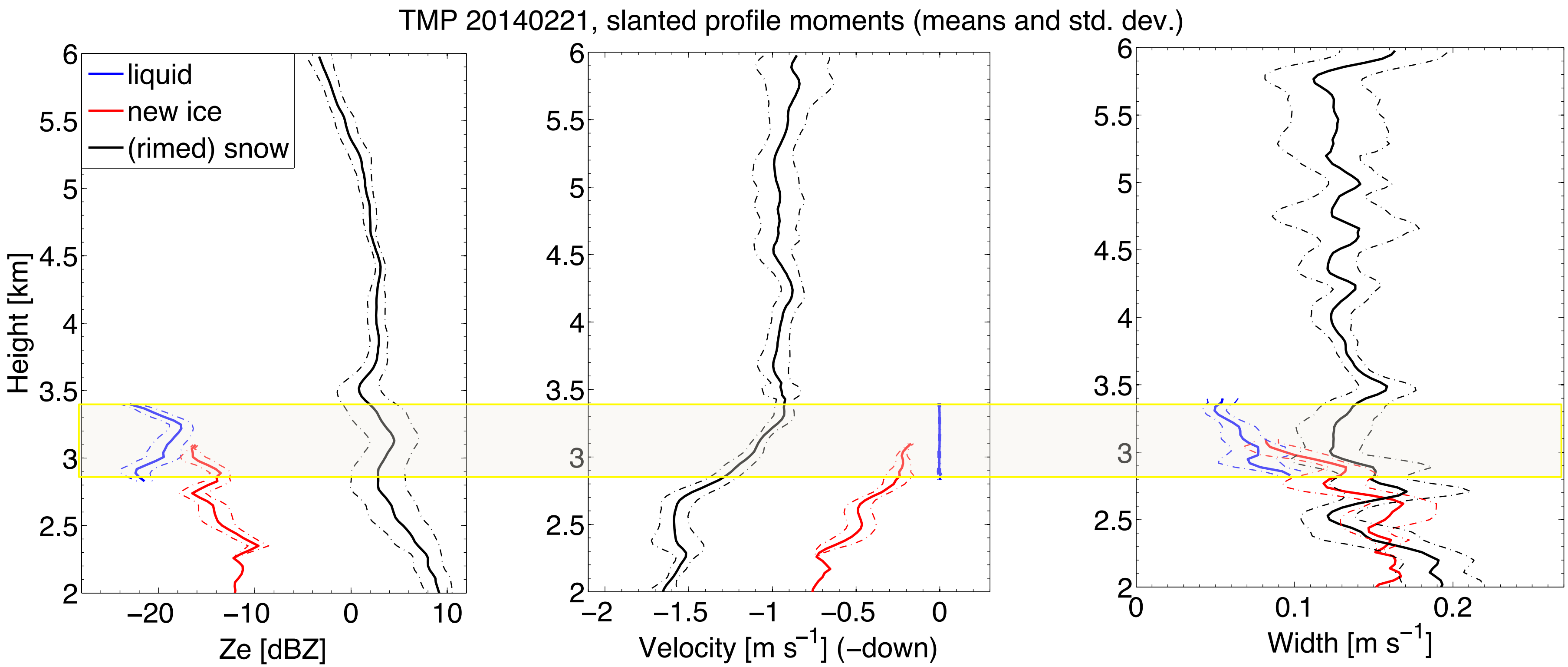


Size-sorting of
rimed particles!

Slanted profiles of moments of noise-separated peaks







Microphysical bin modelling

- Steady state 1D model employing spectral ice/snow microphysics
- Input: vertical profile of T, RH, p, V_{air}, liquid mode PSD*; at top of model: PSD* for snow
  (* resulting in radar moments comparable with obs.)
- Explicitly described microphysical processes: deposition, aggregation, riming
- Shown below: different parameterizations of riming efficiency and evolution of area ratio
- Backscattering: Mie spheres with non-uniform mass distribution (Fabry and Szyrmer 1999)

