



Pomodori

Combining radar **P**olarimetry, weather forecast **M**odel outputs and **D**oppler radar observations for **R**iming analysis

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POMODORI: analysis of riming

- Growth of frozen hydrometeors by **capturing supercooled liquid water** droplets
- **Increase in particle density** and **modification of shape** (up to spherical graupel)



adapted from Garrett and Yuter (2014)

3 frozen hydrometeors of similar size (~ 4 mm) with increasing degree of riming (or **rime mass fraction** = rimed mass / total mass) from pristine dendrite to almost spherical graupel, from L to R.



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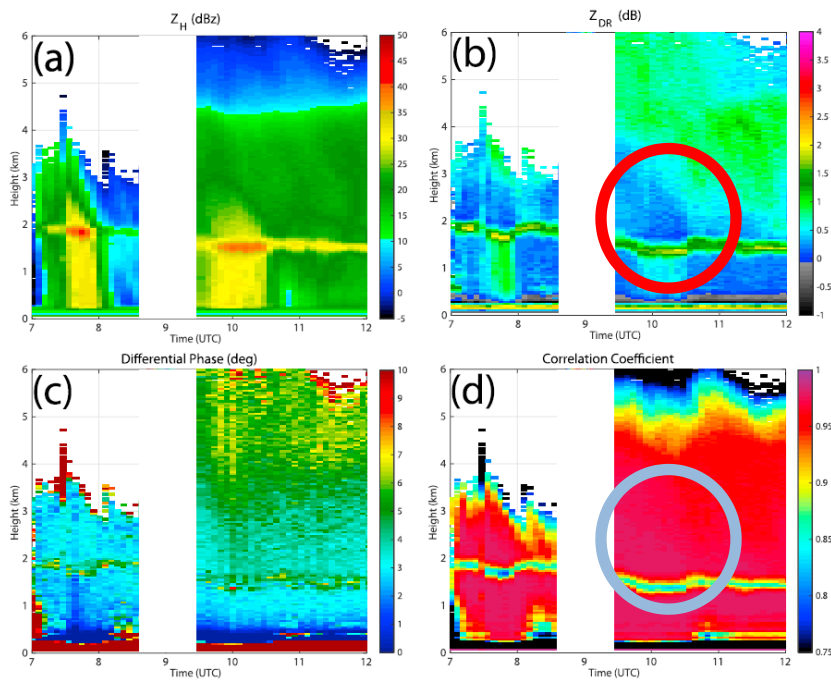
- modified interaction with EM radiation (and thus radar characteristics that are used for deriving precipitation properties)
- link to supercooled liquid water in atmosphere may provide insights into aircraft icing conditions

 How can we detect and quantify riming?



Detection of riming with polarimetric radars

- Intense riming events can be detected via a sagging melting-layer signature in polarimetric radar variables



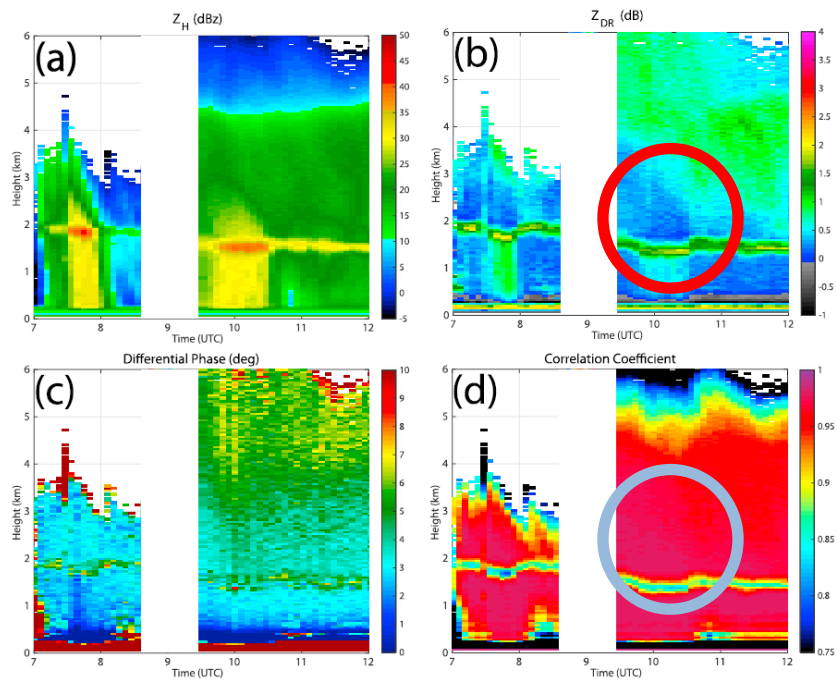
quasi-vertical profiles (QVPs)
of polarimetric variables

adapted from Kumjian et al. (2016)

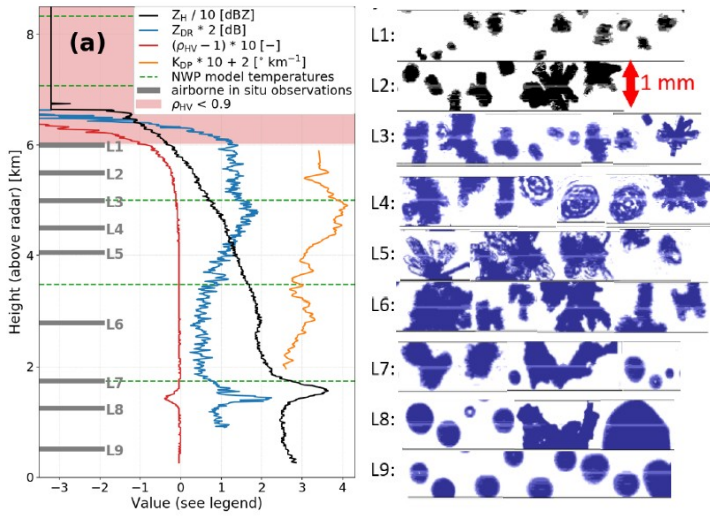


Detection of riming with polarimetric radars

- Intense riming events can be detected via a sagging melting-layer signature in polarimetric radar variables



But what about less intense riming and how to quantify riming from polarimetric measurements?



Non-unique interpretation of polarimetric variables: riming vs. aggregation

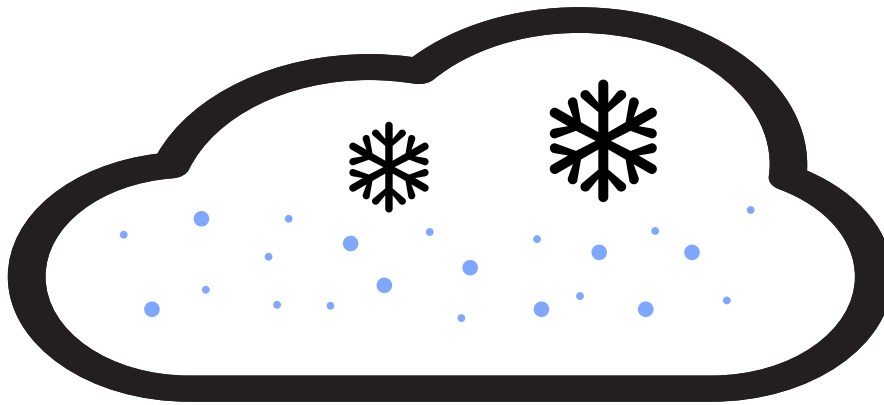
adapted from Trömel et al. (2021), PROM phase 1

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Pomodori

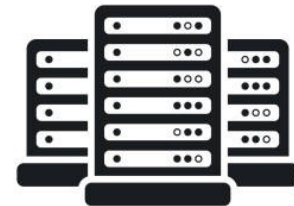


Ka Band Cloud Radar



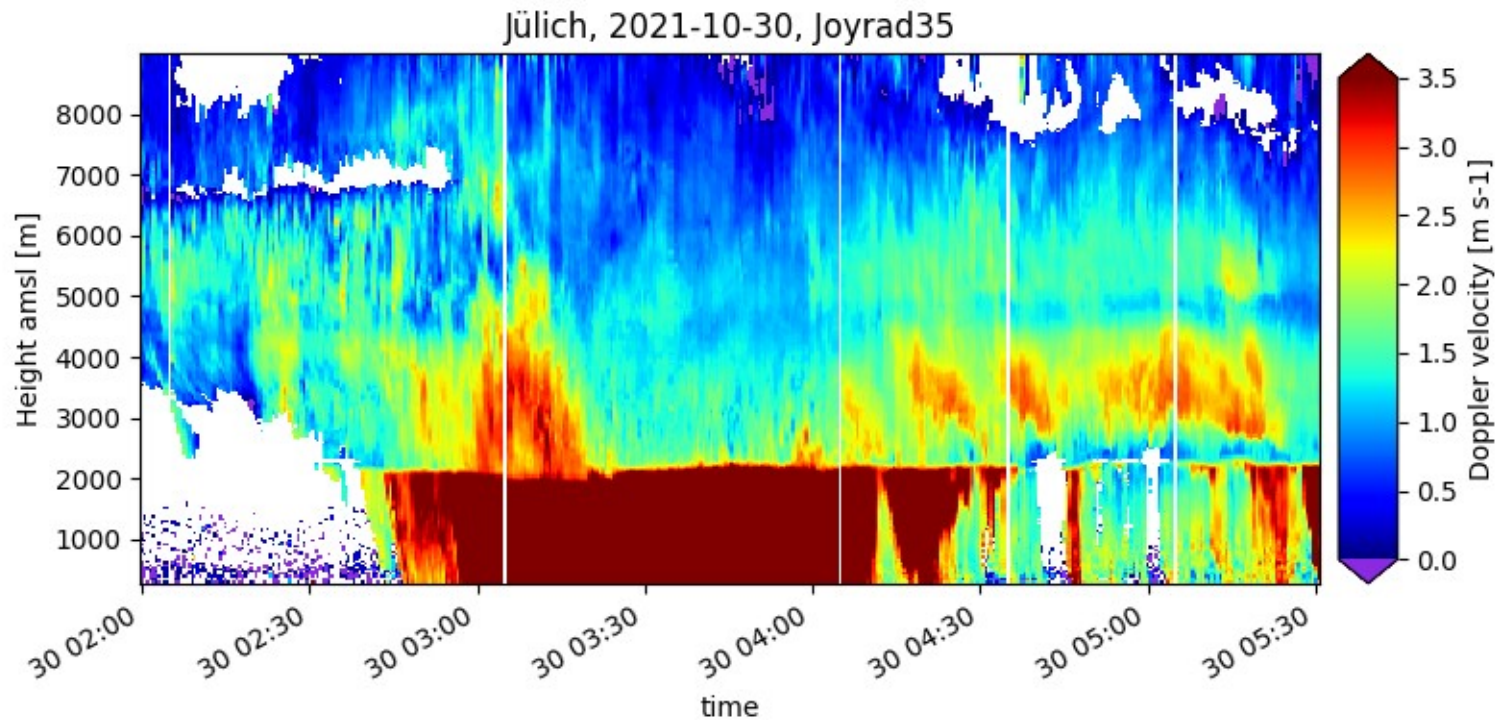
Scanning C Band Radar

+



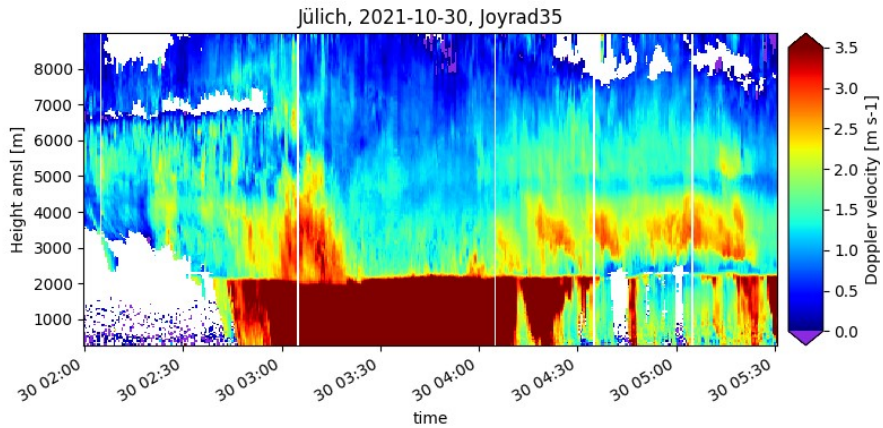


Example: Ka Band Birdbath



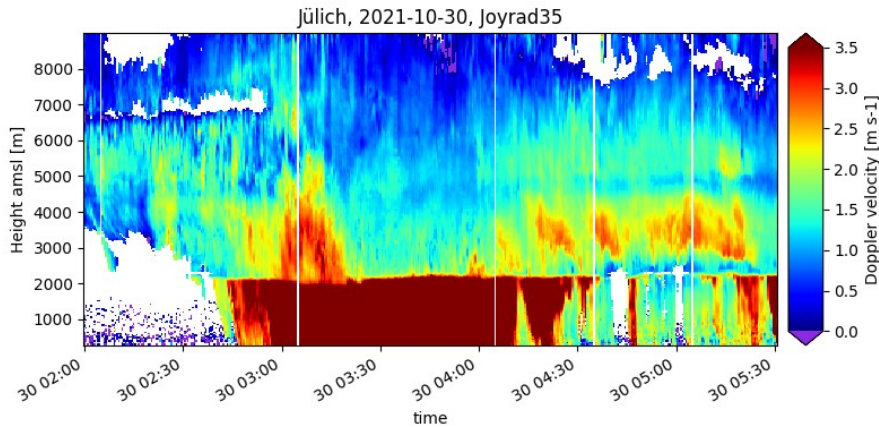


Rime Mass Fraction Retrieval

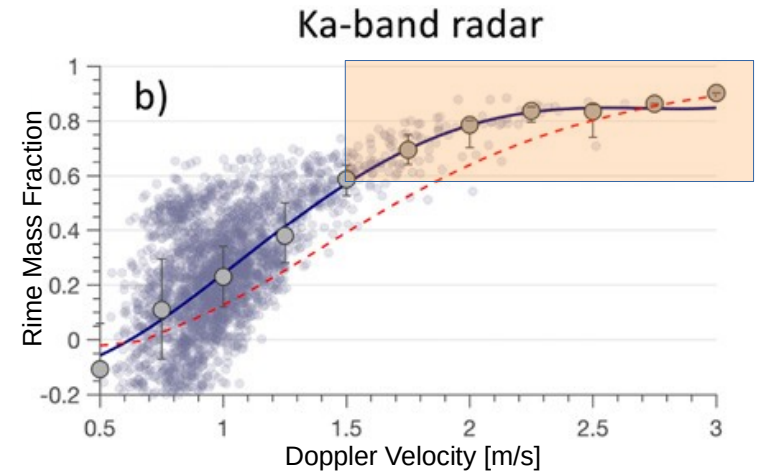




Rime Mass Fraction Retrieval



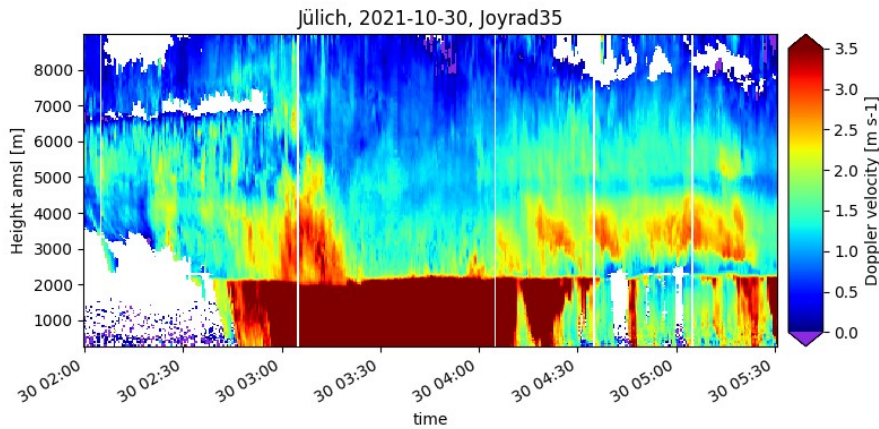
+



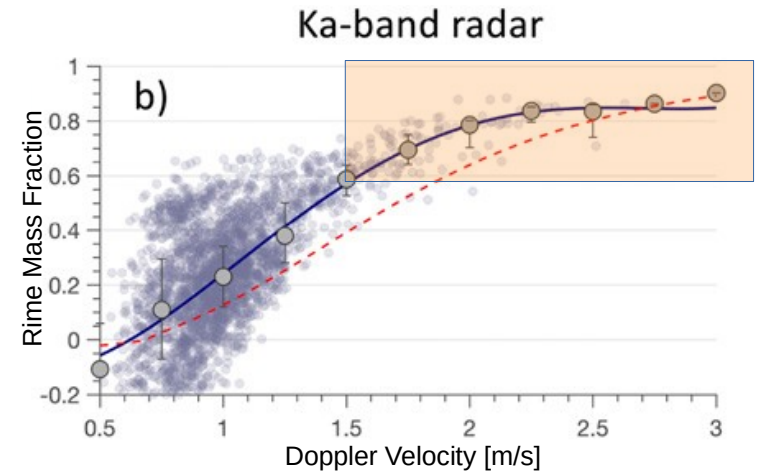
Kneifel, S. & Moisseev, D. JAS, AMS, 2020



