Introduction

Philipp Laub
LOFAR Cosmic Ray Meeting, 08.04.2024

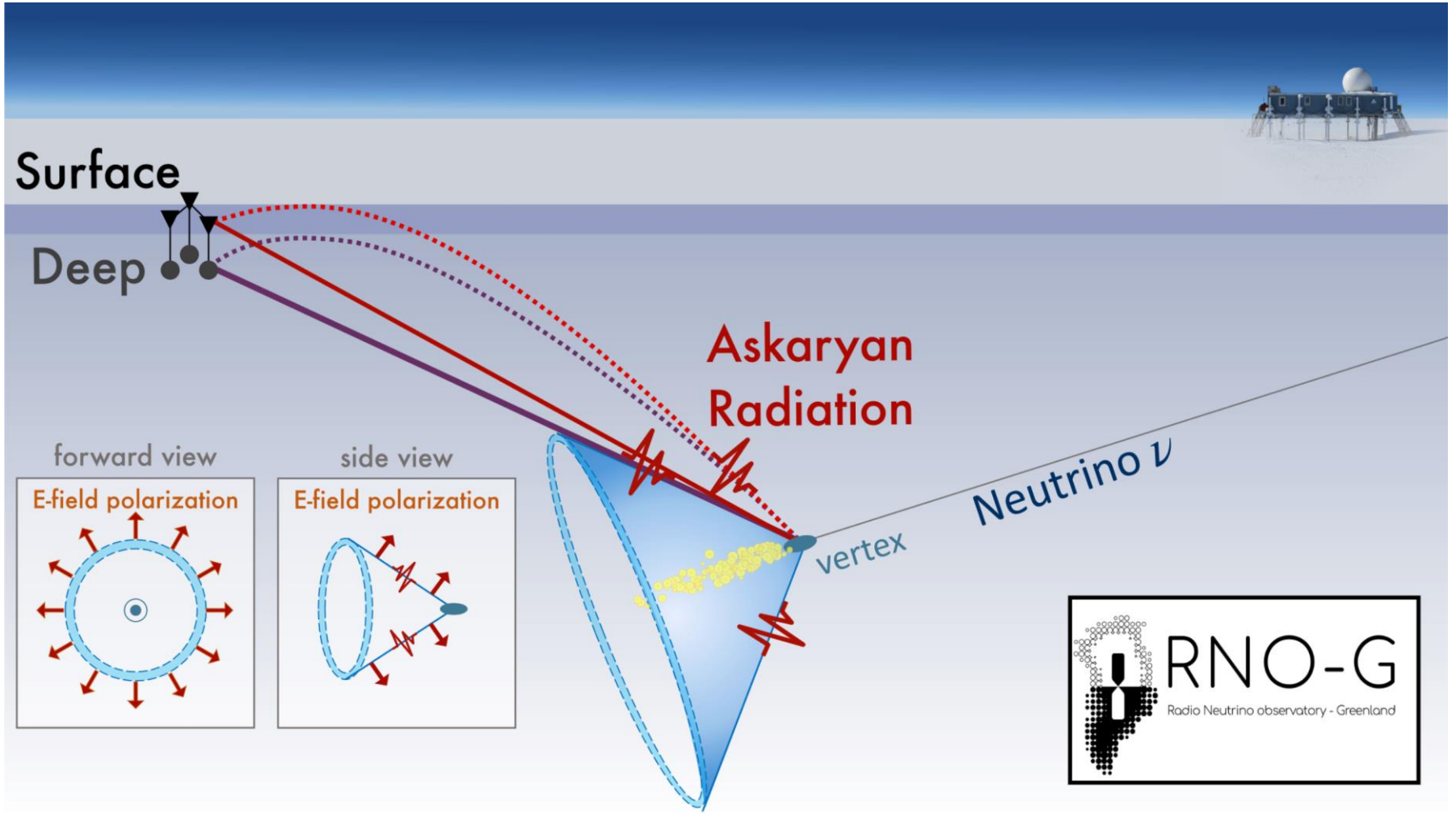
About me

- Bachelor at FAU, Thesis: “Variational preparation of maximally entangled states”
- Master thesis at ECAP
  - Group of Anna
  - RNO-G
  - Title: “Machine-Learning-based Background Identification for the Radio Neutrino Observatory Greenland”
- Since March 2024: PhD project for LOFAR/SKA-low
- Some hobbies/interests: Biking, reading, wood carving, video games, …

Work for RNO-G

Radio Neutrino Observatory Greenland (RNO-G)

Radio detection



- Radio emission from UHE neutrinos in ice

RNO-G collaboration

Radio Neutrino Observatory Greenland (RNO-G)