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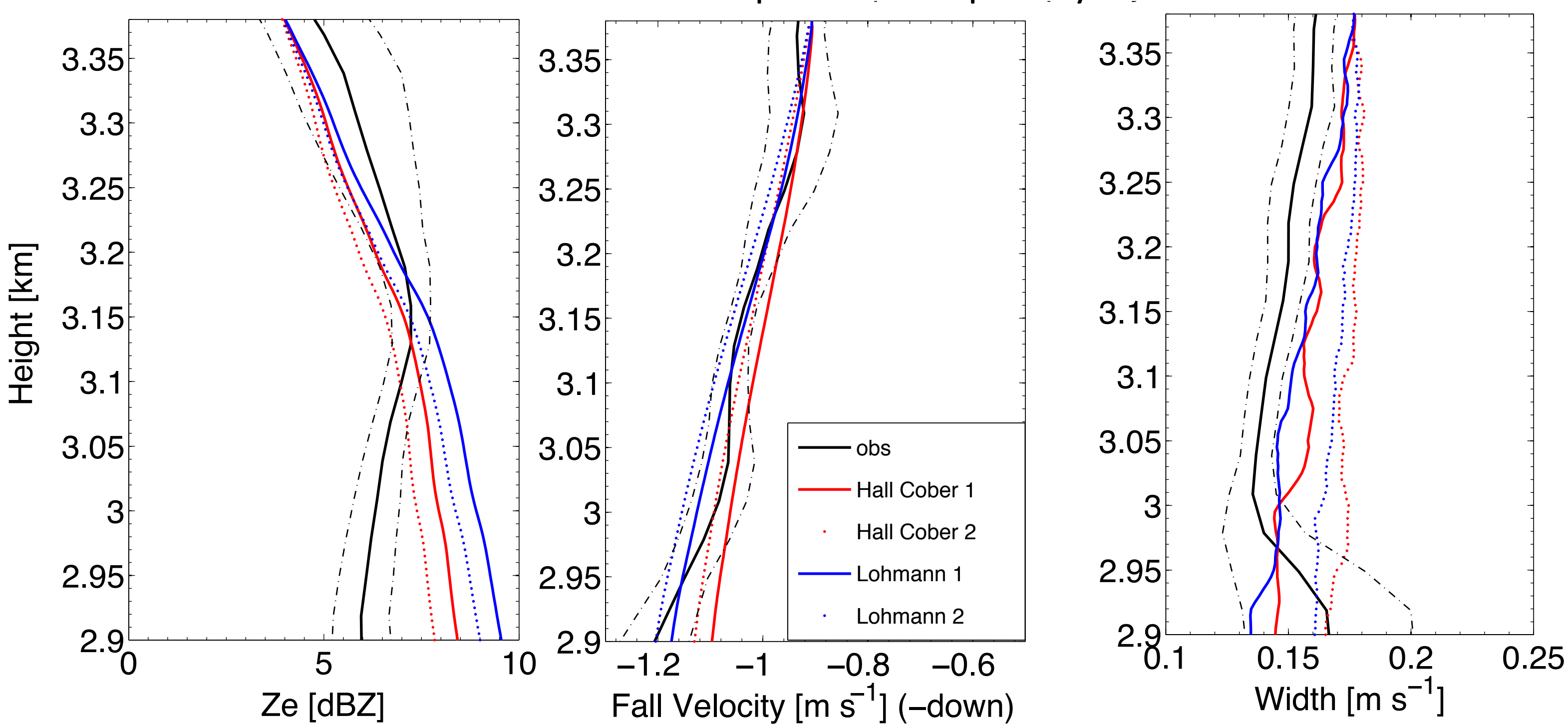
Rimed snow mode profiles in liquid layer



Conclusions and Outlook

- For microphysical process studies in mixed-phase clouds (riming, new ice formation, …) radar Doppler spectra observations offer much more info than cloud radar moments (i.e., Shupe et al., 2004; Luke et al., 2010; Verlinde et al., 2013; Yu et al., 2014)
- To get the story right, we need to pay attention to vertical wind shear and thus follow the evolution of radar Doppler spectra along slanted paths
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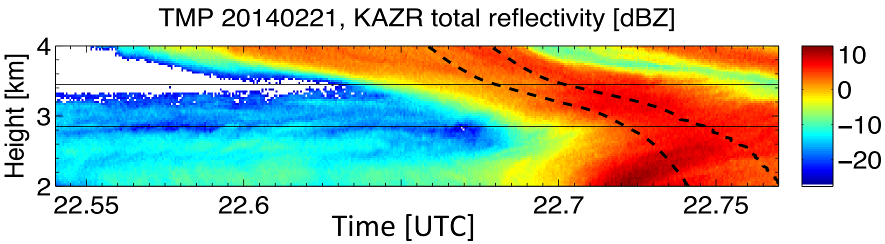
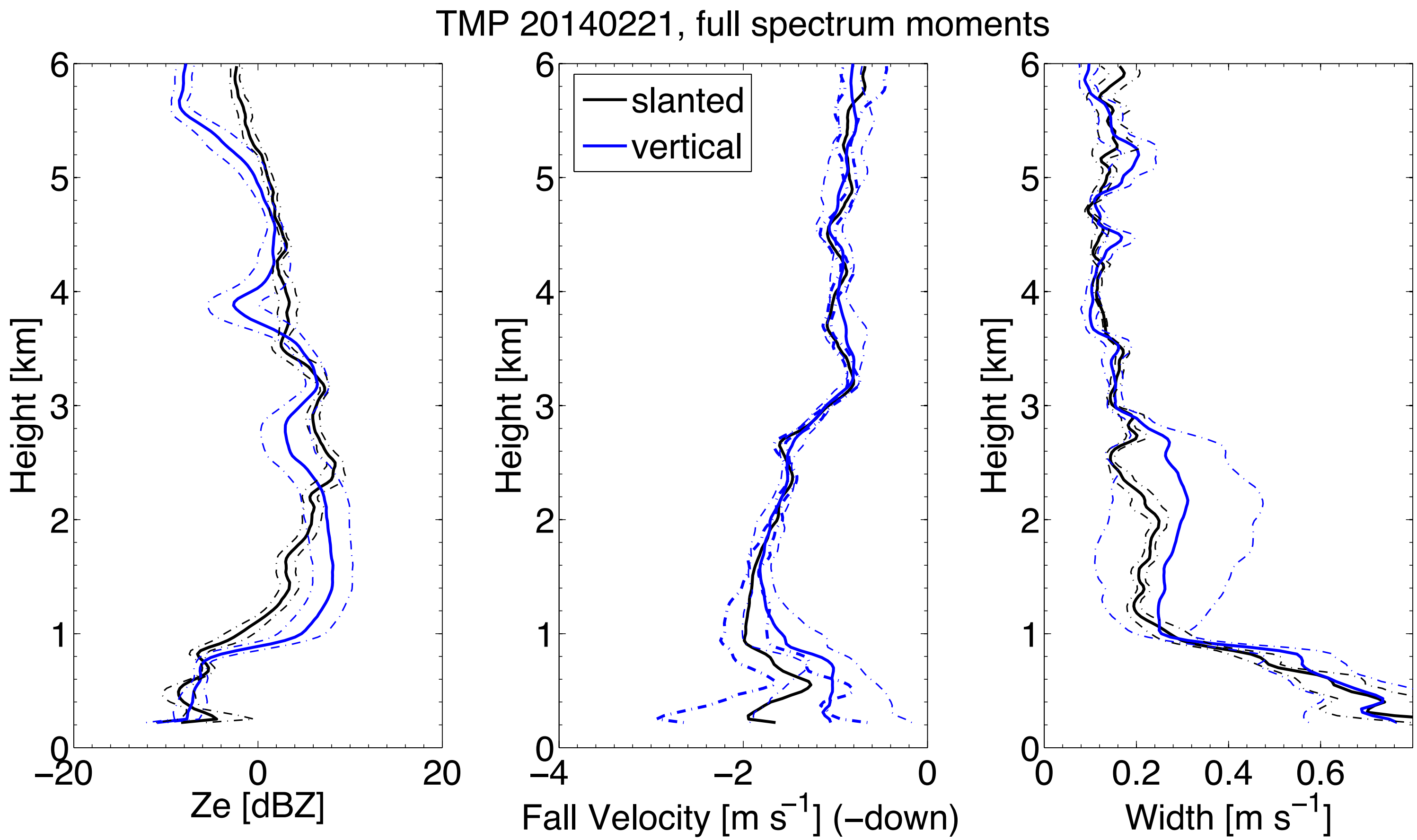
- Thanks
  - BAECC science team
  - For your attention

