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DFG

SPP 2115

Project overview:

CHARACTERIZATION OF OROGRAPHY-INFLUENCED RIMING AND SECONDARY ICE PRODUCTION AND THEIR EFFECTS ON PRECIPITATION RATES USING RADAR POLARIMETRY AND DOPPLER SPECTRA (CORSIPP)

Veronika Ettrichrätz (Post Doc)

Anton Kötsche (PhD)

PI: Heike Kalesse-Los, Max Maahn

GENERAL QUESTION

What processes affect snowfall formation and snowfall rates in orographically influenced terrain and what are their external drivers?

Why?:

Research Gap:

- ➢Only sparse observations at remote mountaineous regions
- ➢Which processes dominate, what is the impact on precipitation rates, what are external drivers in complex terrain is poorly understood

THE CORSIPP CAMPAIGN (15.11.2022 – 06.06.2023)

SPP 2115

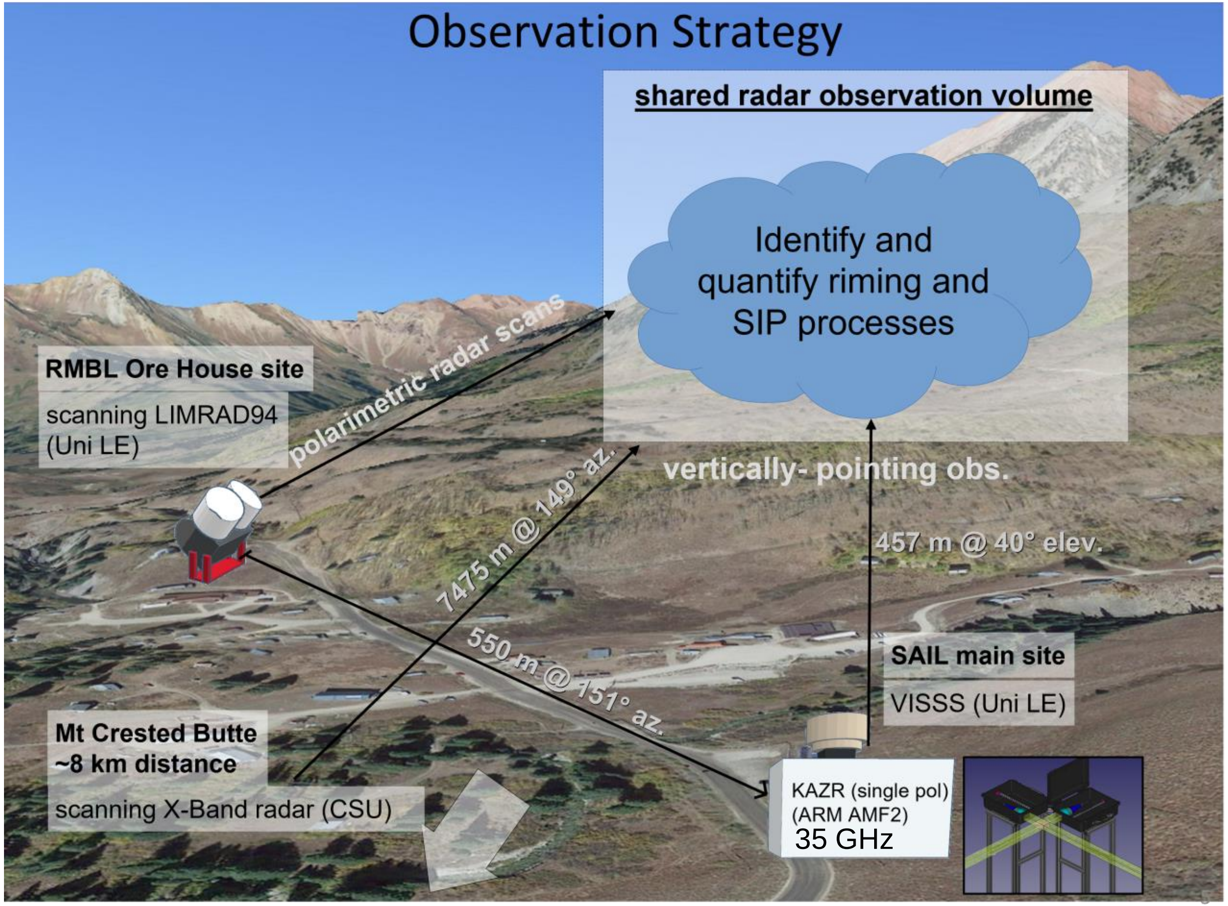
94 GHz Dual-Pol W-Band Cloud Radar LIMRAD94

Court: Ben Schmatz

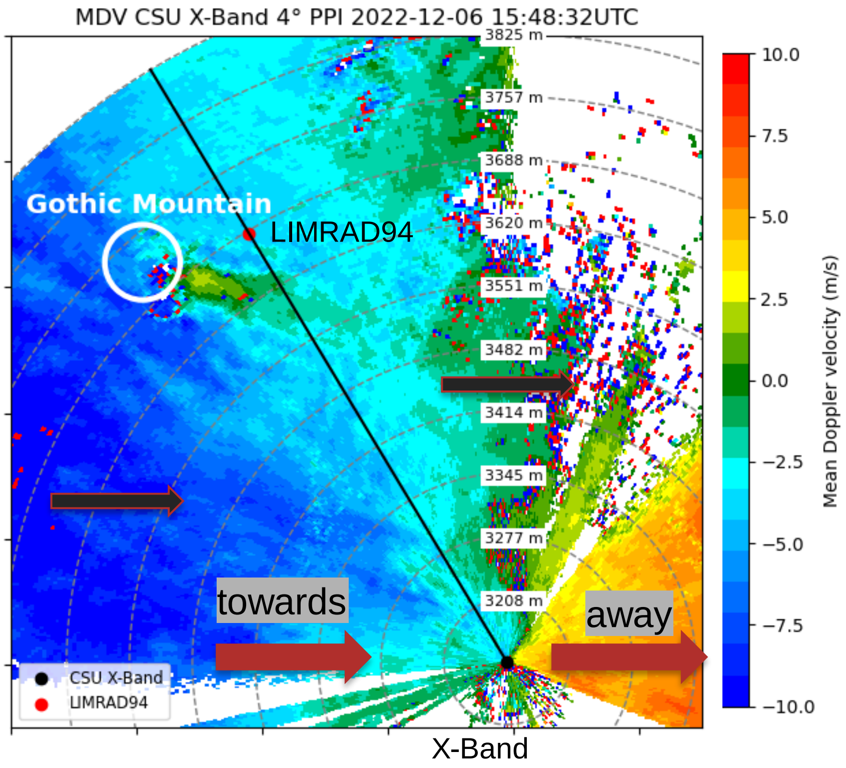
In-Situ Snowfall Camera VISSS

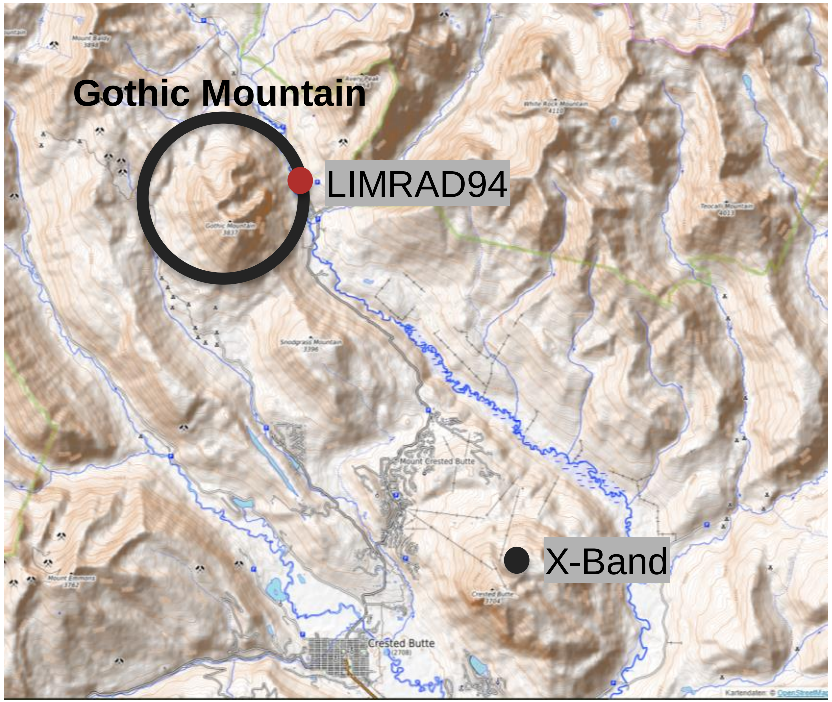
Court: Isabelle Steinke

Heike Kalesse-Los (PI), Maximilian Maahn (PI), Veronika Ettrichrätz (Postdoc), Anton Kötsche (PhD Student)


Observation Strategy
shared radar observation volume
Identify and quantify riming and SIP processes
RMBL Ore House site
scanning LIMRAD94 (Uni LE)
polarimetric radar scans
vertically- pointing obs.
7475 m @ 149° az.
457 m @ 40° elev.
550 m @ 151° az.
SAIL main site
VISSS (Uni LE)
Mt Crested Butte ~8 km distance
scanning X-Band radar (CSU)
KAZR (single pol) (ARM AMF2)
35 GHz

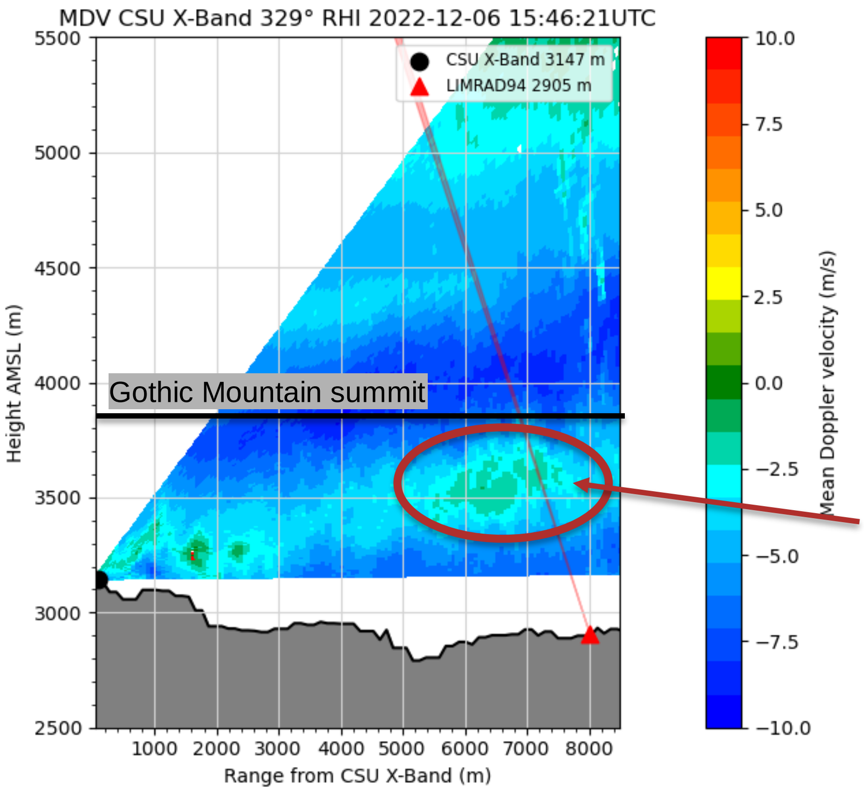
Turbulence on site during westerly flow





veronika.ettrichraetz@uni-leipzig.de | anton.koetsche@uni-leipzig.de

Turbulence on site in westerly flow



Area of lee induced flow disturbance (**ALIFD**)

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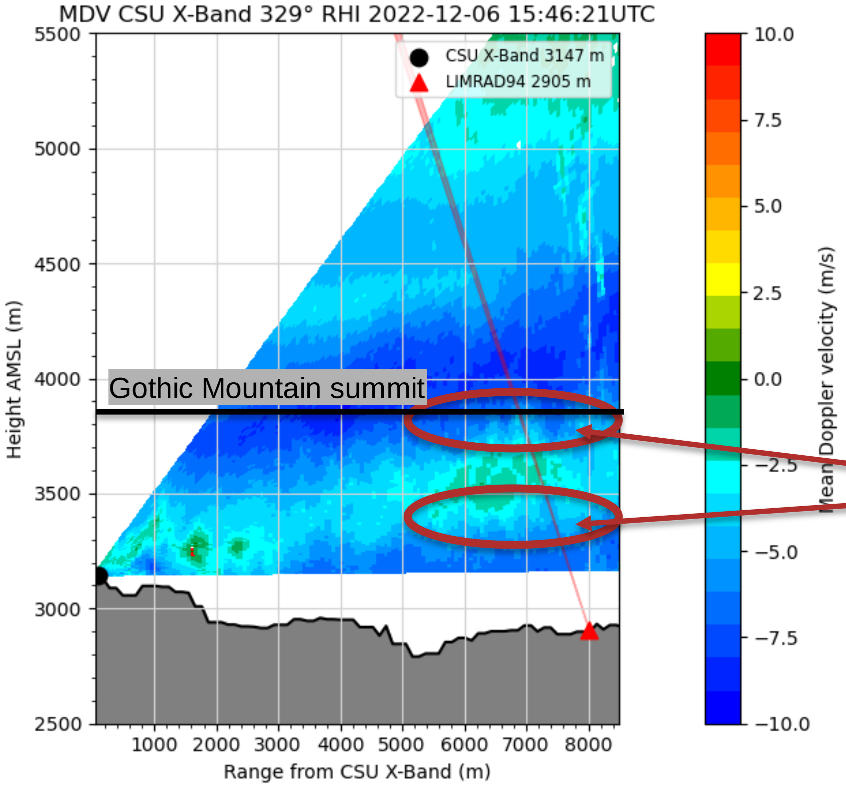
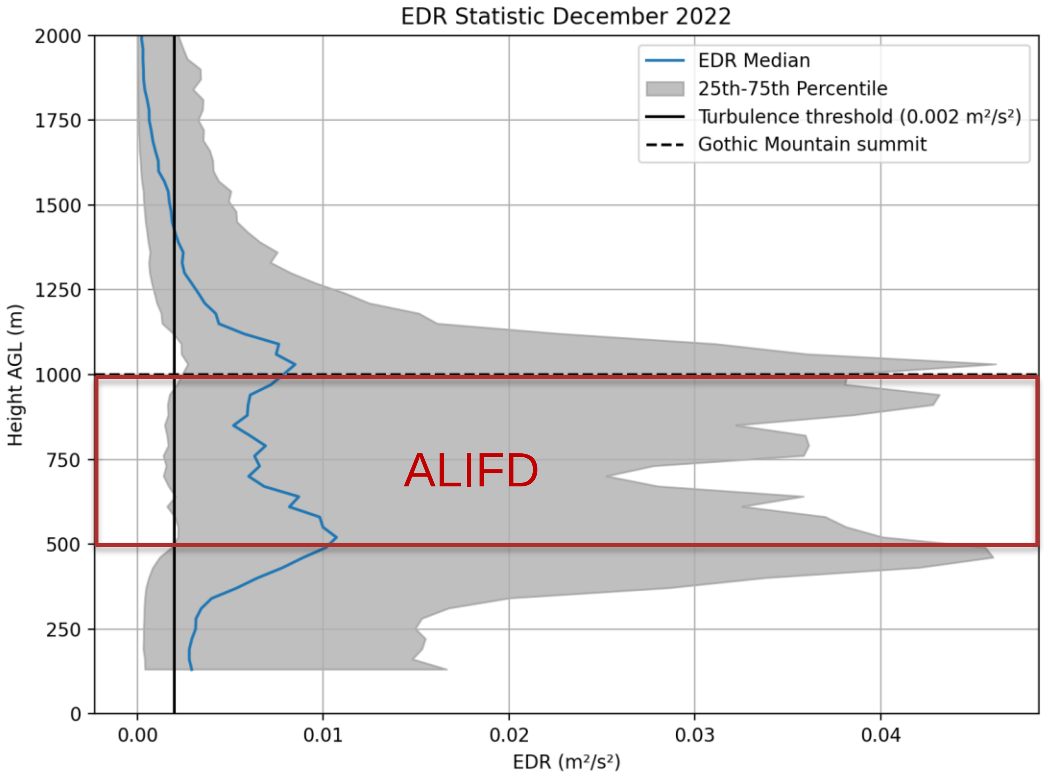
Turbulence on site in westerly flow



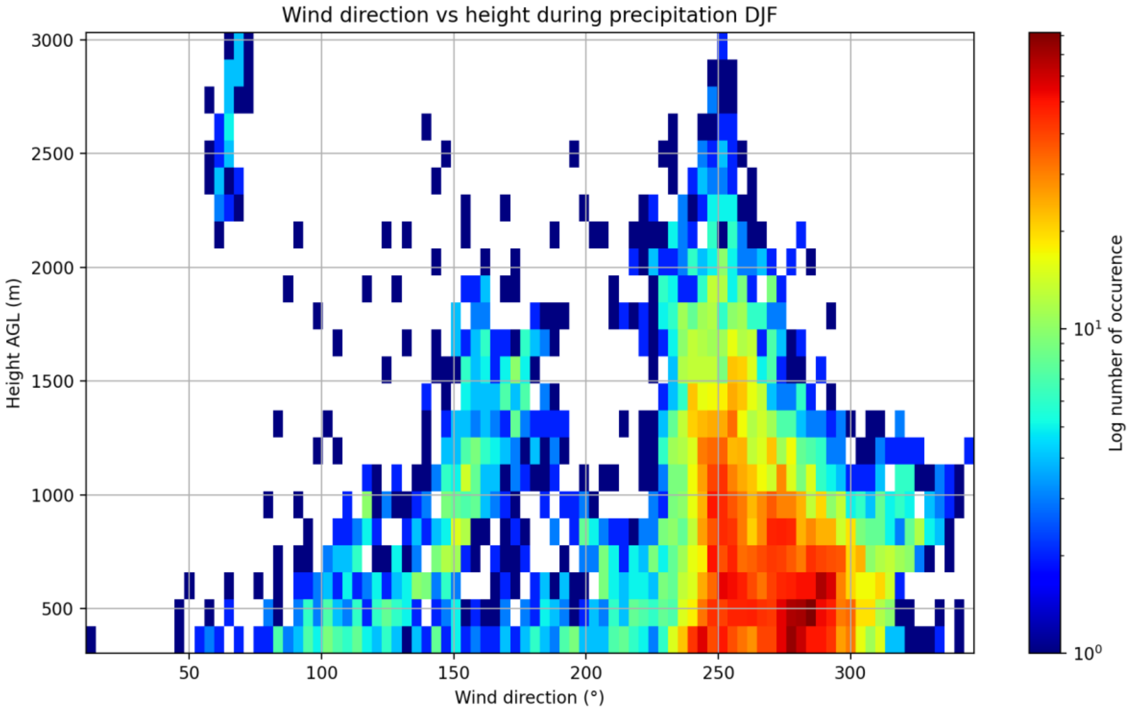
Enhanced wind shear along the edges of the ALIFD
(at around 500m and 1000m AGL)

Turbulence on site in westerlie flow



- Eddy dissipation rate **(EDR)** as proxy for turbulence
- rate at which turbulence kinetic energy dissipates in the atmosphere
- Processed by Teresa Vogl from KAZR MDV (Vogl et al., 2022)
- Empirical turbulence threshold of 0.002 m2/s3 exceeded almost all the time
- Two shear layers along the edges of the ALIFD at 500 and 1000m

