

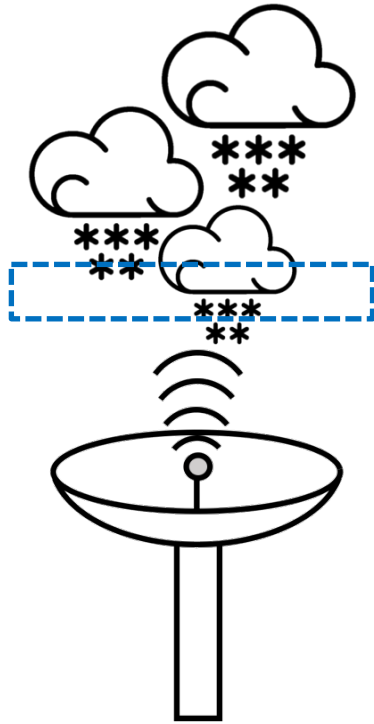
Snowfall microphysics retrieved from X- and W-band Doppler spectrograms: a deep-learning based approach

A-C Billault-Roux¹, G. Ghiggi¹, L. Jaffeux², A. Martini³, N. Viltard³, A. Berne¹

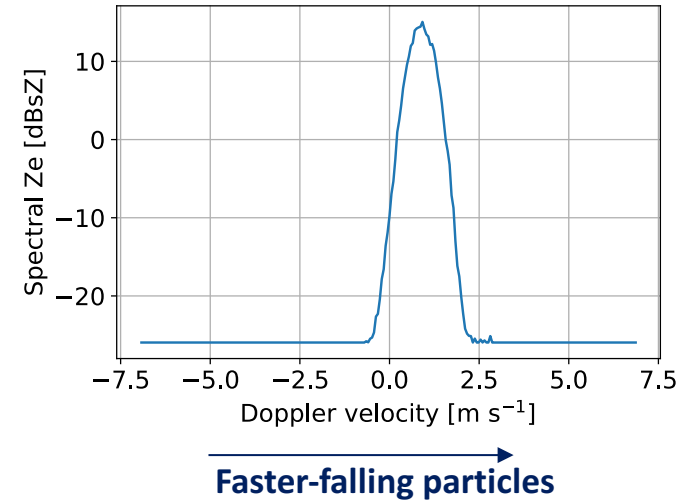
¹EPFL, Switzerland / ²LAMP, France / ³LATMOS, France



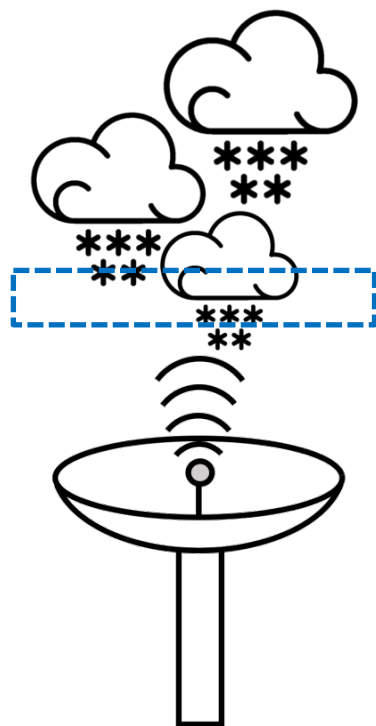
Underlying physics: radar Doppler spectra



Doppler spectrum: radar reflectivity as a function of Doppler velocity



Underlying physics: radar Doppler spectra



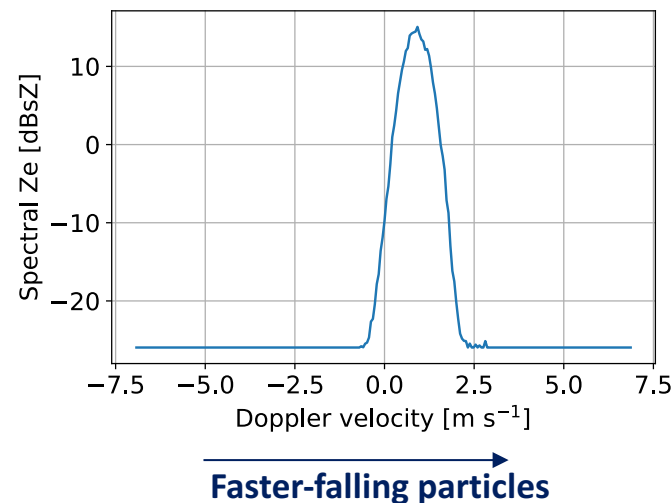
Snow particle microphys.

- scattering
- aerodynamic

Atmospheric parameters

Radar properties

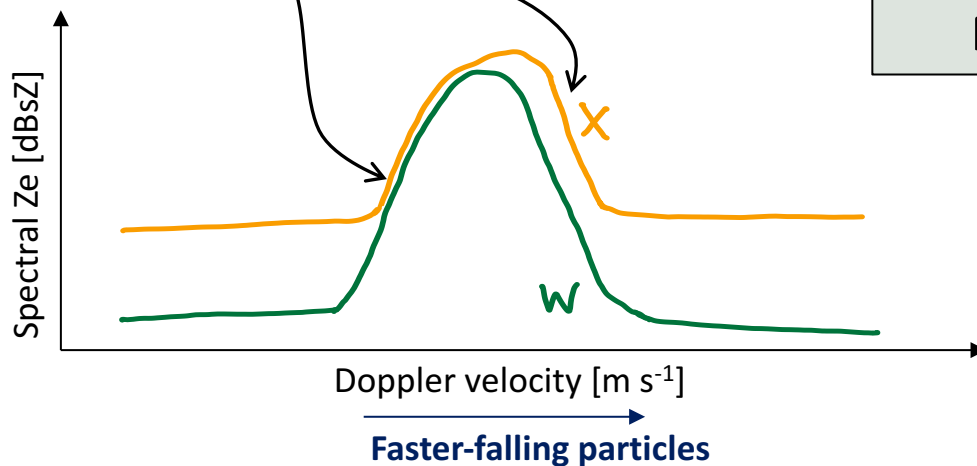
Doppler spectrum: radar reflectivity as a function of Doppler velocity



Underlying physics: dual-frequency Doppler spectra

- Rayleigh/Mie scattering regimes:

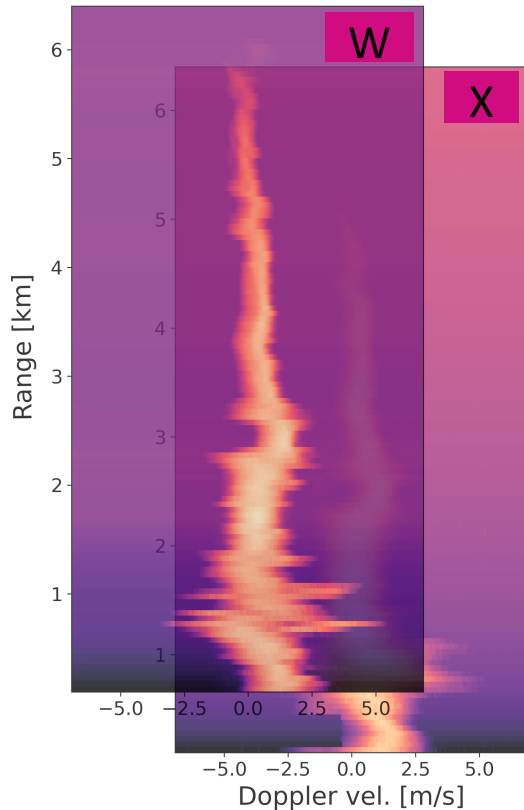
- Small particles: $Ze_x \approx Ze_w$
- Large particles: $Ze_x > Ze_w$



**More frequencies
=
More info!**

- DFR ($= Ze_x - Ze_w$) depends on particle size + density

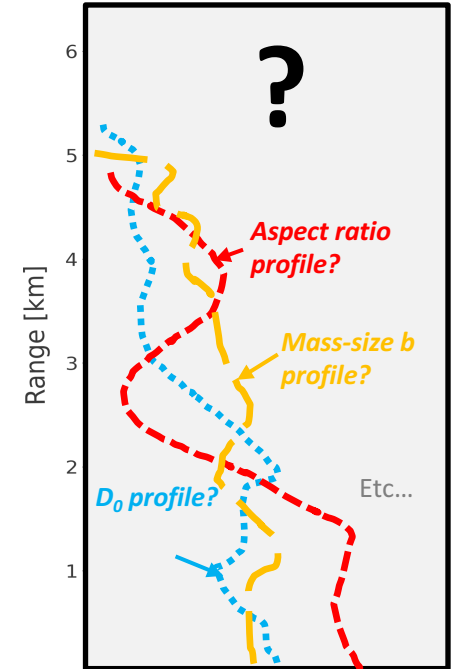
Objective: solve an inverse problem



X- and W-band
spectrograms

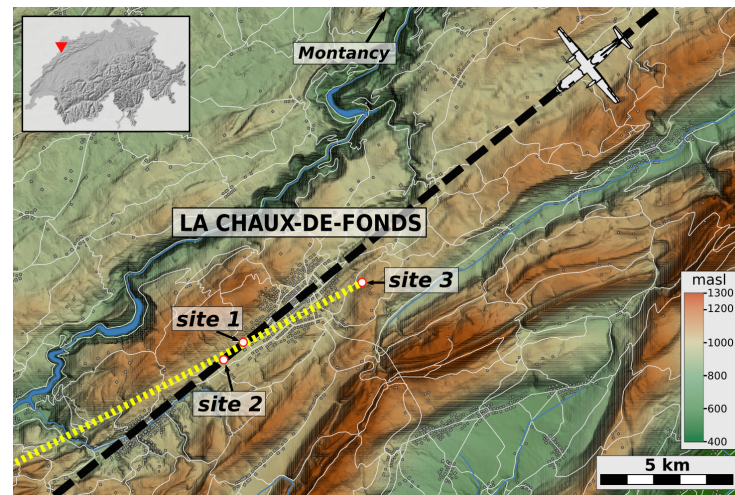
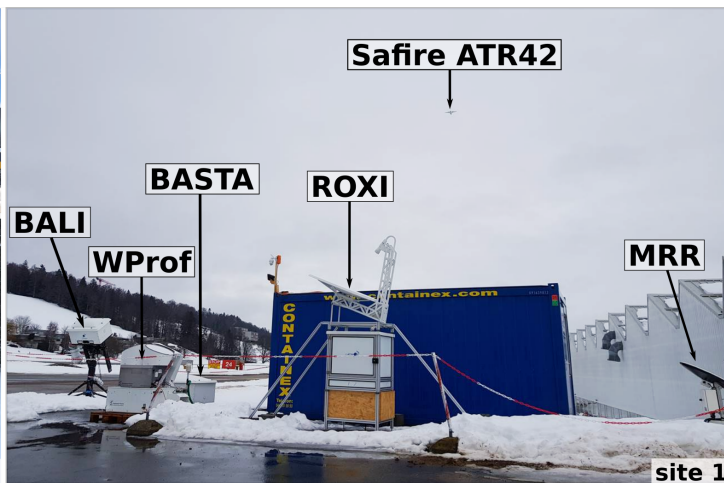
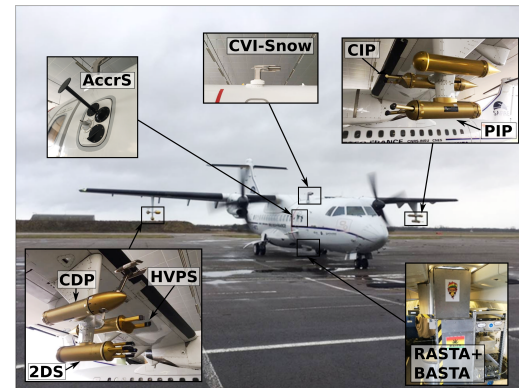


Vertical profiles of
microphysical variables



Data

- ICE GENESIS campaign 2021, La Chaux-de-Fonds:
 - ground-based & airborne sensors
 - remote-sensing & in-situ measurements



Data

- 2 radars: WProf (94 GHz) + ROXI (9.4 GHz)
- Data processing:
 - Correction of artifacts
 - Dynamic calibration correction (*matching ZeX/ZeW at cloud top*)
 - Remap to common grid
- Evaluation of algorithm: aircraft in-situ measurements