Come and see our poster this afternoon!

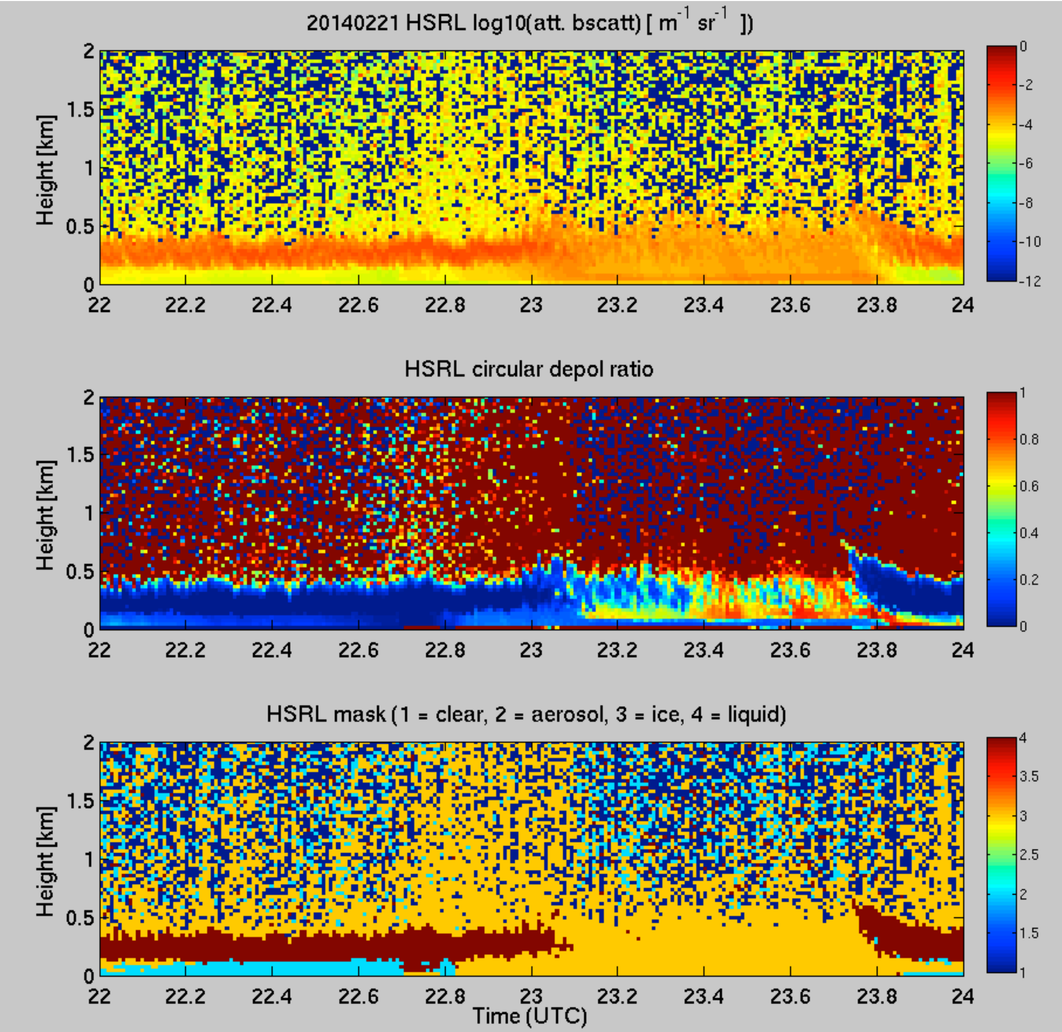
backup slides…

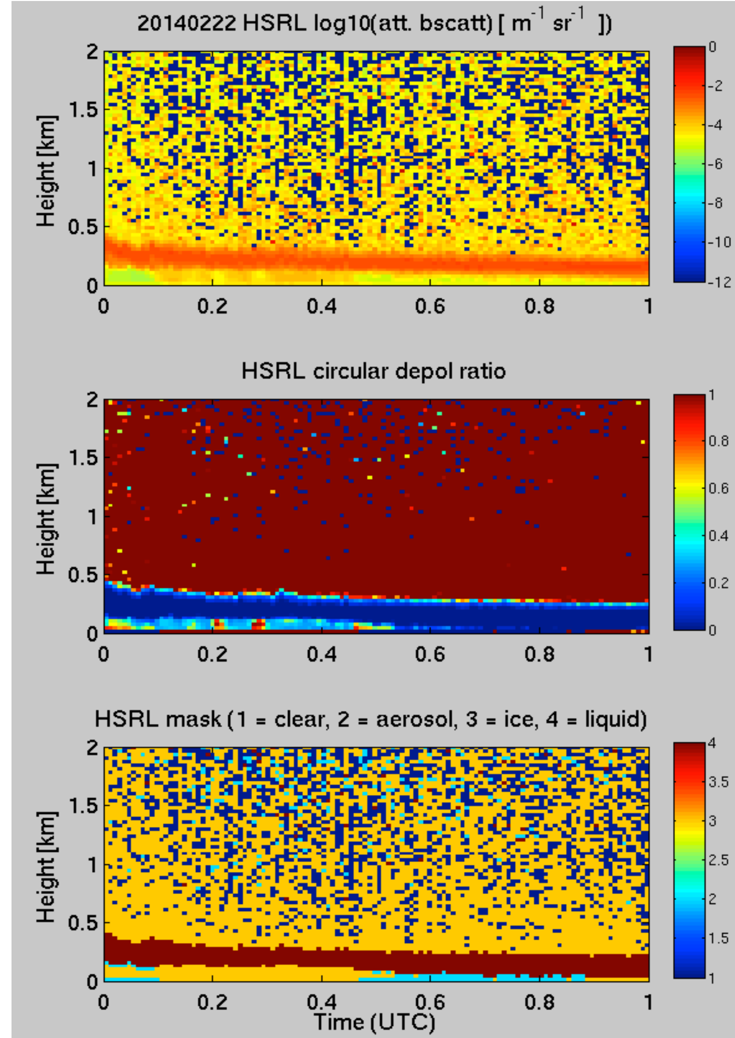
Averaged vertical vs slanted profiles