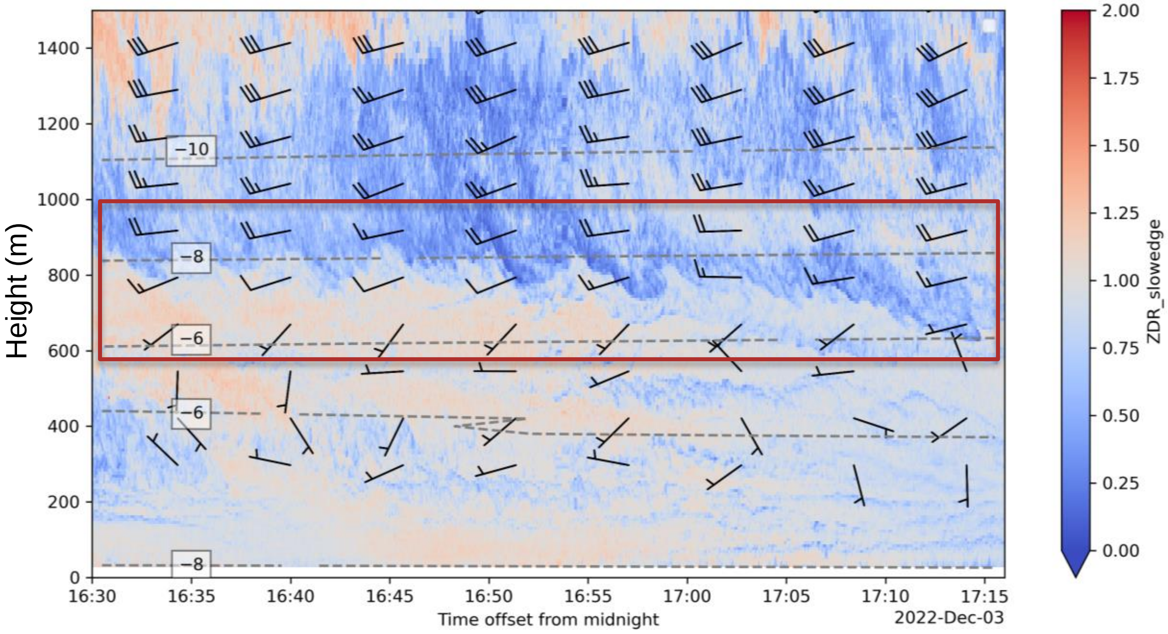
Main wind direction on site DJF



- Main wind direction during precipitation events with >0.5 mm/h
- Mainly WSW-WNW

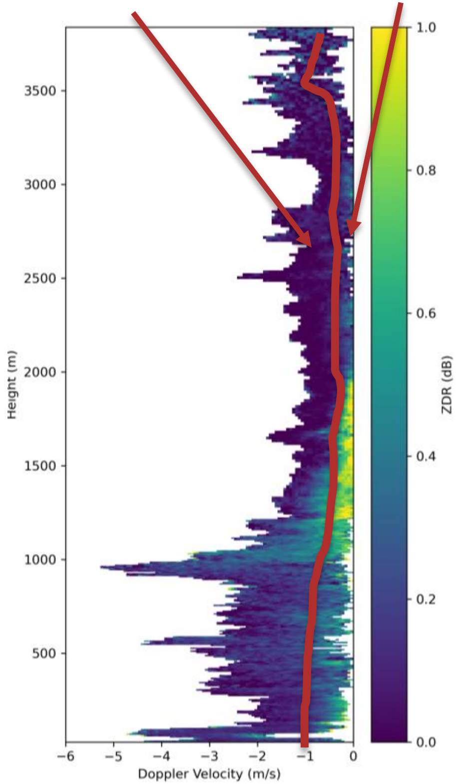
Helmholtz waves in spectral polarimetry

sZDR slow edge



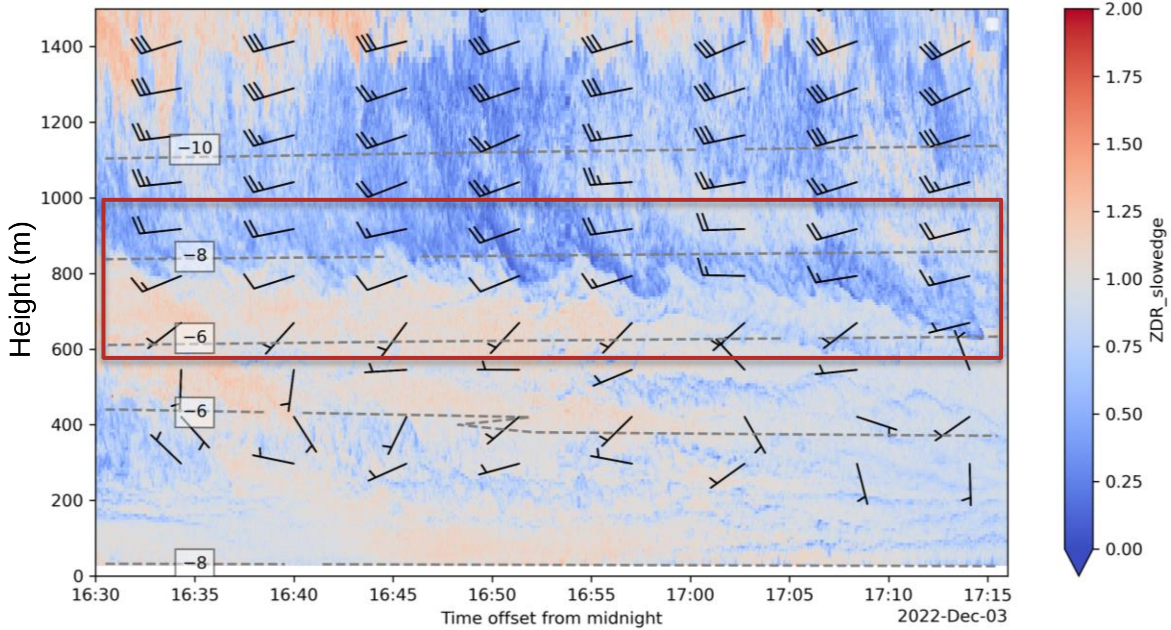
Fast two thirds

Slow third



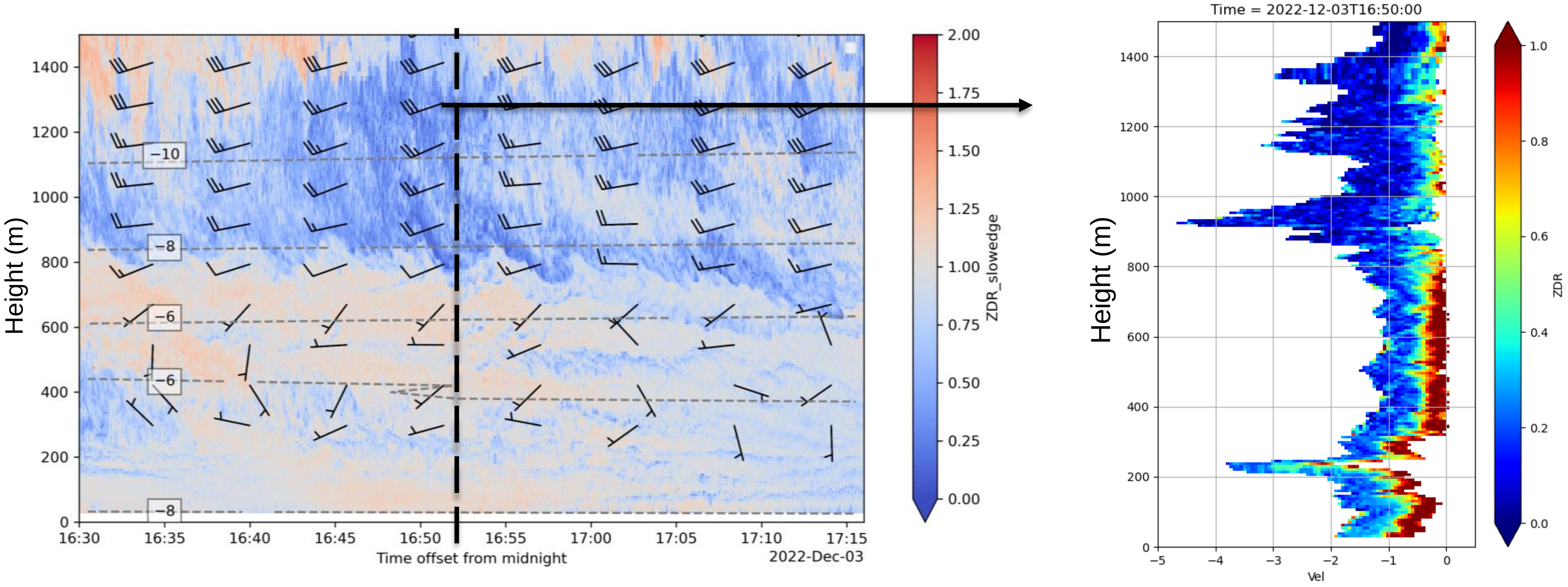
Helmholtz waves in spectral polarimetry

sZDR slow edge



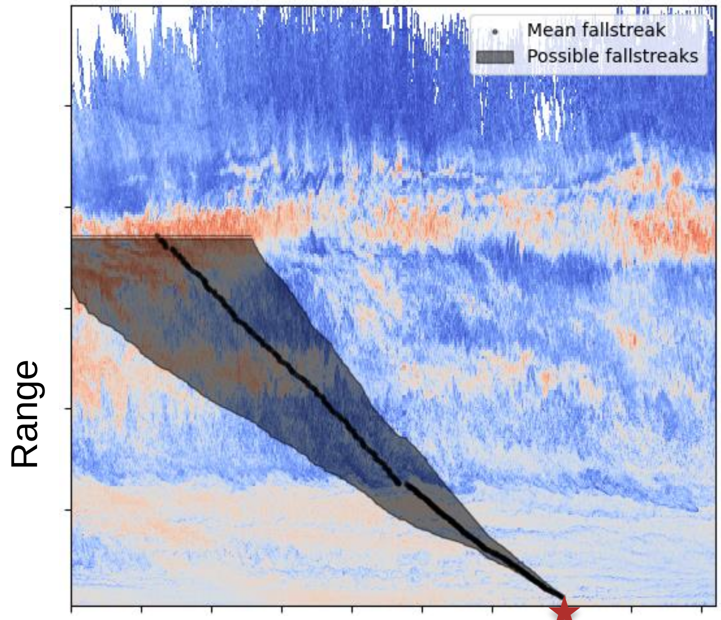
- Kelvin-Helmholtz waves along the shear layer between blocked valley flow and unblocked flow aloft
- Potentially interesting for SIP processes: Longer residence time, enh. Ice-ice collision, stronger riming/aggregation

Helmholtz waves in spectral polarimetry



PRECIP RATES AND SPECTRAL ZDR (sZDR) AND KDP

sZDR Slow Edge

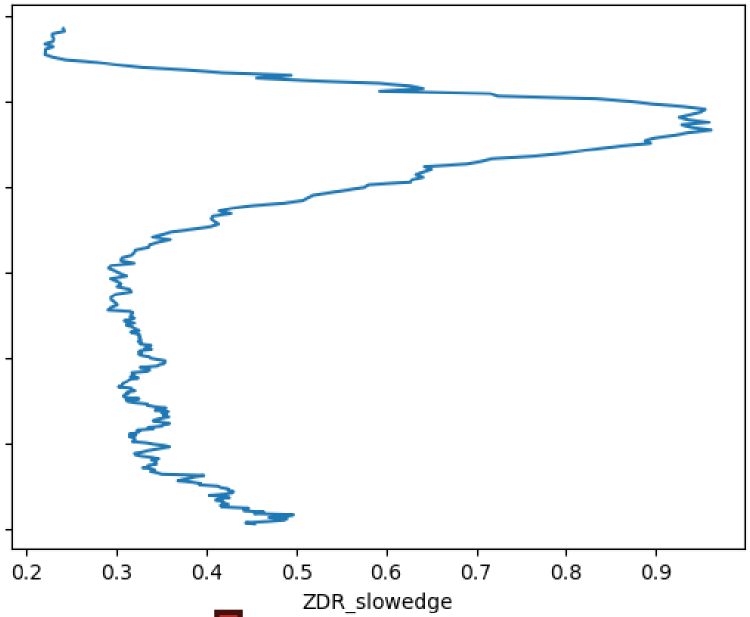


Precip. Rate on ground

Median of fallstreak region

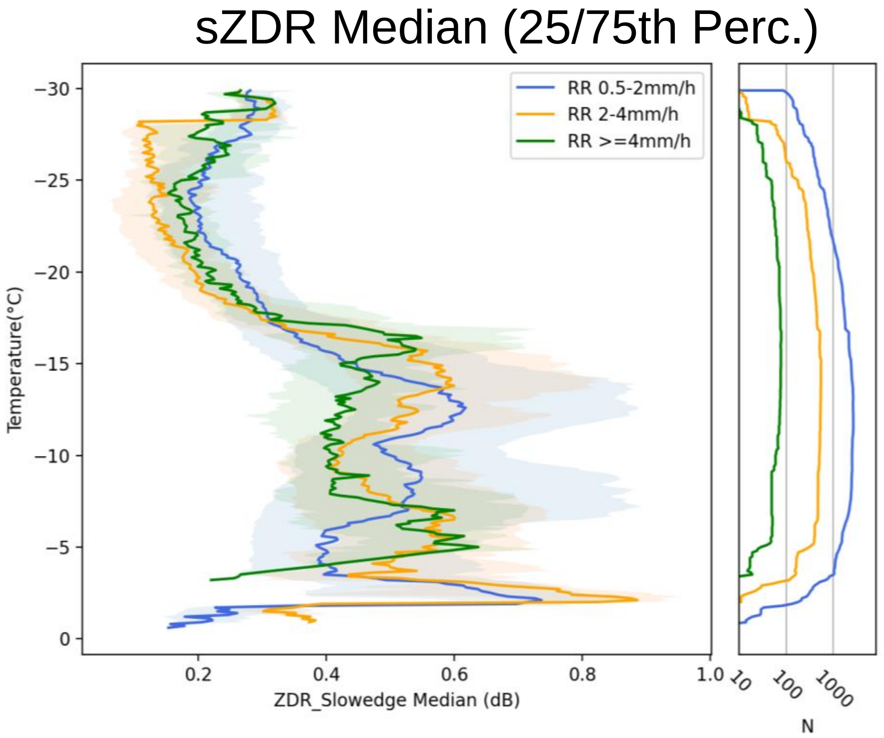
Median of fallstreak area

sZDR Slow Edge

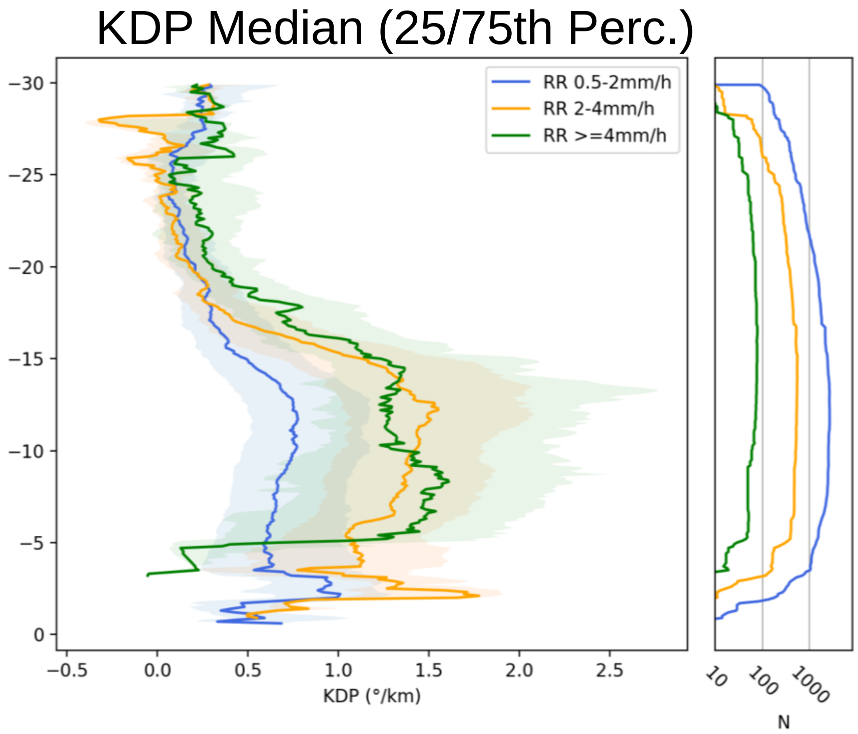


Averaging many profiles by Mean and Median

EDR filtered Profiles along fallstreaks December 2022

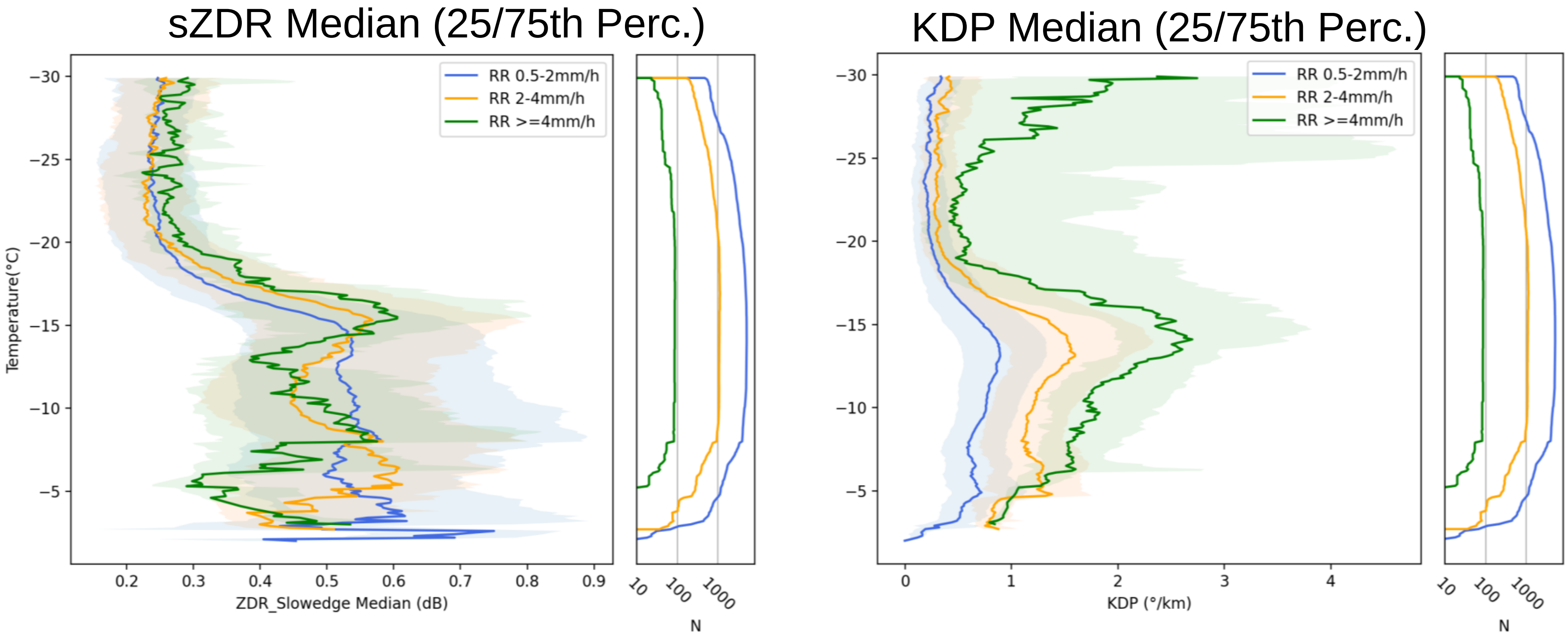


Second peak in sZDR below at -5 due to turbulence aloft?