Detector and station layout

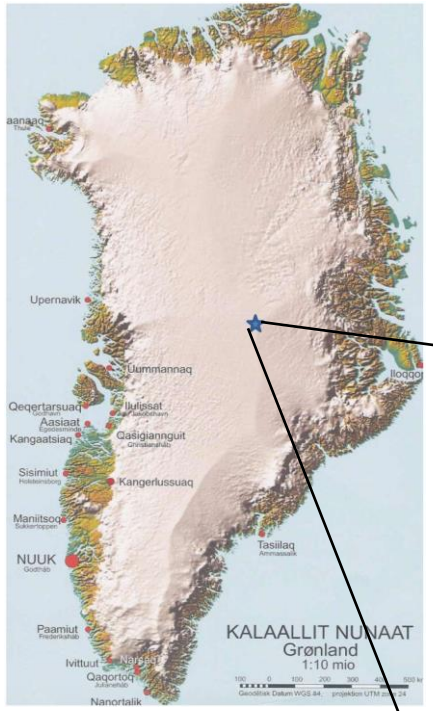


RNO-G collaboration

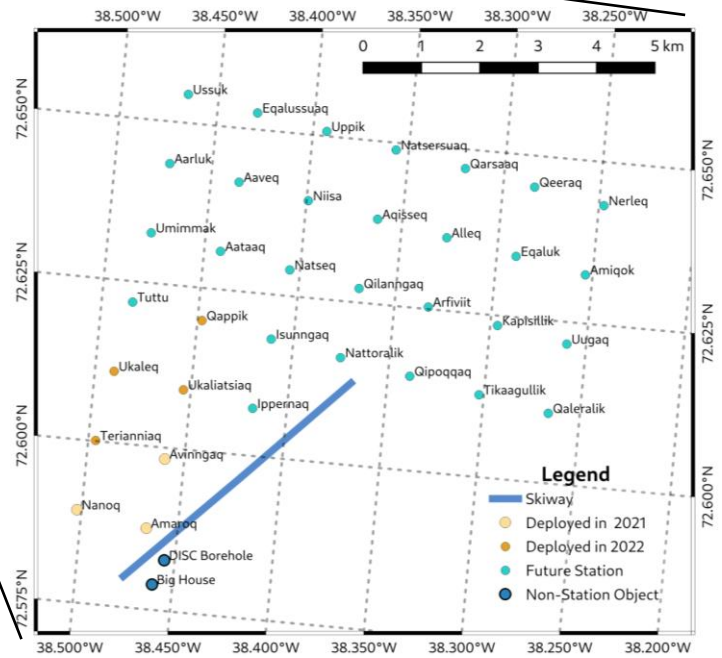
- Summit Station, Greenland

Radio Neutrino Observatory Greenland (RNO-G)

Detector and station layout



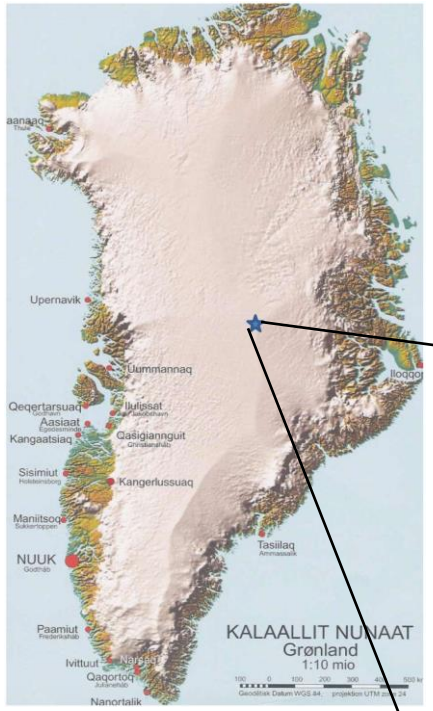
RNO-G collaboration



- Summit Station, Greenland
- 35 stations planned
- 7 stations already deployed

Radio Neutrino Observatory Greenland (RNO-G)