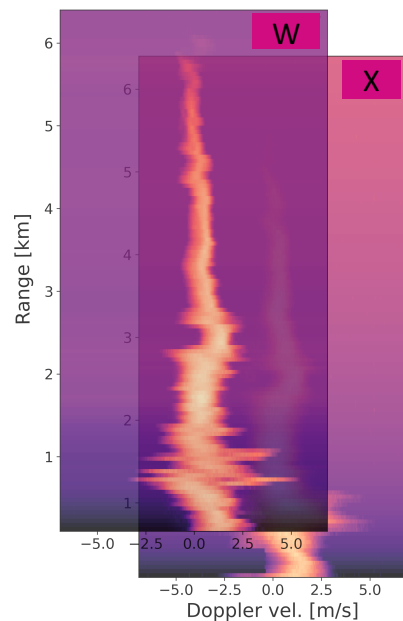
WProf



ROXI

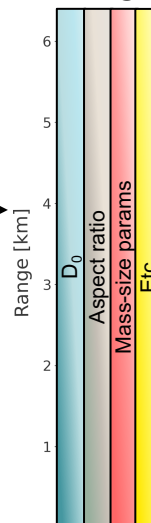
Retrieval framework

(S_X, S_W) : True spectrograms



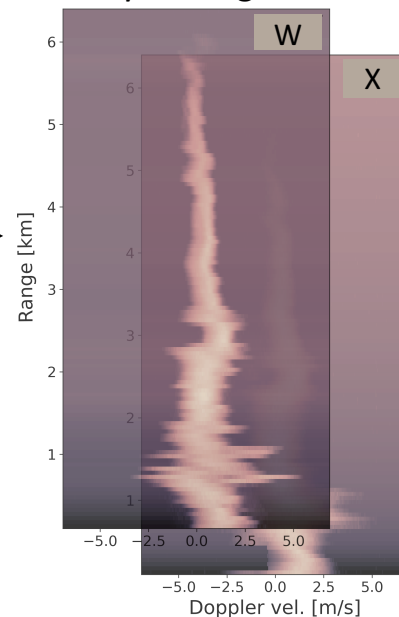
encoder

Latent space:
Microphys. variables
at each range gate



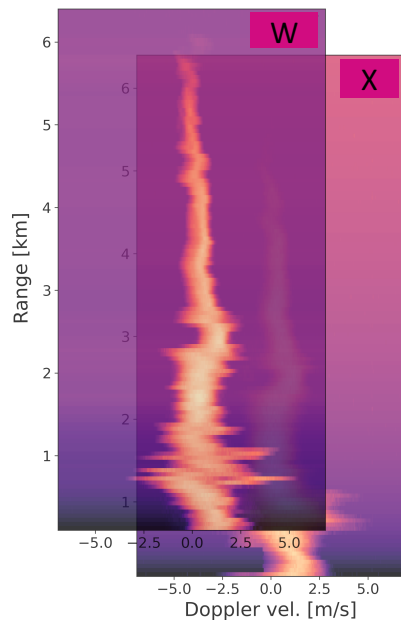
decoder

$(\tilde{S}_X, \tilde{S}_W)$: Reconstructed spectrograms



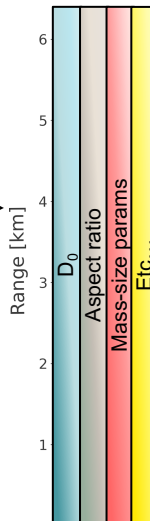
Retrieval framework

(S_X, S_W) : True spectrograms



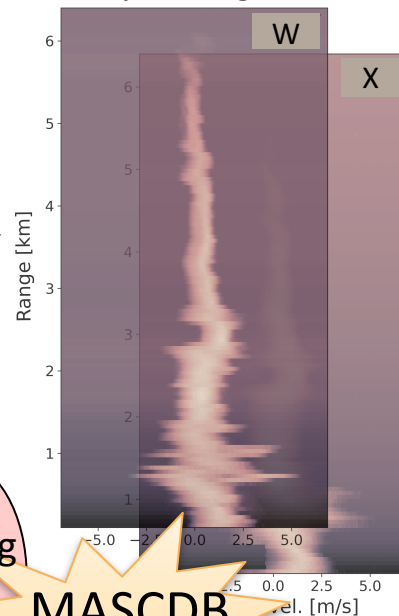
encoder

Latent space:
Microphys. variables
at each range gate



decoder

$(\tilde{S}_X, \tilde{S}_W)$: Reconstructed spectrograms



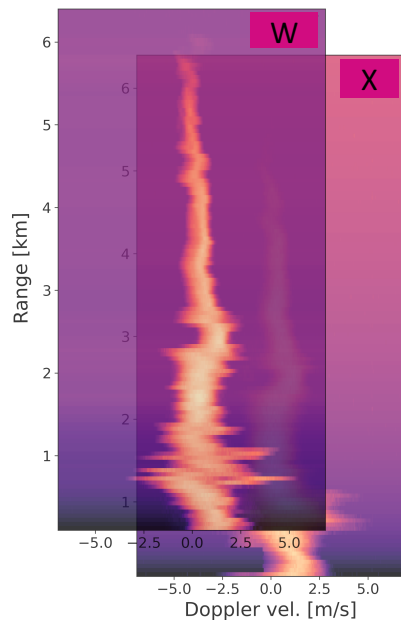
**Differentiable
emulator of scattering
model: trained on
synthetic dataset**

MASCDB
Grazioli et al. 2022

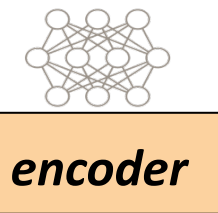
PAMTRA
Mech et al. 2021

Retrieval framework

(S_x, S_w) : True spectrograms

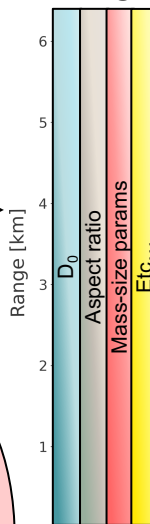


Encoder: maps spectrograms to latent variables
Convolutional NN: reduces ill-posedness