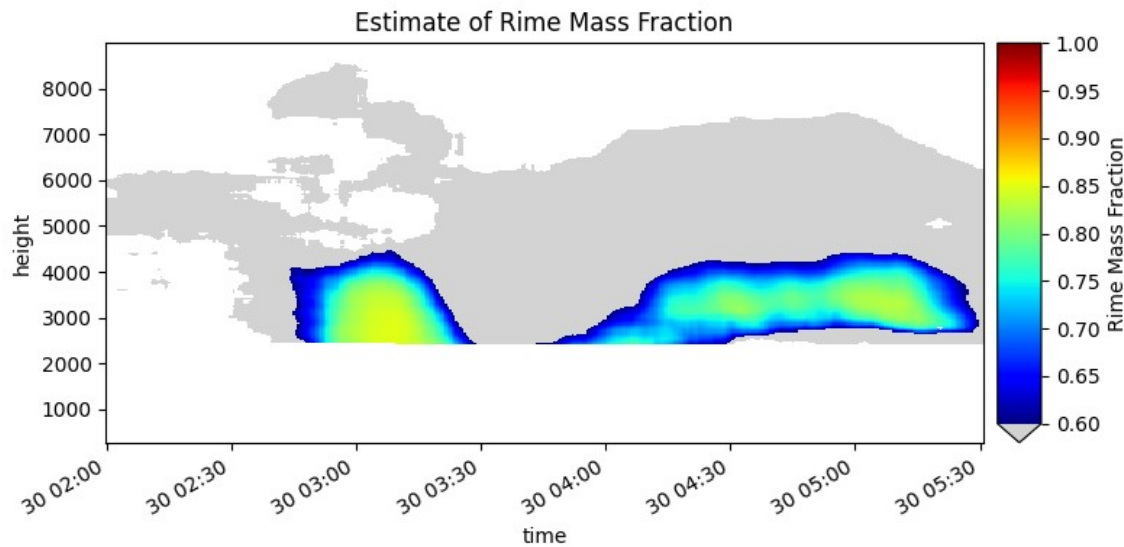
Rime Mass Fraction Retrieval



+

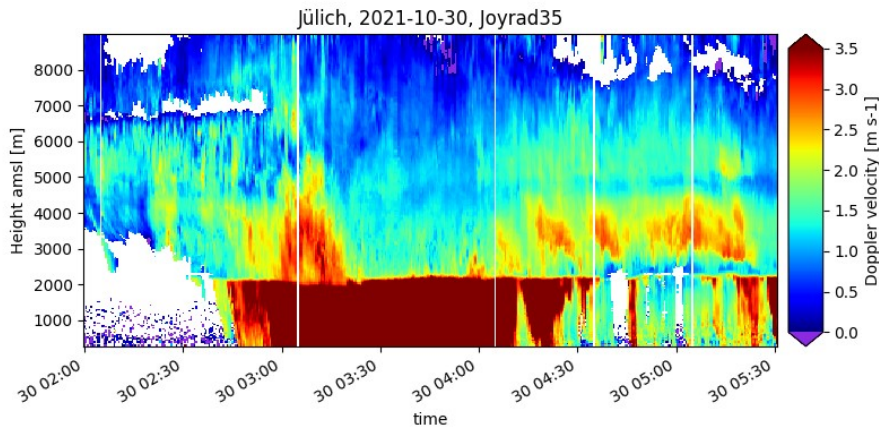


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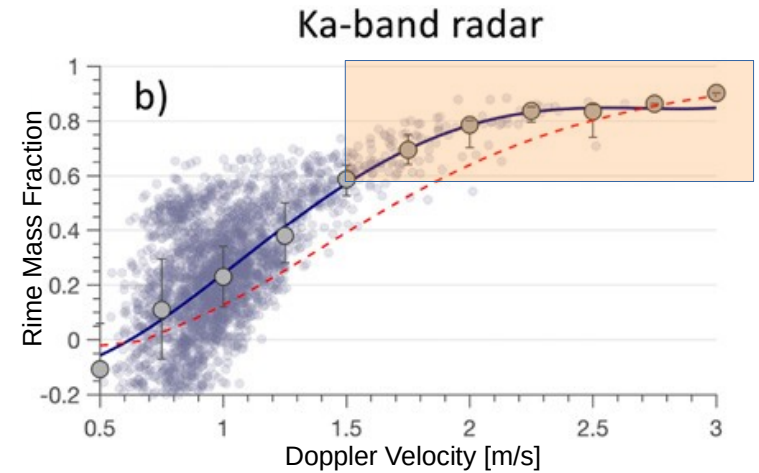




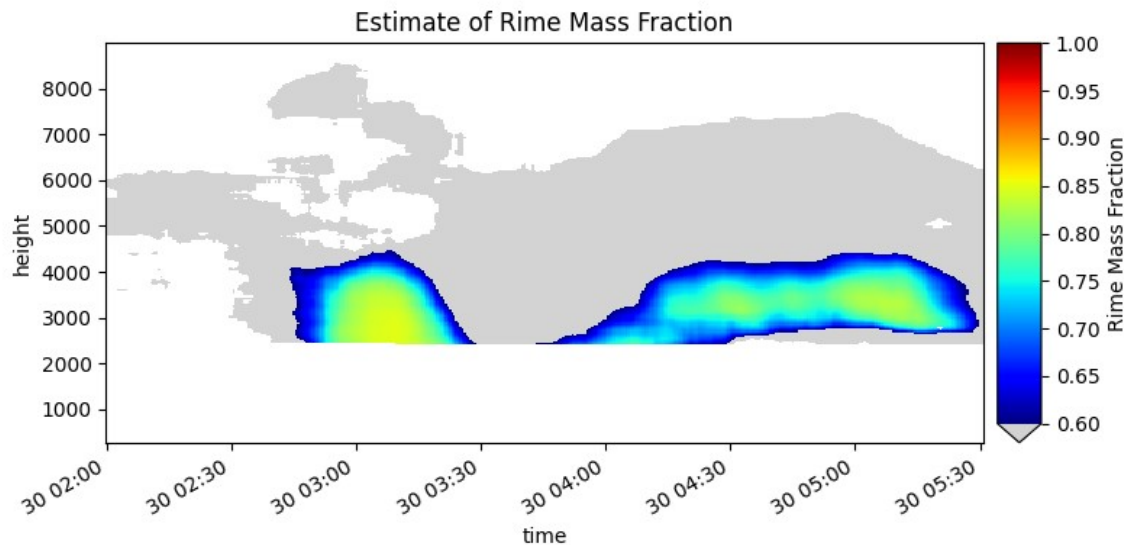
Rime Mass Fraction Retrieval



+



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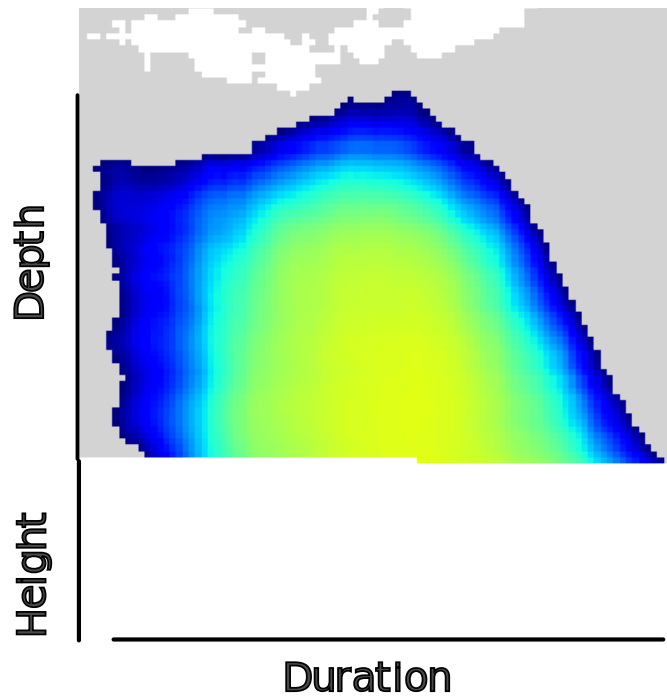


Preprocessing:

- Only stratiform situations
- Only area above melting layer

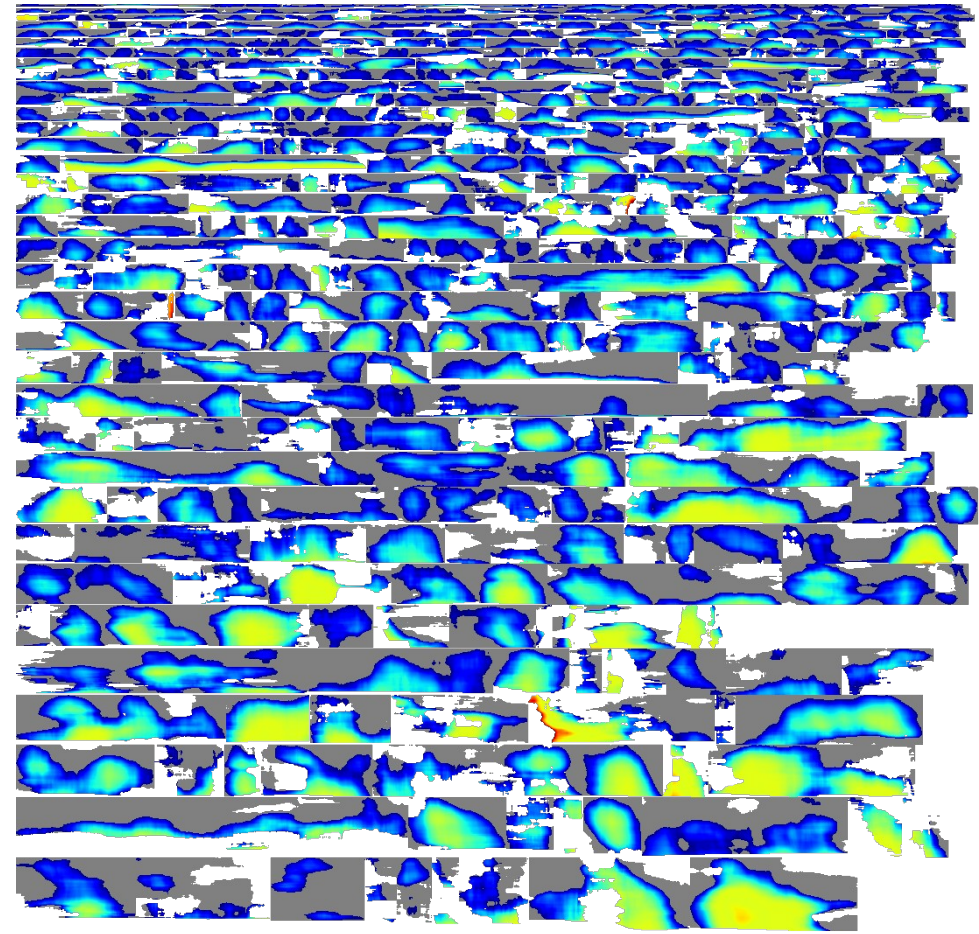
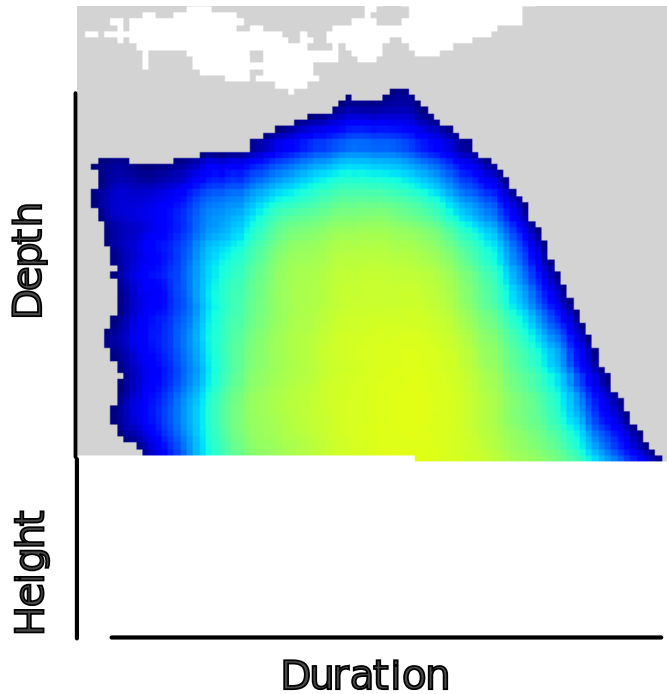


Split into Events!



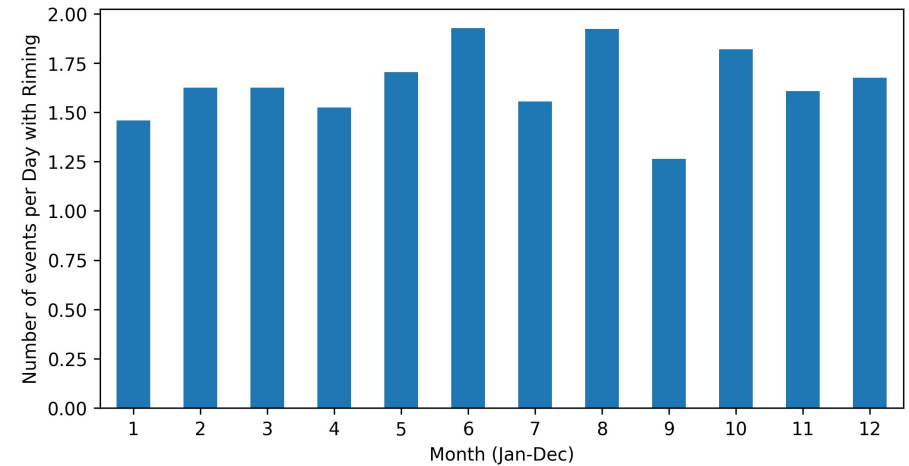
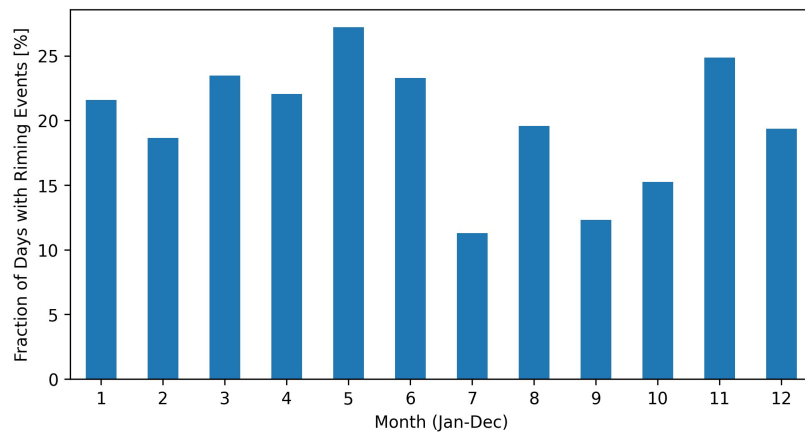


Split into Events!