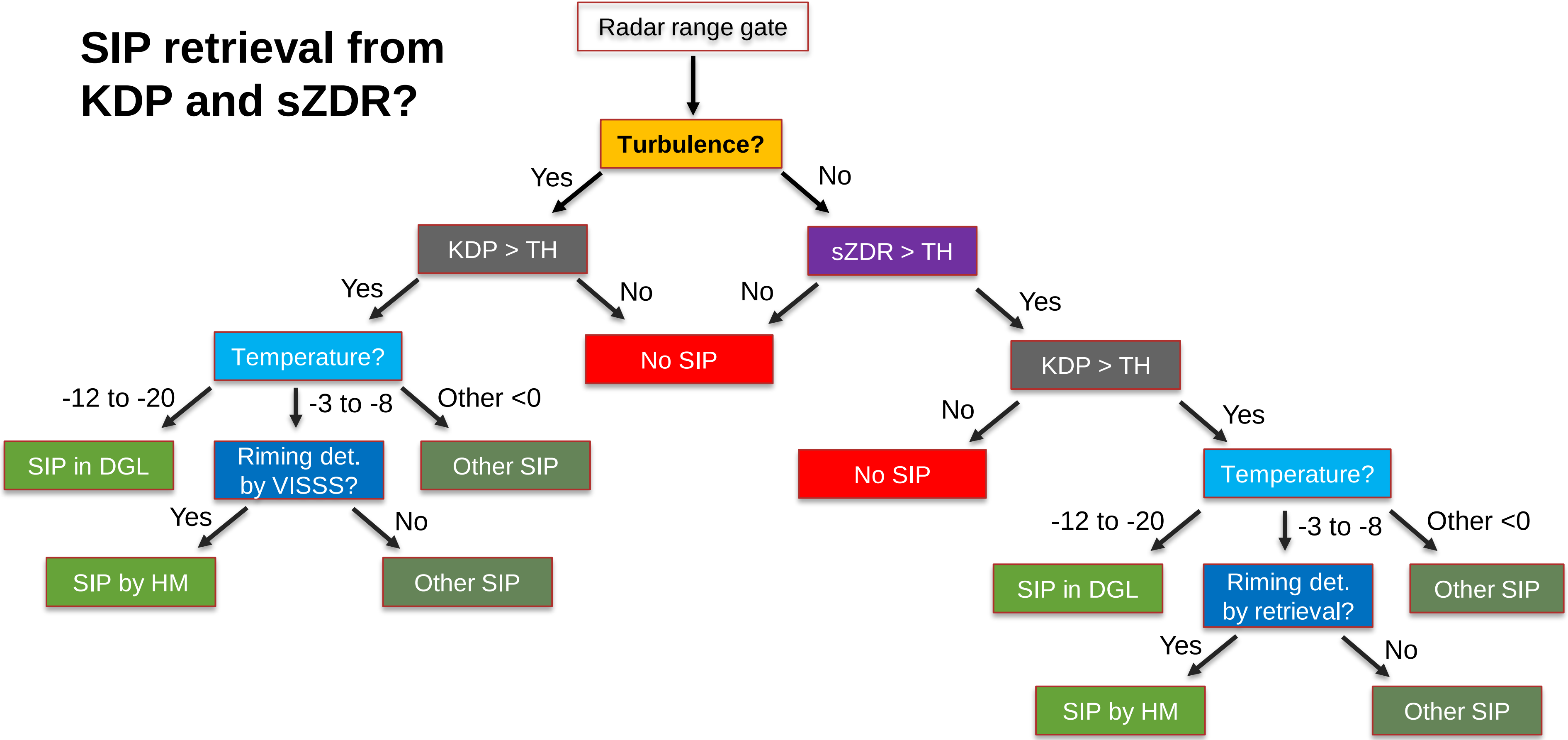
More constant KDP below DGL

EDR filtered Profiles along fallstreaks January 2023

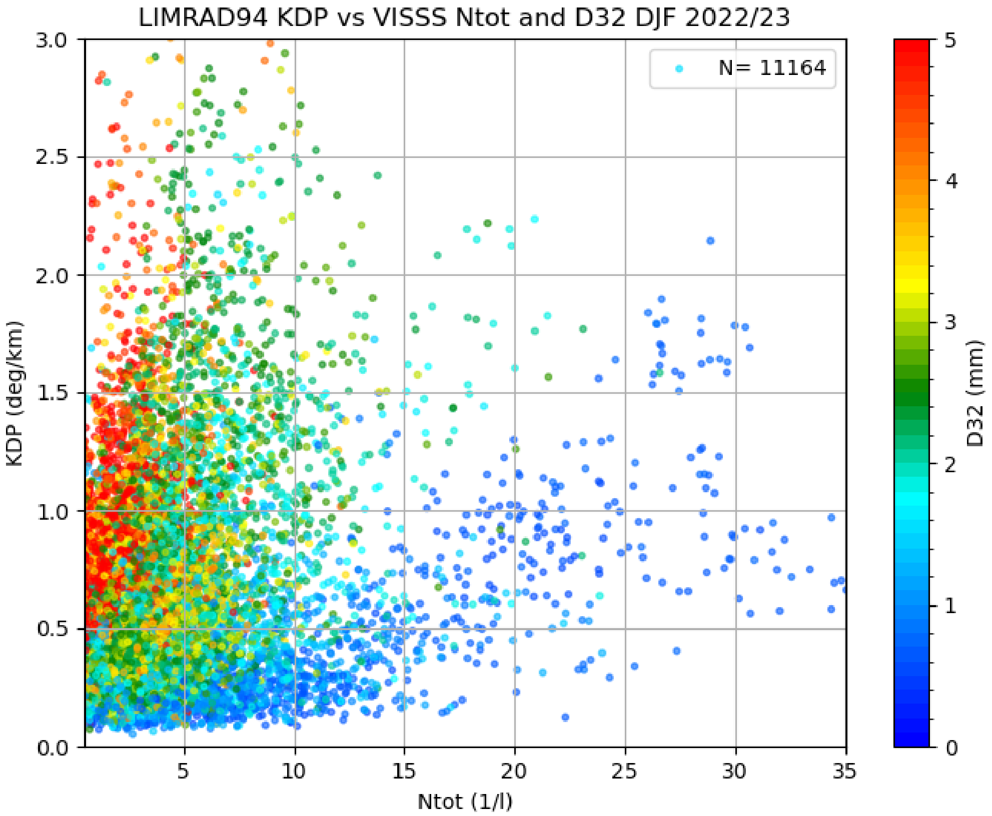


Aggregation decreases KDP constantly towards surface
Higher KDP related to higher precip. rates

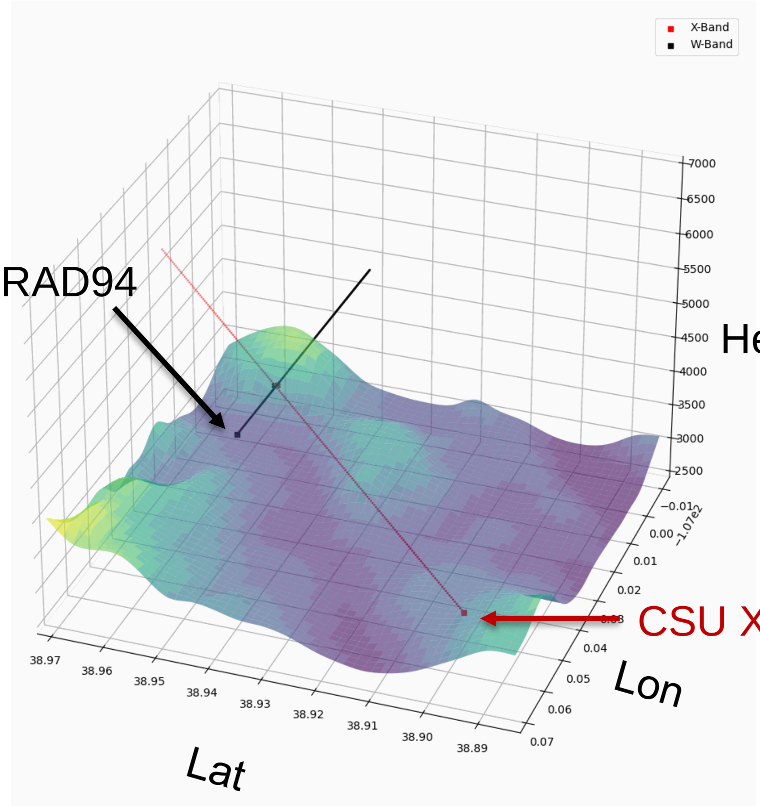
SIP retrieval from KDP and sZDR?

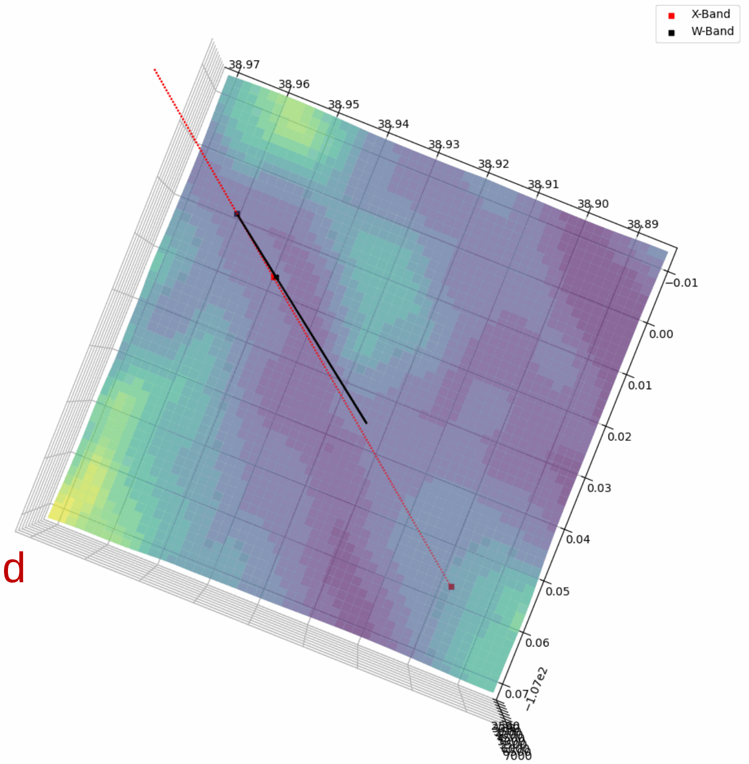


WHICH PARTICLESIZES ARE RELATED TO KDP SIGNATURES?

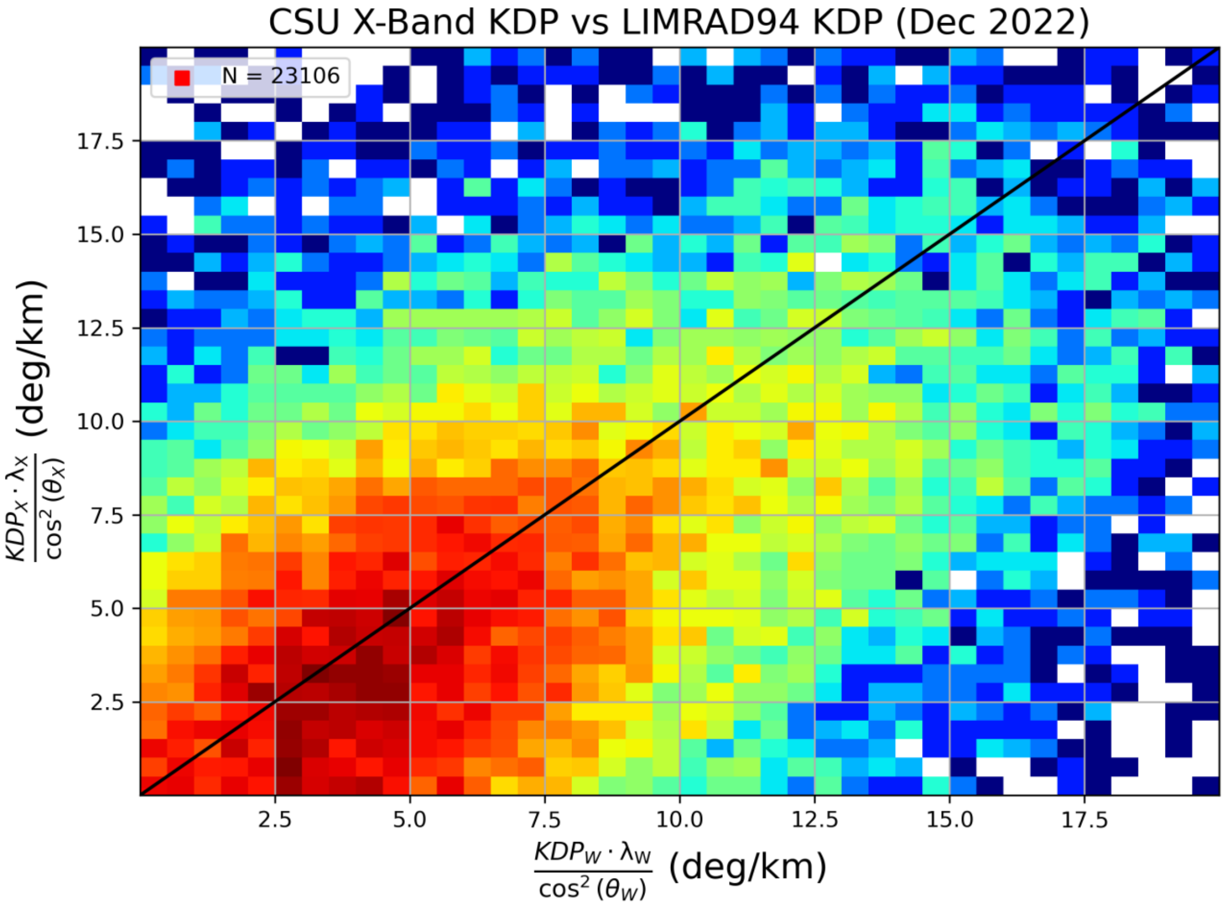


- LIMRAD94 KDP spatially averaged (median) between 100 and 500 m AGL (52 range gates)
- LIMRAD94 KDP temporally averaged (median) to fit the VISSS time resolution of one minute.
- Colors are mass weighted mean diameter (D32) = proxy for the mean mass-weighted diameter of the particle population



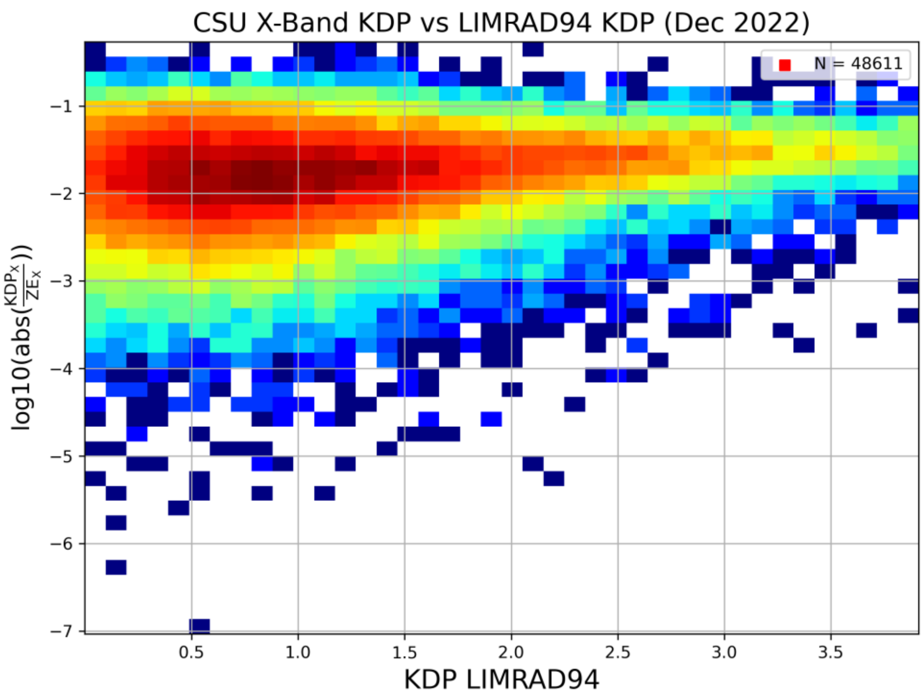


Mapping of W-Band Beam and X-Band Beam during the RHI scans of the X-Band

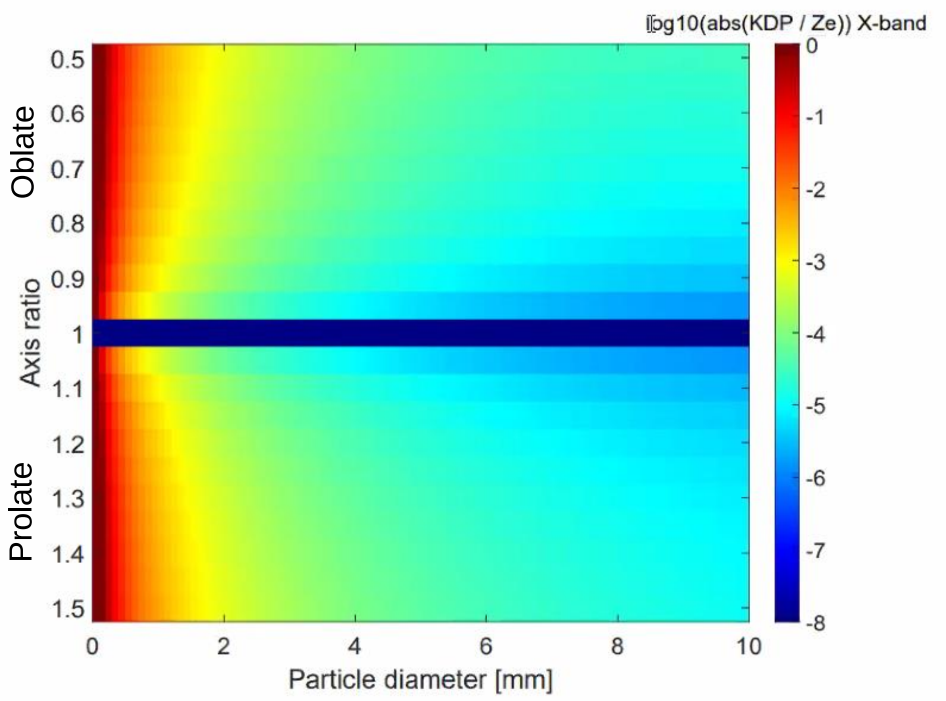


- KDP of both radars scales well when corrected for wavelength and elevation angle