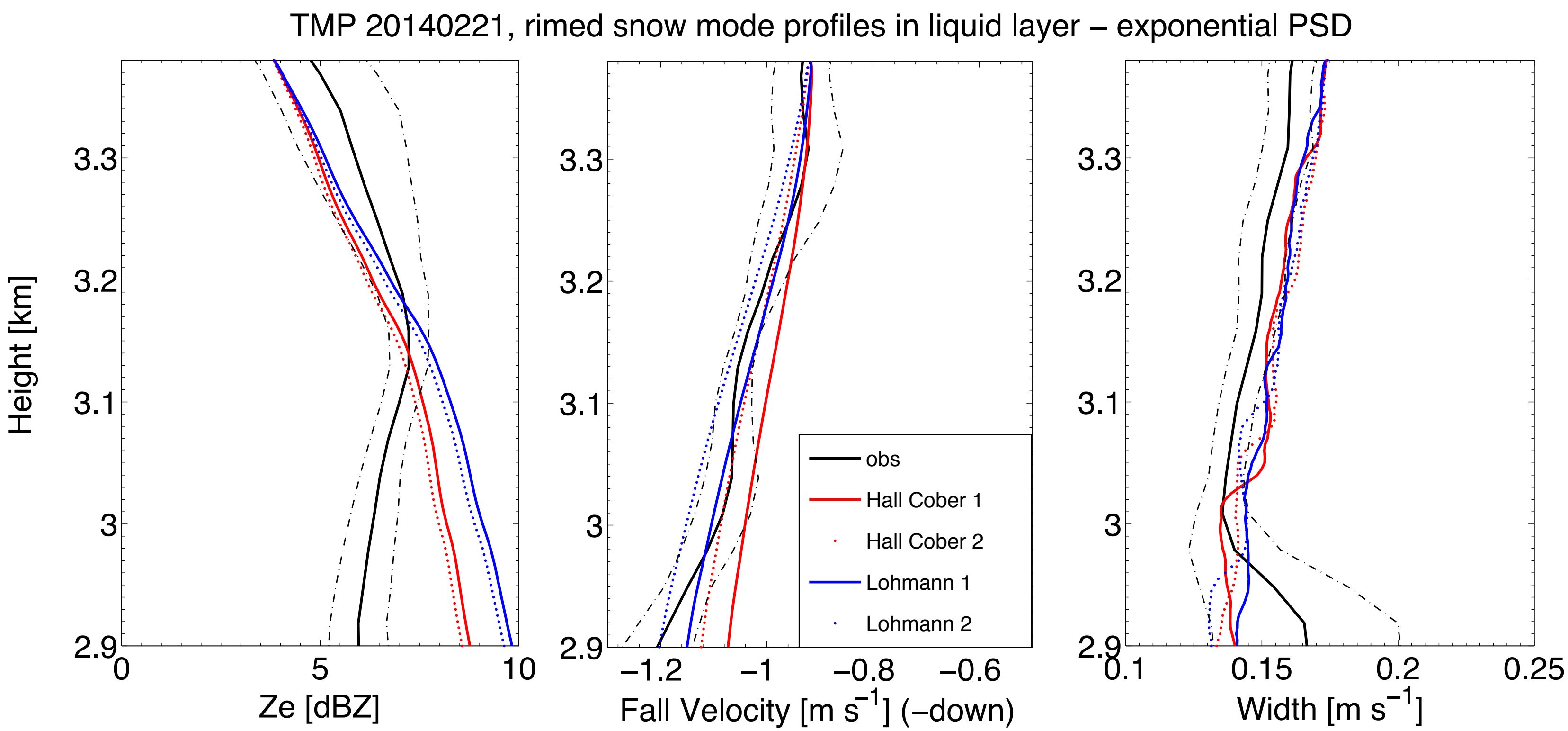
20140221-22 HSRL 22-01UTC





- HSRL: base of liquid layer ~0.13 km, fully extinguished < 0.4 km