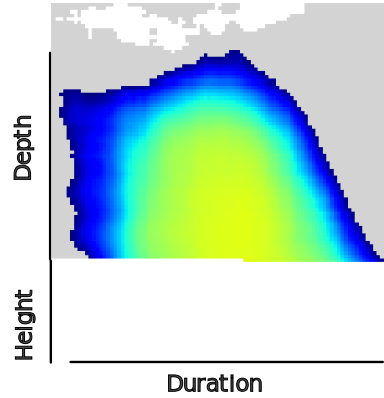


How often?



→ Riming about every 5. day, multiple events per day

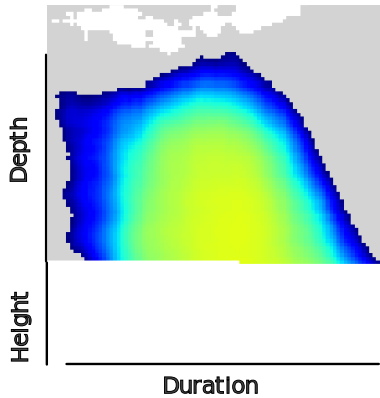
(See also Kneifel, S. & Moisseev, D. JAS, AMS, 2020 for more frequency analyses)



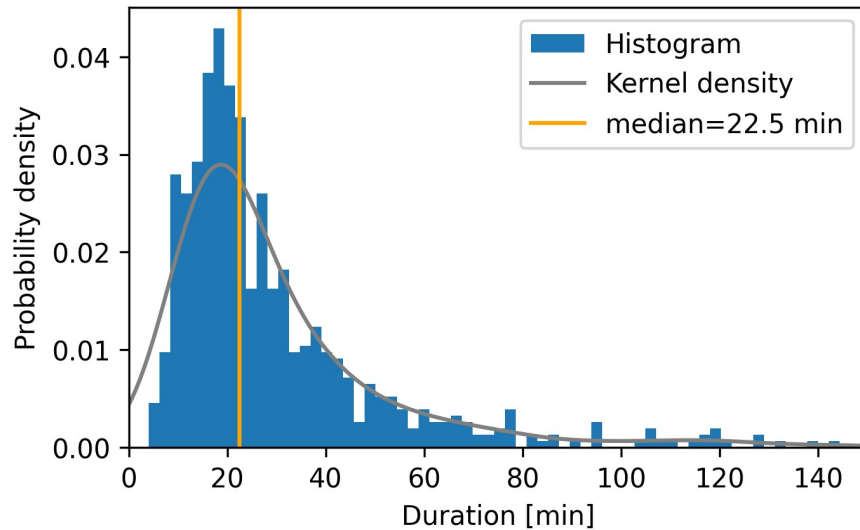
Duration, Height?



Duration, Height?

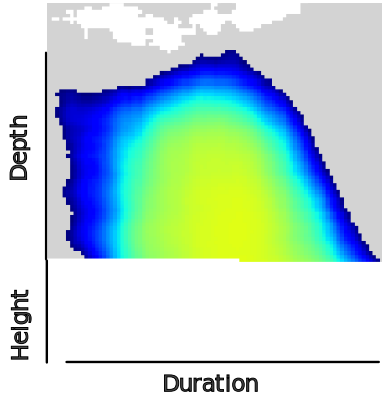


How Long?
→ Median 22 min



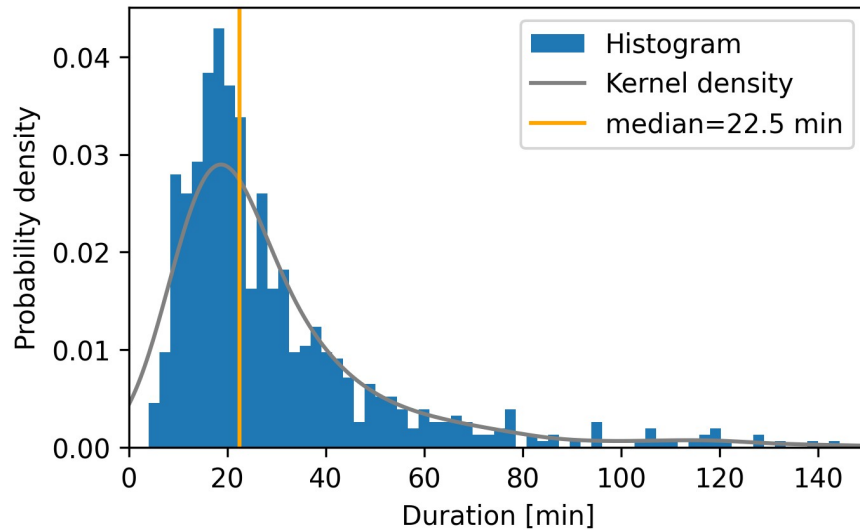


Duration, Height?



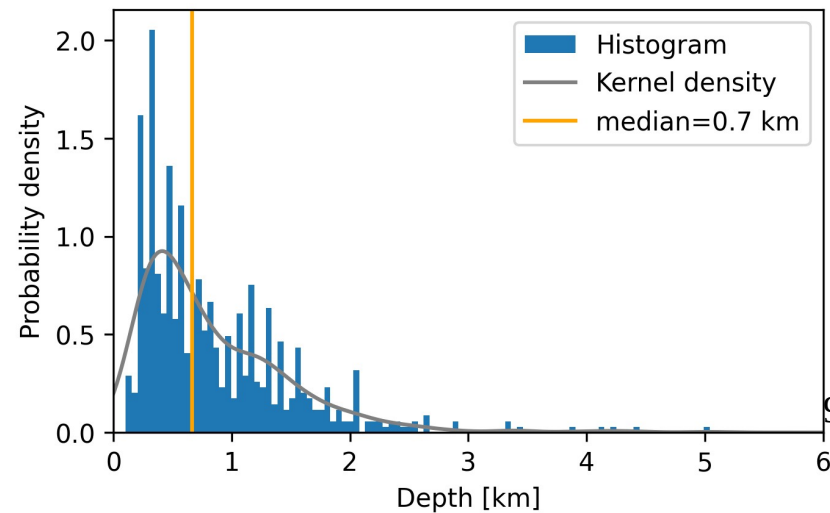
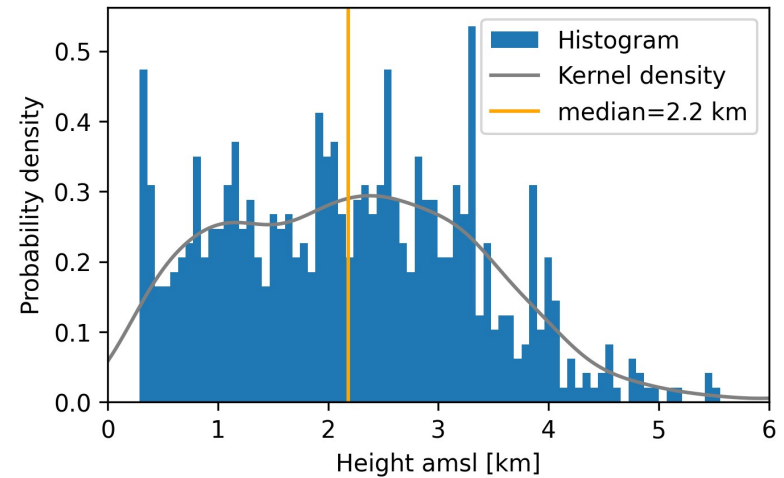
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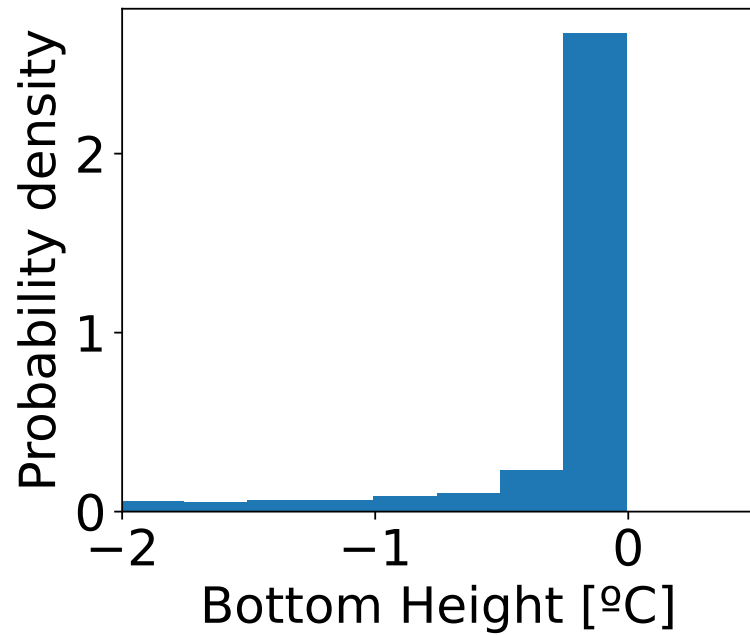
How High?

→ 0-4km, ~1km thick



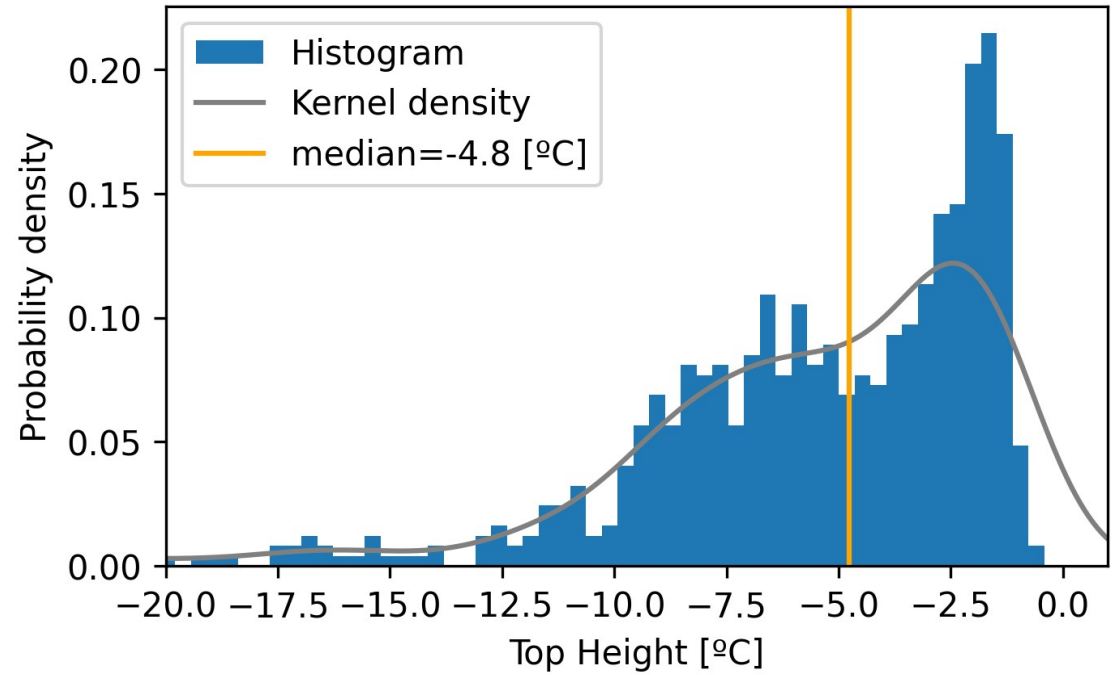
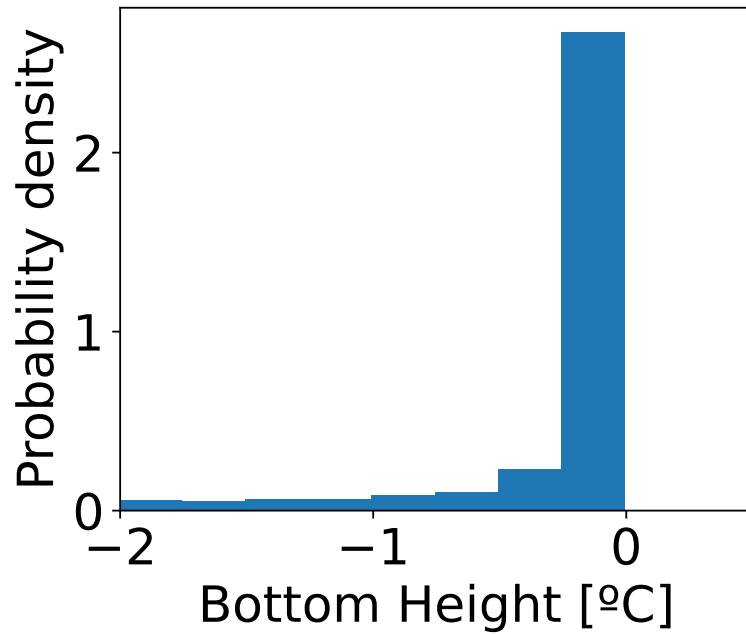


Temperature?