Ratio of X-Band ZE and KDP to estimate size of particles producing KDP



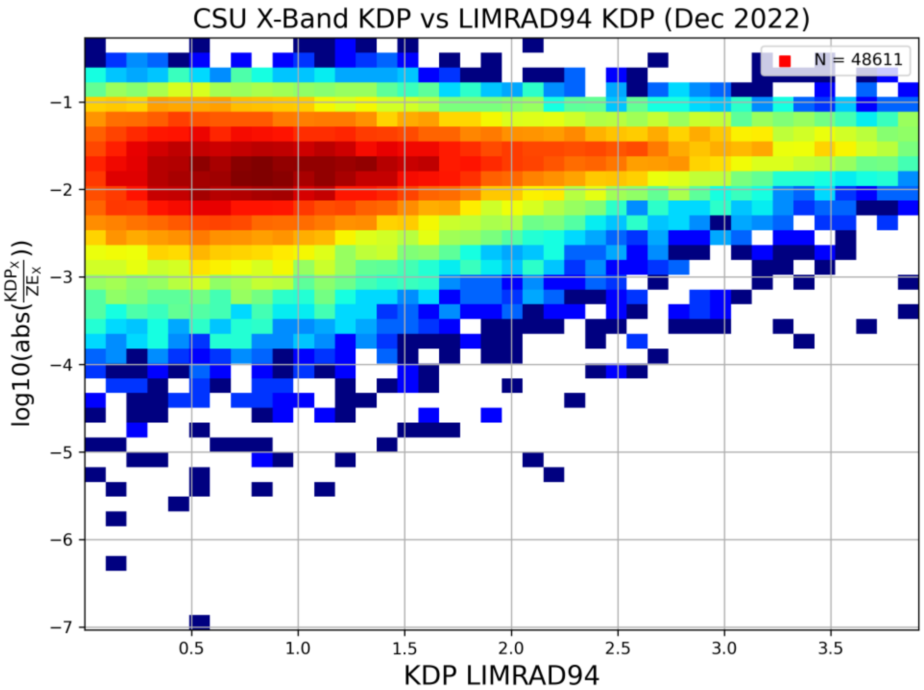
X-band KDP/ZE ratio vs W-band KDP



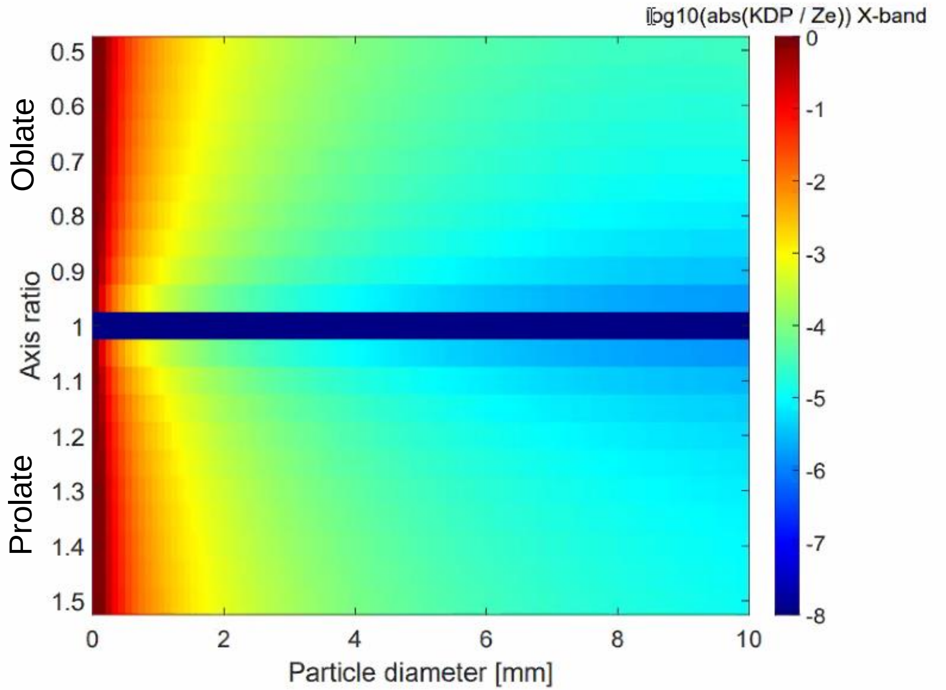
Simulation by Alexander Myagkov

Suggests that particles below 1mm size are responsible for high KDP

Ratio of X-Band ZE and KDP to estimate size of particles producing KDP



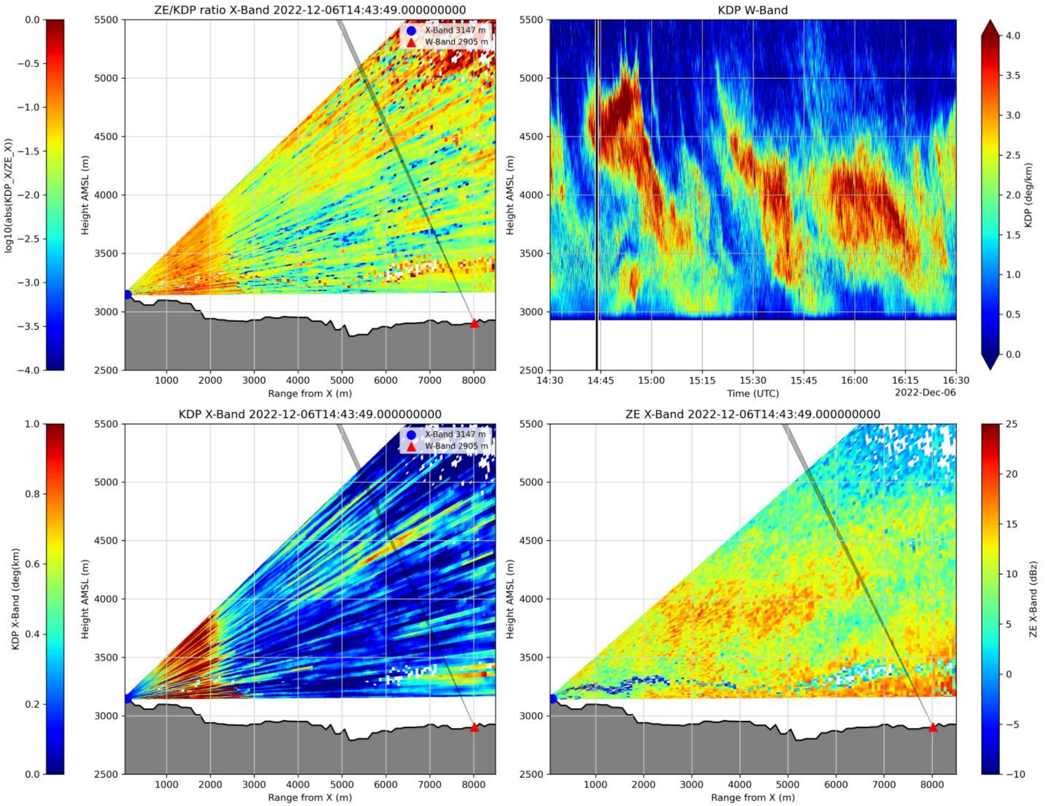
X-band KDP/ZE ratio vs W-band KDP



Simulation by Alexander Myagkov

Paper in progress

Animated evolution of W-Band KDP fallstreaks in X-Band RHI Scans On Dec 6th 2022



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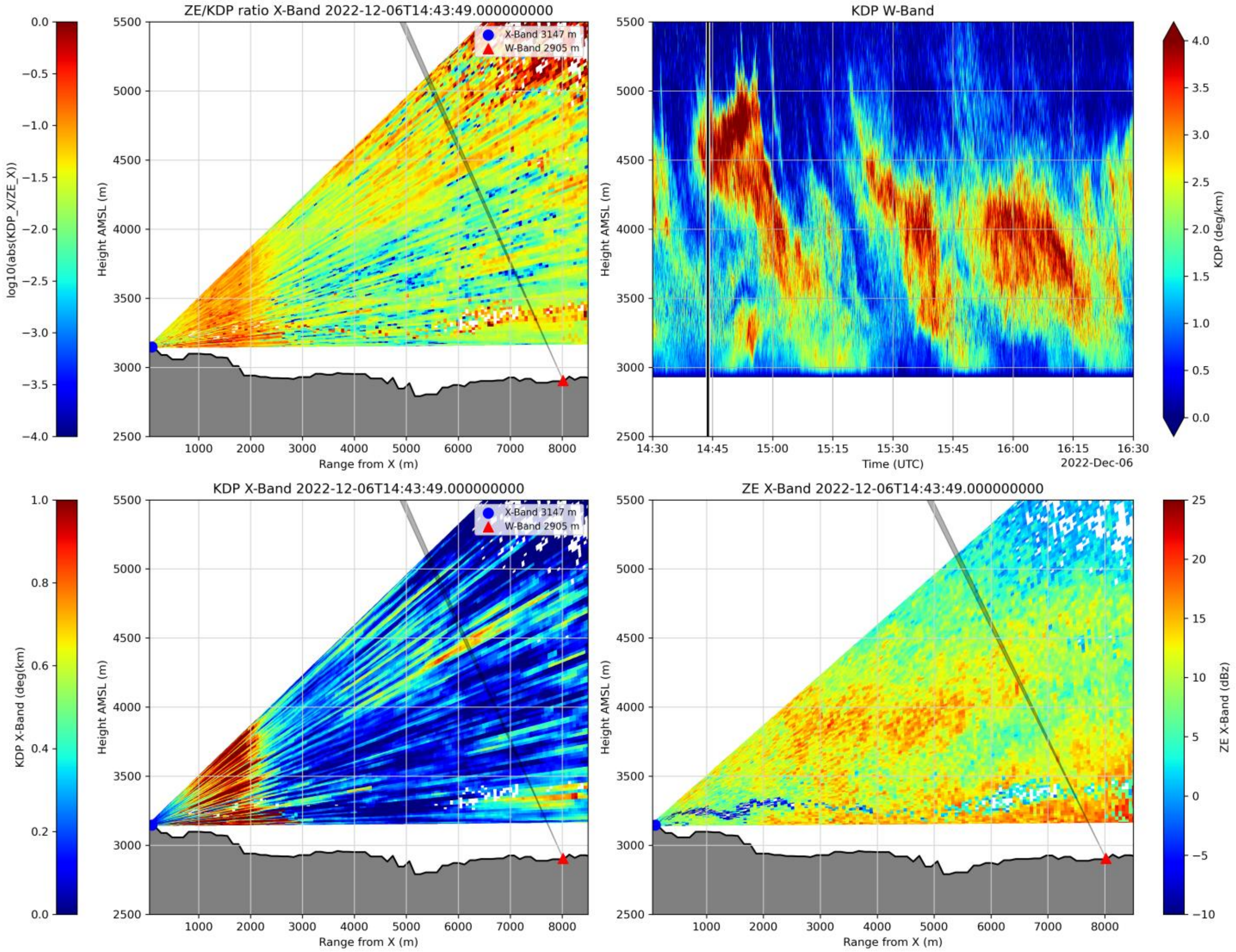
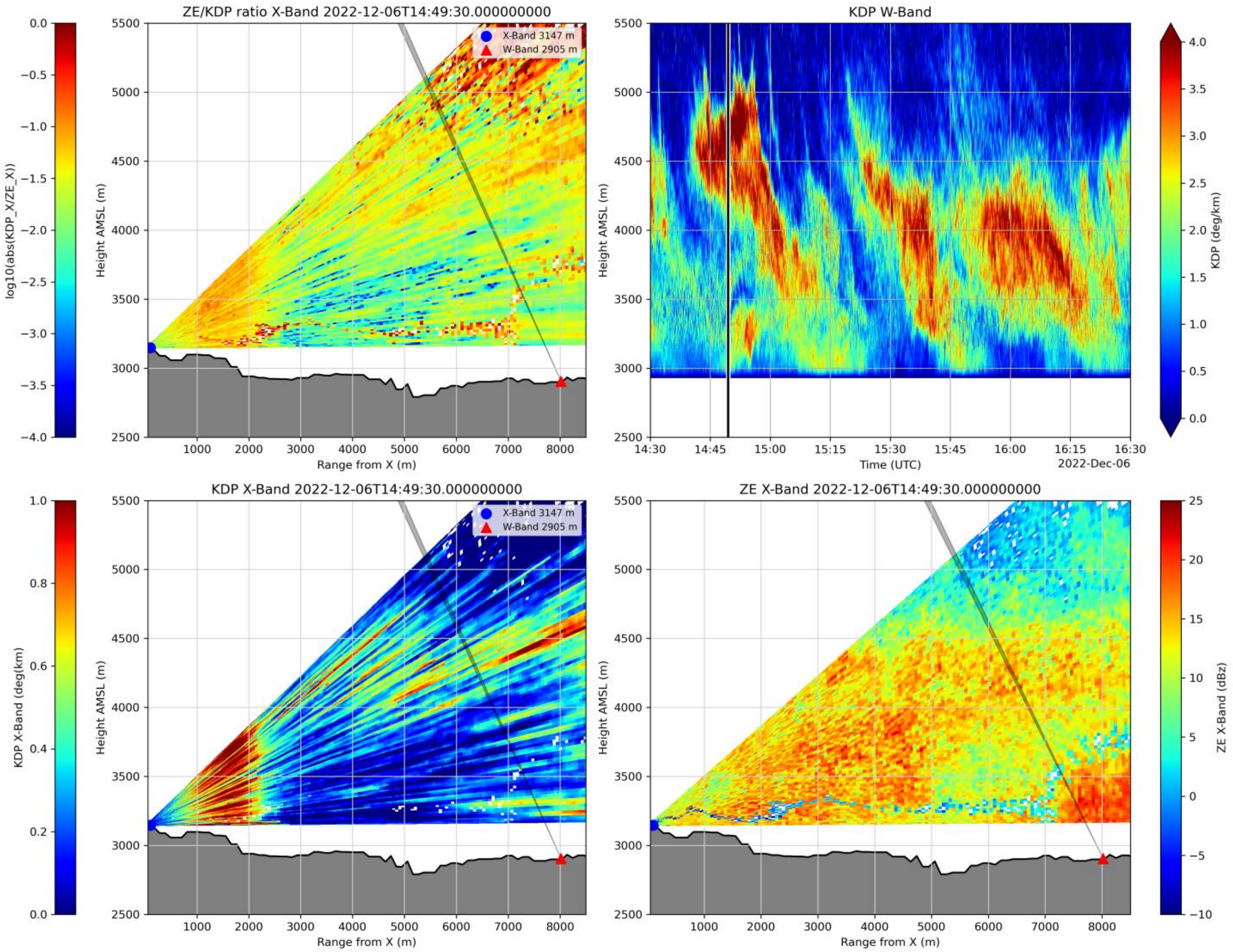


ZE/KDP ratio X-Band 2022-12-06T14:43:49.000000000
log10(abs(KDP_X/ZE_X))
Height AMSL (m)
Range from X (m)
X-Band 3147 m
W-Band 2905 m
KDP W-Band
KDP (deg/km)
Time (UTC)
2022-Dec-06
KDP X-Band 2022-12-06T14:43:49.000000000
KDP X-Band (deg(km)
ZE X-Band 2022-12-06T14:43:49.000000000
ZE X-Band (dBz)



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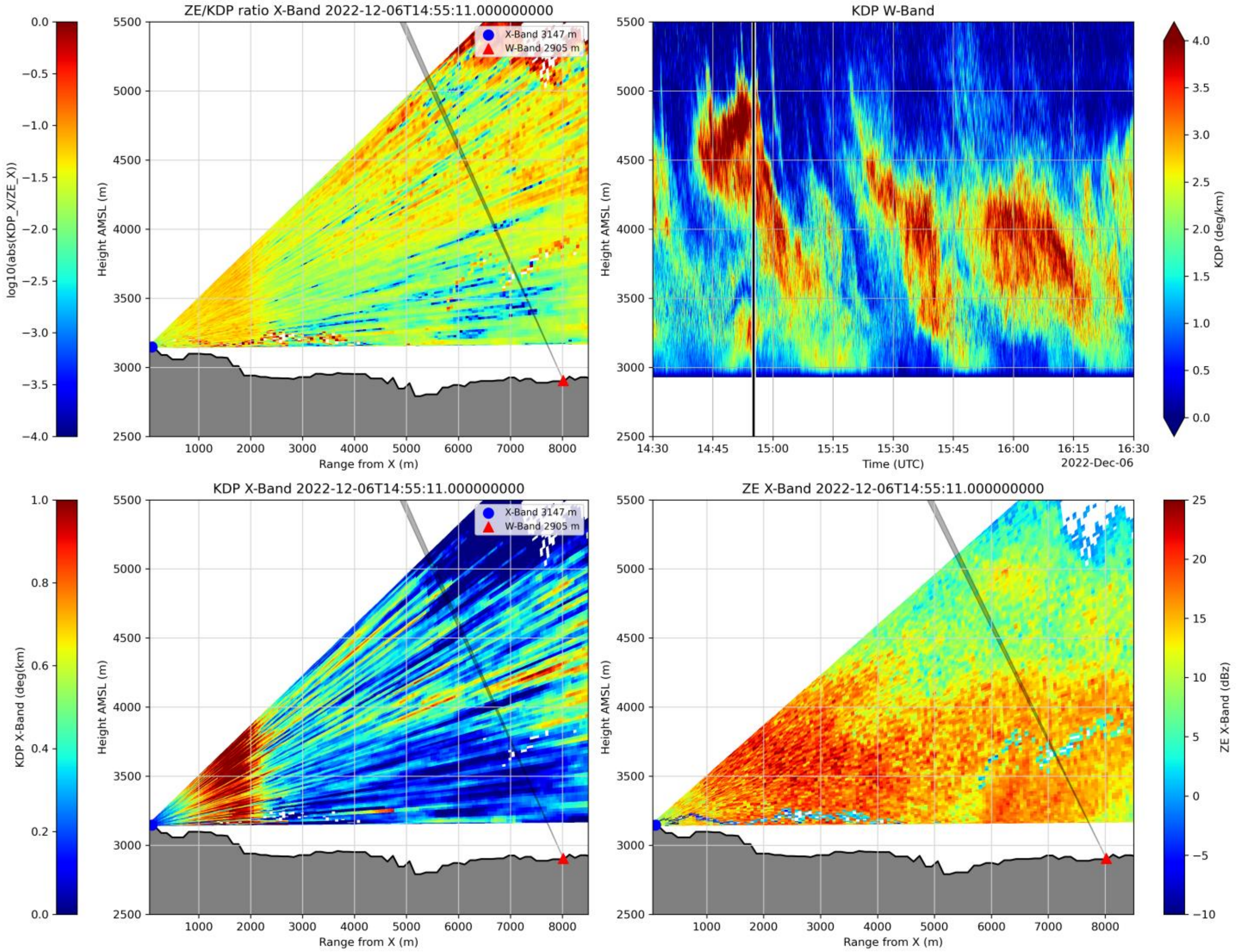

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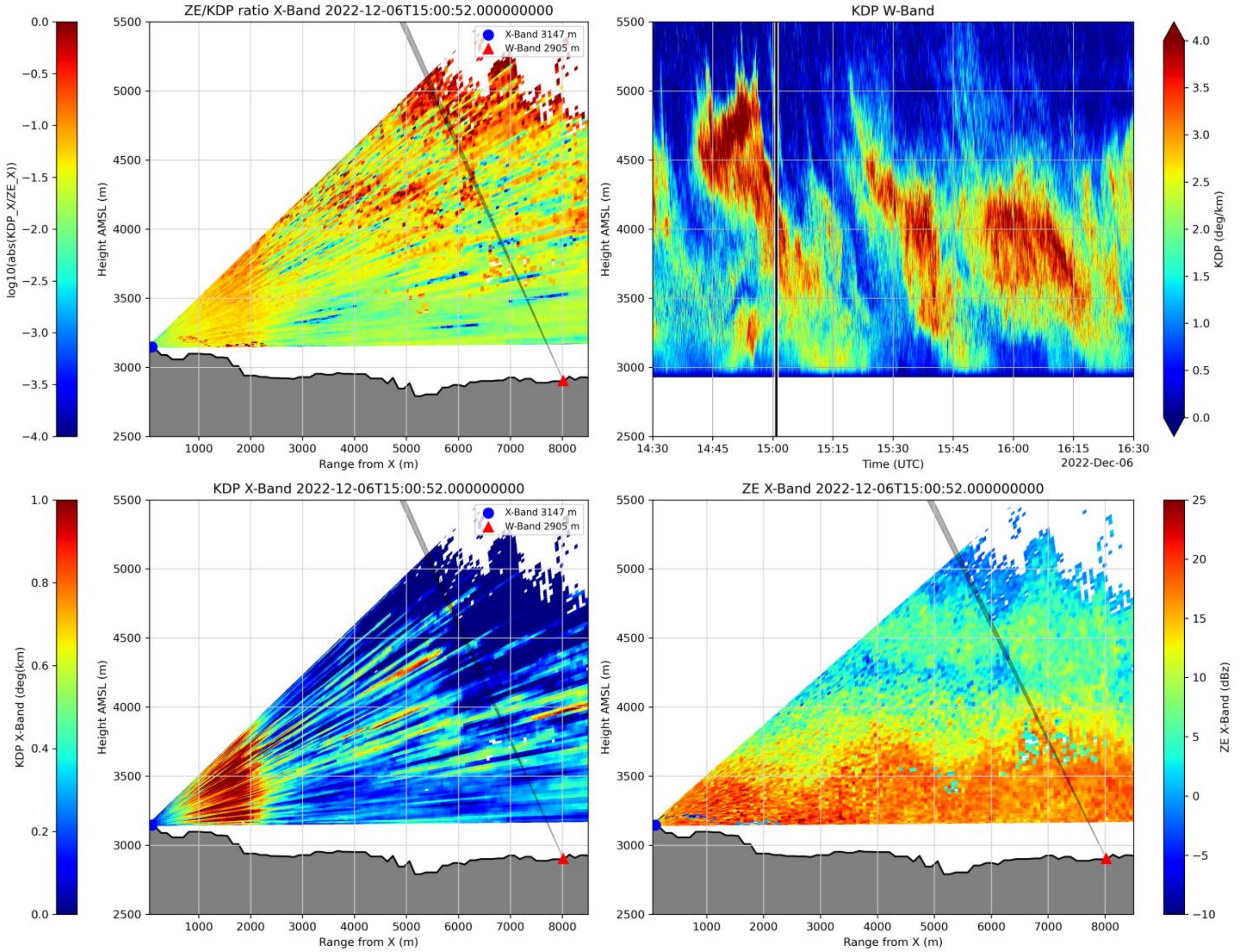
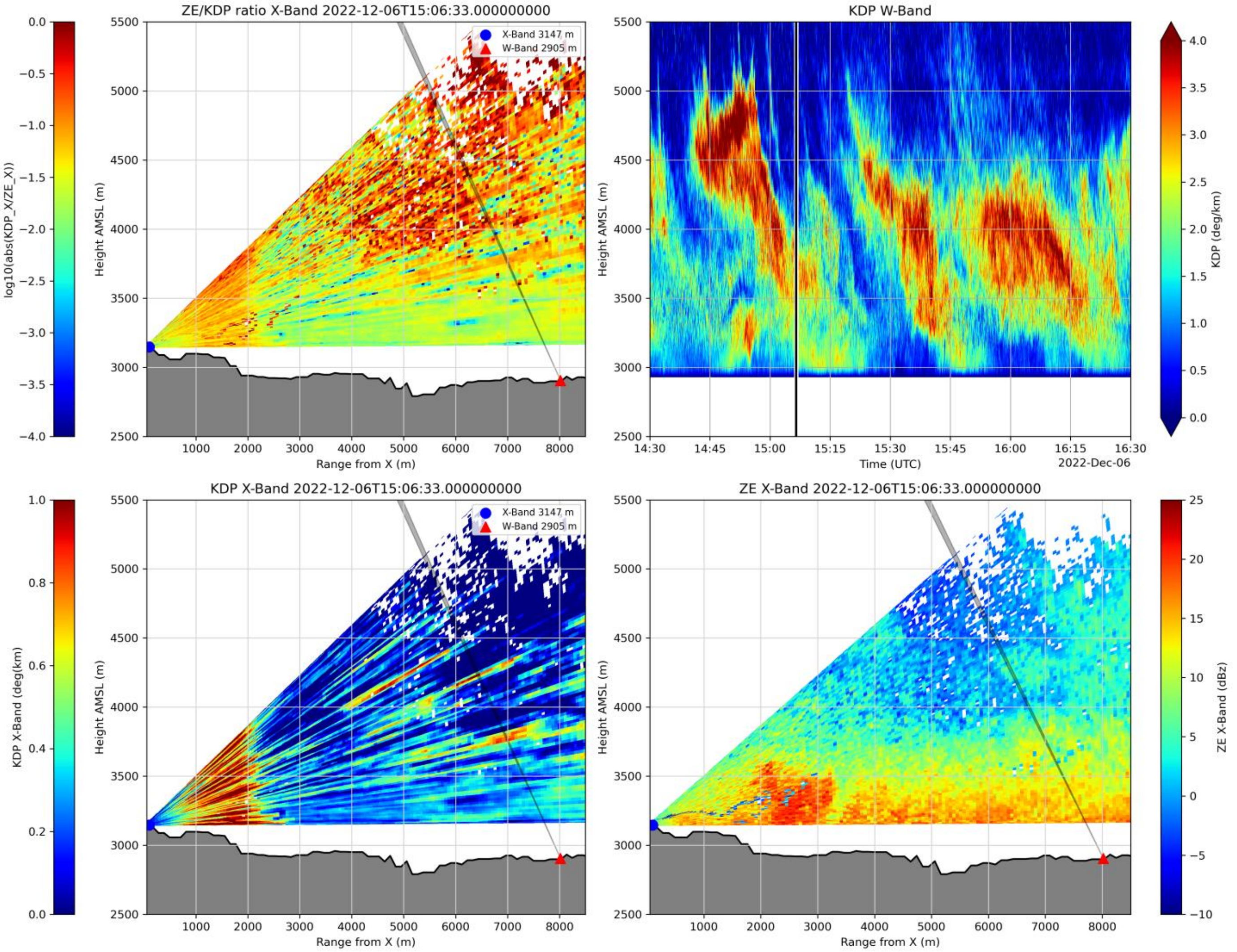