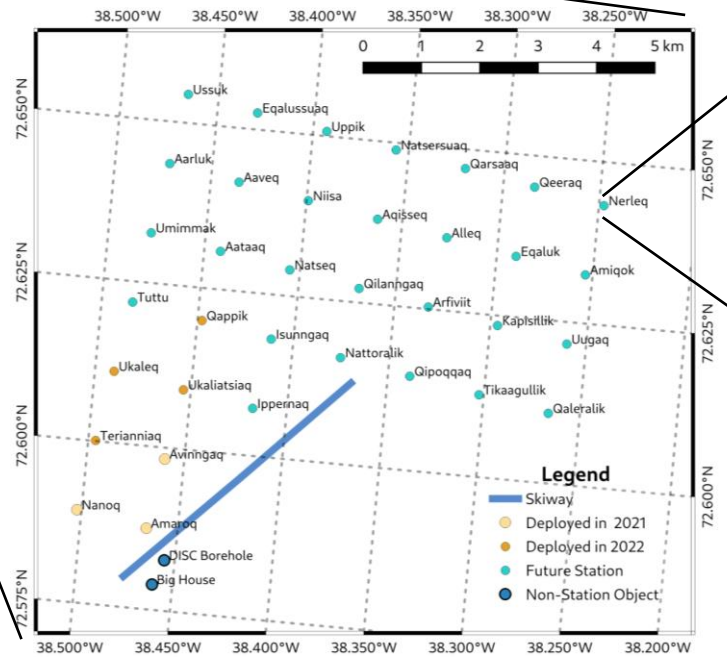
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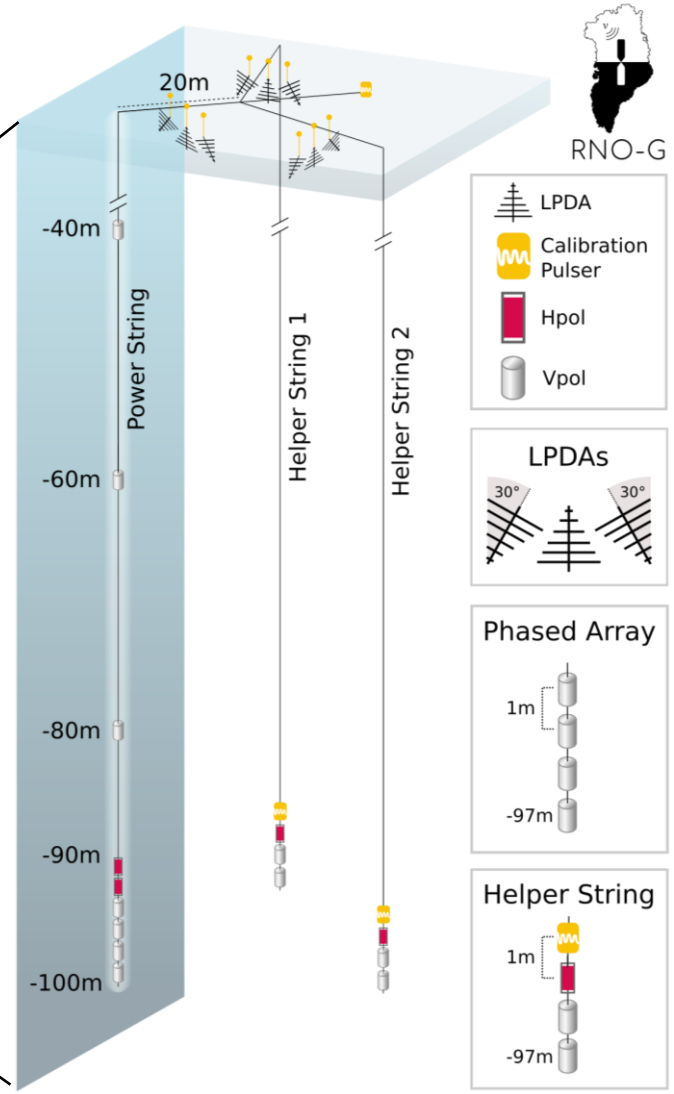


RNO-G collaboration

- Summit Station, Greenland
- 35 stations planned
- 7 stations already deployed

- Deep part: neutrino detection (not used here)
- **Surface part:** 9 LPDA antennas (buried in ice)
  - 6 downward-facing antennas
  - **3 upward-facing antennas**