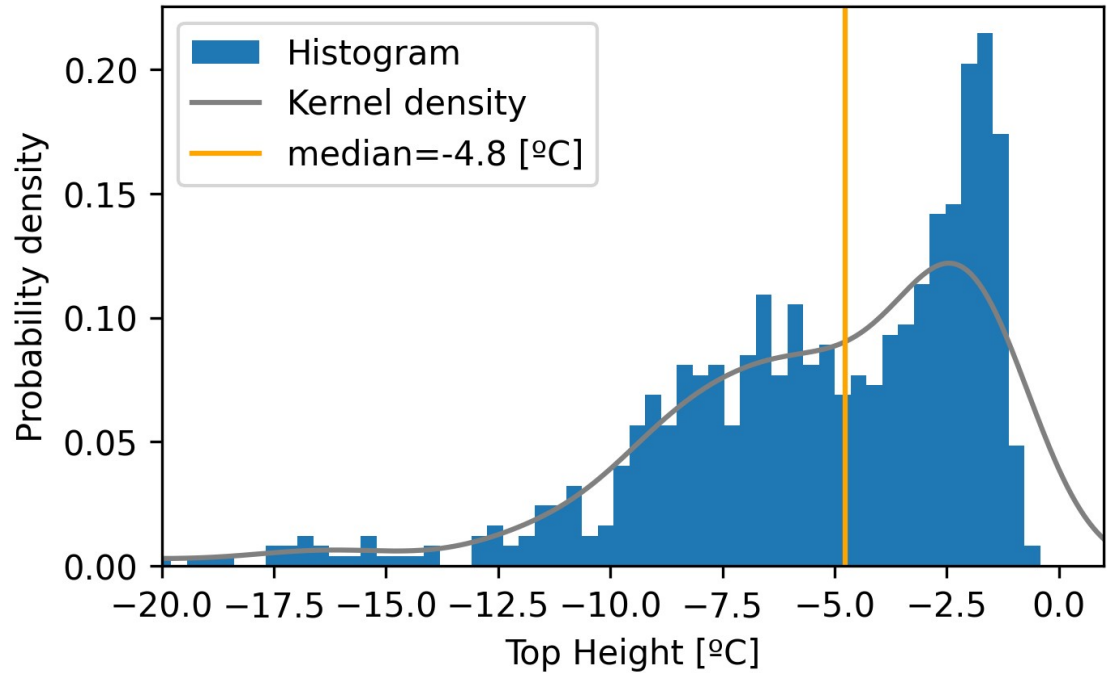
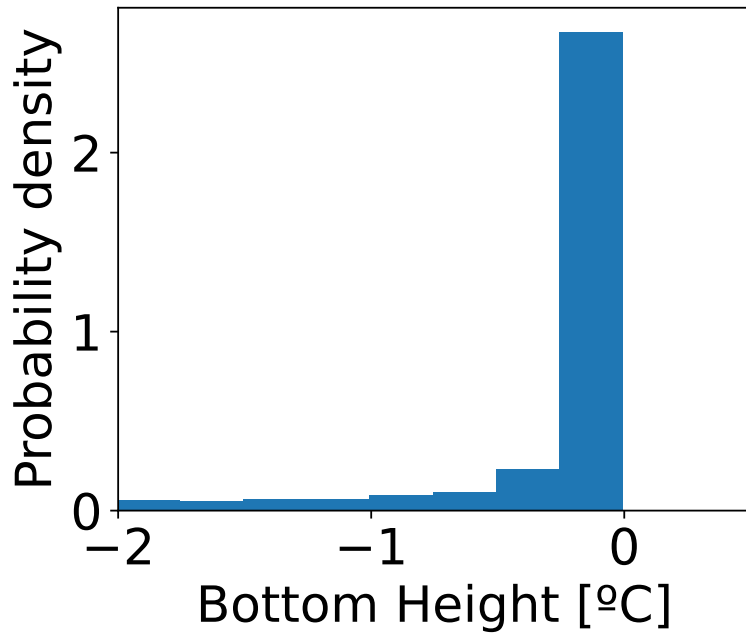


Temperature?





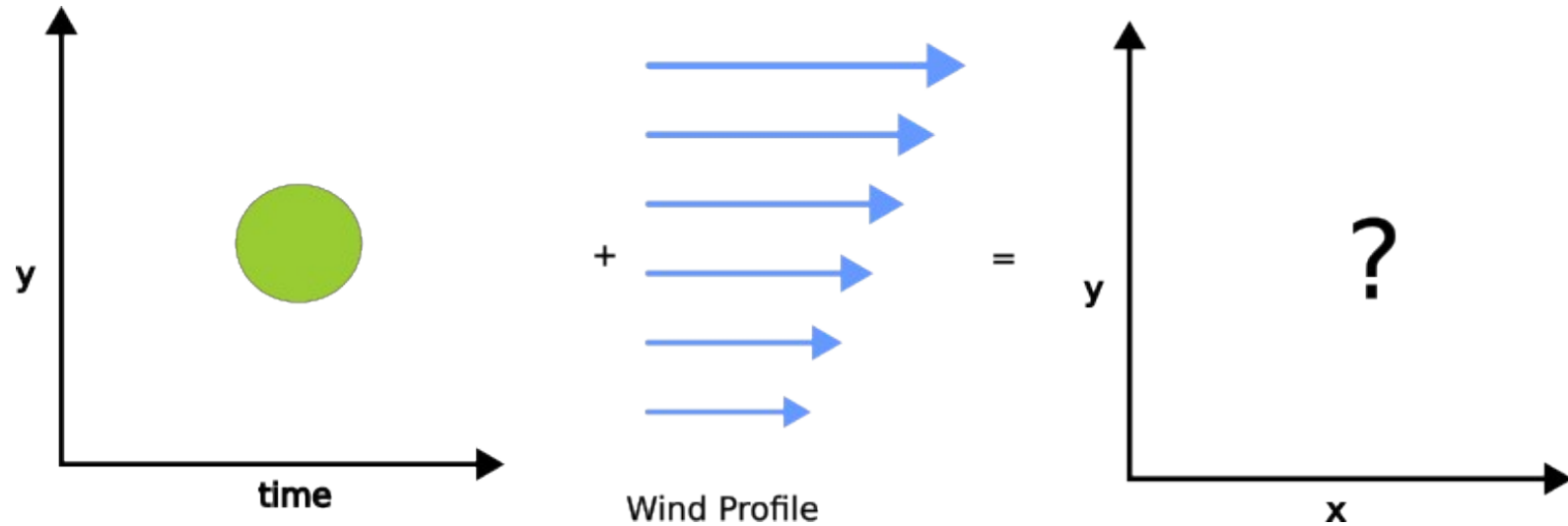
Temperature?



→ From range between 0°C and -15°C until melting layer

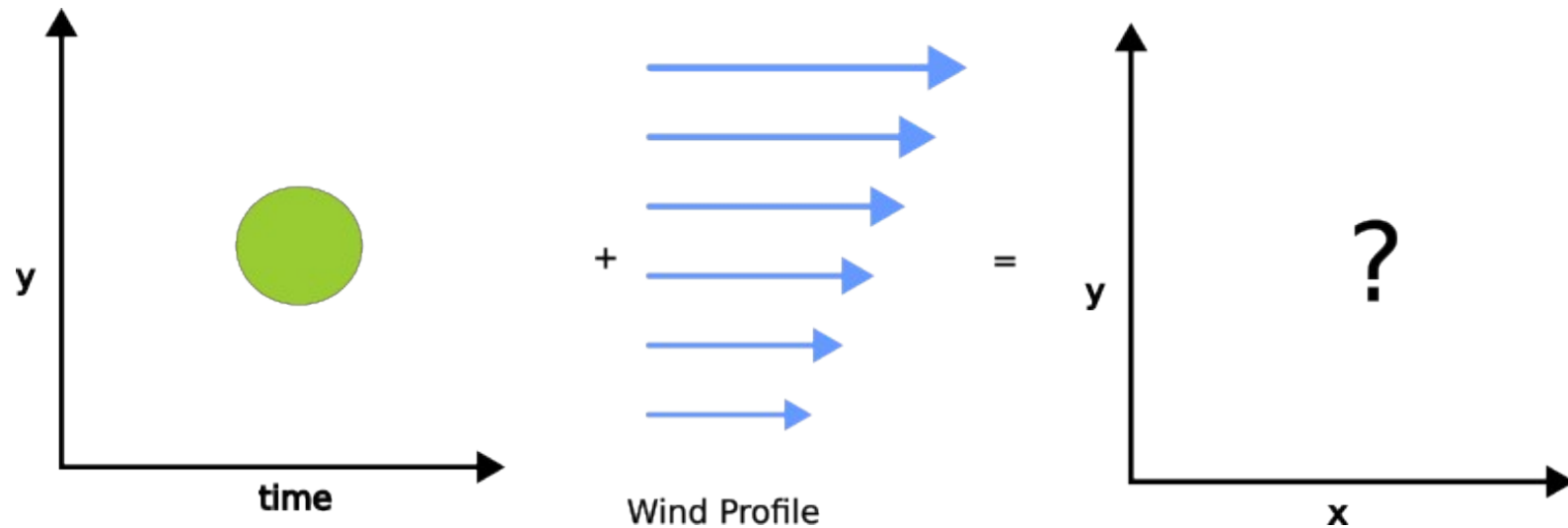


How Wide?





How Wide?

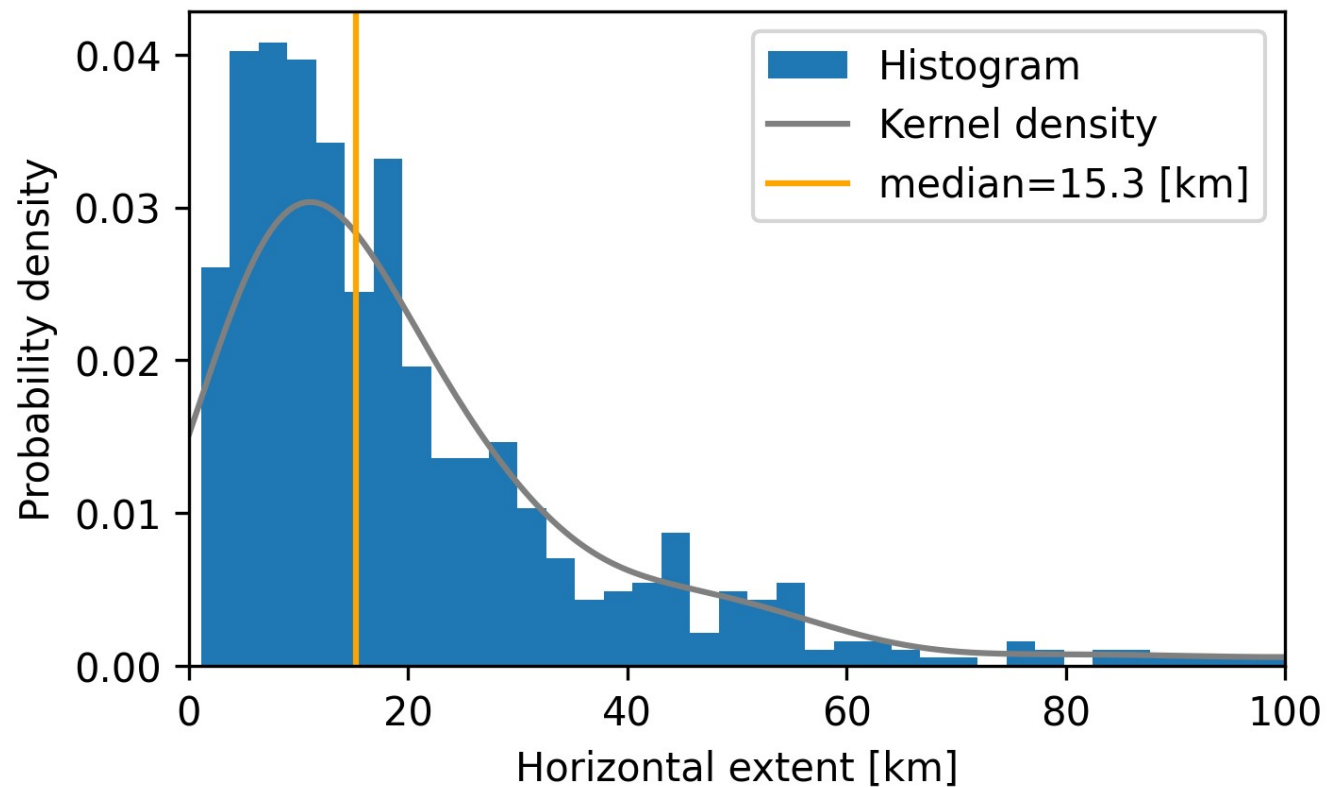


→ Static horizontal advection of the airmass where we see riming, using weather model wind profile

(I spent some time trying different methods to infer spatial structures from time-height measurements, let me know if you have ideas or want to discuss :))



How Wide?



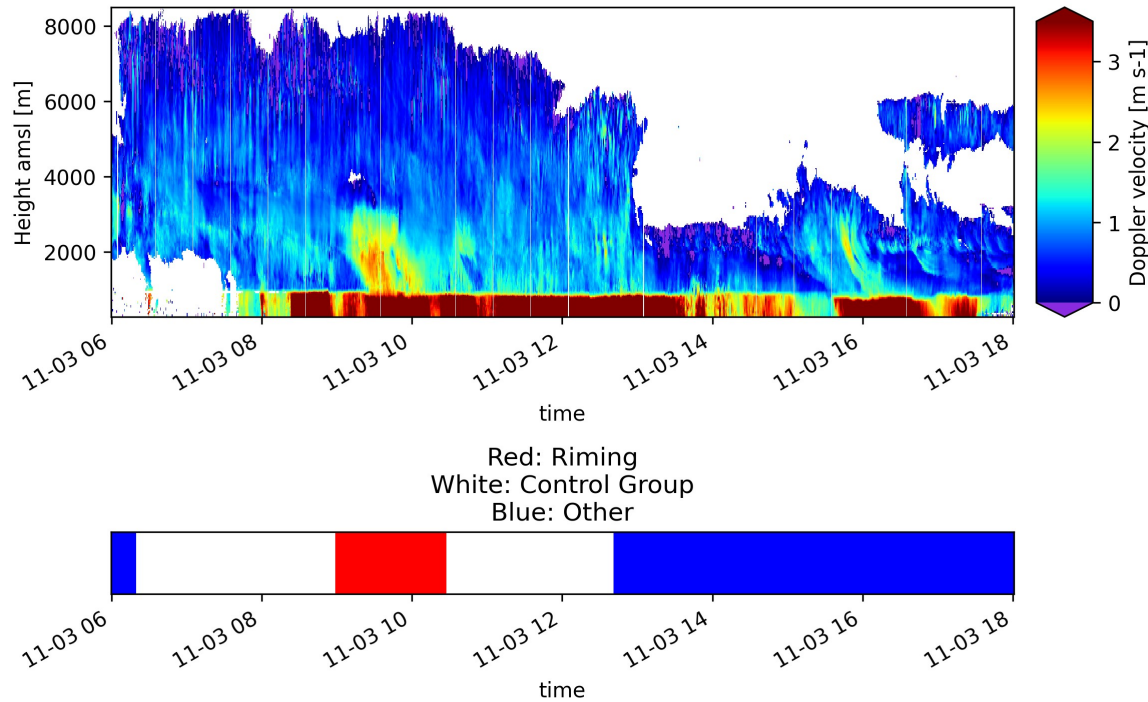


Comparison Lindenberg - Jülich

	Jülich	Lindenberg
Period	13 years	13.5 years
Events total	701	874
Days Riming	20.0%	13.9%
↓ <i>Median</i> ↓		
Duration	22.5 min	23 min
Height	2.18 km	2.02 km
Depth	0.67 km	0.63 km
RMF	0.665	0.661

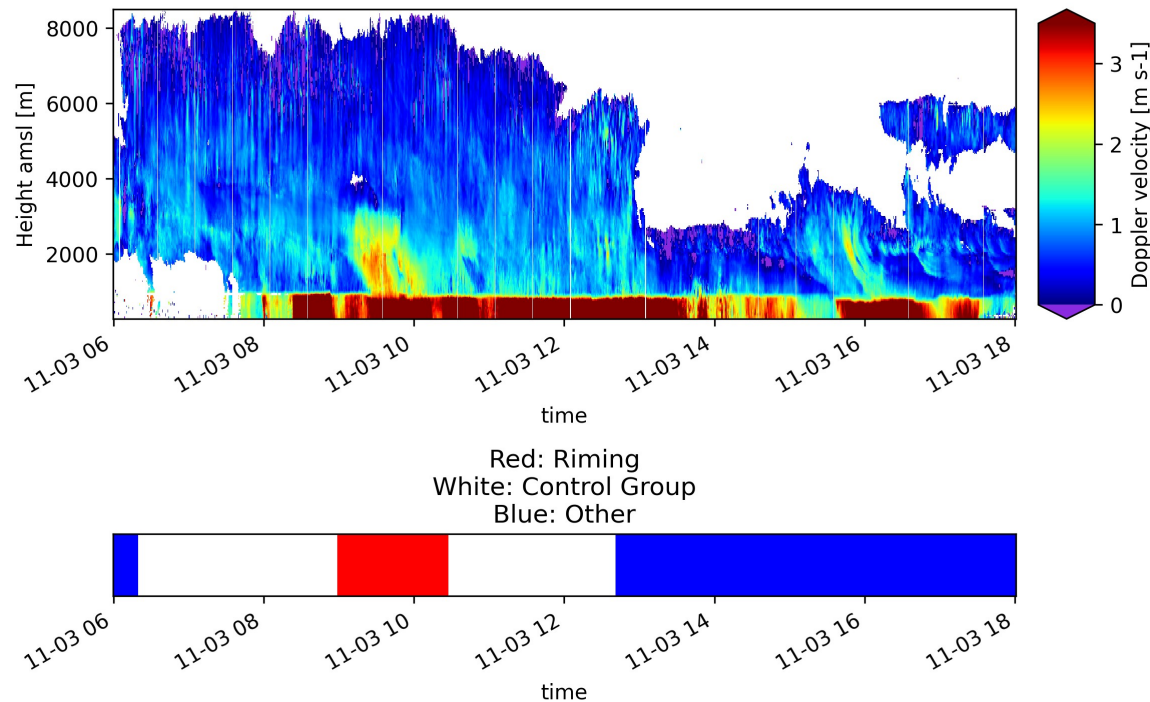


Traces of riming in other datasets?