ZE/KDP ratio X-Band 2022-12-06T15:00:52.000000000
KDP W-Band
KDP X-Band 2022-12-06T15:00:52.000000000
ZE X-Band 2022-12-06T15:00:52.000000000
X-Band 3147 m
W-Band 2905 m
log10(abs(KDP_X/ZE_X))
KDP (deg/km)
KDP X-Band (deg(km)
ZE X-Band (dBz)
Height AMSL (m)
Range from X (m)
Time (UTC)
2022-Dec-06



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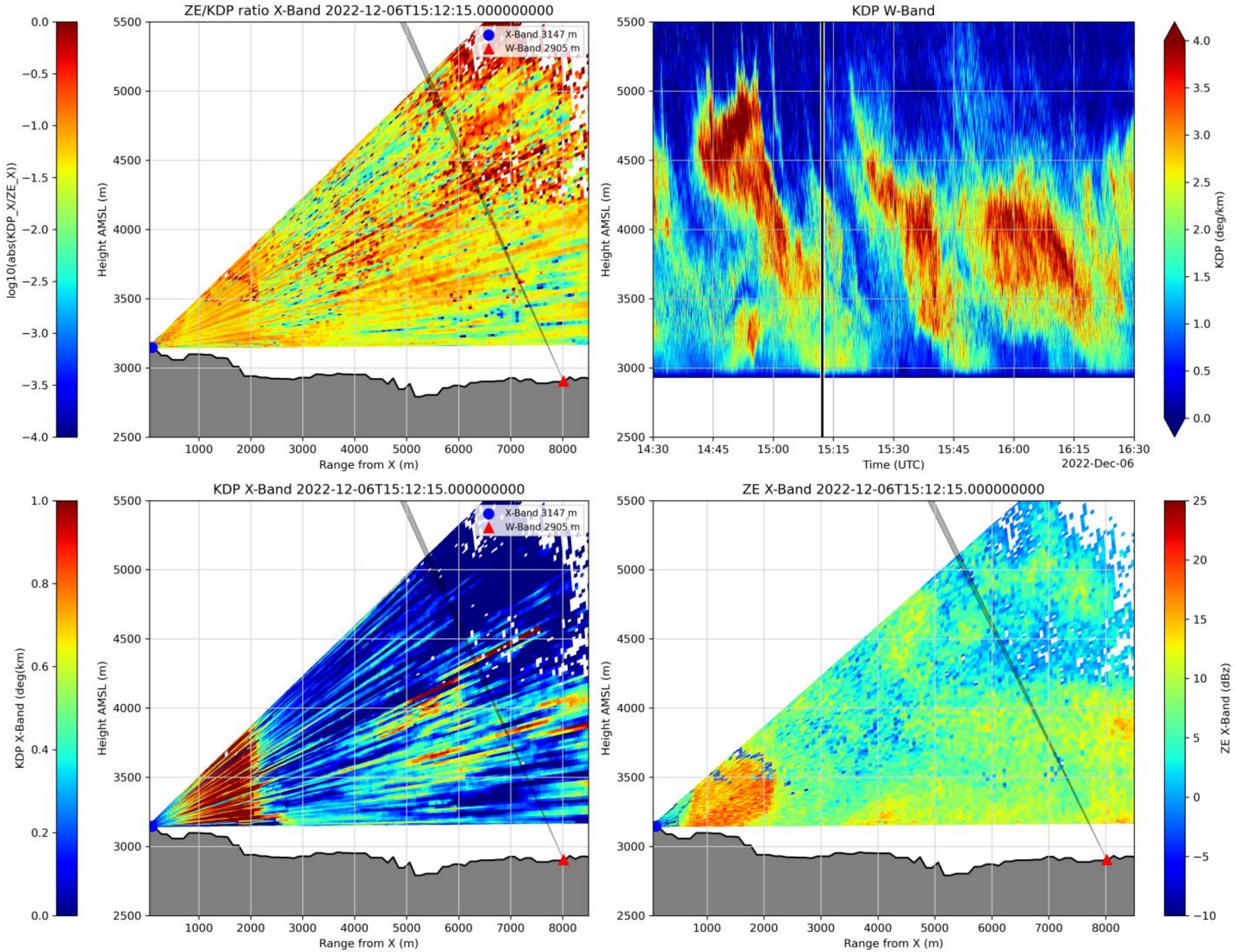
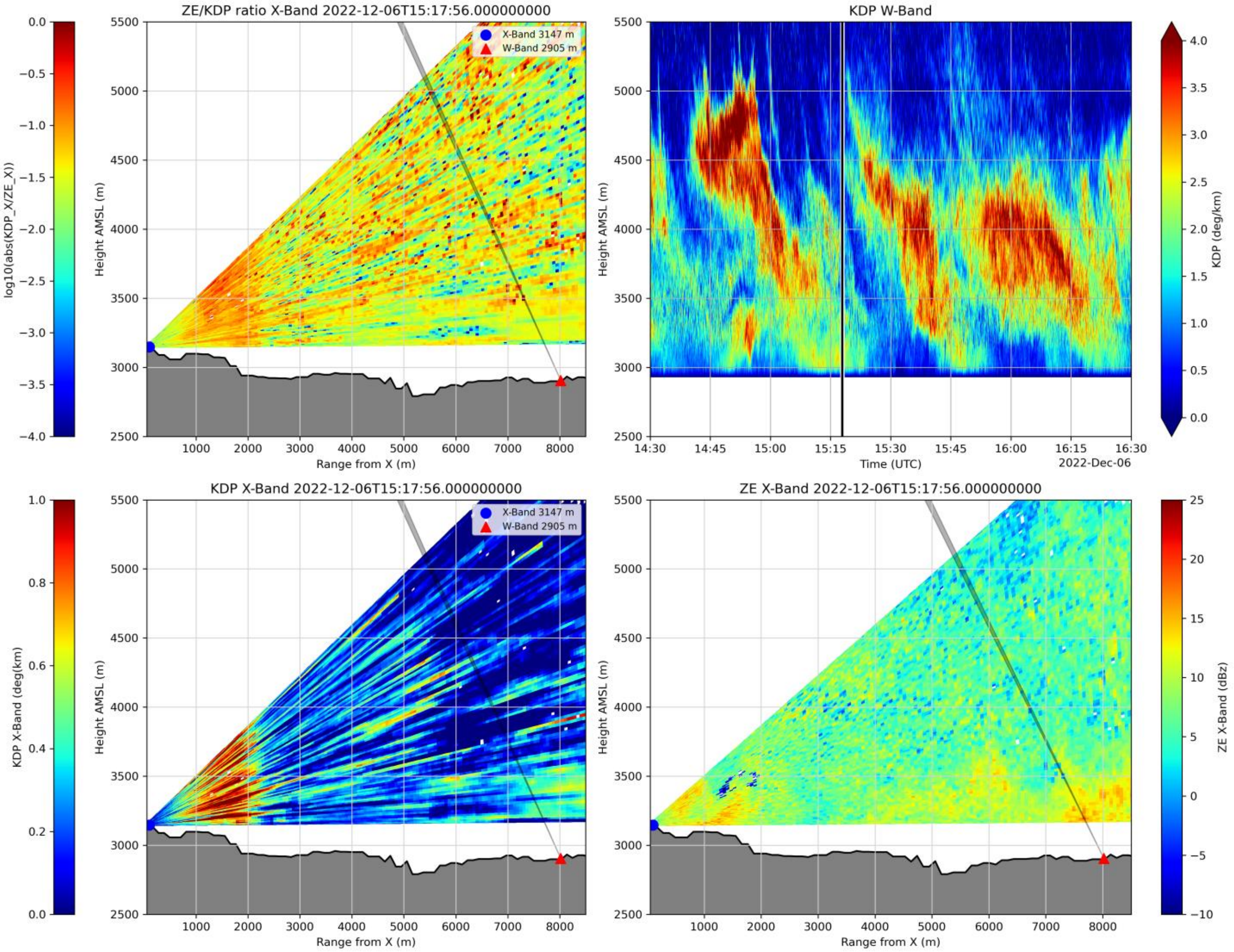
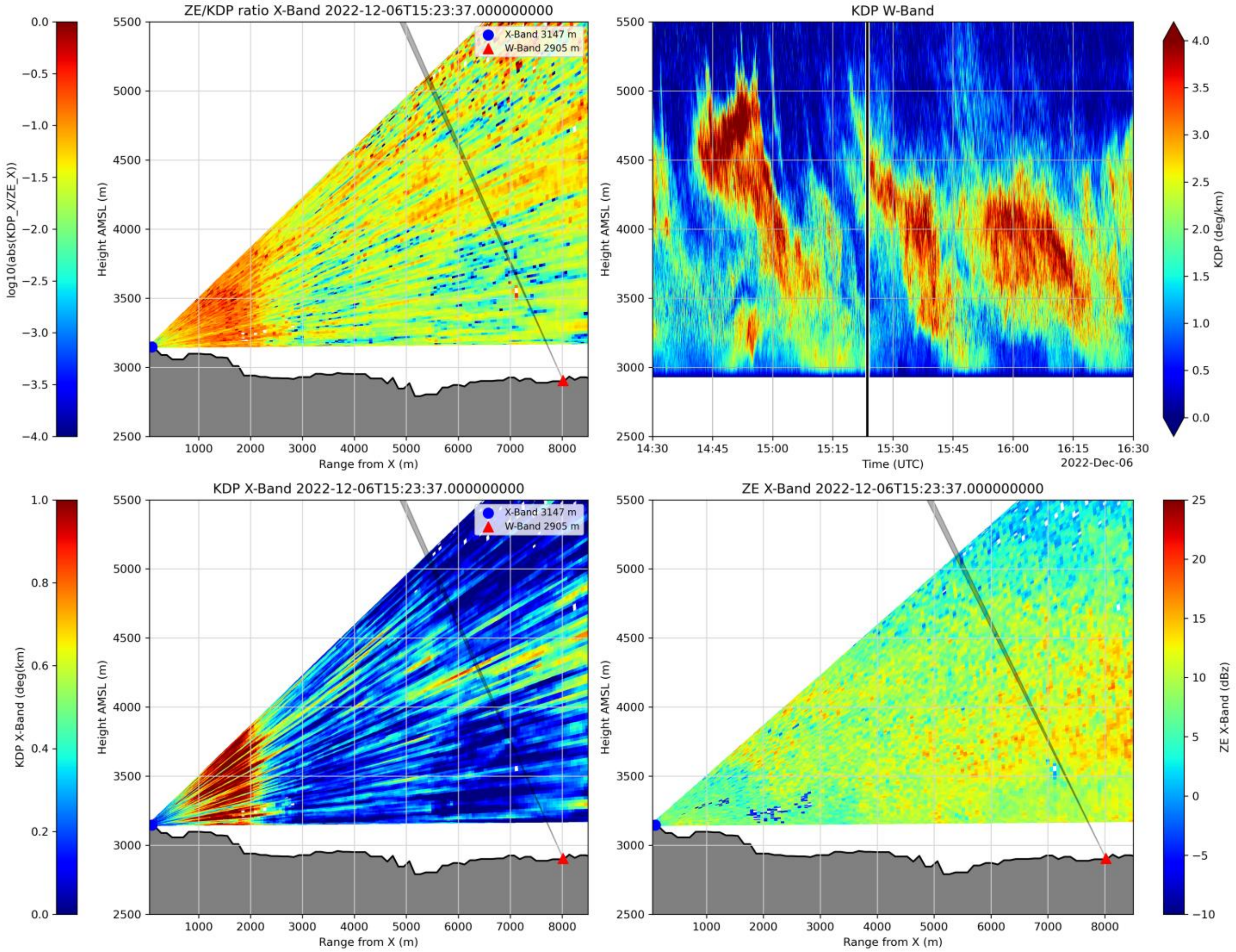
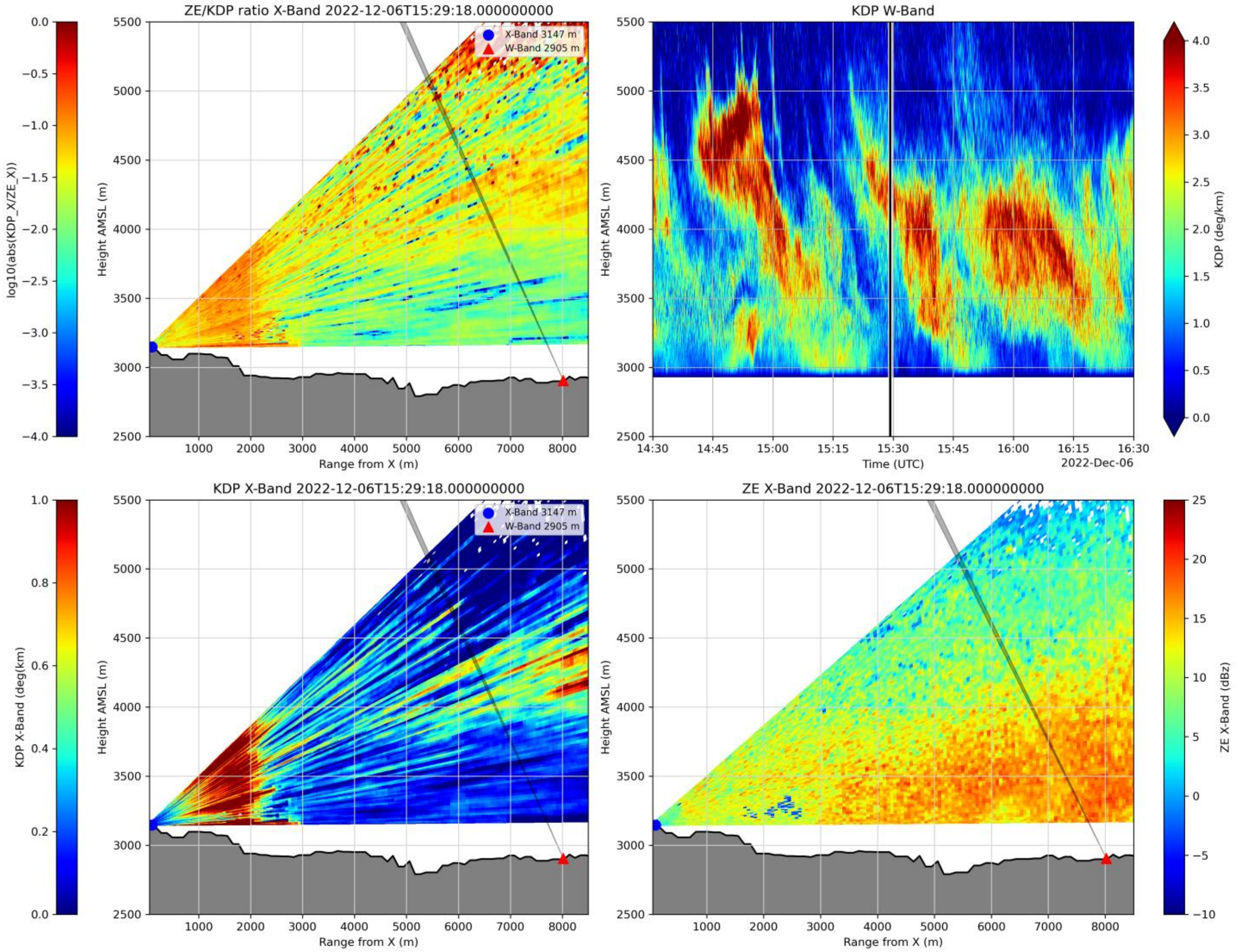


ZE/KDP ratio X-Band 2022-12-06T15:12:15.000000000
log10(abs(KDP_X/ZE_X))
Height AMSL (m)
Range from X (m)
X-Band 3147 m
W-Band 2905 m
KDP W-Band
KDP (deg/km)
Time (UTC)
2022-Dec-06
KDP X-Band 2022-12-06T15:12:15.000000000
KDP X-Band (deg(km)
ZE X-Band 2022-12-06T15:12:15.000000000
ZE X-Band (dBz)


ZE/KDP ratio X-Band 2022-12-06T15:17:56.000000000
X-Band 3147 m
W-Band 2905 m
log10(abs(KDP_X/ZE_X))
Height AMSL (m)
Range from X (m)
KDP W-Band
Time (UTC)
2022-Dec-06
KDP (deg/km)
KDP X-Band 2022-12-06T15:17:56.000000000
KDP X-Band (deg(km)
ZE X-Band 2022-12-06T15:17:56.000000000
ZE X-Band (dBz)



ZE/KDP ratio X-Band 2022-12-06T15:23:37.000000000
log10(abs(KDP_X/ZE_X))
Height AMSL (m)
Range from X (m)
X-Band 3147 m
W-Band 2905 m
KDP W-Band
Time (UTC)
2022-Dec-06
KDP (deg/km)
KDP X-Band 2022-12-06T15:23:37.000000000
KDP X-Band (deg(km)
ZE X-Band 2022-12-06T15:23:37.000000000
ZE X-Band (dBz)