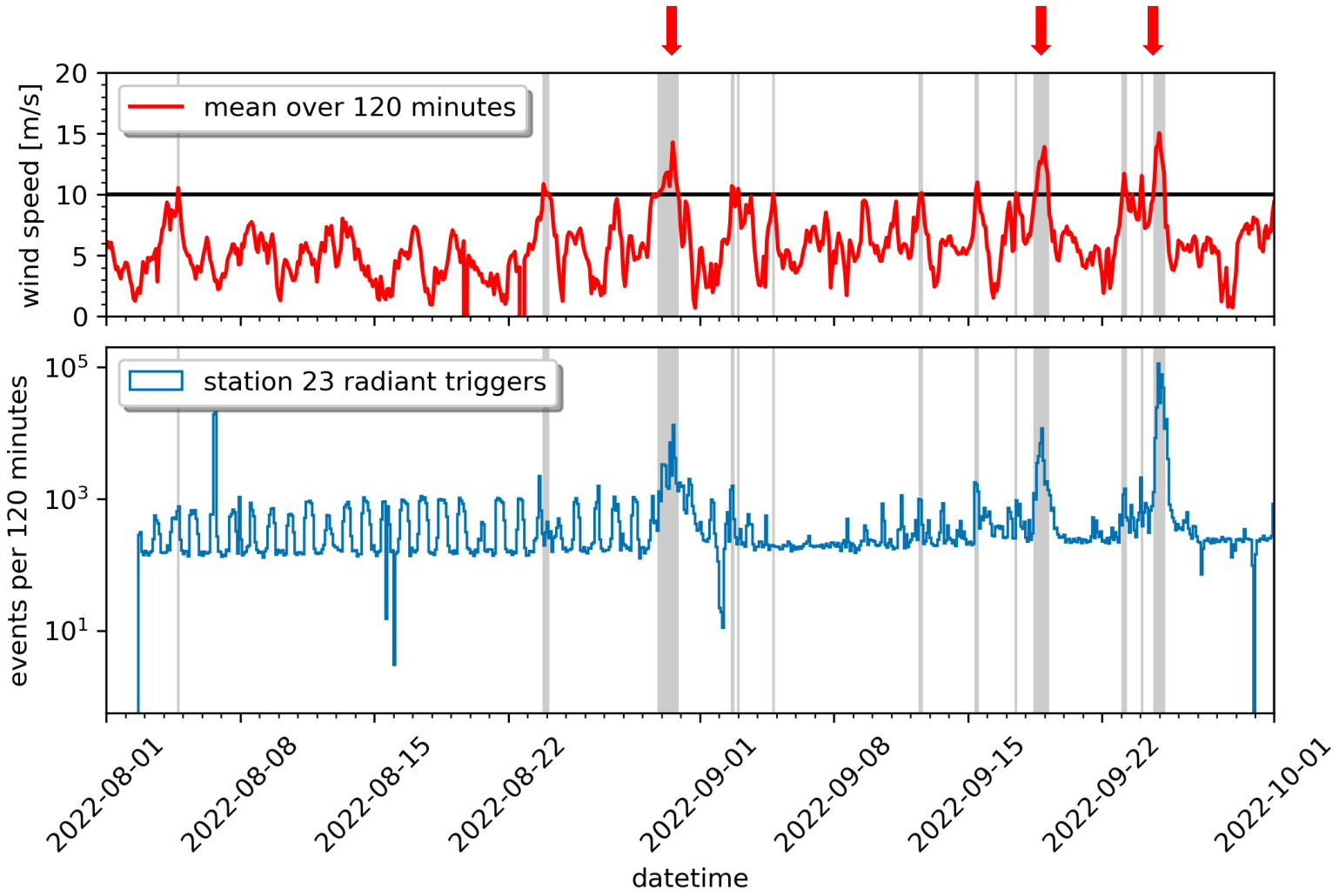


Backgrounds

Wind events

- Multiple natural and anthropogenic backgrounds
- Furthermore: **Wind events**
  - Impulsive events
  - Appear during high-wind periods
  - Physics of wind events not yet understood (potentially linked to triboelectric effect)
  - Huge temporary background
  - **Goal**: identify wind events

  → Event clustering

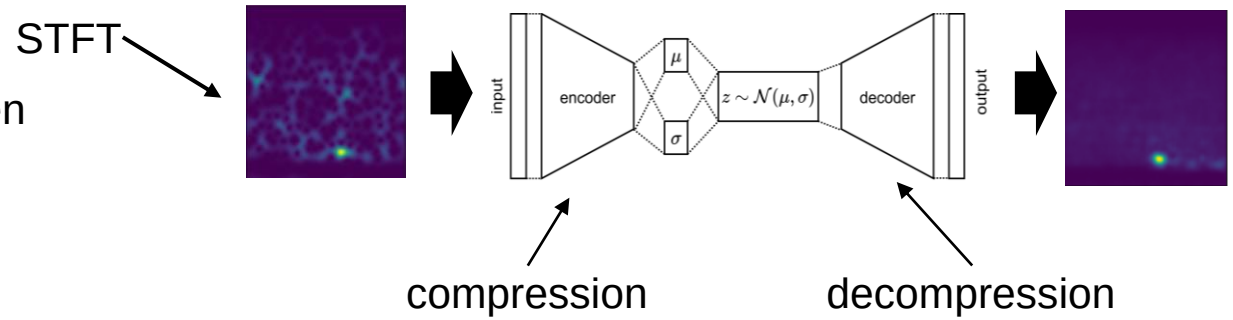


Clustering method

Algorithm (T. Glüsenkamp PoS (ICRC2023) 1056):