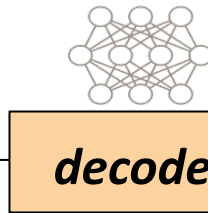


encoder

Latent space:
Microphys. variables at each range gate

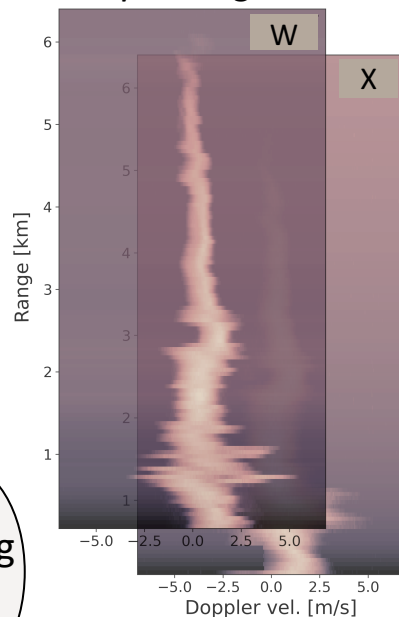


Differentiable emulator of scattering model: trained on synthetic dataset



decoder

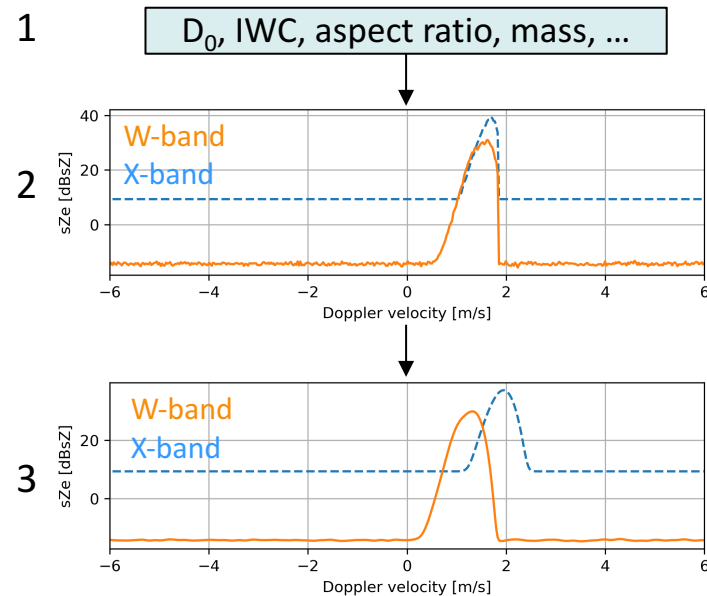
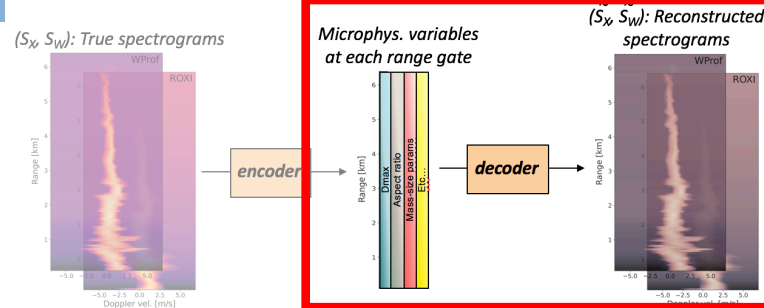
$(\tilde{S}_x, \tilde{S}_w)$: Reconstructed spectrograms



Loss

Framework: decoder

- Generating synthetic training (& testing) set:
 - Sample realistic microphysical parameters: constrain using **MASC data + literature**
 - Spectra simulated with **PAMTRA**, with hypotheses:
 - PSD**: exponential $N(D) = N_0 \exp(-D/D_0)$
 - Scattering model**: SSRGA
 - Additional variables:
 - Radial wind, turbulent broadening



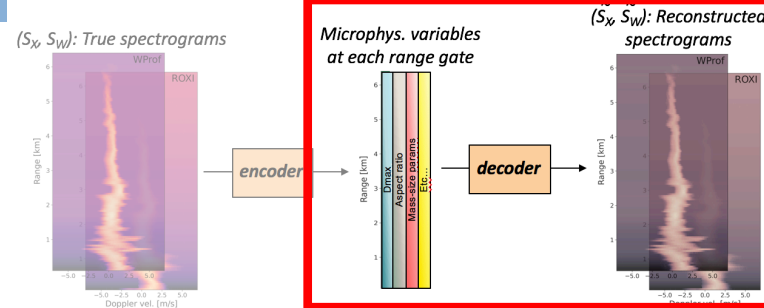
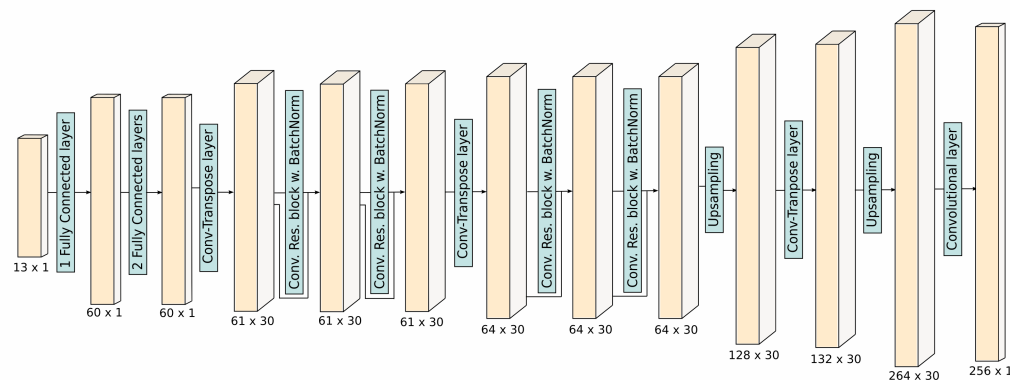
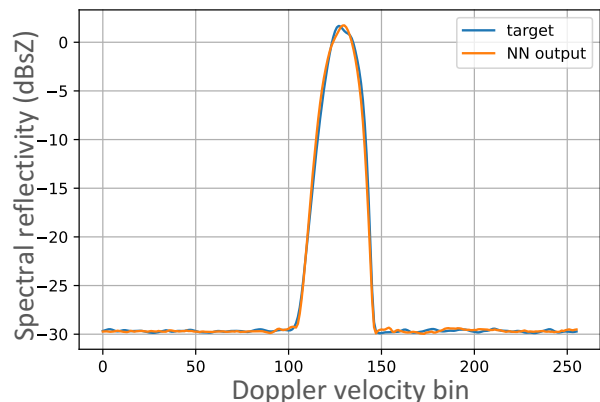
Framework: decoder