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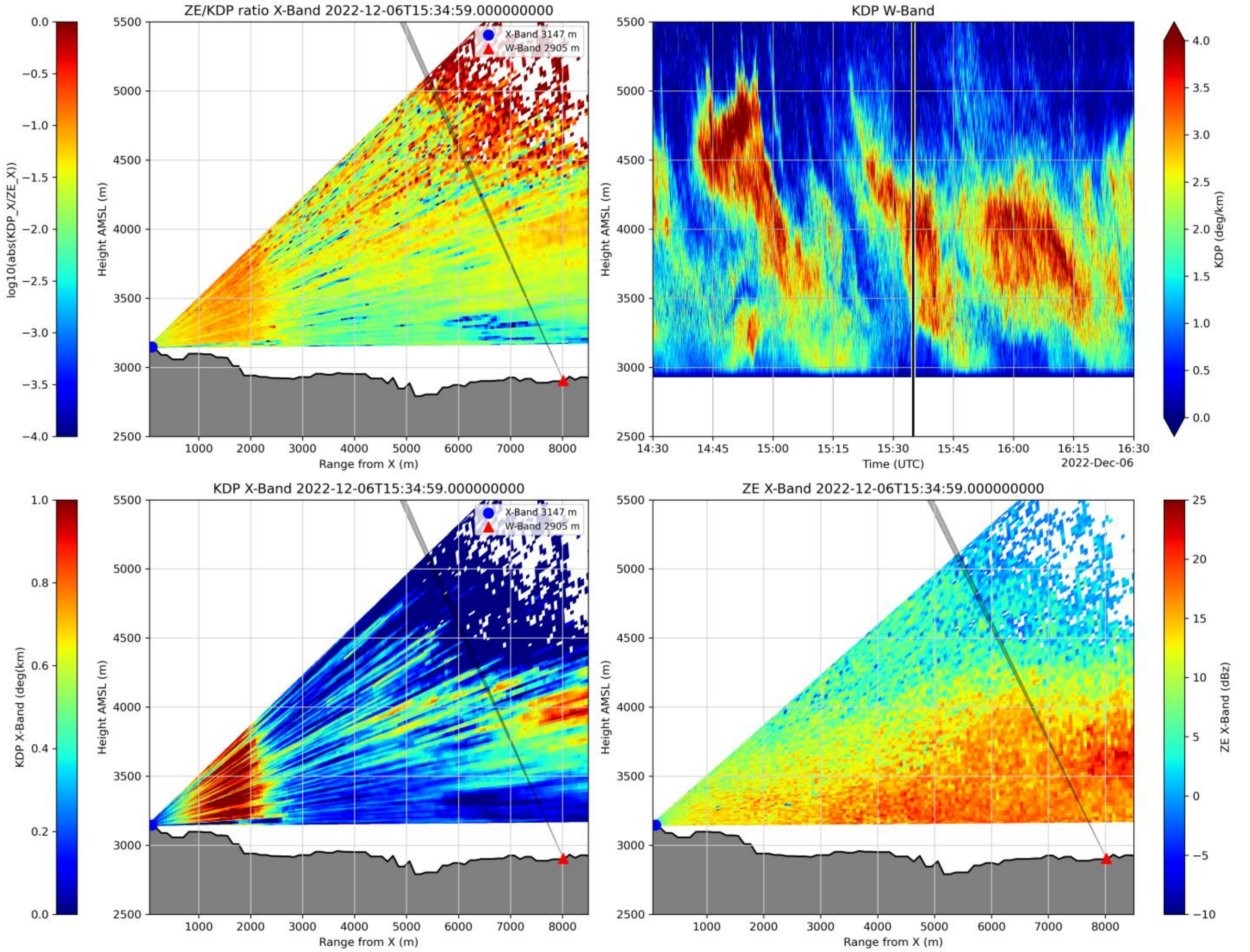

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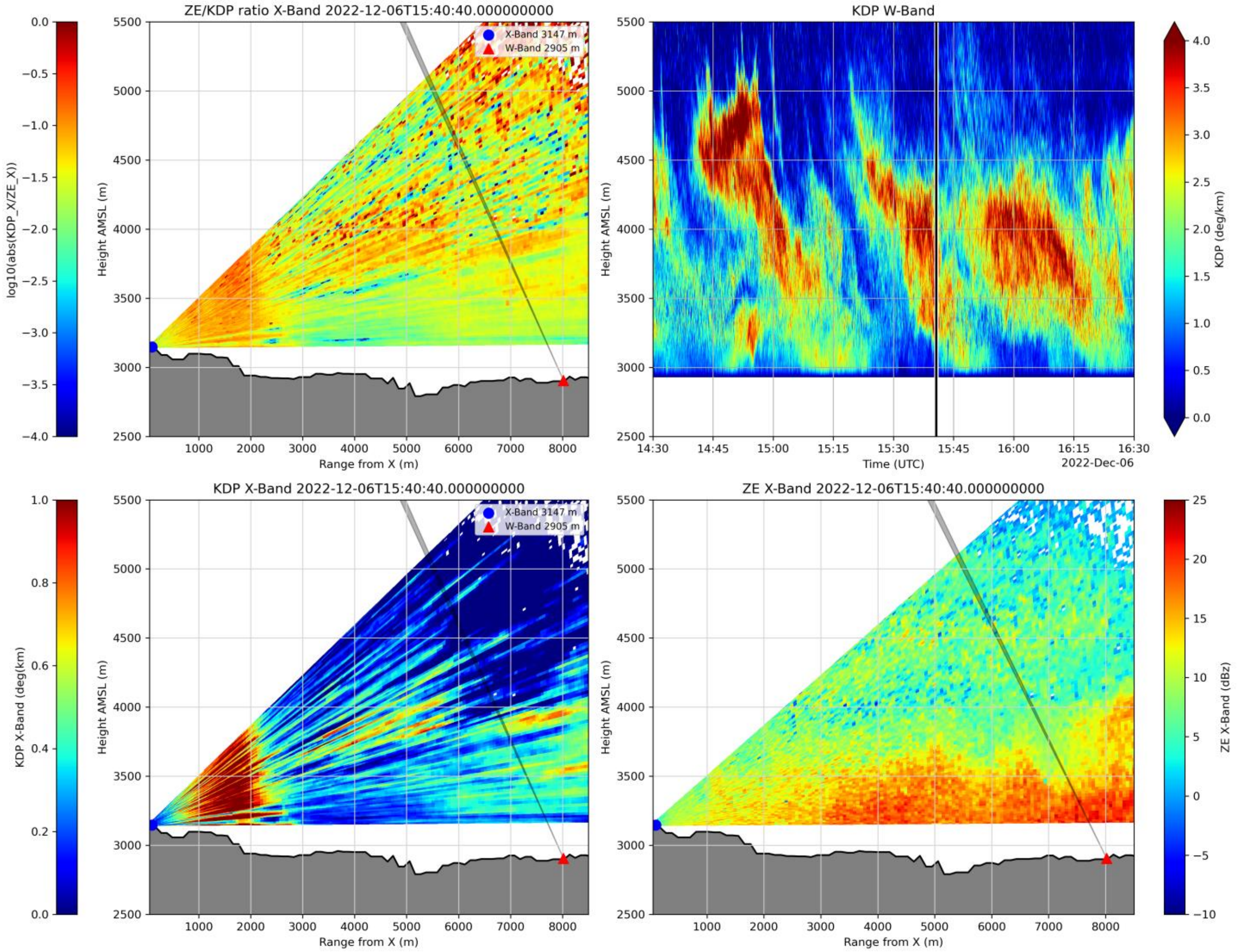

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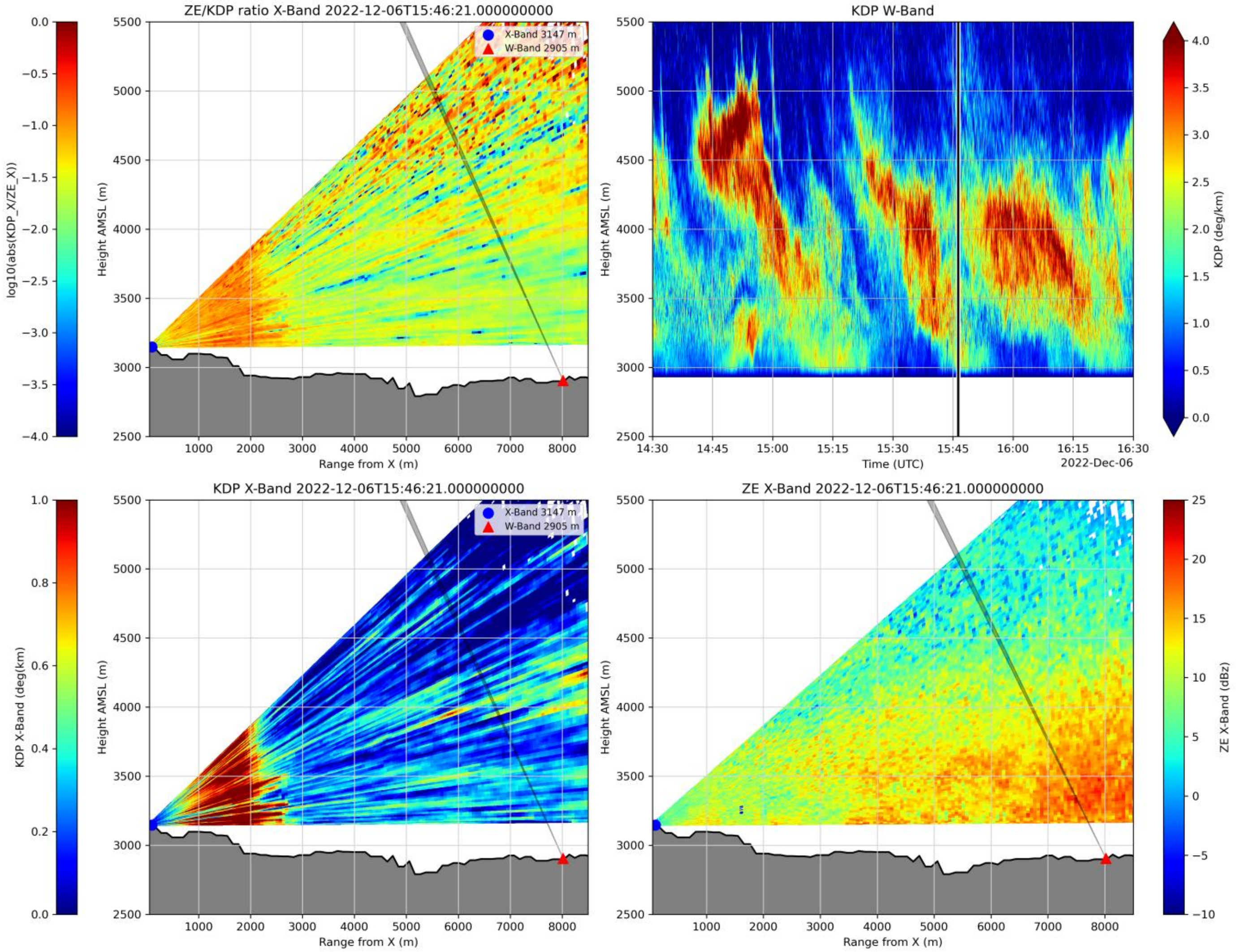

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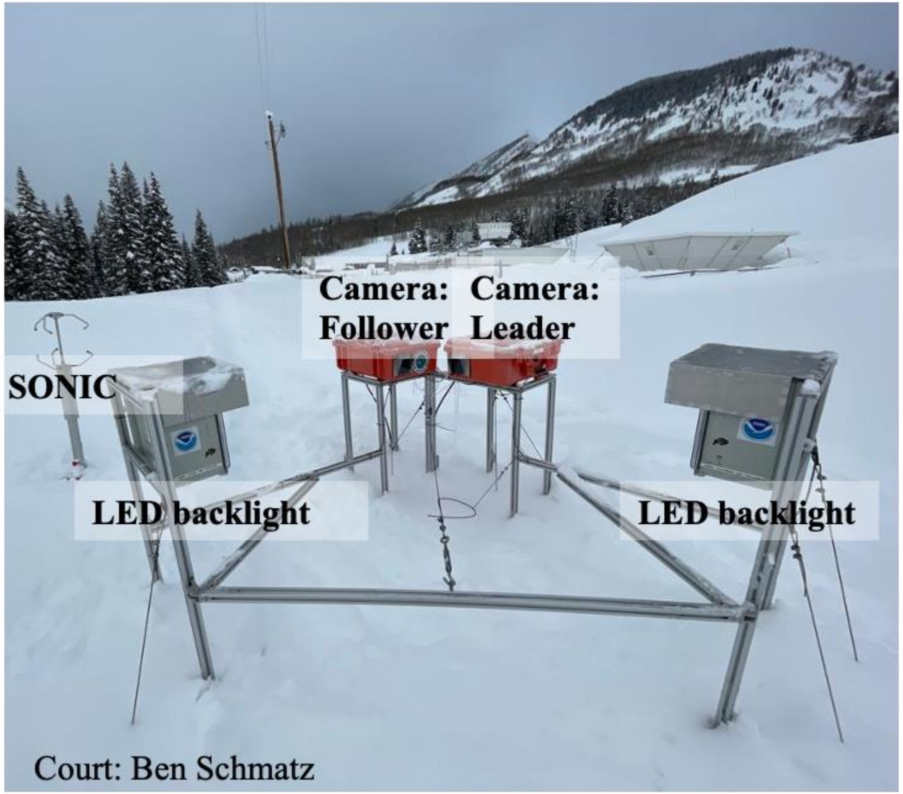
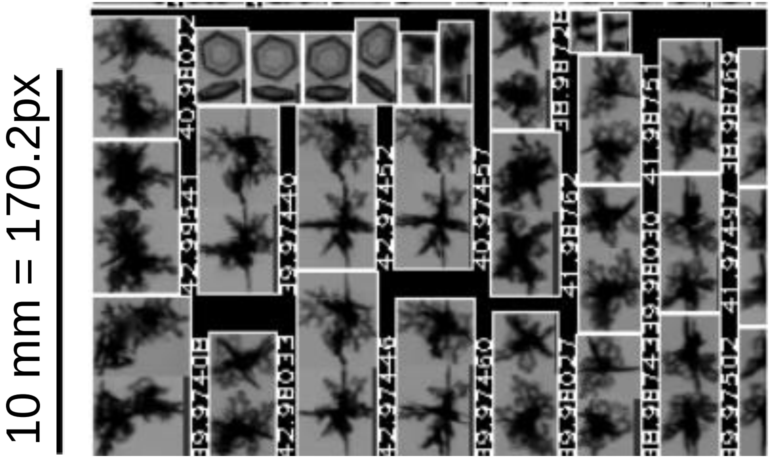
VIDEO IN SITU SNOWFALL SENSOR (VISSS) (Maahn et al., 2023)



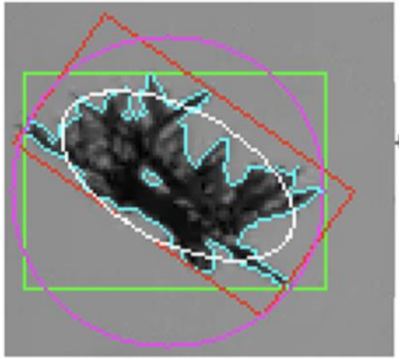
- Two camera systems
- Size, Number, Shape, Complexity

- Framerate: 250 Hz
- Measurement volume: approx. 8 x 8 x 6 cm
- Minimum detection size: 200 µm



WORKING ON A SHAPE ALGORITHM – WHAT PARAMETERS TO USE?

- 152 variable vectors as input
  - Dfit, Dmax, Droi, angle, area, aspectRatio, blur, **contourFFT**, **contourFFTstd**, **contourFFTsum**, perimeter, perimeterEroded, pixKurtosis, pixSkew, complexity, dequiv, **sorted_fq, amp_rat, amp_rat_sort**, distance, Area_via_Dmax, Perimeter_via_Dmax, area_method_diff, perimeter_method_diff, **amp_rat_max_value, amp_rat_max_index, contourFFT_max_value, contourFFT_max_index**
  - Maximum and difference of the 2 cameras
  - Three different fits for some parameters
  - For the first 16 wavenumbers:
    - ContourFFT, sorted_fq
    - amp_rat, amp_rat_sort

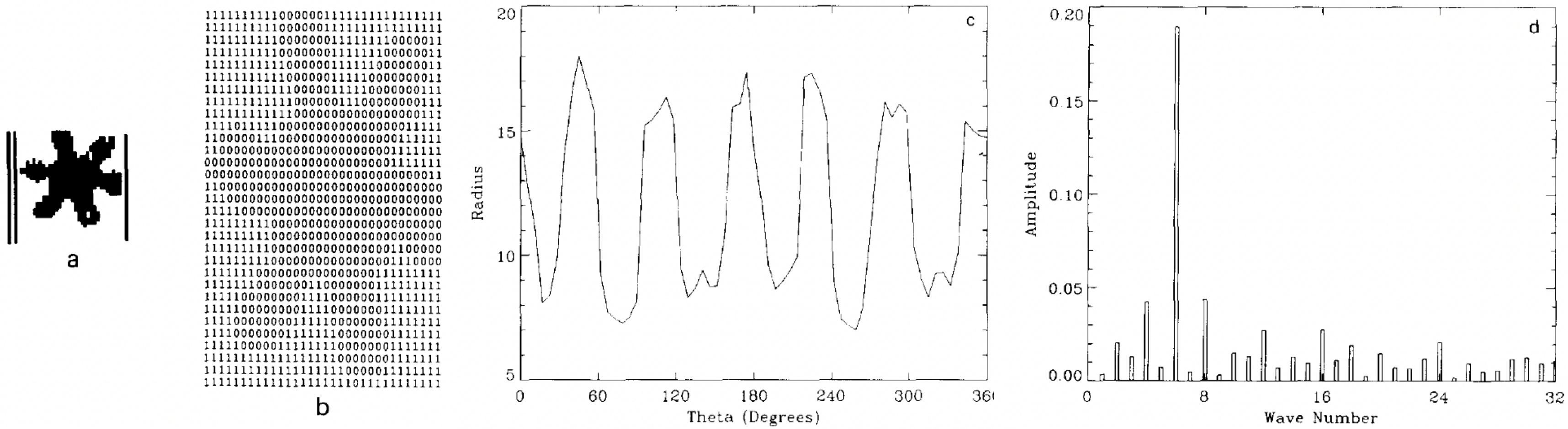


(Maahn et al., 2023)

CALCULATION OF "CONTOUR" VARIABLES

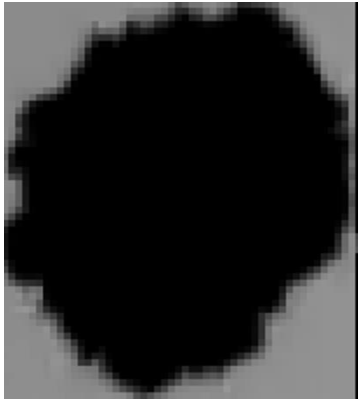
- 1. Transformation from cartesian to radial representation
- 2. Computing the fouriertransformation of the Theta-Radius-Funktion (FFT)

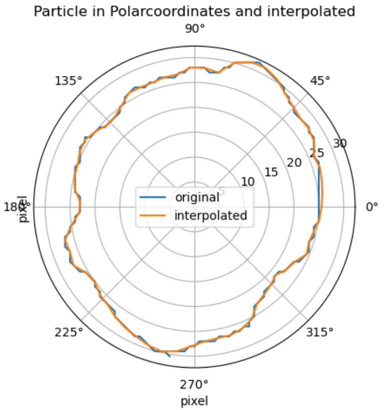
S.J. Moss, D.W. Johnson / Atmospheric Research 34 (1994) 1–25

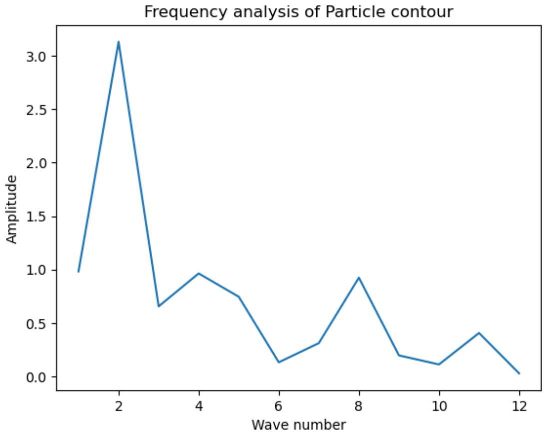


CONTOUR VARIABLES

- contourFFT: Amplitude at 1-16 wave numbers
- contourFFTstd: Standard Deviation of amplitudes (1-16 wave numbers)
- contourFFTsum: Sum of amplitudes (1-16 wave numbers)
- amp_rat = Amp_n/ Amp_1
- amp_rat_max_value, amp_rat_max_index
- contourFFT_max_value, contourFFT_max_index

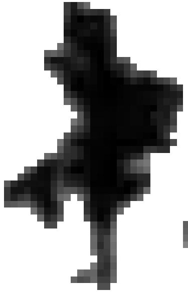




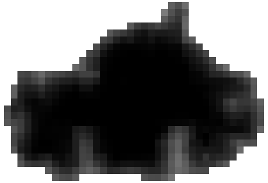


HOW TO CLASSIFY ICE PARTICLES?