1. Train Variational autoencoder (VAE) on events of a chosen station

   → VAE learns to extract most important features



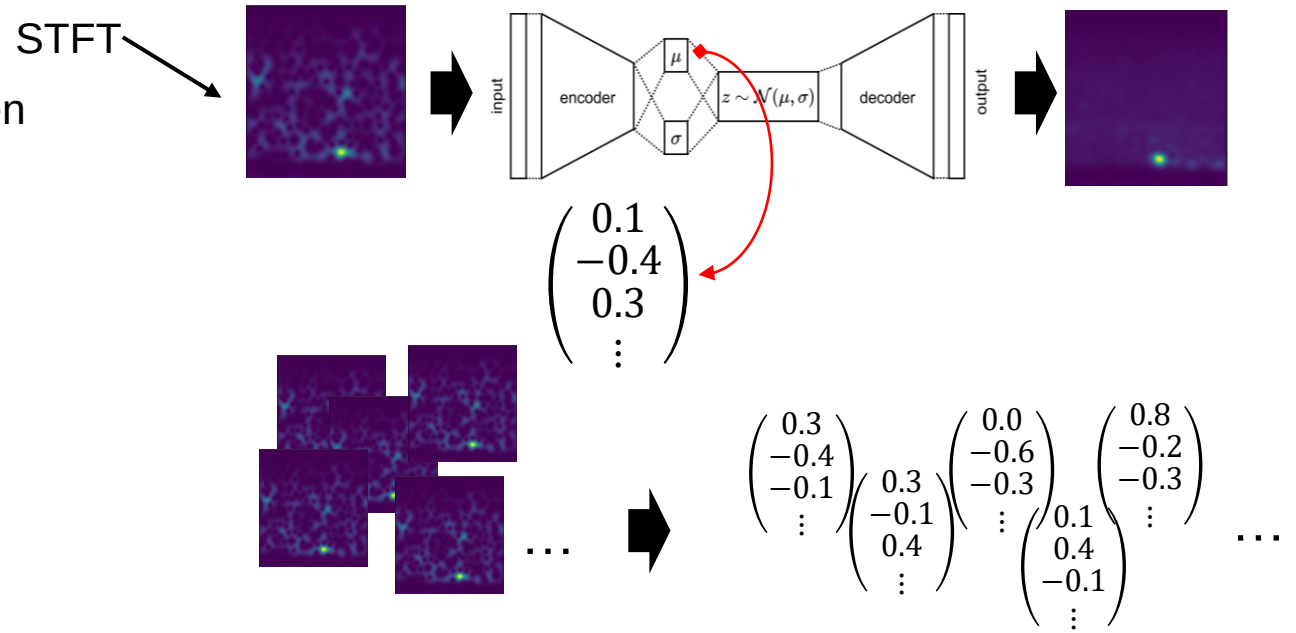
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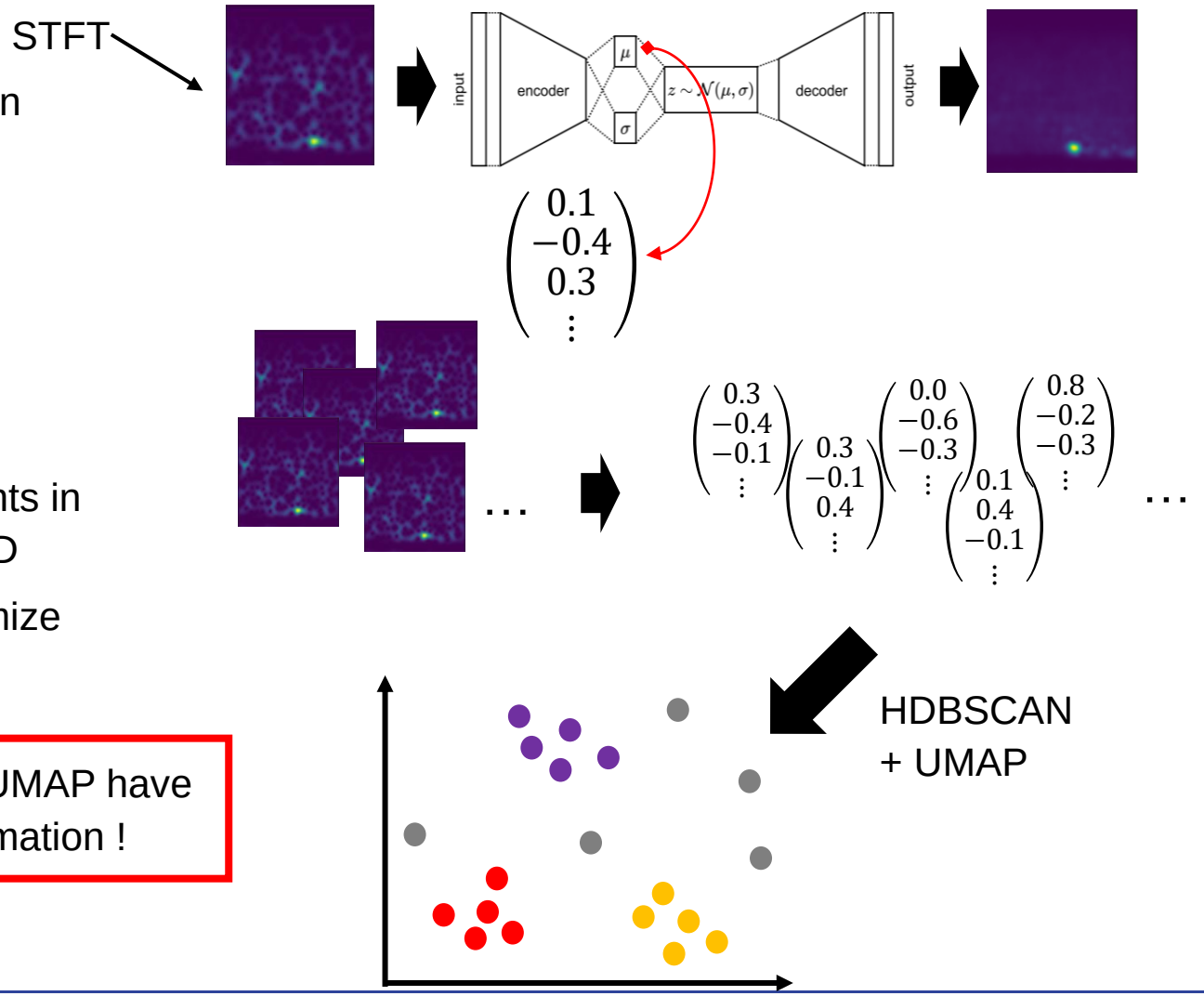
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2. Use encoder to represent triggered events as vectors of features (latent space, here 9-dimensional)

3. Use clustering algorithm (here HDBSCAN) to cluster events in latent space + use UMAP to represent encoded data in 2D
   → Manually inspect and assess clustering output and optimize parameters