- Train/ val/ test dataset: (~60M/ ~10M/~10M)

Microphysical +
atm. variables

Doppler spectrum
at X & W-band

- NN architecture: Fully connected layers + Conv + Conv-Transpose layers + Resblocks
- Accuracy: >90% overlap on test set (for X & W)



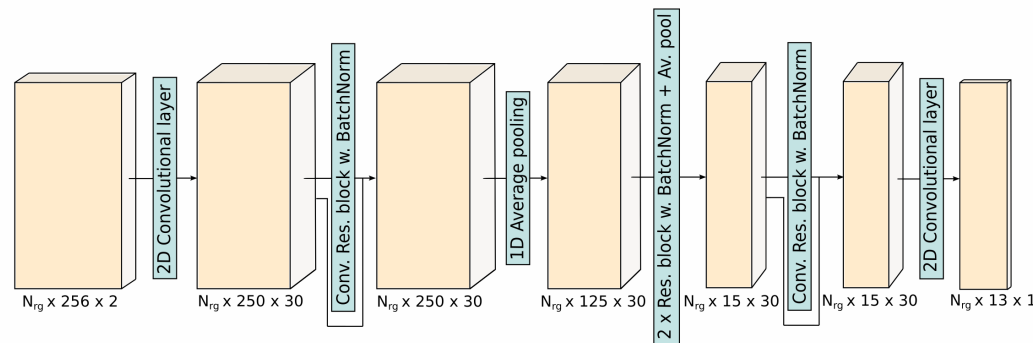
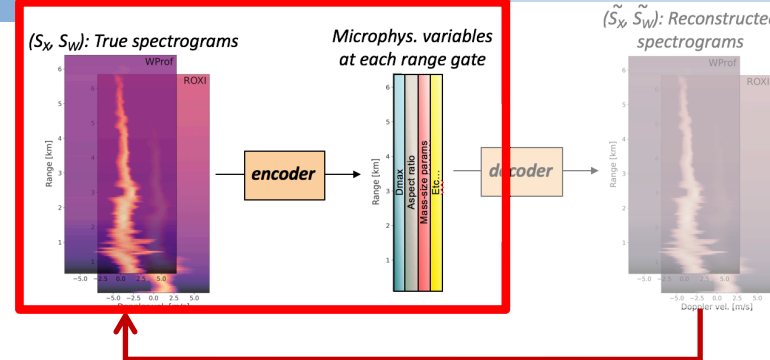
Framework: encoder

- Encoder: **maps ROXI & WProf spectrograms** to latent space *(/!\ real data directly!)*

- Latent space re-mapped to spectrograms via **pretrained decoders** (decoder parameters are now **frozen**)

- $Loss = (S_X - \tilde{S}_X)^2 + (S_W - \tilde{S}_W)^2$ *(Reconstructed spectrograms should match true ones)*

- Architecture: 2D conv., Resblocks
 - Convolutions: capture spatial consistency** $\rightarrow$ reduce ill-posedness

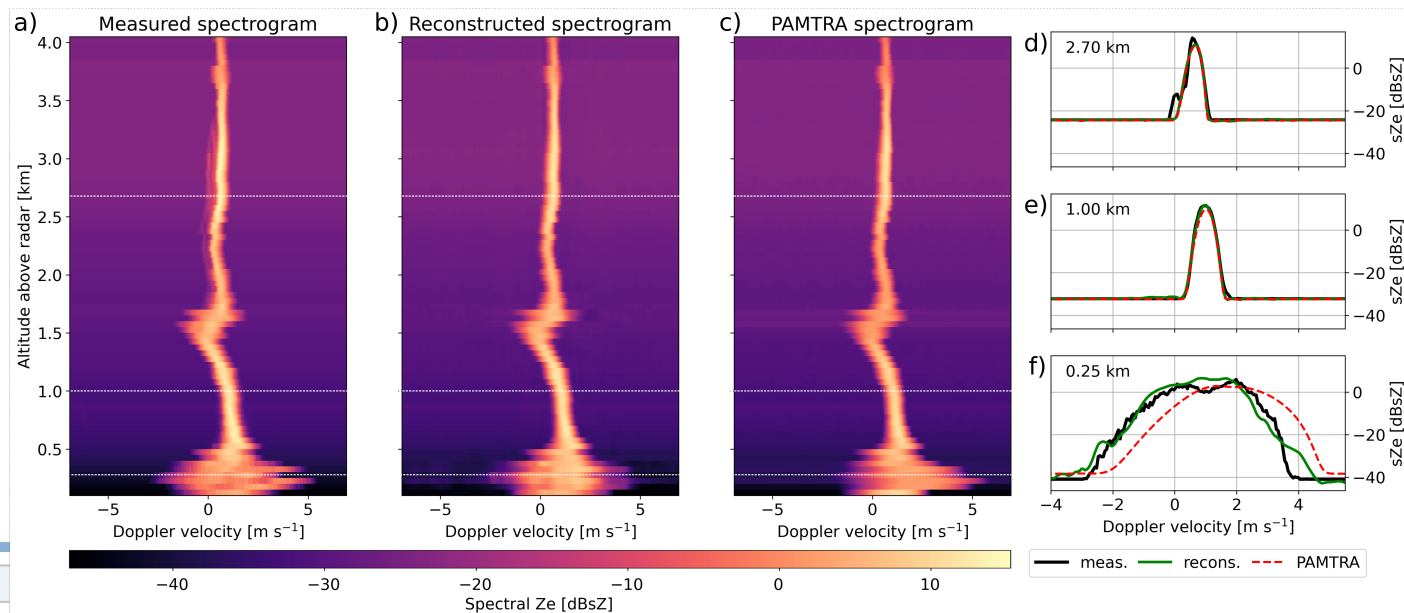


Results

- Training is successful: Pipeline converges + Reconstructed spectrograms are satisfactory
- Profiles of latent variables are retrieved with an ensemble approach (train several decoders + encoders → mean profiles (w. std))