- No distinguishable liquid layer 23.1-23.8 UTC – strong precipitation

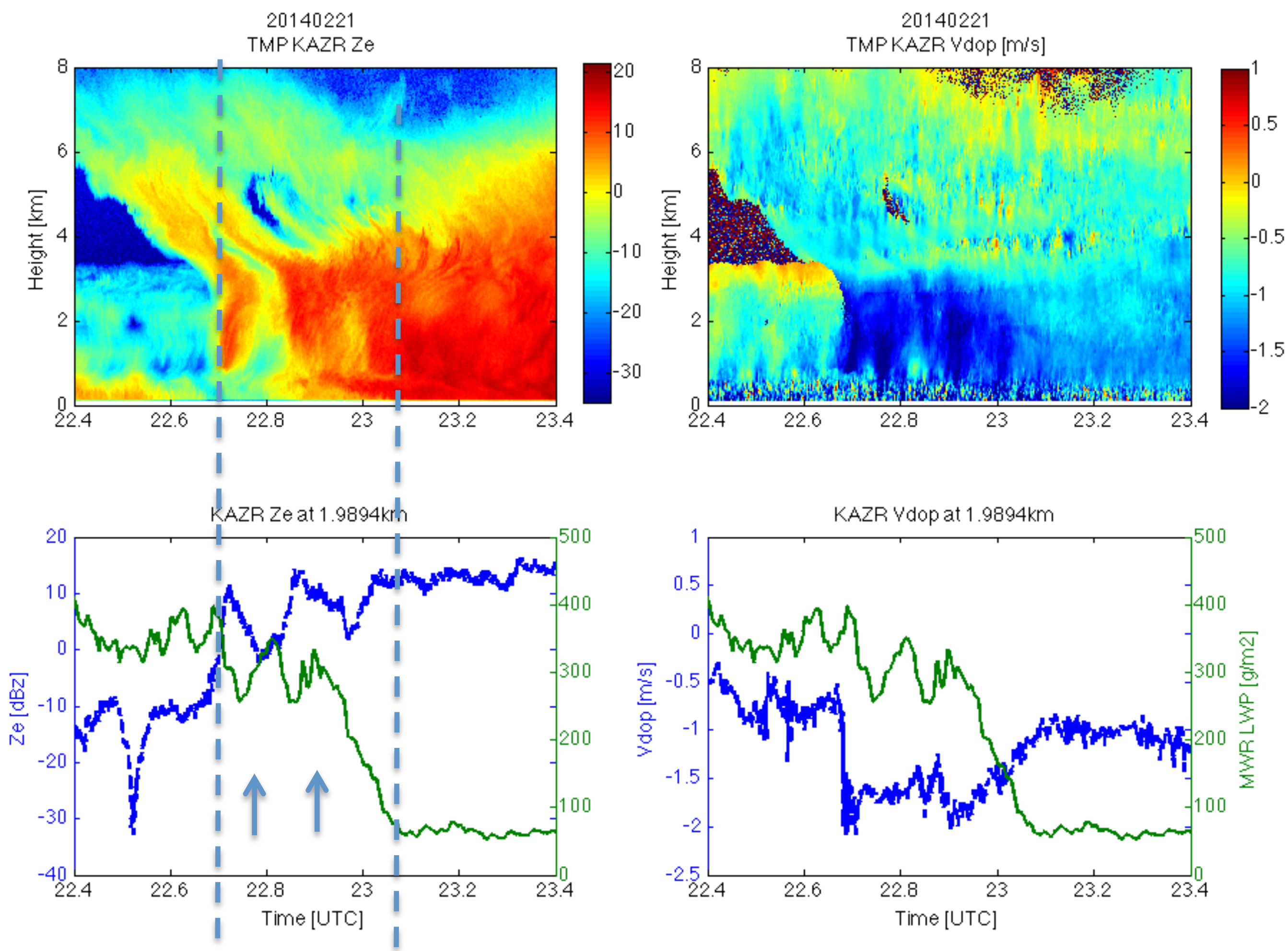
Microphysical bin modelling – Different PSD assumption