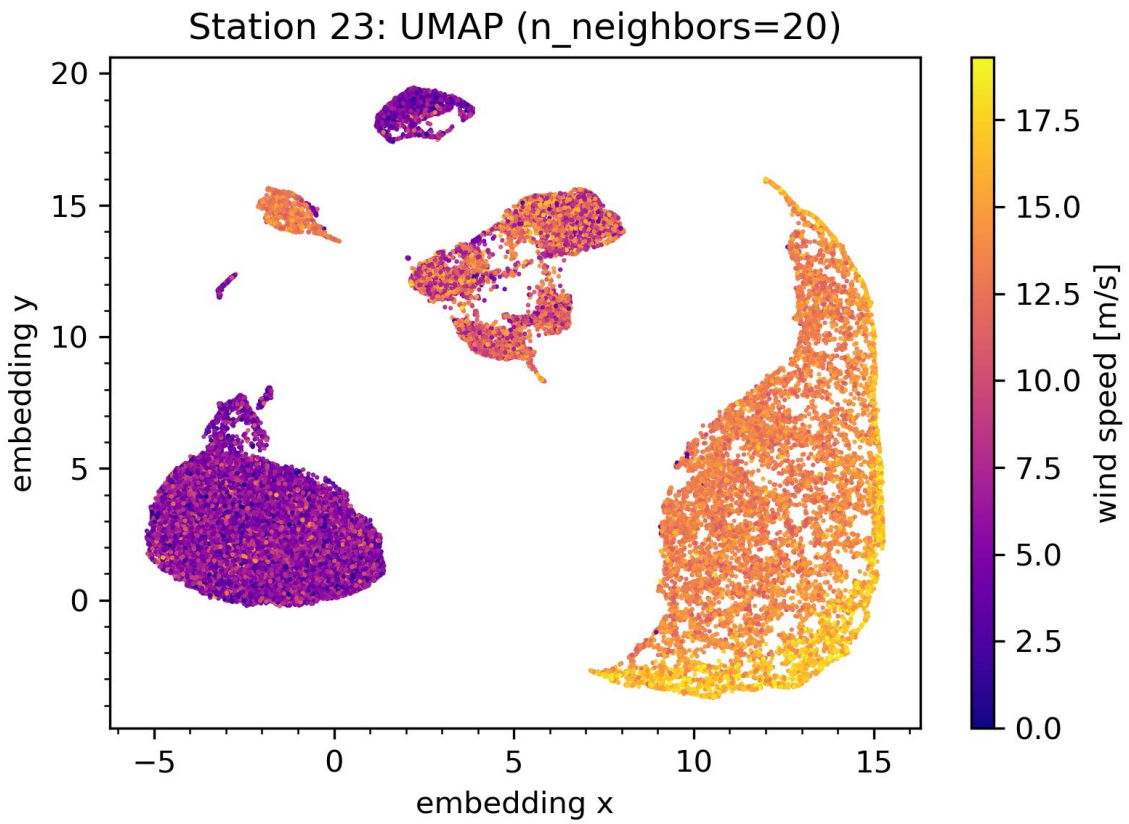


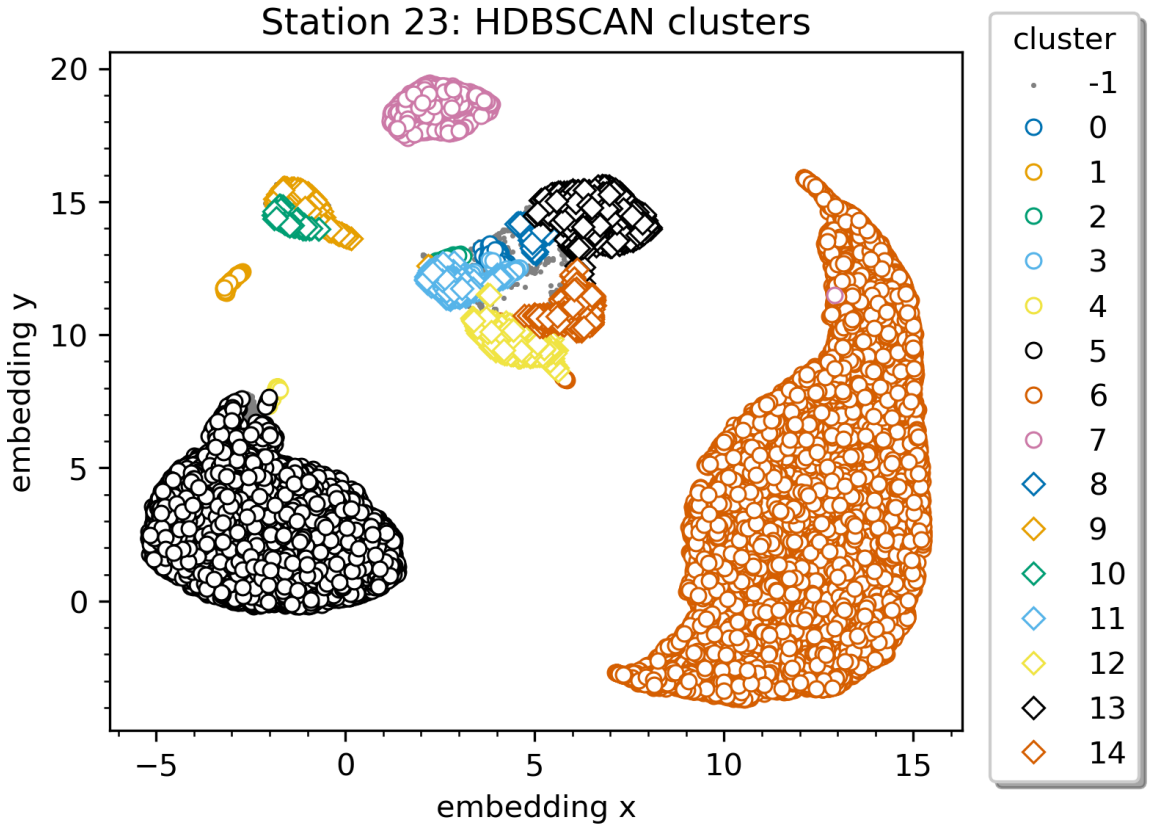
Neither VAE nor HDBSCAN or UMAP have access to any weather information !