W-band spectrograms:

- True
- Reconstructed through pipeline
- Reconstructed with PAMTRA from retrieved variables (safety check)



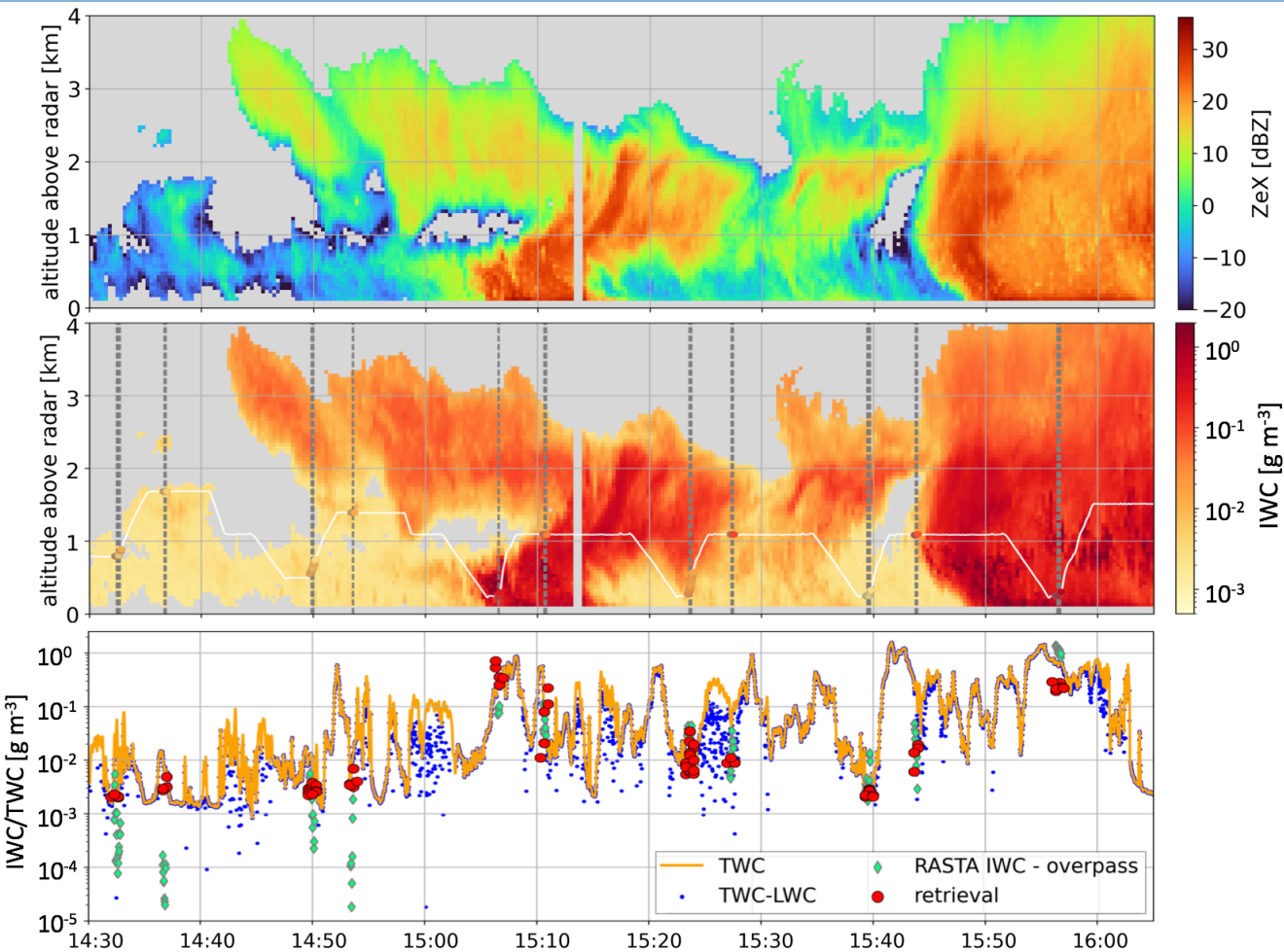
Example

ICE GENESIS (Jan. 2021,
Swiss Jura)