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Control Group:

- no riming (obviously)

In the 0 °C to -15 °C range at least 250 m with:

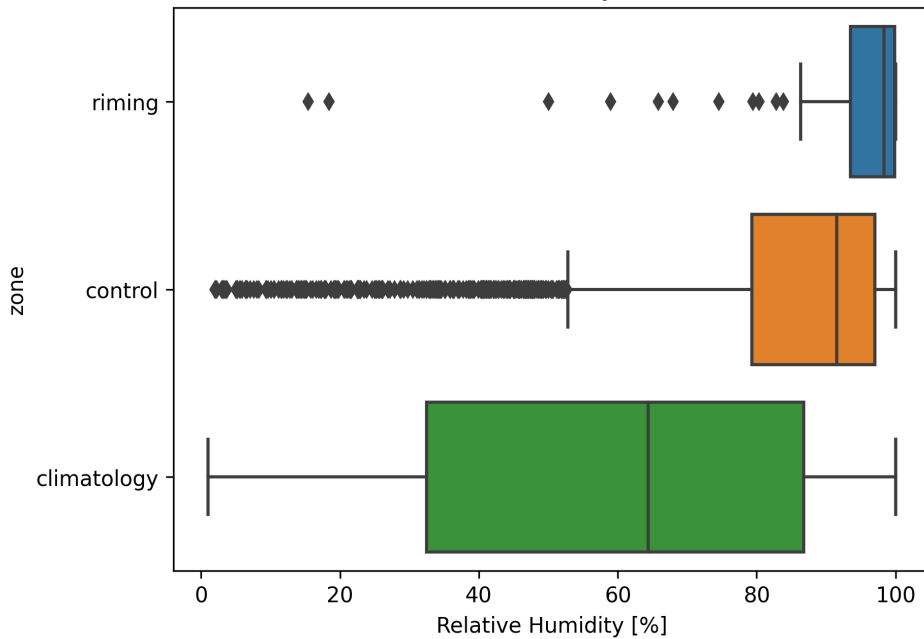
- Falling Hydrometeors (Cloudnet)

- Stratiform (low variance in MDV, Kneifel 2020)



Lindenberg Radiosonde Data

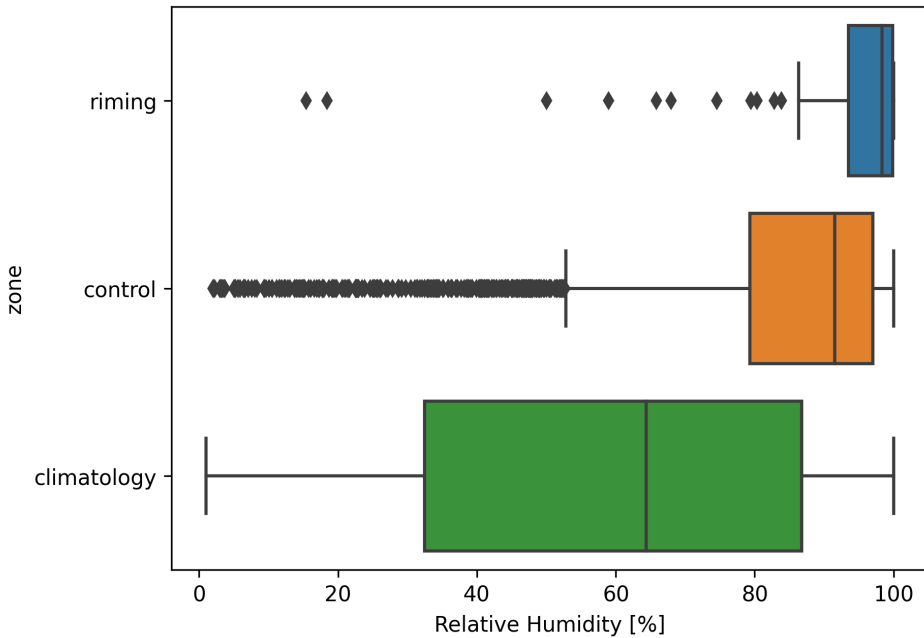
Relative Humidity at -5°C



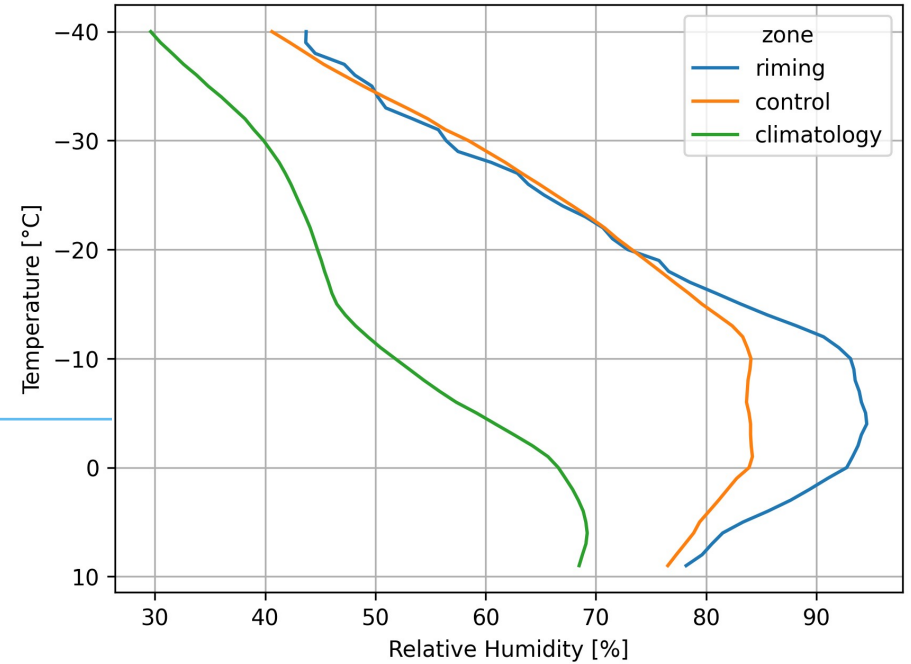


Lindenberg Radiosonde Data

Relative Humidity at -5°C

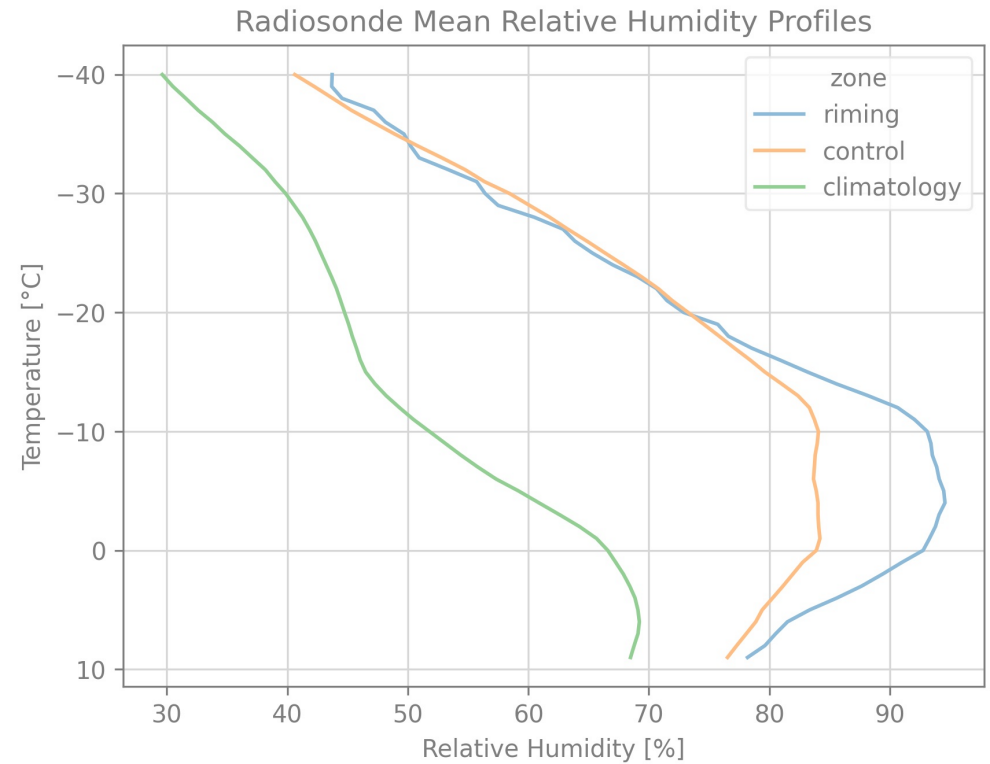


Radiosonde Mean Relative Humidity Profiles





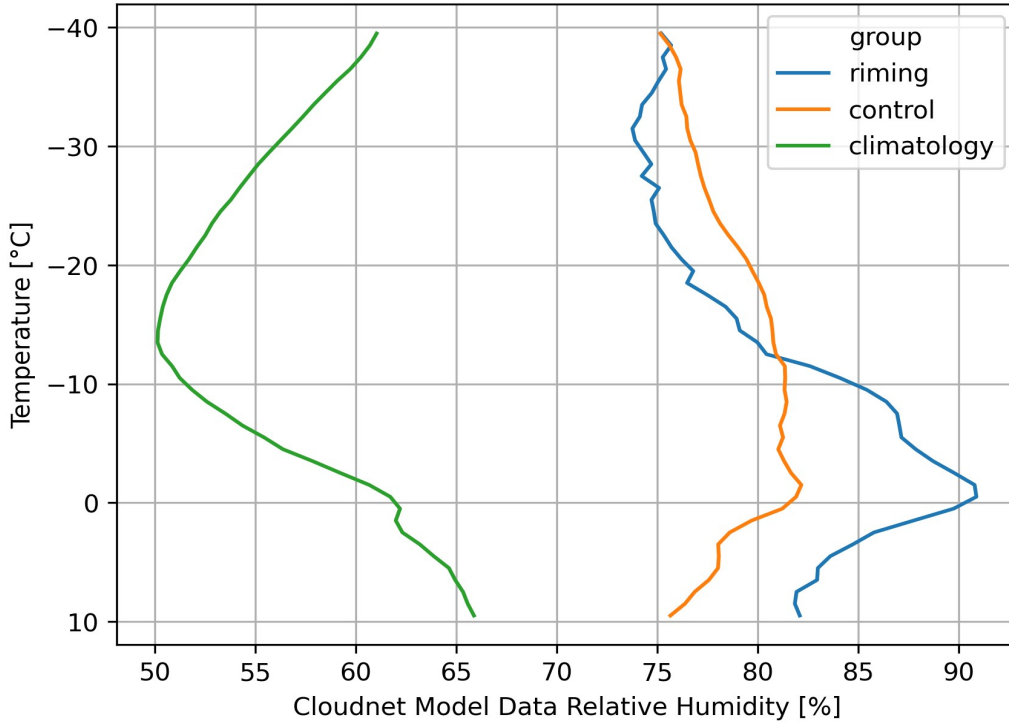
ECMWF Model Data



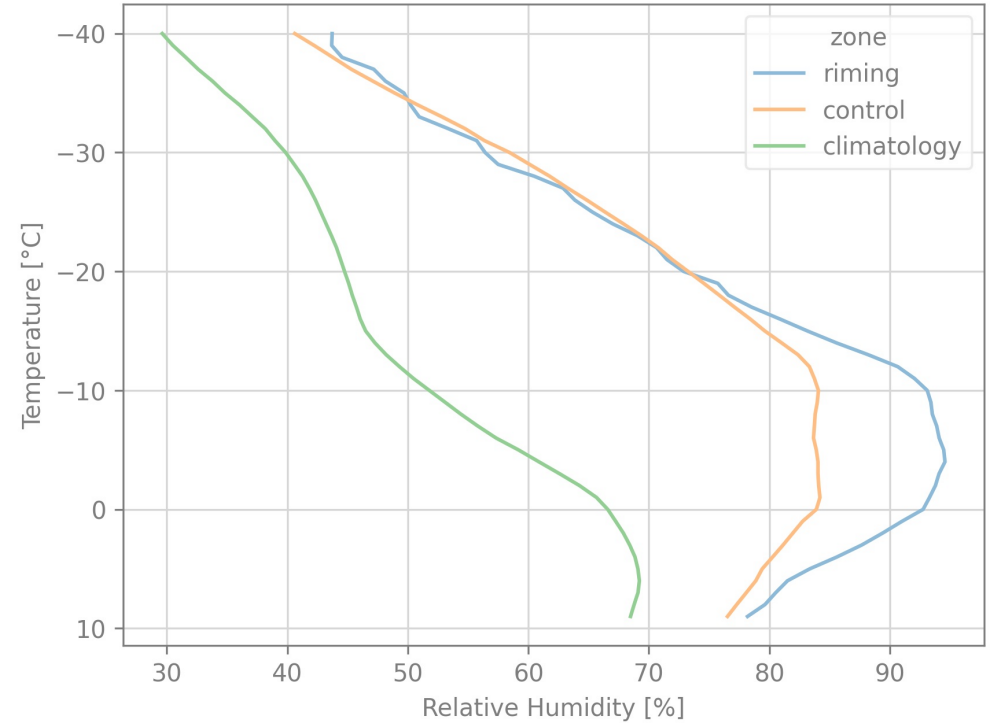


ECMWF Model Data

lindenberg Cloudnet Model Data Relative Humidity



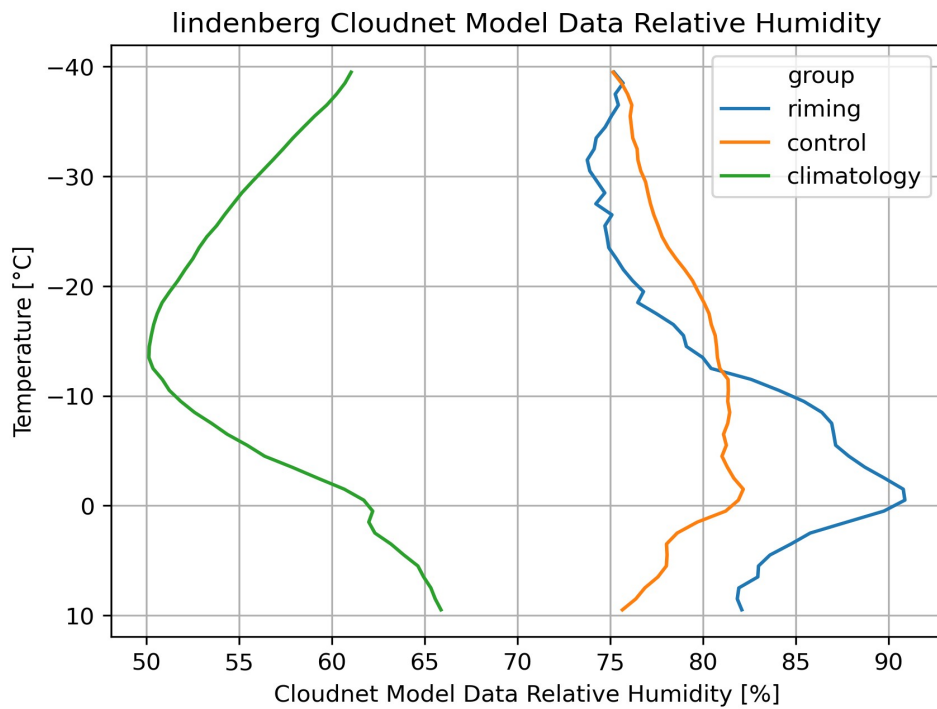
Radiosonde Mean Relative Humidity Profiles