Assuming exponential PSD: no sensitivity in spectrum width

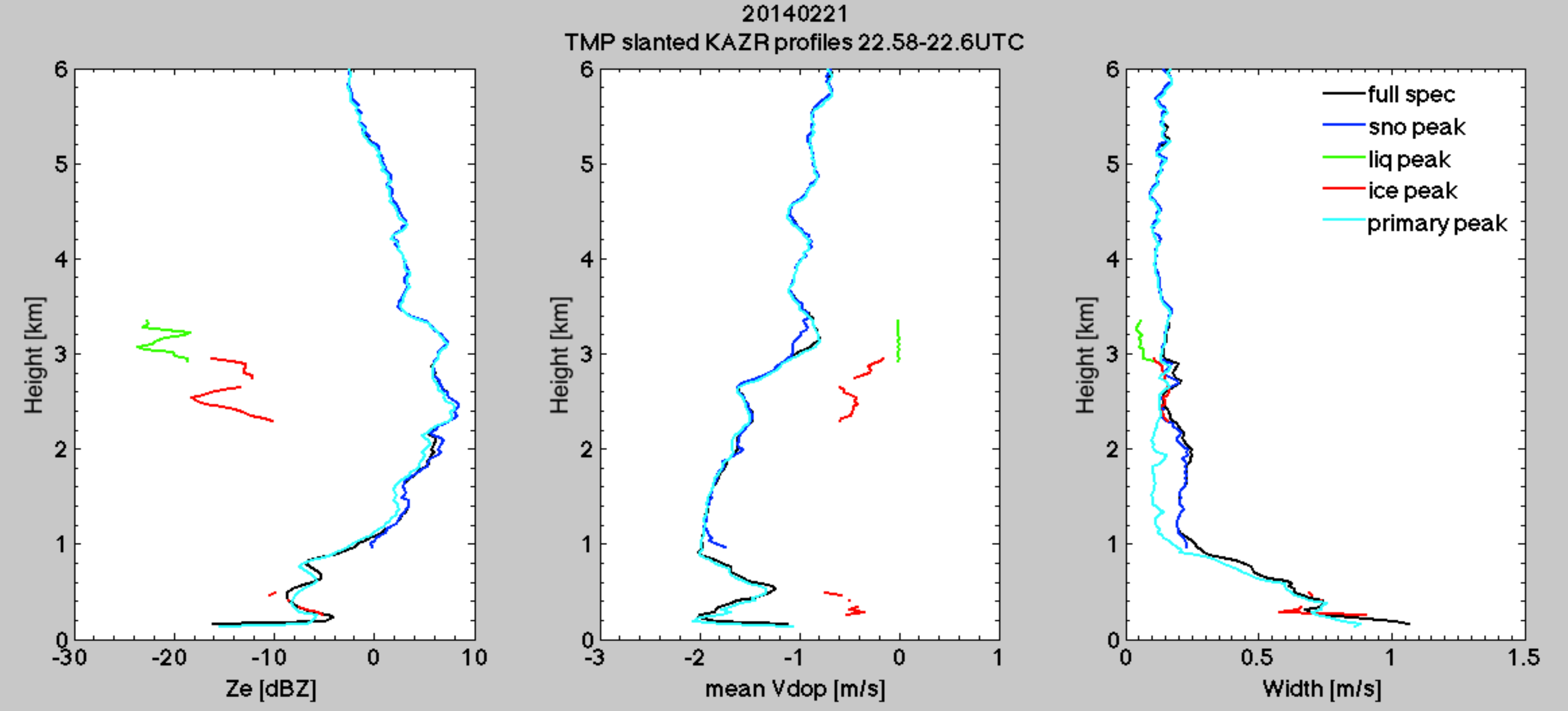
20140221 22-24 UTC, Correlation of KAZR-Ze, VDop and MWR-LWP?

- Check correlation between MWR-LWP and Ze or Vdop 2km



- Due to riming, LWP gets gradually depleted when front moves in, thus there is negative correlation between Ze and LWP between 22.6-23 UTC
- - fastest falling particles (-2 m/s) when fall streaks of front move in and riming takes place (high LWP), riming depletes the LWP, thus particles grow less (via aggregation) (and fall slower) after 23UTC when LWP is below 100 g/m2

mean+std of profiles (from consecutive peak determination)
(22.58-22.60UTC = 2nd part of fall streak)
comparison full spec profiles with noise-separated liq+ice+snow+primary peak profiles



- Ze: full spectrum mean and primary peak and sno peak mean are identical
- Vdop: : full spectrum mean and primary peak mean are identical
- Vdop: in liquid layer, Vdop_full > Vdop sno (correct) BUT when ice is present Vdop full = Vdop sno (why?)
- Width: at 1- 3.km full spectrum mean is much higher than primary peak mean (because several noise-separated peaks (liq+ice+sno) are included in the full spectrum width determination but NOT in the primary peak width

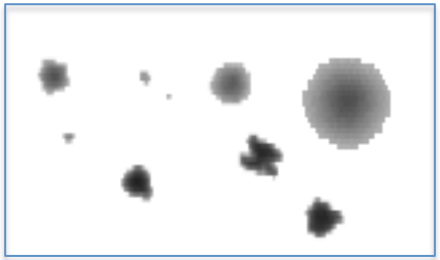
20140221 photos from PIP movies*

22:20-22:30 UTC movies (b4 front)
- Smaller roundish ice particles
- Very few small dendrites

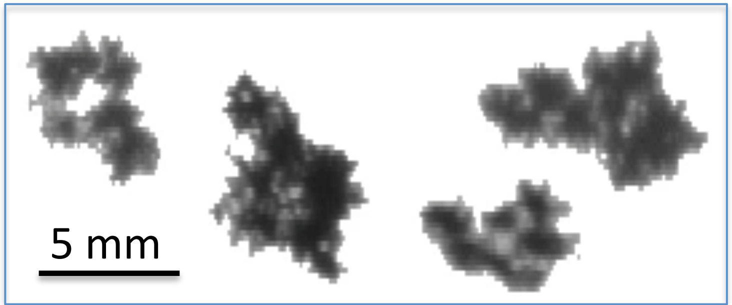
22:40-22:45 UTC movies (start of front moving in)
- Big dendrites (oriented, slower)
- Small aggregates (?, faster)
- Particles often out of focus, impossible to tell shape!