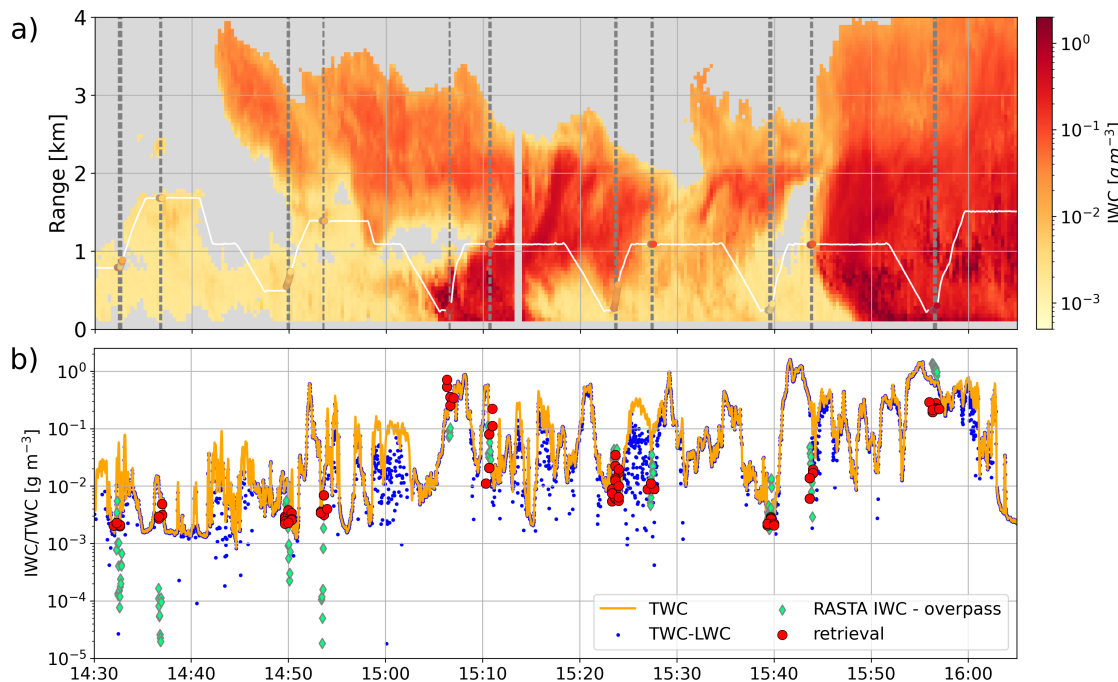
X-band reflectivity

Retrieved IWC

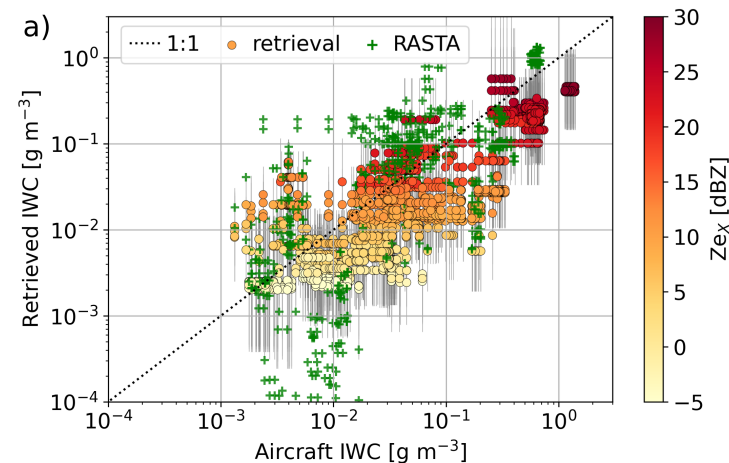
Comparison with
aircraft in-situ
measurements



Comparison with in-situ data: IWC

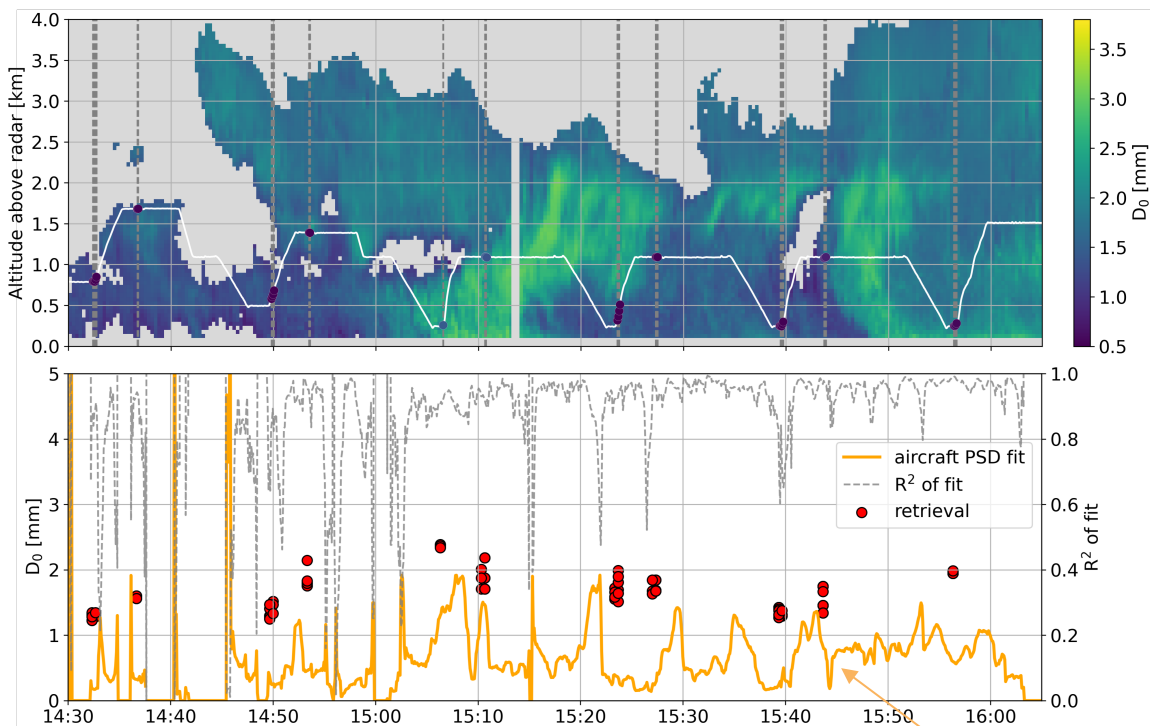


✓ Agreement is fair (noisy: different volumes...)



Comparison with in-situ data: D_0

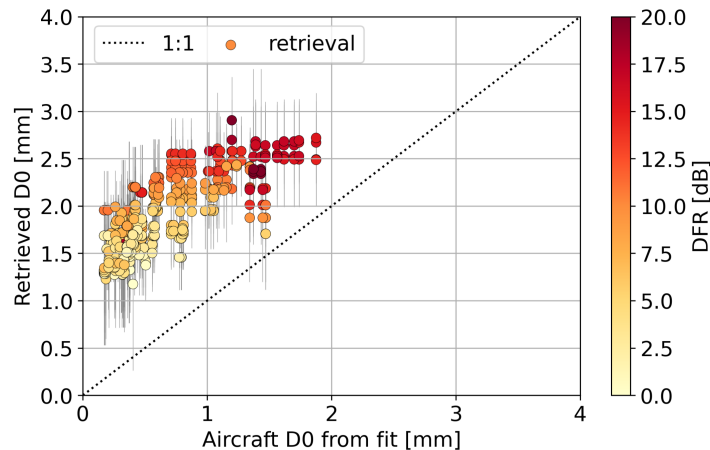
$$N(D) = N_0 \exp(-D/D_0)$$



✗ Strong bias!