e-bass guitar



dancing man with top hat



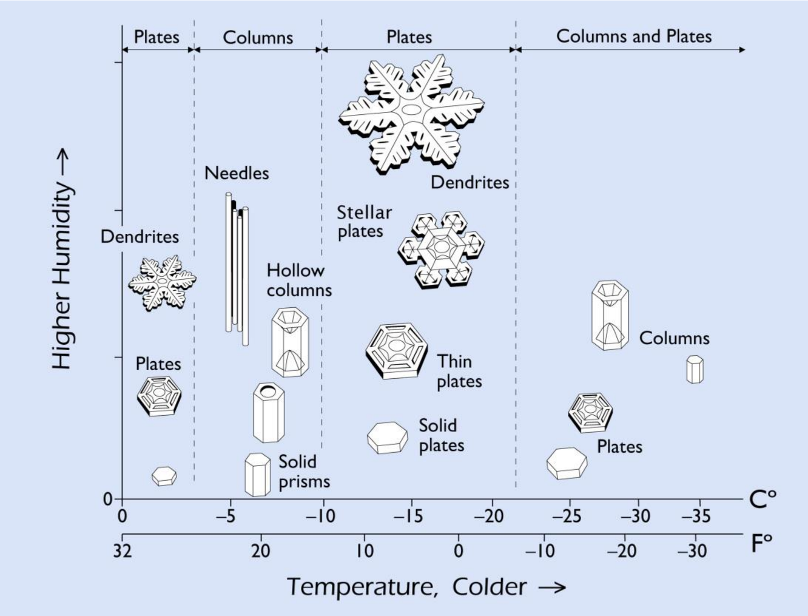
a cool car

Goat rides a scooter

https://www.its.caltech.edu/~atomic/snowcrystals/class/class-old.htm *by Libbrecht*

ICE/SNOW CRYSTAL MORPHOLOGY DIAGRAMS

- *by Nakaya and Sekido 1936, Magono and Lee 1966, Pruppacher and Klett 1997, Bailey and Hallett 2009, and Libbrecht 2012*
- *Description of crystal habits as a function of temperature and water vapour supersaturation with respect to ice*

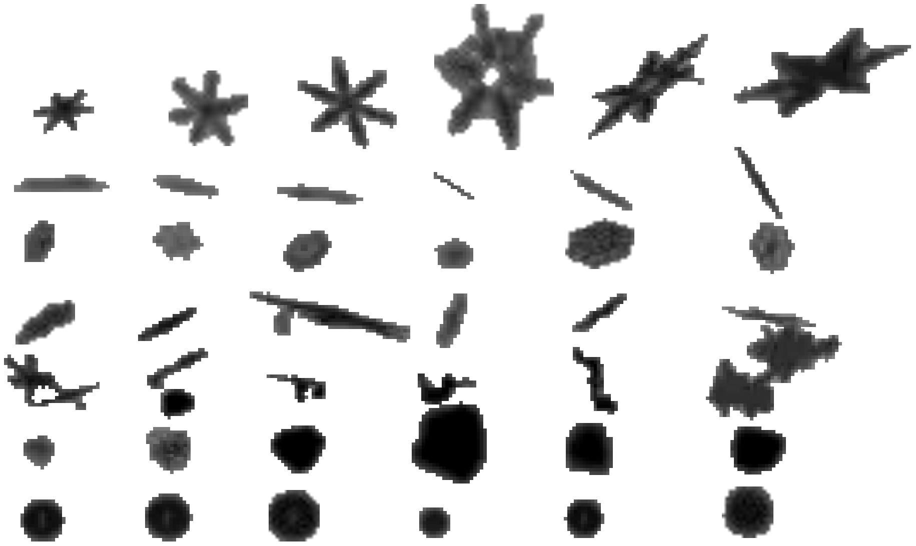


https://snowcrystals.com/
by Libbrecht

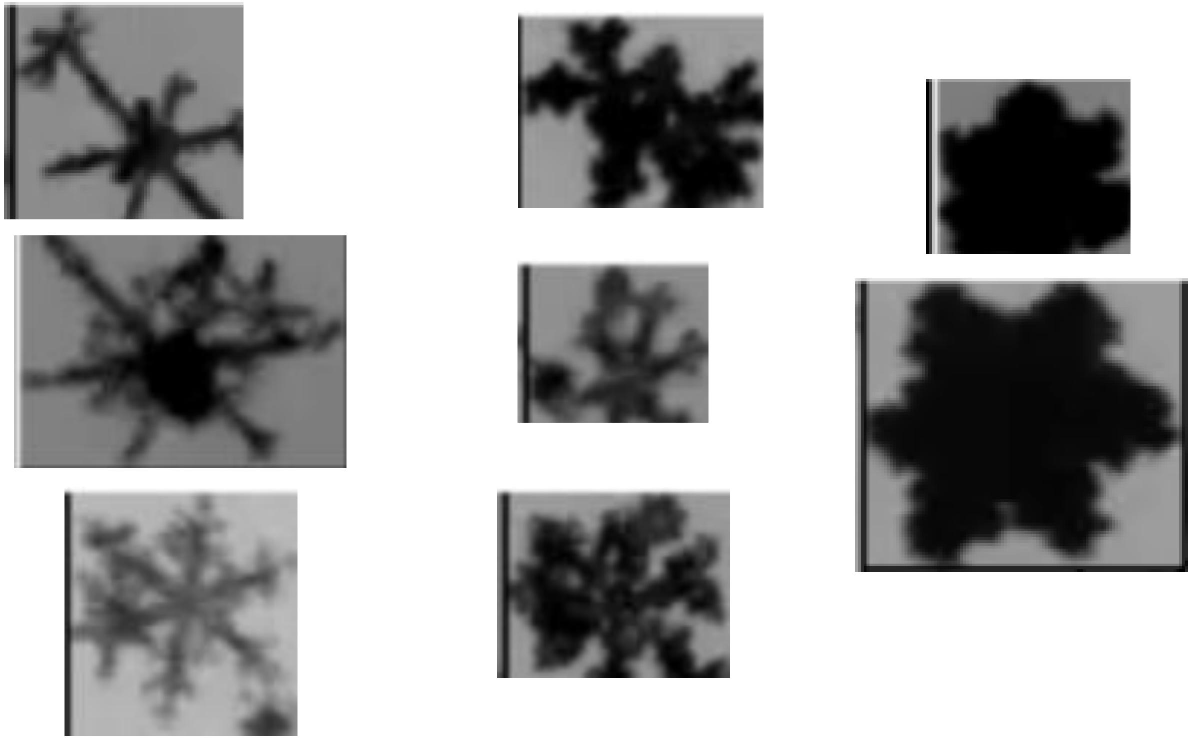
Nakaya Diagram

ICE PARTICLE CLASSES

- Stellars
- Needles/ Columns
- Plates
- Ufos
- Aggregates
- Graupel
- Sphericals
- Too_small — Dmax < 5 px (0.29 mm)
- For each class 200 particles



WHAT KIND OF PARTICLE SHAPE IS THIS?



Aggregates, Dendrites, or already Graupel?

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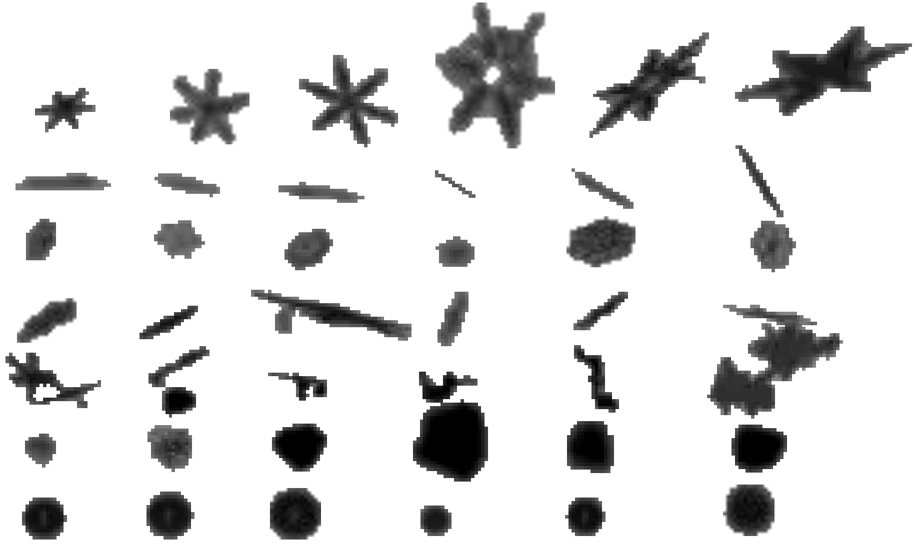
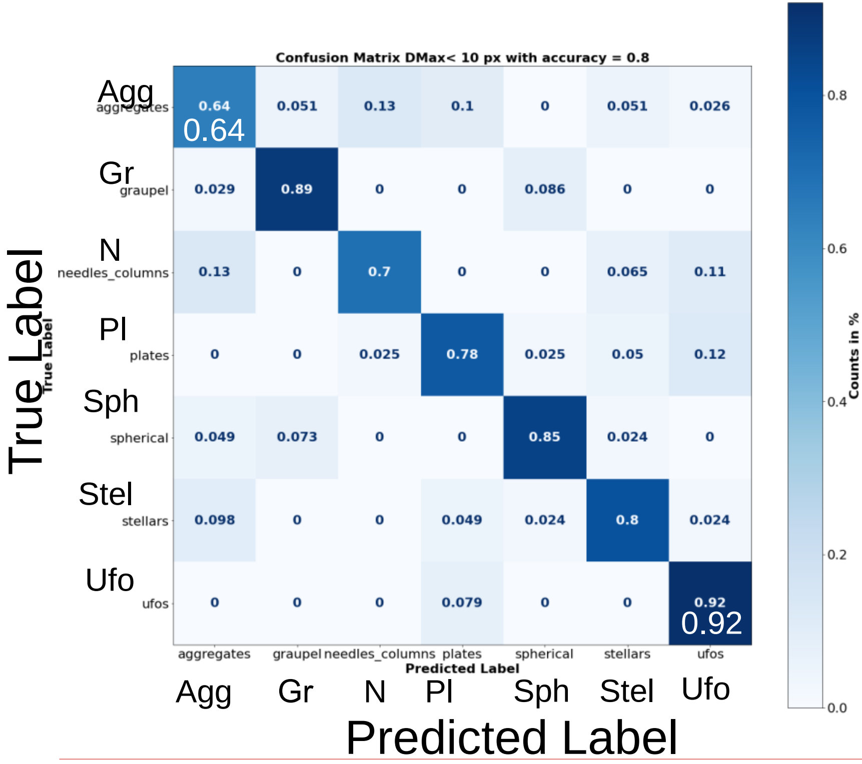
POTENTIAL CLASSIFICATION PROBLEMS

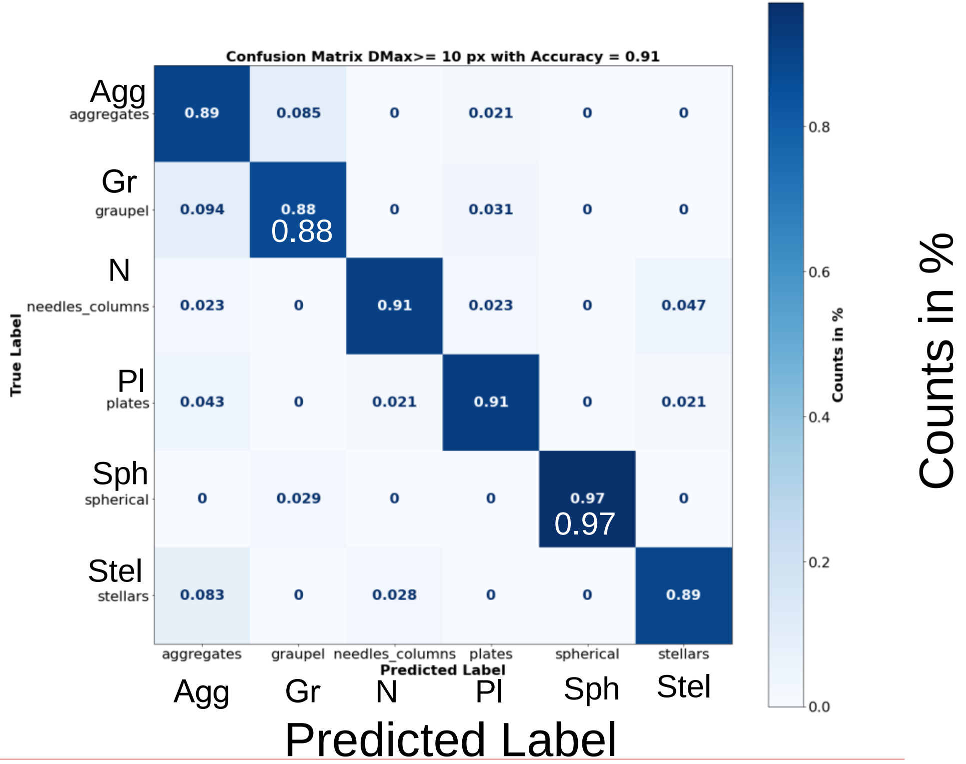


- Stellars
- Needles/ Columns
- Plates
- Ufos
- Aggregates
- Graupel
- Sphericals
- Too_small Dmax < 5 px (0.29 mm)
- For each class 200 particles, too few particles, too perfect ones …
- Unclassified: probabilty <=50 % for one shape

HOW TO CLASSIFY ICE PARTICLES?

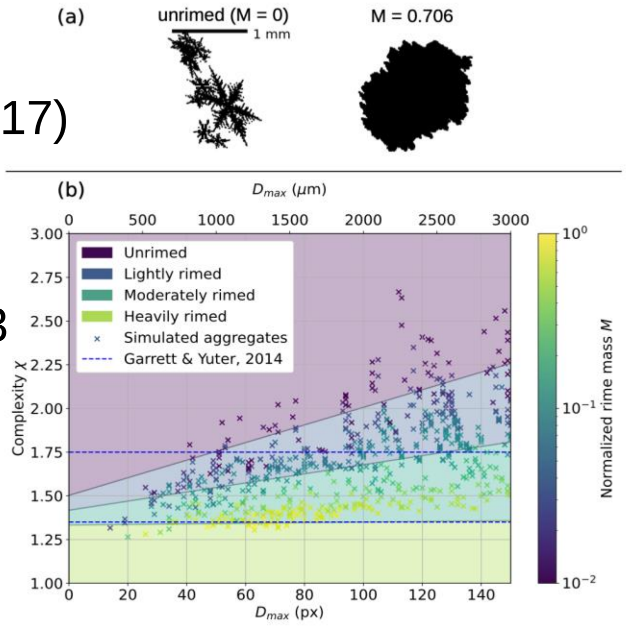
Confusion matrix for small and large particles, HistGradientBoostingClassifier





HOW MUCH IS A PARTICLE RIMED?

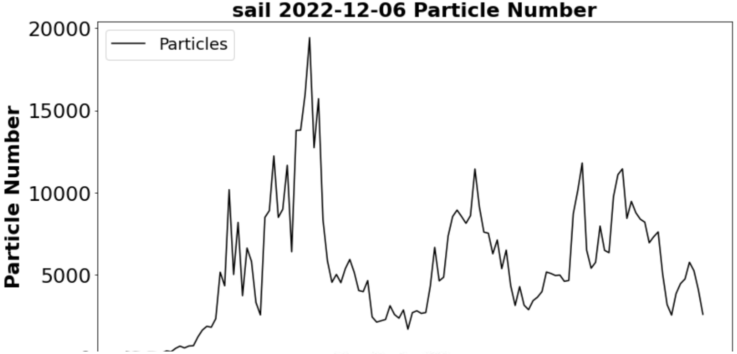
- <u>In-situ method:</u>
- Riming changes shape to more spherical particles
- Complexity **χ**: Perimeter/(2√(**π***Area)) Gergely et al. (2017)
- Sphere: **χ**=1
- Not size independent, larger particles have larger **χ**
- Relation between **χ**, M and size by Maherndl et al. 2023
  - *M* < 0.01 unrimed
  - 0.01-0.1 lightly rimed
  - 0.1-1 moderately rimed
  - *M* ≥ 1.0 heavily rimed

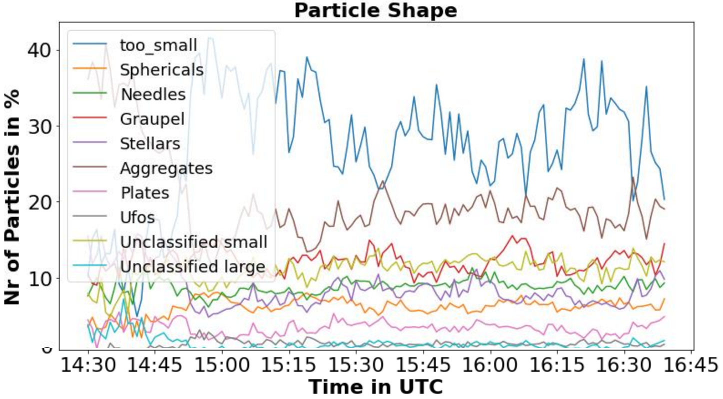


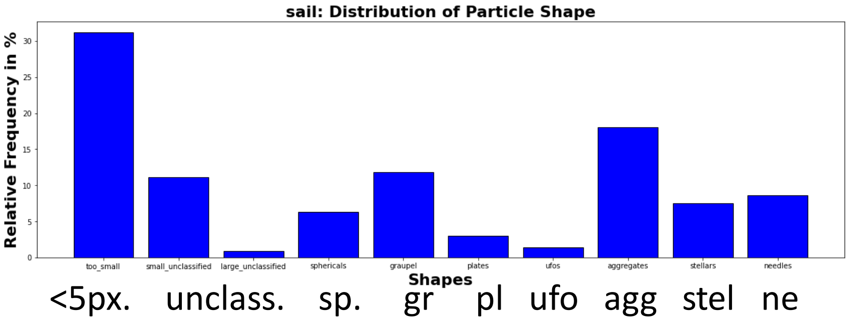
Maherndl et al. (2023)

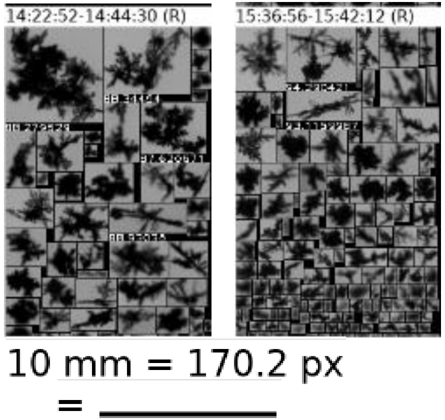
CASE STUDY

PARTICLE SHAPE DISTRIBUTION, IN GOTHIC ON 2022-12-06, SAIL





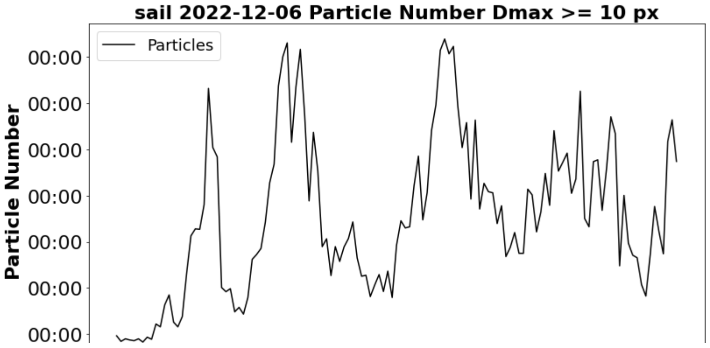


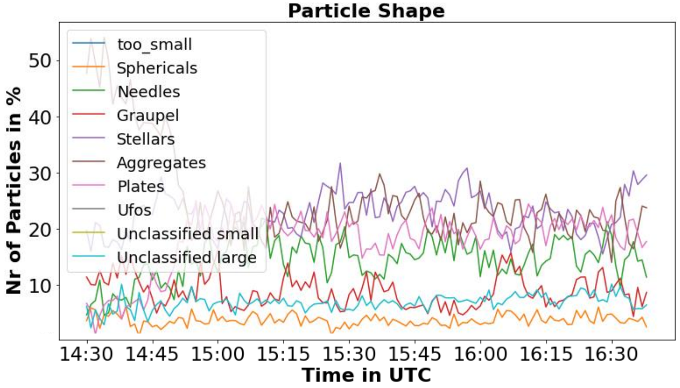


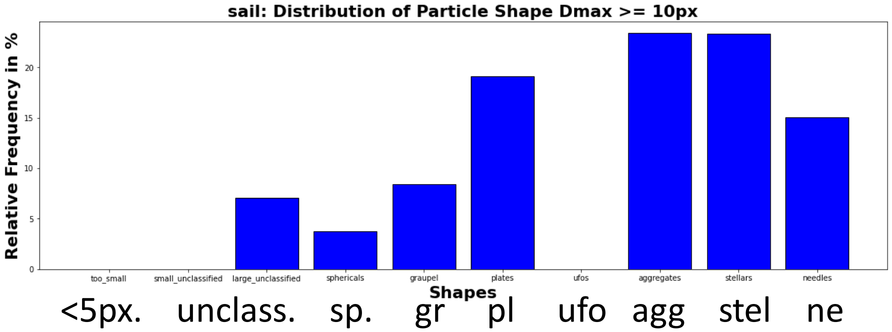
- large mixture of different particle shapes
- high number of too small particles
- small particles have stronger problems by classification