HDBSCAN: doi: 10.1007/978-3-642-37456-2_14; software: doi:10.21105/joss.00861
UMAP: arXiv: 1802.03426 [stat.ML]; software: doi:10.21105/joss.00861

Clustering results

Station 23





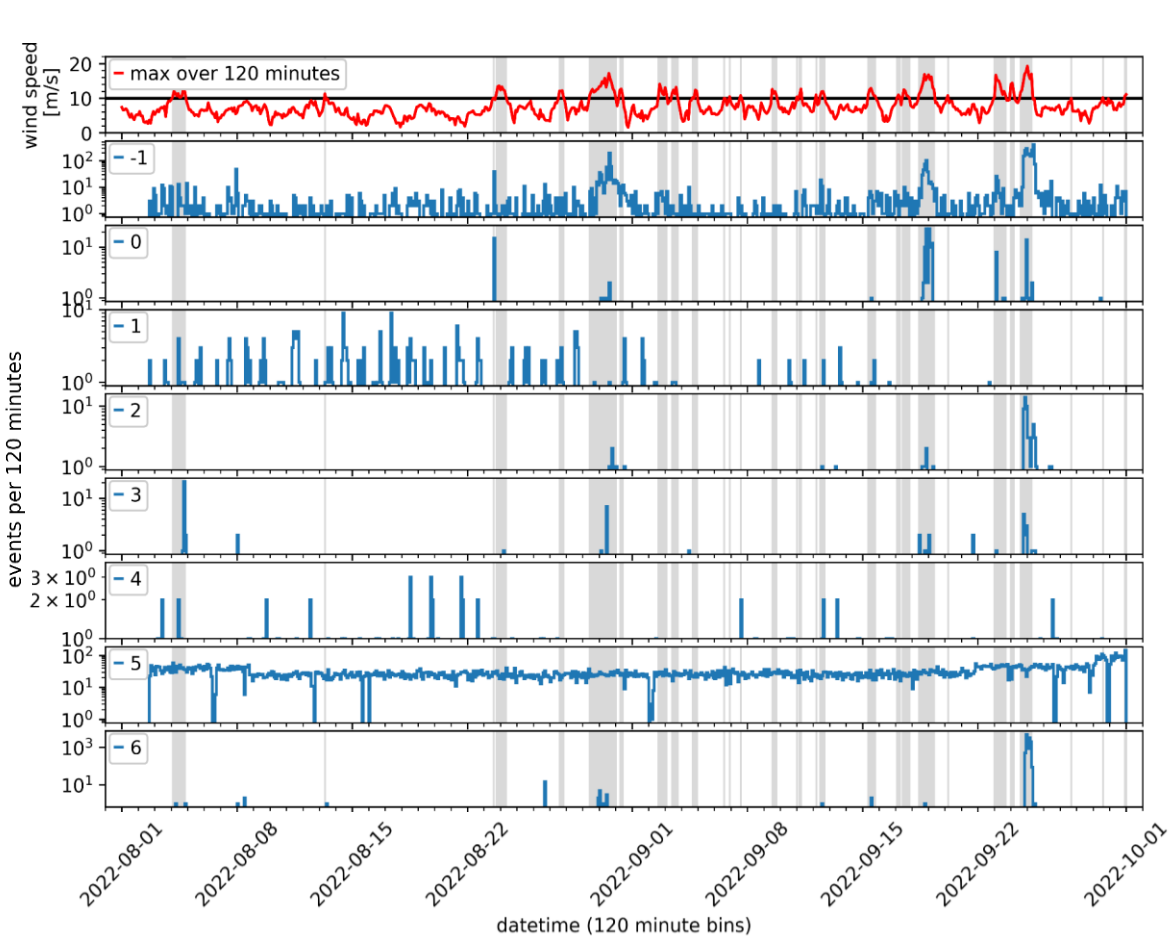
→ Method finds “blobs” of events with exclusively high wind speeds > 10 m/s

→ Multiple clusters of different sizes (cluster -1 are outliers/unclustered)