ECMWF Model Data

Lindenberg

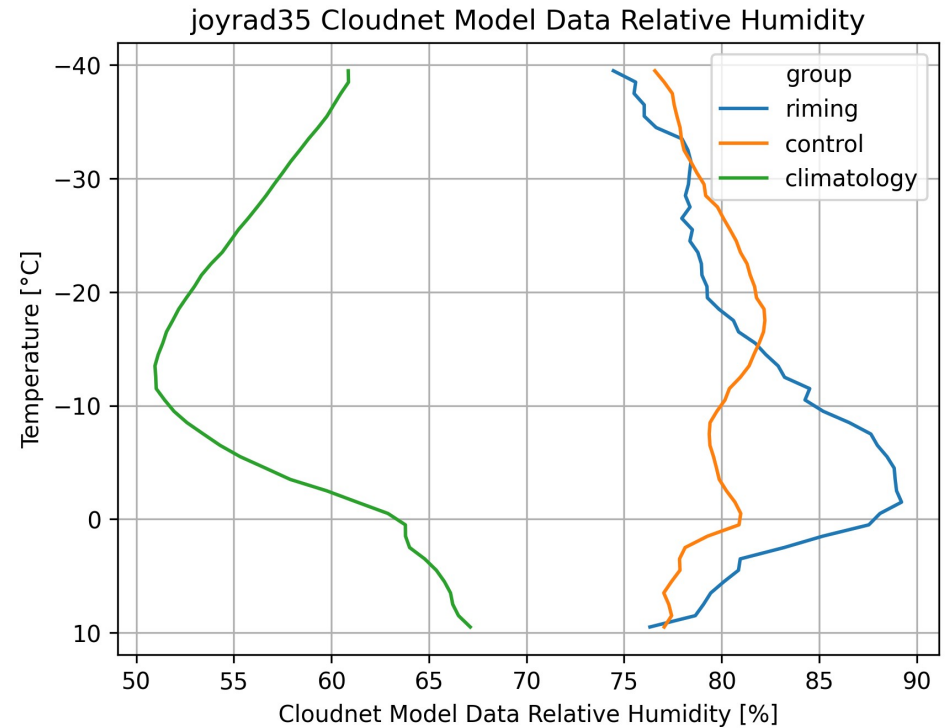
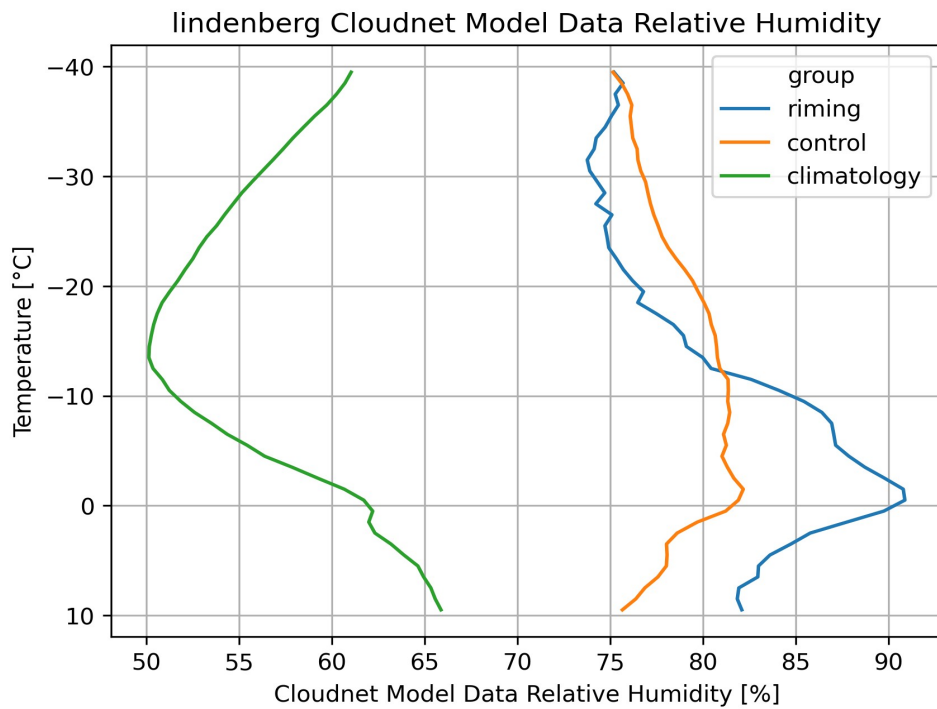




ECMWF Model Data

Lindenberg

Jülich





Summary of Results



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- Some typical numbers: 20 min long, 1 km thick, 15 km wide, between 0°C and -15 °C.



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- We created a dataset of riming events
- Some typical numbers: 20 min long, 1 km thick, 15 km wide, between 0°C and -15 °C.
- Longterm statistics reveal significantly higher humidity in model and radiosonde data between 0°C and -15°C during riming.



What are the implications?



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→ The general event dimensions indicate that a majority of them can be detected by the operational C-Band radars



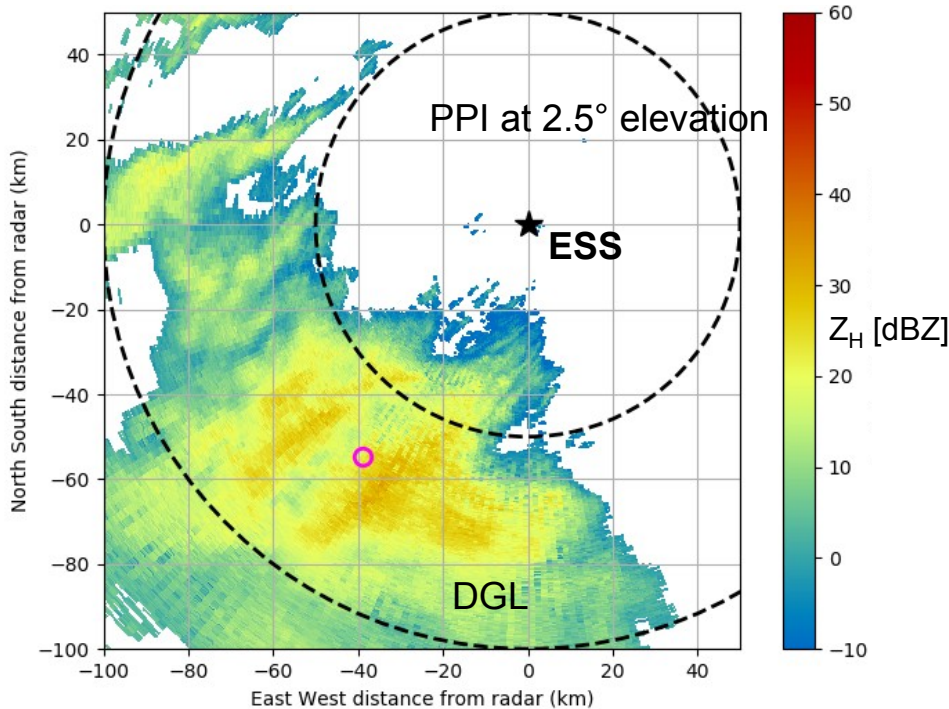
What are the implications?

- The general event dimensions indicate that a majority of them can be detected by the operational C-Band radars
- Model data contains valuable information and can possibly support a (machine learning) retrieval for rime mass fraction



DWD polarimetric C-band radar data – do they rime?

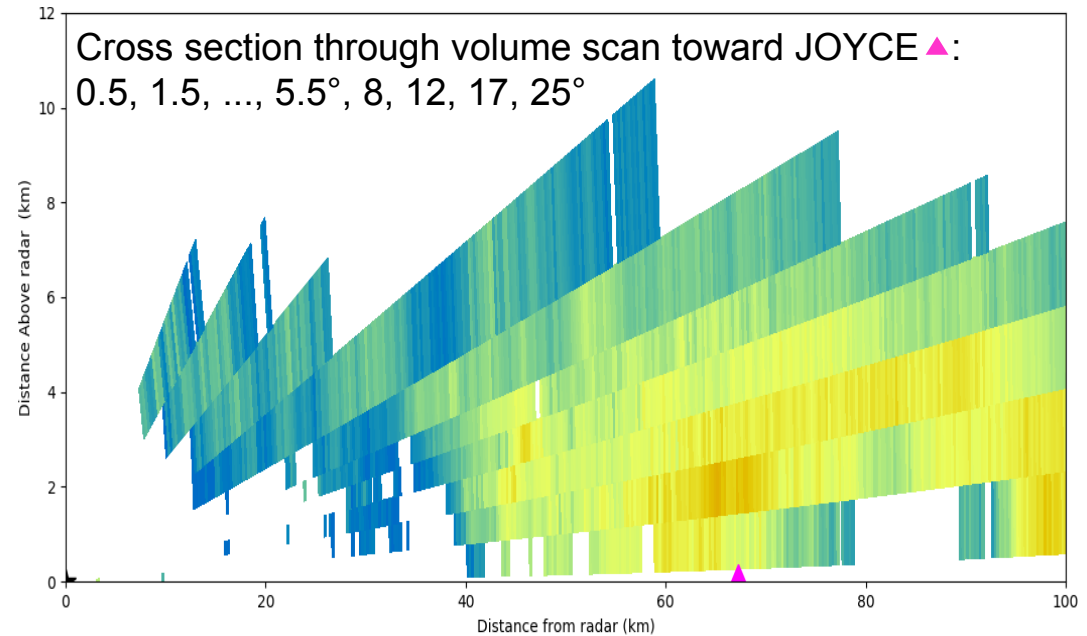
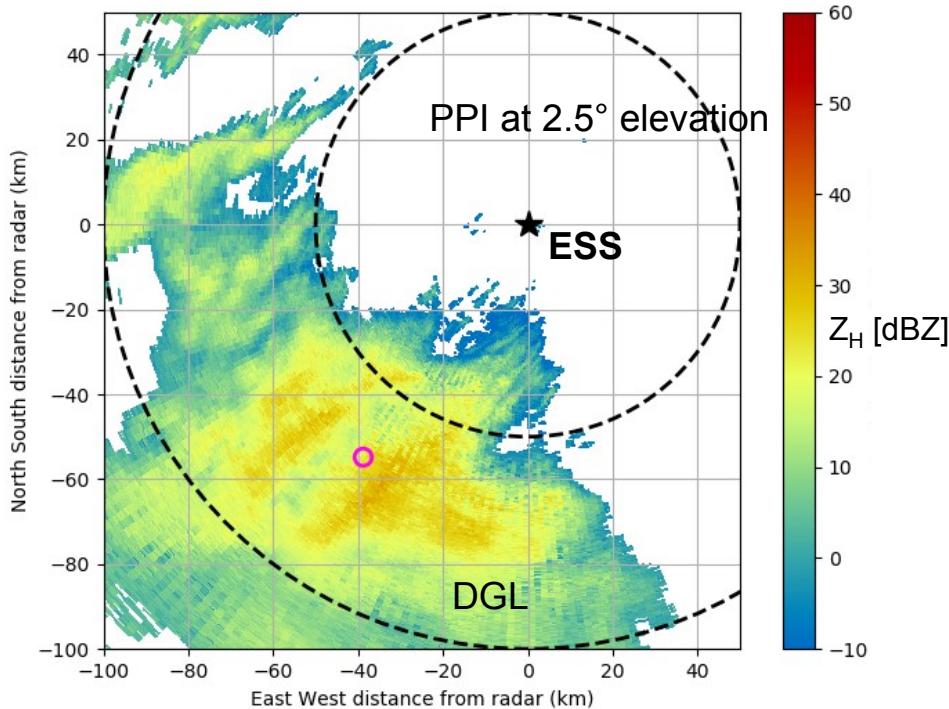
Example: Essen (**ESS**) radar for 30 Oct 2021 ~ 03:00 UTC,
here: riming is identified (and can be quantified) from JOYCE vertical Ka-band radar ○ measurements



Cross section through volume scan toward JOYCE ▲:
0.5, 1.5, ..., 5.5°, 8, 12, 17, 25°

DWD polarimetric C-band radar data – do they rime?