- Small particles underrepresented in train set
- Strong sensitivity to scattering model parameterization

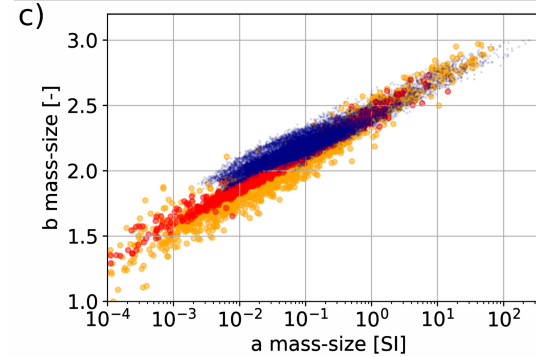
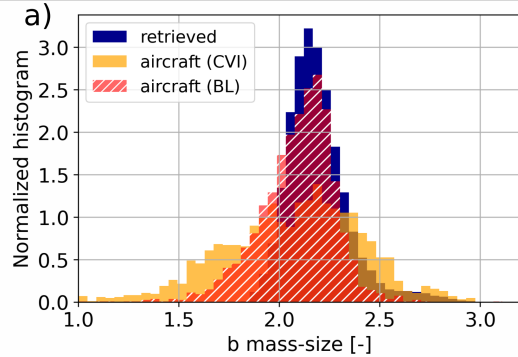
✓ Still good confluctuation (OK for process-oriented analysis)



Exponential fit to aircraft PSD

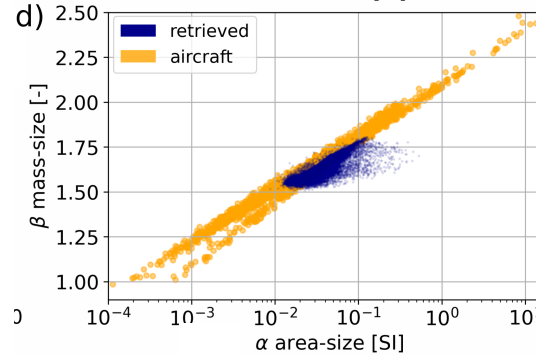
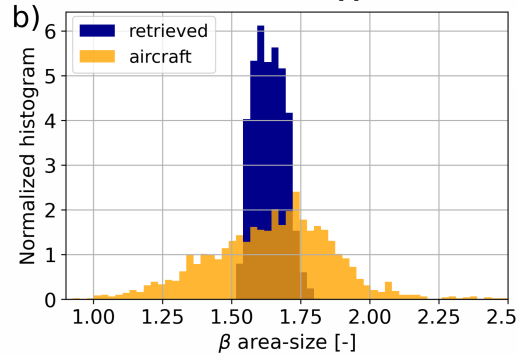
Comparison with in-situ data: a , b , α , β

$$m = aD^b$$

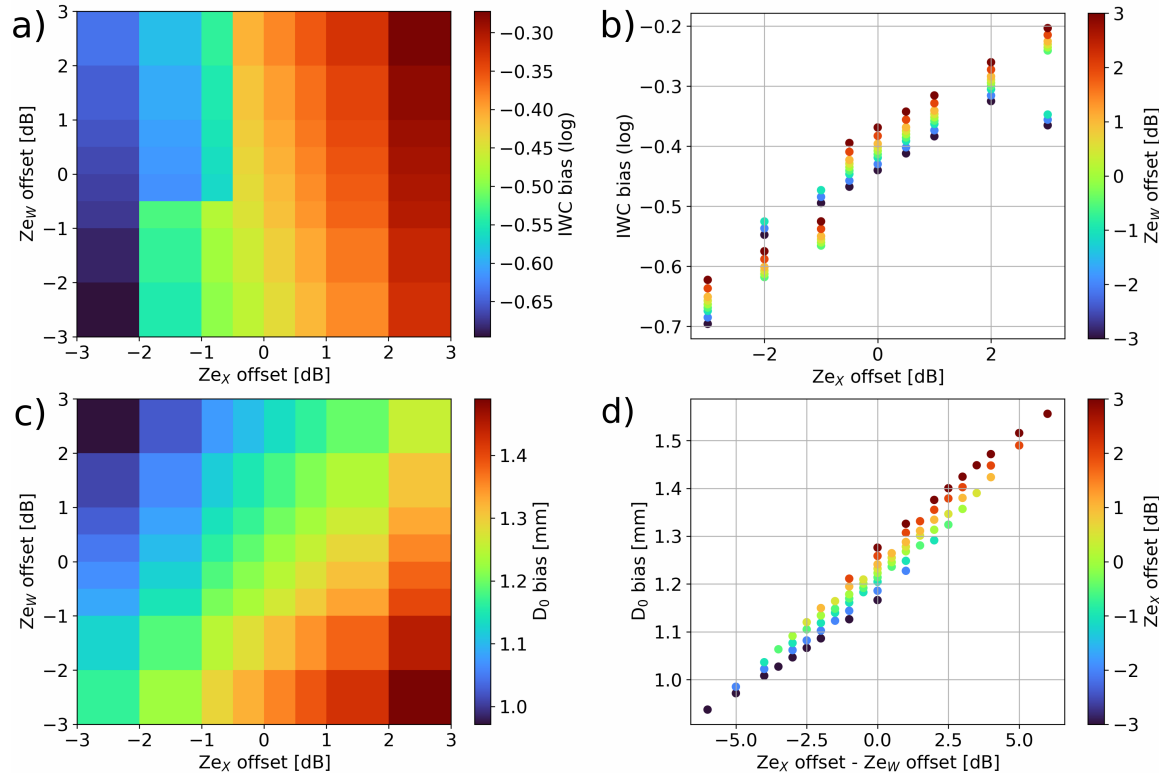


Broader aircraft
distributions: noise +
smaller volumes

$$A = \alpha D^\beta$$



Sensitivity analysis: effect of Ze calibration/attenuation



Ze bias =>
moderate IWC and D_0 bias

Conclusion

- ✓ Novel method: **framework can be generalized to other ill-posed retrieval** problems
- ✓ Enables retrieval of **seven** microphysical properties
- ✓ Validation through **comparison with in-situ** aircraft measurements (ICE GENESIS 2021 campaign)

Microphysical parameters

- ✓ Ice water content
- ✓ D_0 (size parameter)
- ✓ Aspect ratio
- ✓ Mass-size relation coefs (a,b)
- ✓ Area-size relation coefs (α , β)

+ *Atmospheric parameters*: radial wind / turb.

Thank you!



Questions, suggestions, ...:

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