22:48-22:50 UTC movies (in front moving in, riming!)
- small dendrites (horizontally oriented, slower)
- Rimed roundish particles
- Particles often out of focus, impossible to tell shape!

23:00 UTC movies (within frontal system)
- Big dendrites (oriented, slower, sometimes tumbling)
- Roundish aggregates (?, faster)
- Tiny ice particles



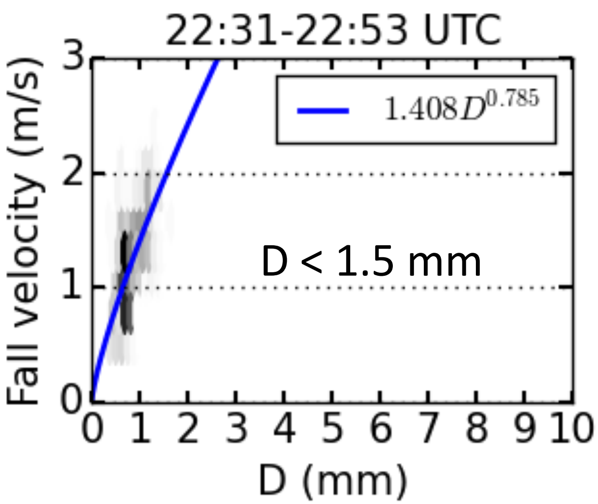
23:12 UTC movies (high Ka-X-DWR)
- Large fluffy aggregates (sometimes chain-like)

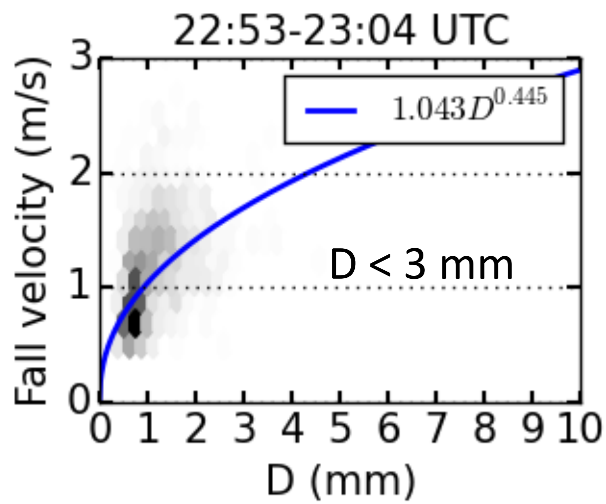


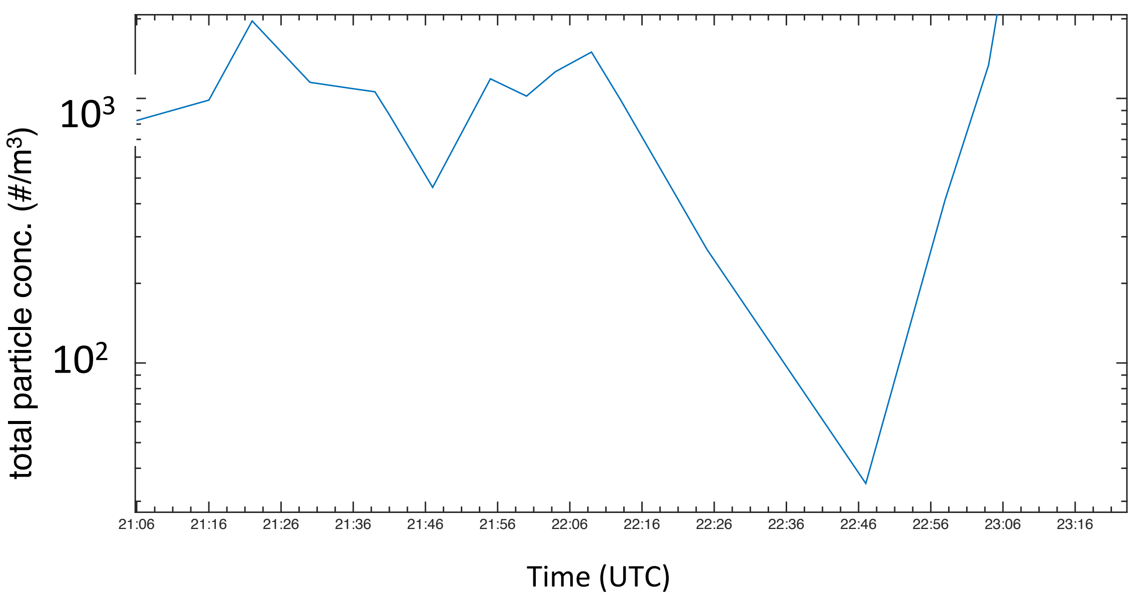
*: screenshots of individual particles without zooming