CASE STUDY

PARTICLE SHAPE DISTRIBUTION DMAX >=10PX, 0.58MM, IN GOTHIC ON 2022-12-06, SAIL



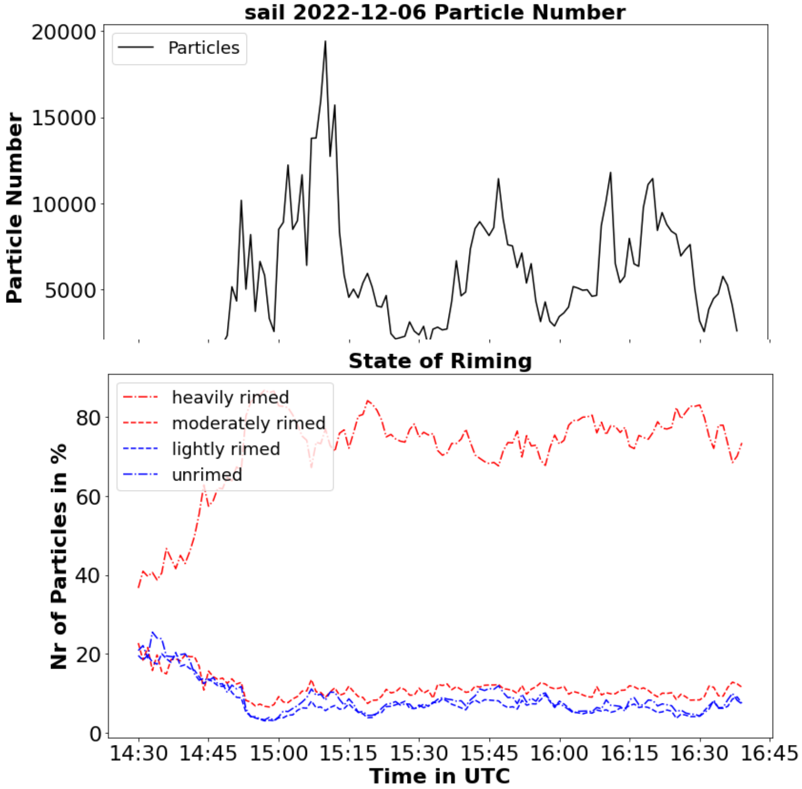


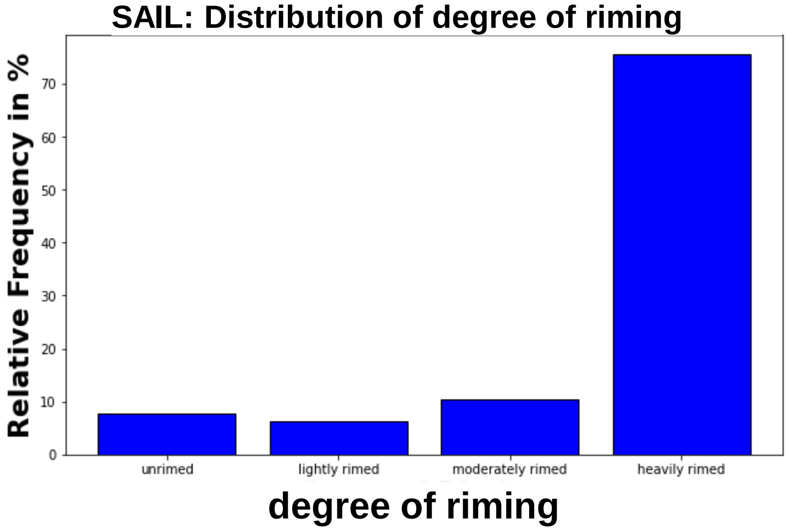


- mostly aggregates and stellars
- plates and needles
- some graupel
- few unclassified particles

CASE STUDY

Degree of Riming in Gothic on 2022-12-06, SAIL





$M < 0.01$, 0.01-0.1, 0.1-1, $M \geq 1.0$

- extrem high number heavily rimed
- high number of small (compact) particles

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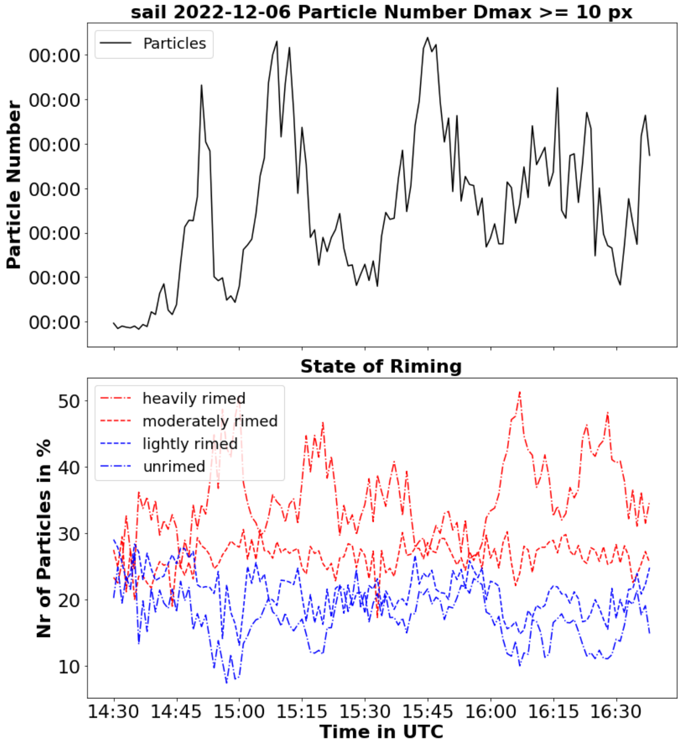
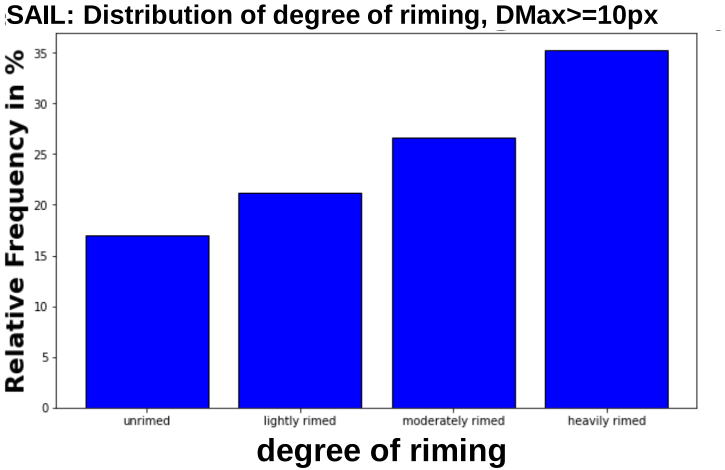
CASE STUDY

Degree of Riming DMax >=10px, 0.58MM, in Gothic on 2022-12-06, SAIL





$M < 0.01$, 0.01-0.1, 0.1-1, $M \geq 1.0$

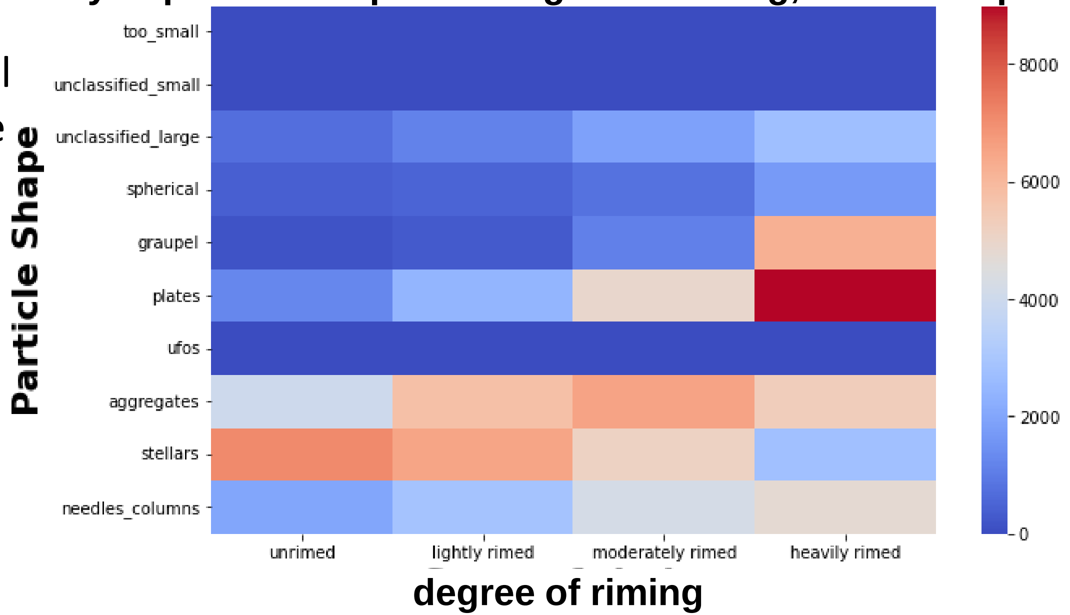
- more rimed particles than unrimed particles
- some unrimed particles
- many heavily rimed particles

CASE STUDY

Degree of Riming vs. Particle Shape in Gothic in December 2022, SAIL, DMax >= 10px

Frequency of particle shape and degree of riming, DMax>=10px

<5px.
unclass. small
unclass. large
sp.
gr
pl
ufo
agg
stel
ne

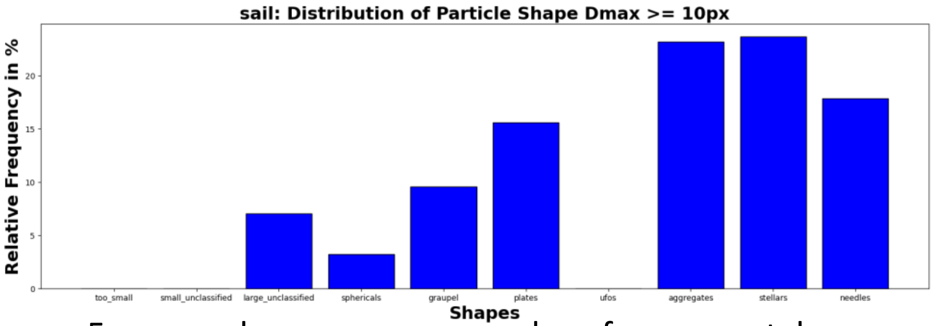


$M < 0.01$, 0.01-0.1, 0.1-1, $M \geq 1.0$

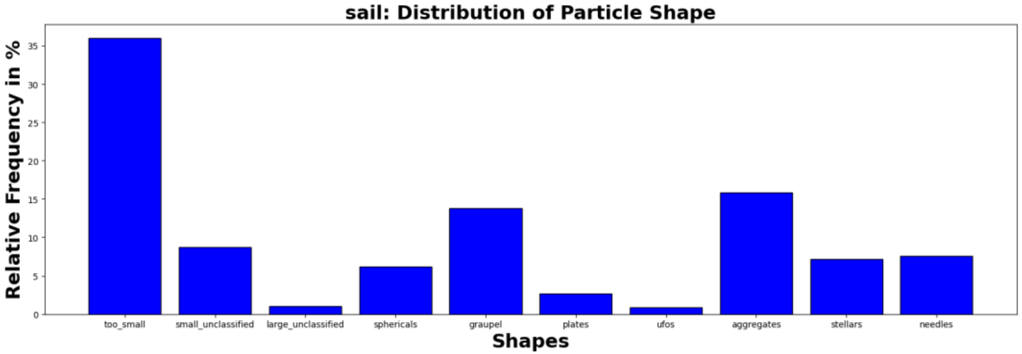
- small/ compact particles
  -> heavily rimed
- plates, graupel
  -> heavily rimed
- aggregates
  -> lightly & moderate rimed
- stellars
  -> mostly unrimed

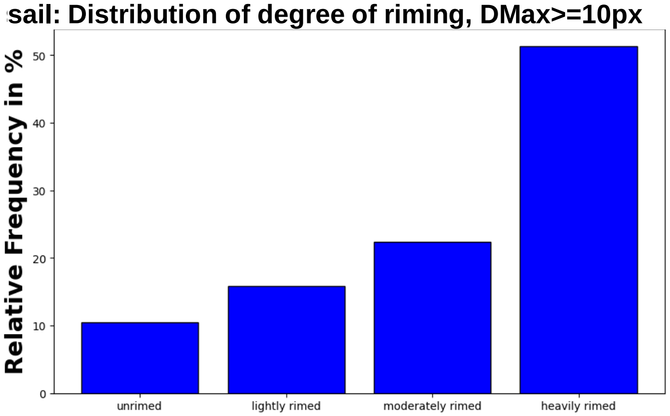
CASE STUDY

Degree of Riming vs. Particle Shape in Gothic on 2022-12-06, SAIL, DMax >= 10px



<5px. unclass. sp. gr pl ufo agg stel ne





degree of riming

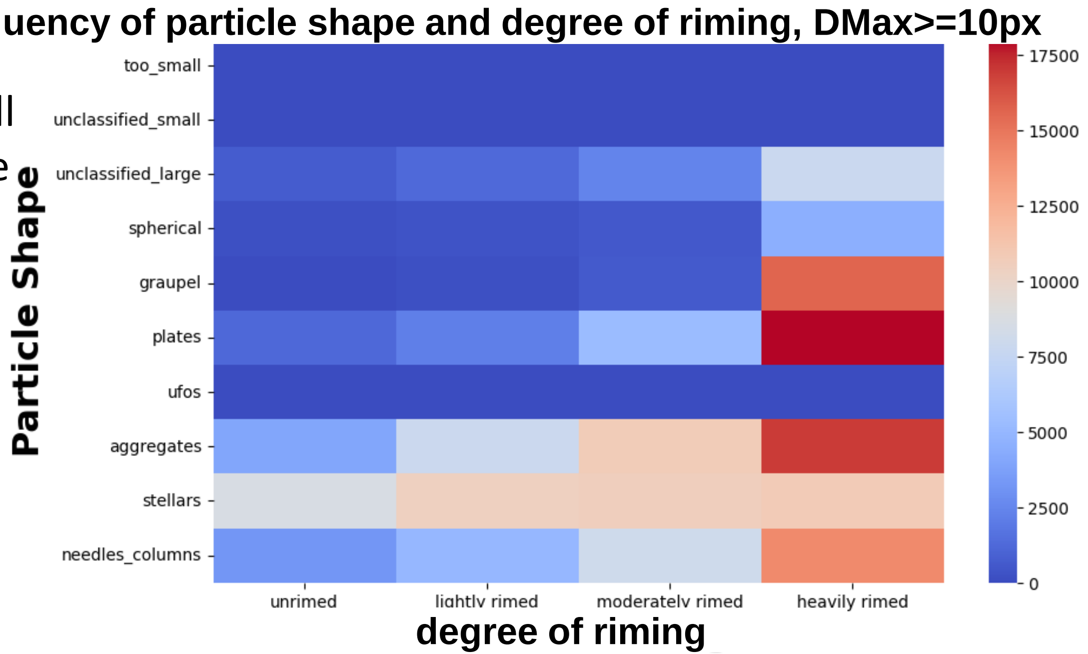
$M < 0.01$, 0.01-0.1, 0.1-1, $M \geq 1.0$

- too_small most particles
- unclassified large less than unclassified small
- mostly stellars, aggregates,
- needles and plates
- some graupel
- more rimed particles than unrimed particles

CASE STUDY

Degree of Riming vs. Particle Shape in Gothic in December 2022, SAIL, DMax >= 10px

<5px.
unclass. small
unclass. large
sp.
gr
pl
ufo
agg
stel
ne



$M < 0.01$, 0.01-0.1, 0.1-1, $M \geq 1.0$

- small/ compact particles
  -> heavily rimed
- plates, graupel
  -> heavily rimed
- aggregates
  -> more rimed
- stellars
  -> less rimed
- needles
  -> why heavily rimed?

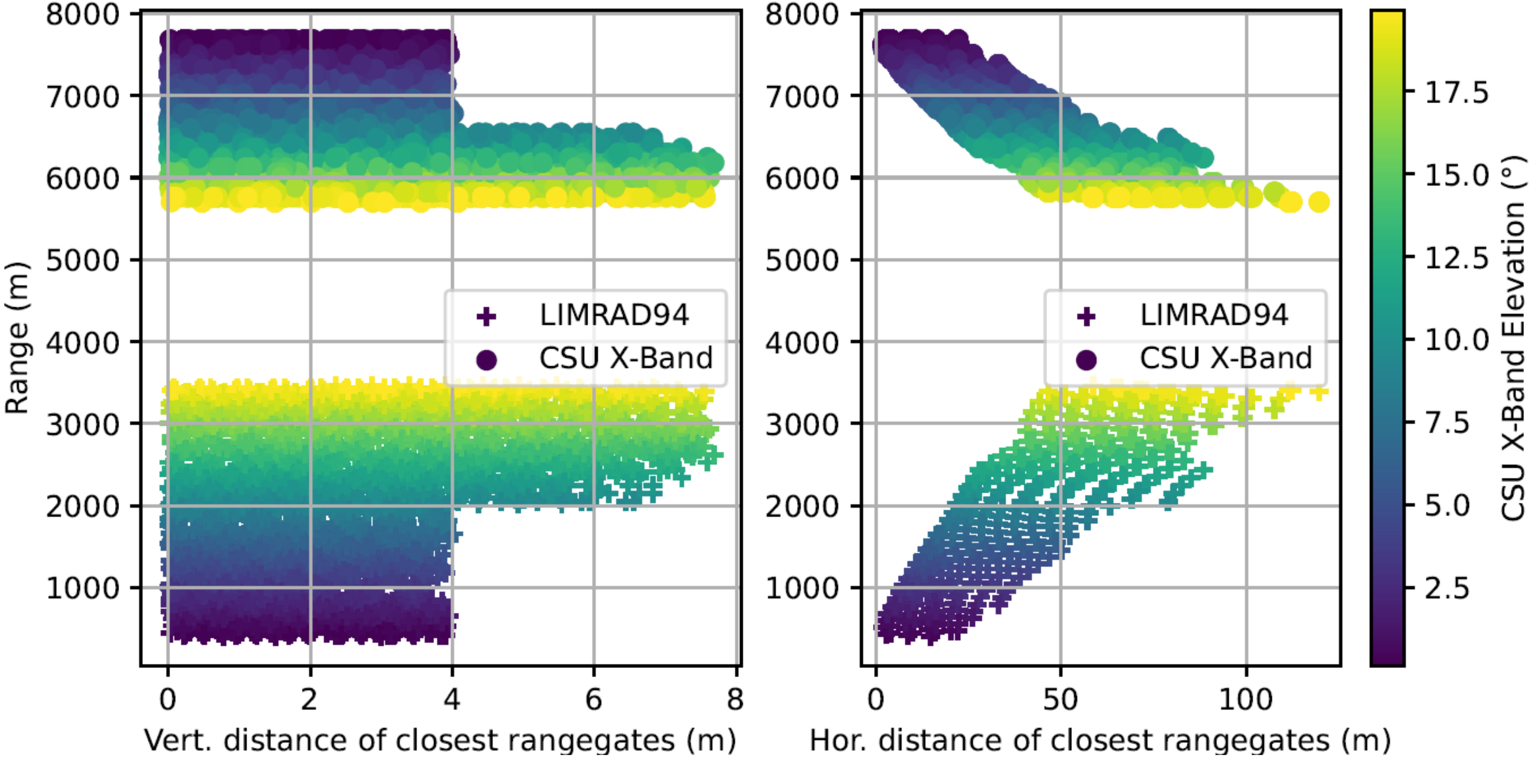
WHAT WE DID:

- Wind and turbulence study
- Precipitation rate and polarimetric variables
- Relation between particle size and KDP
- Relation between wavelength ratio and KDP
- KDP during Fallstreaks
- Algorithm for shape detection
- Case studies and statistics of particle properties (size, shape, riming)
- Presentations/Posters at AGU, Snowfall Workshop, ...
- Drafts in the pipeline

HOW WE WANT TO GO ON:

- Combine particle properties with Radar variables
- Include polarimetric parameters to PAMTRA
- Estimate polarimetric scattering properties

BACKUP: DISTANCE OF X/W RANGE GATES



BACKUP: WIND RETRIEVAL