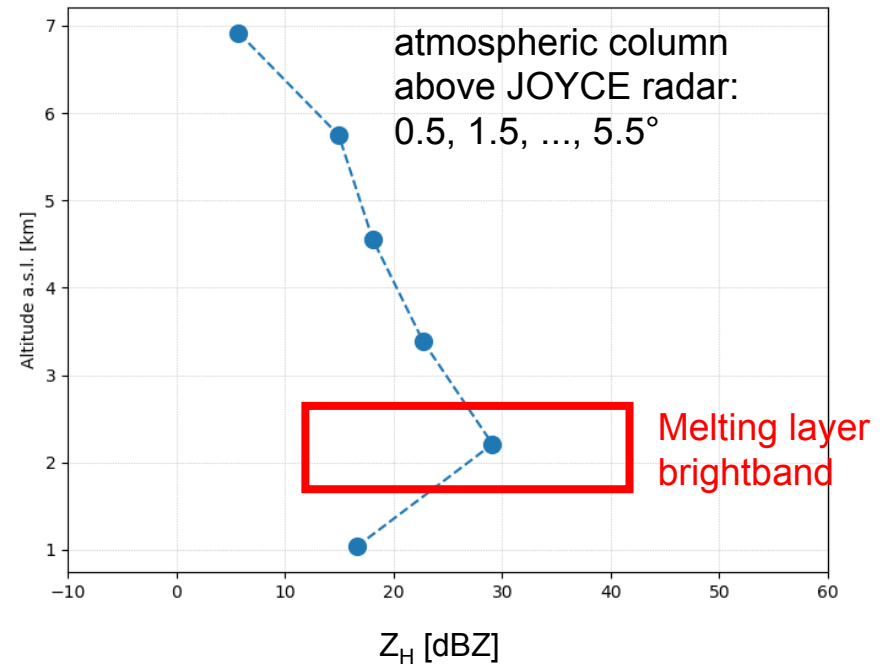
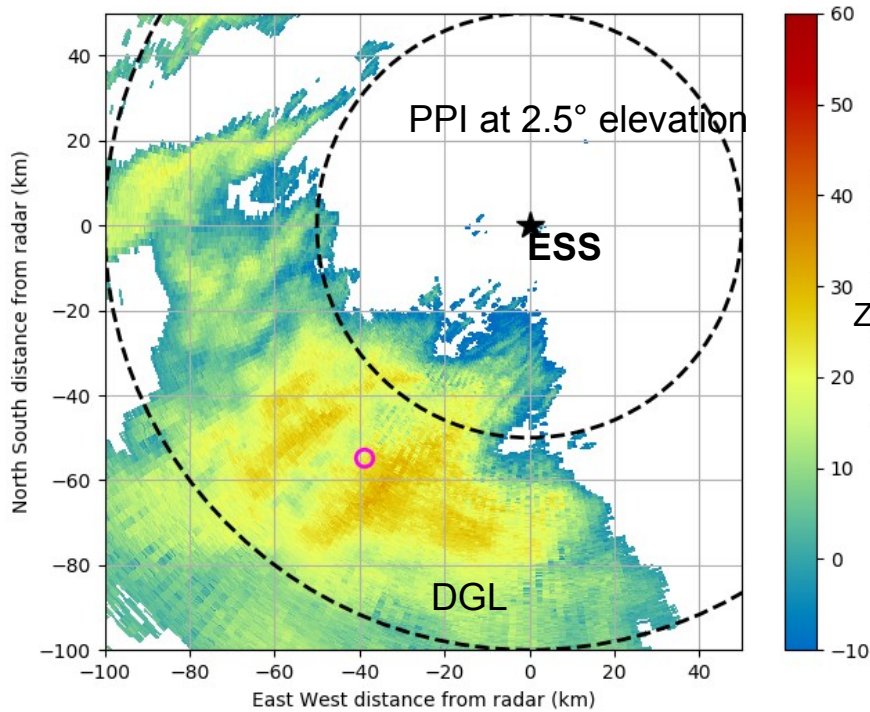
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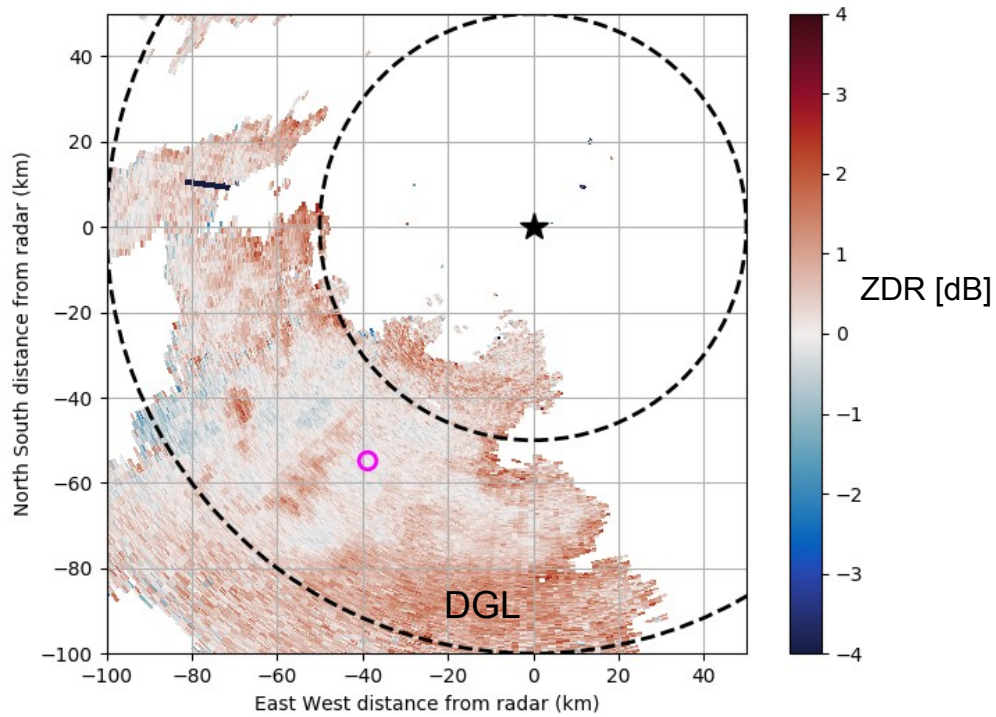
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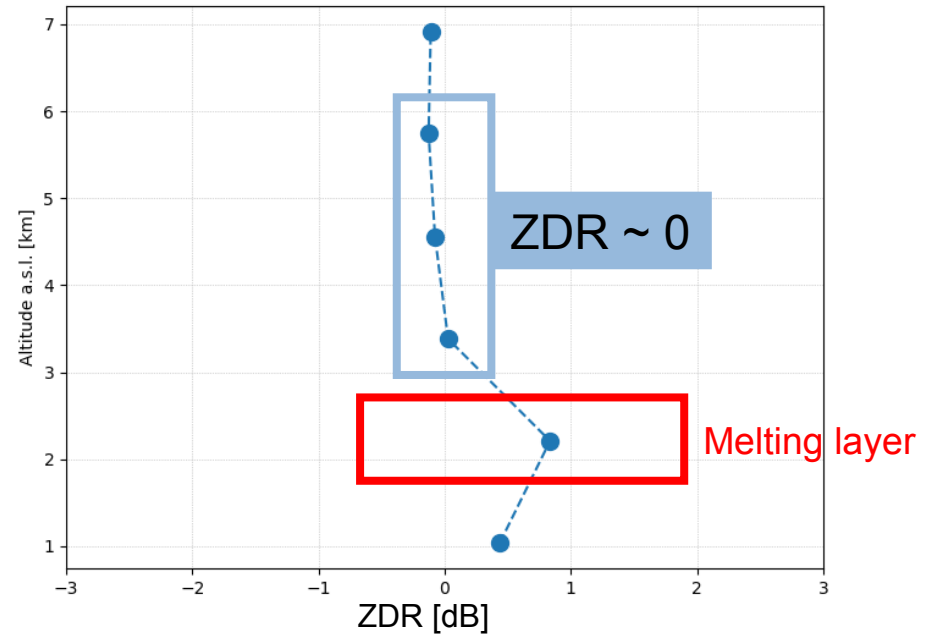
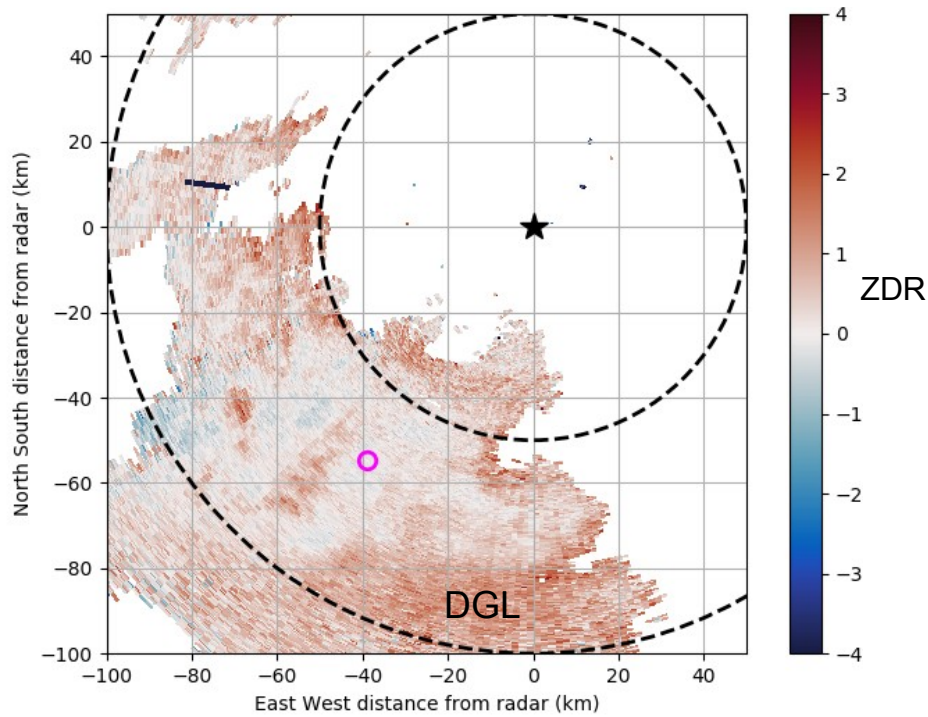


DWD polarimetric C-band radar data – do they rime?



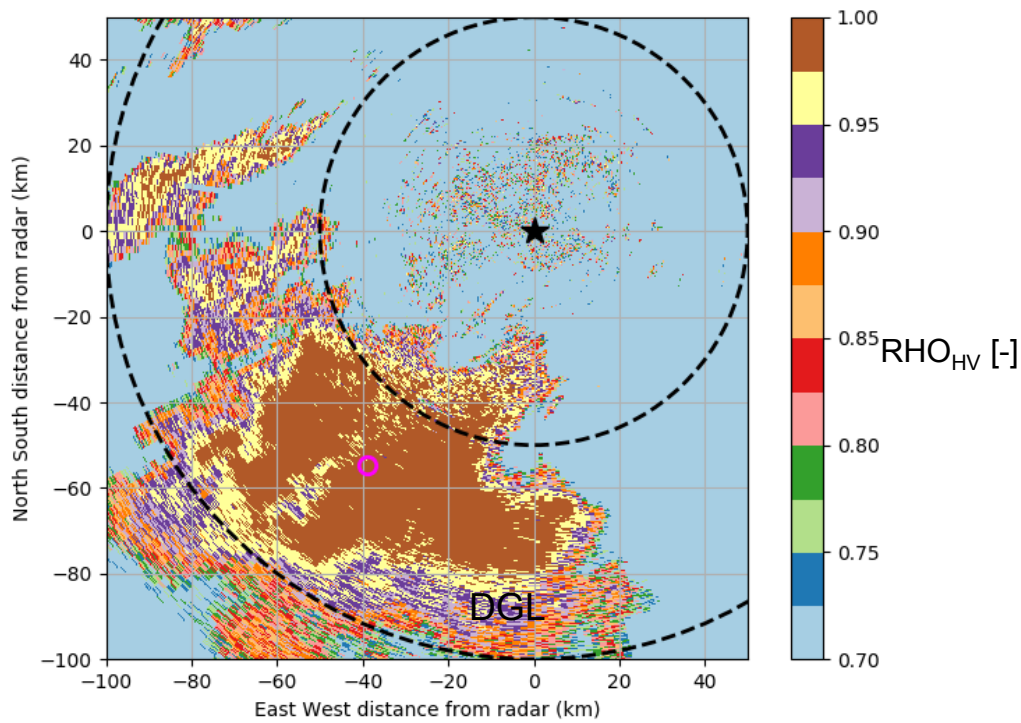


DWD polarimetric C-band radar data – do they rime?





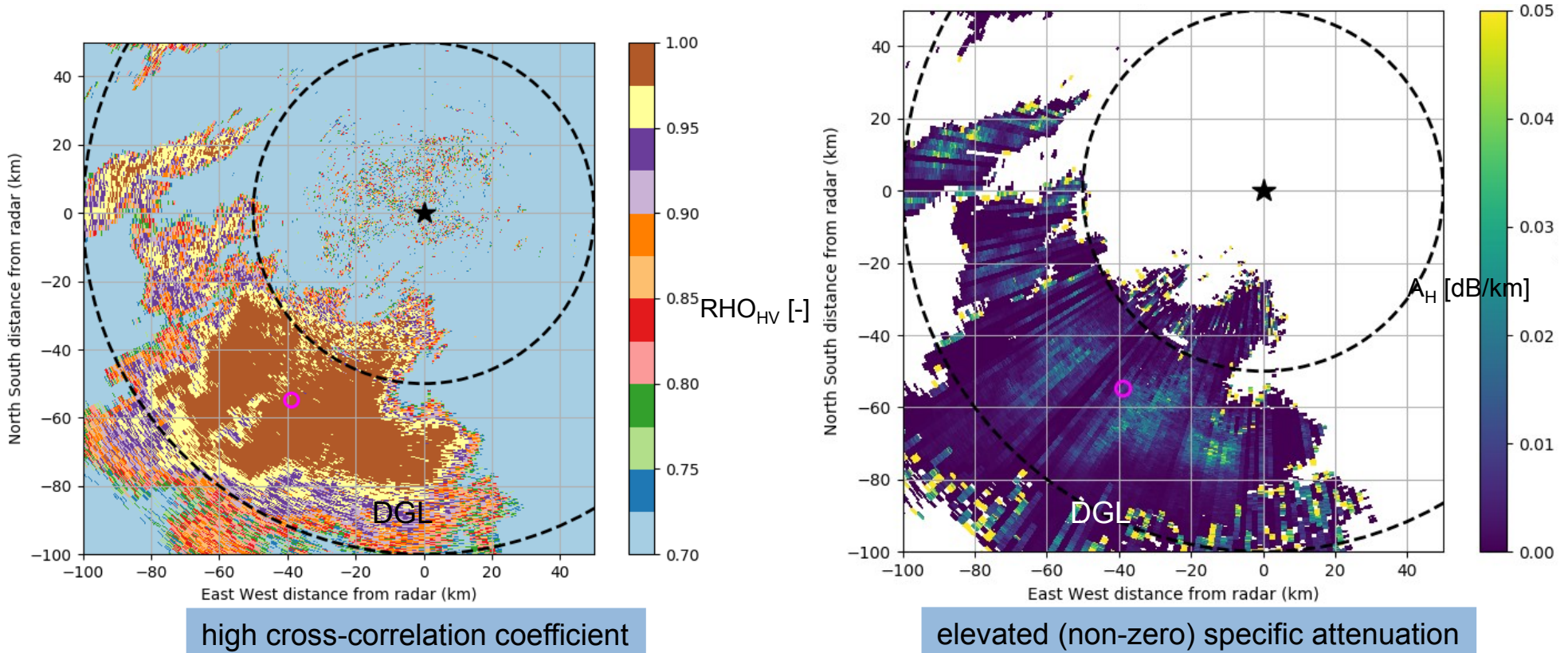
DWD polarimetric C-band radar data – do they rime?



high cross-correlation coefficient

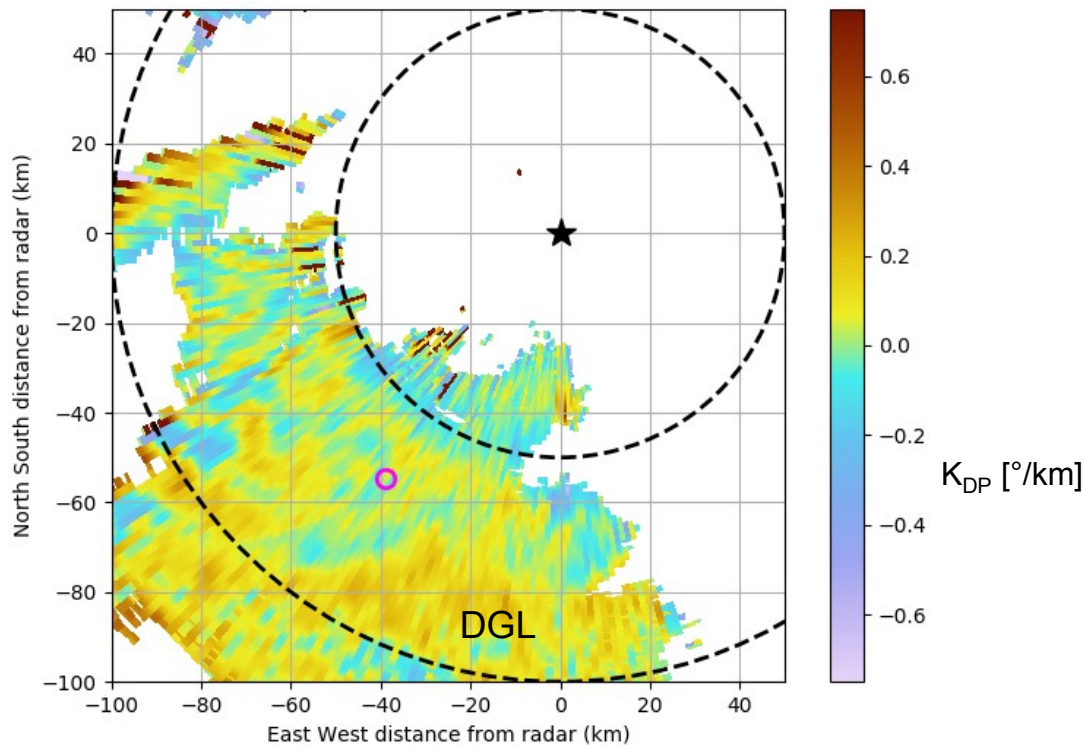


DWD polarimetric C-band radar data – do they rime?