20140221 in-situ data (D. Moisseev)

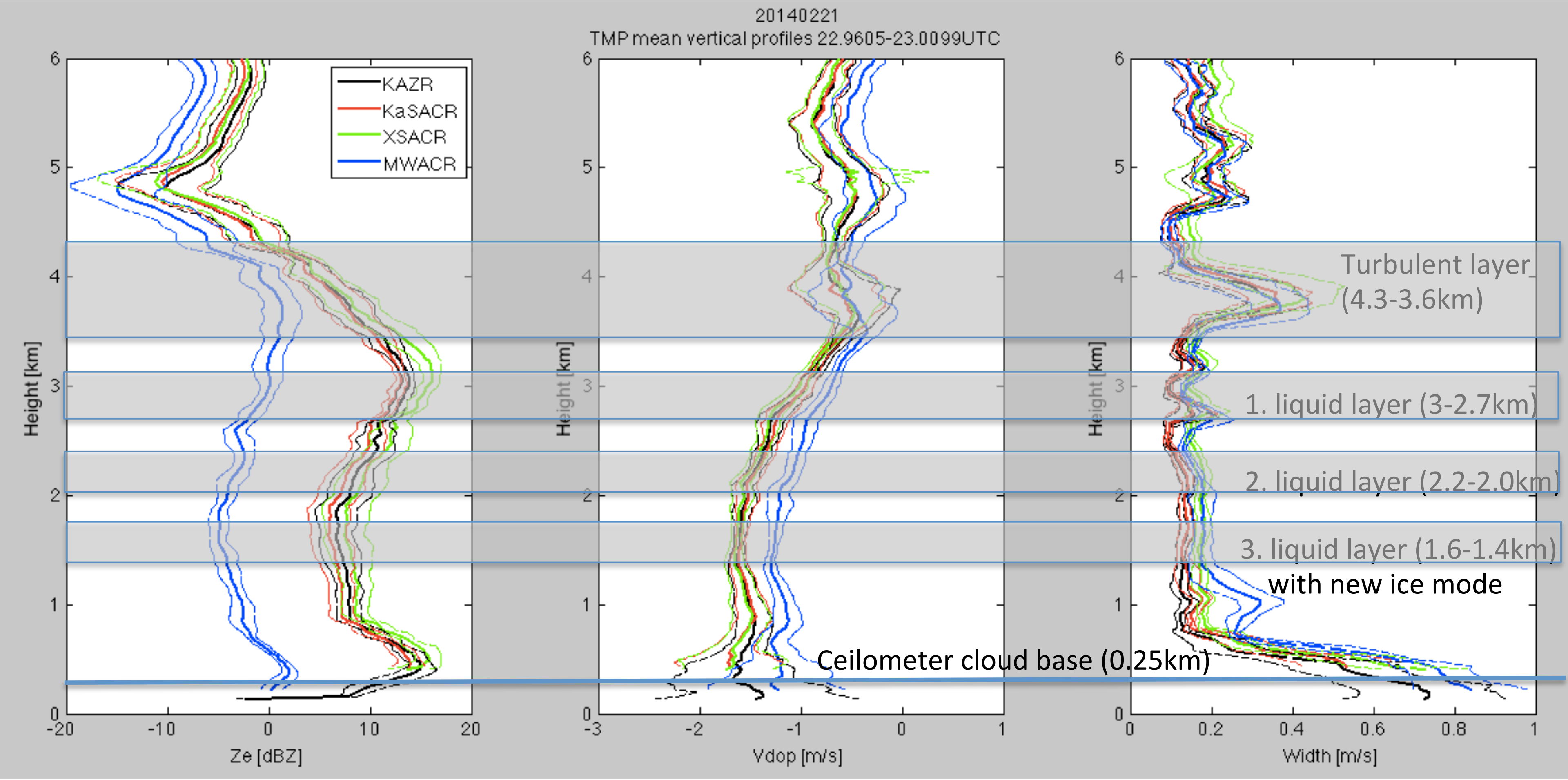
- PIP = NASA Particle Imaging Package
- Fall velocity-size relations:







20140221, 22.96-23.01 UTC: radar moment profiles (3min means + std)



MWACR is mispointing

Table taken from BAECC_ARM_Cloud_Radar_Operations_v2.docx

7 Radar configuration

The radars will be configured to maximize performance for multi-frequency retrieval in vertical mode. The configuration is summarized in the tables below.

Table 1 Configuration for zenith pointing operations

Parameter	KAZR	MWACR	Ka-SACR	X-SACR
Waveform	Pulse compression, short	Short	Short	Short
Pulse width (ns)	4000, 333	333	333	333
PRF (Hz)	2820	7690	2870	768.13
Nyquist velocity (m/s)	6	6	6	6
Range (km)	15	15	15	15
Gate spacing (m)	25-30	25-30	25-30	25-30
FFT length	512	512	512	512
Window	Hann	Hann	Hann	Hann
Spectral average	11	30	11	3
Dwell time (s)	2	2	2	2
Range resolution (m)	60, 50	50	50	50
Doppler resolution (cm/s)	2.37	2.37	2.37	2.37
Sensitivity at 2 km (dBz); single pulse	-29, -13		-25	-12
Beamwidth (°):	0.2	0.38	0.19	1.27