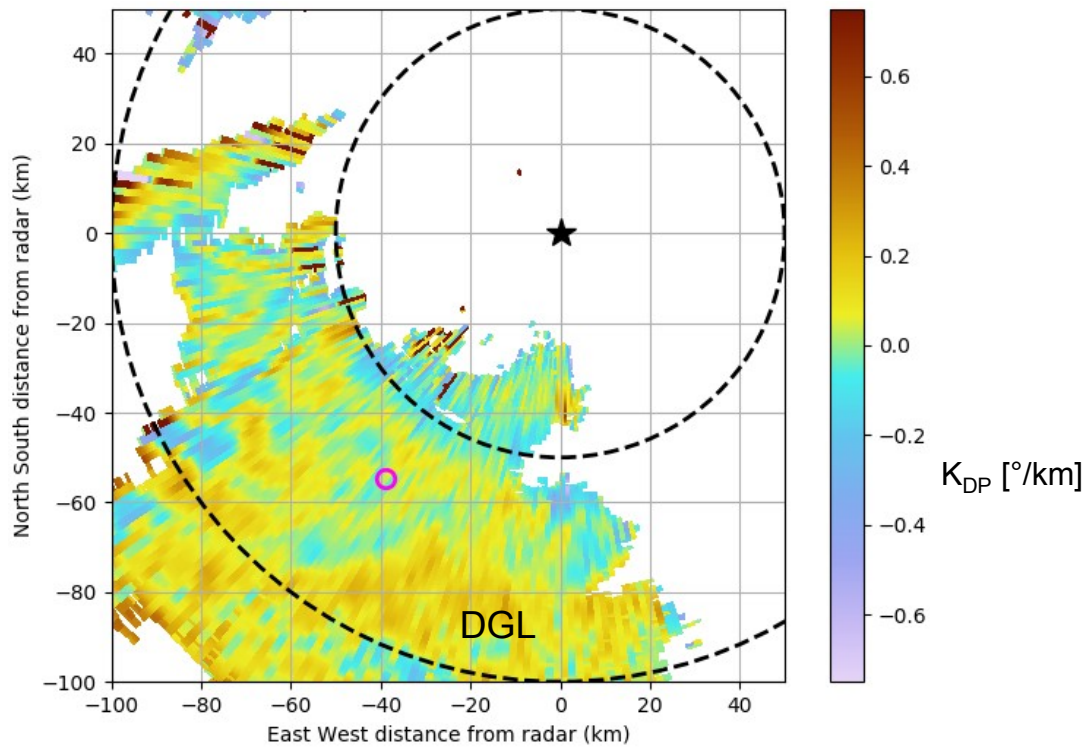
DWD polarimetric C-band radar data – do they rime?



'unremarkable' specific differential phase



DWD polarimetric C-band radar data – do they rime?



Summary of strong riming (RMF up to 0.85):

- Z_H increase
- $ZDR \sim 0$
- RHO_{HV} high (very close to 1)
- A_H elevated
- K_{DP} unremarkable

To Do:

- smoothing of polarimetric variables
(\rightarrow spokes + CVP)
- K_{DP} 'under development' at DWD
- signatures of different 'degrees' of riming

'unremarkable' specific differential phase



Appendix

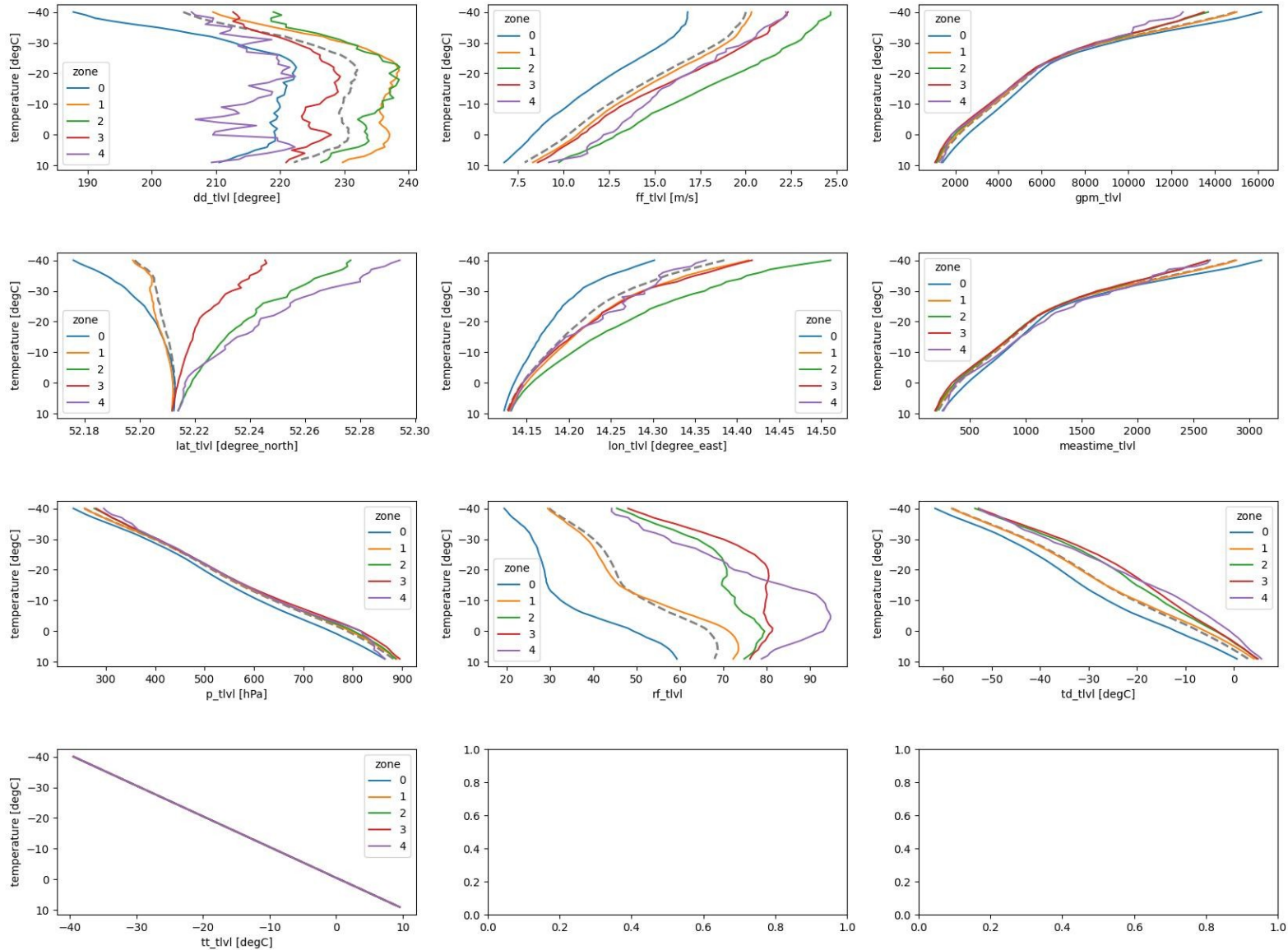


Blog Link

<https://www.meteo.physik.uni-muenchen.de/~paul.ockenfuss/blog/>

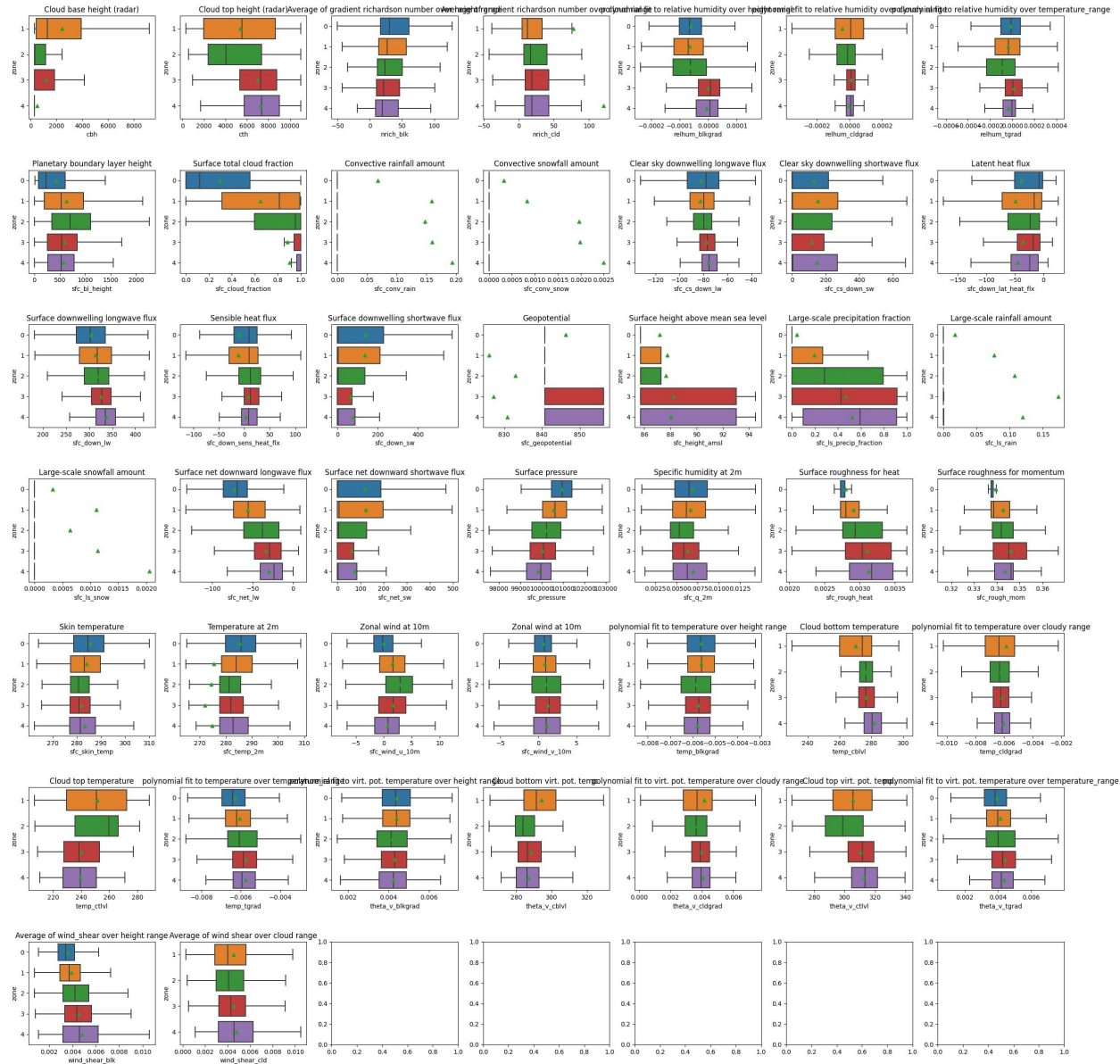


Radiosonde Lindenberg



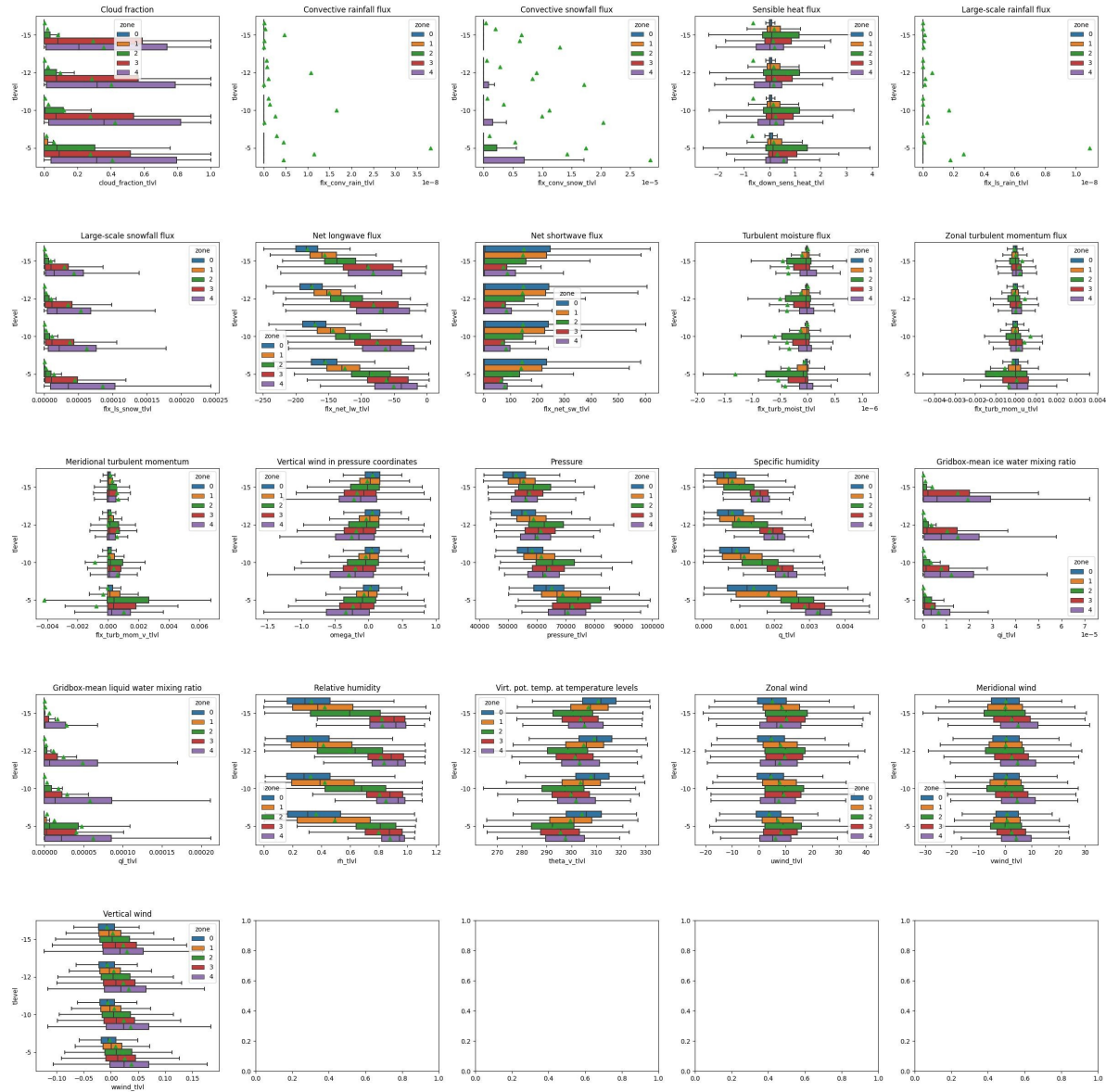


Model single level Jülich





Model temperature level Jülich





Scans