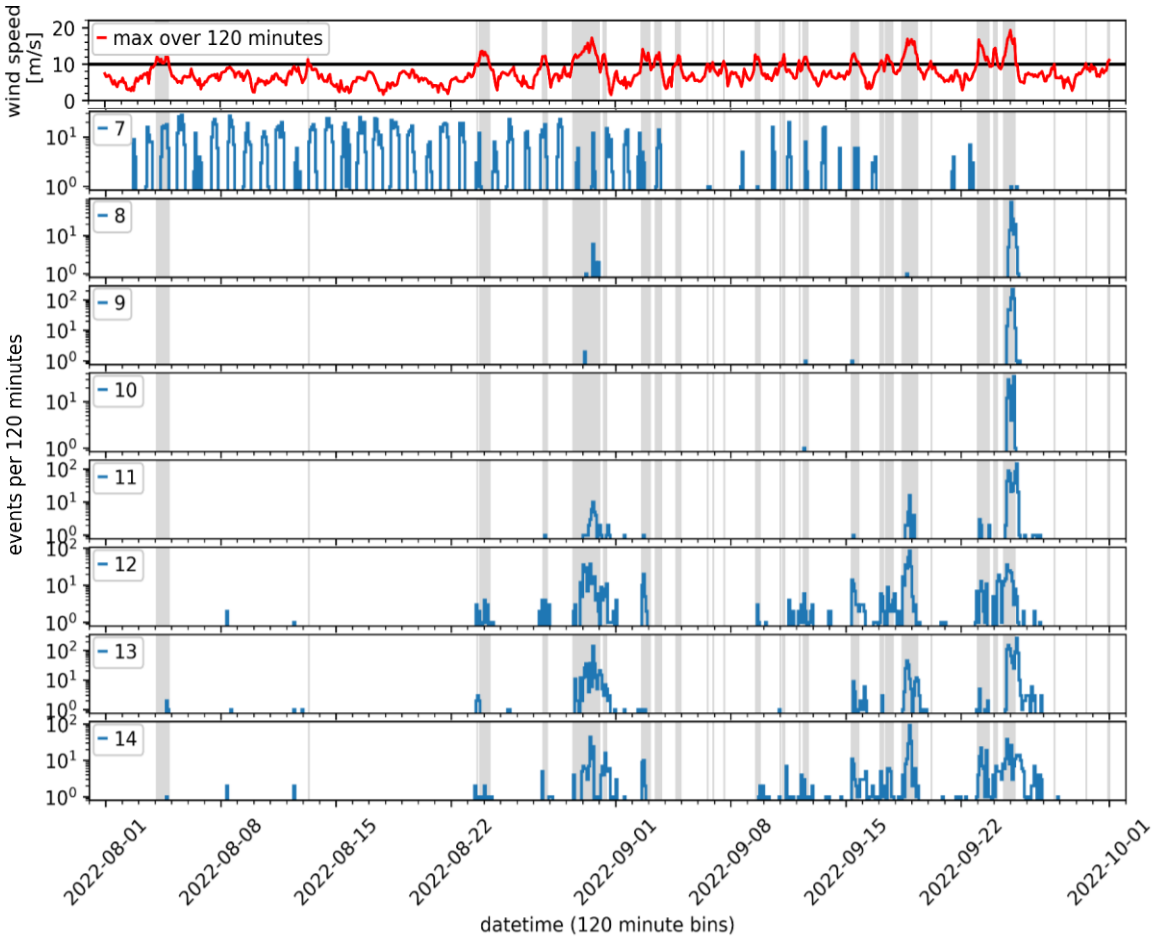
Clustering results

Station 23

- Event rate per cluster and wind speed vs. time:



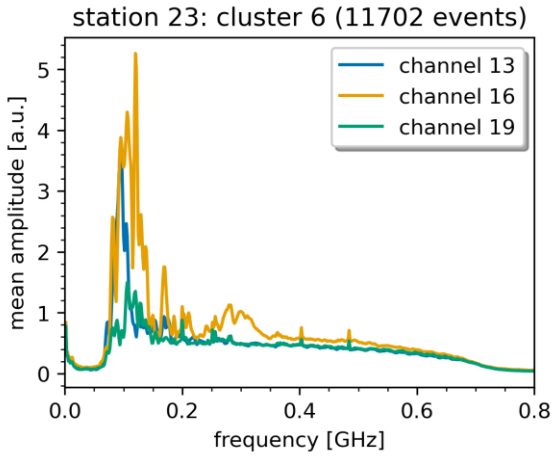
clusters

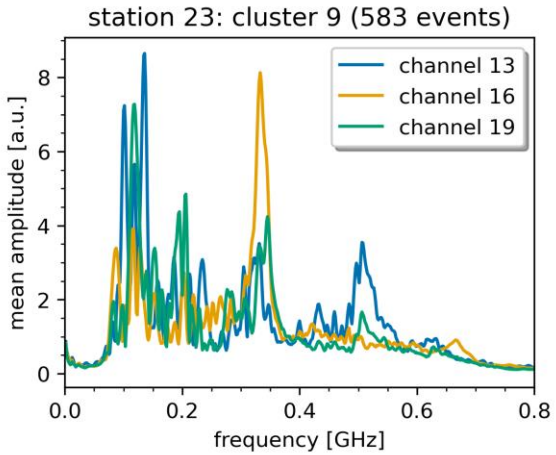


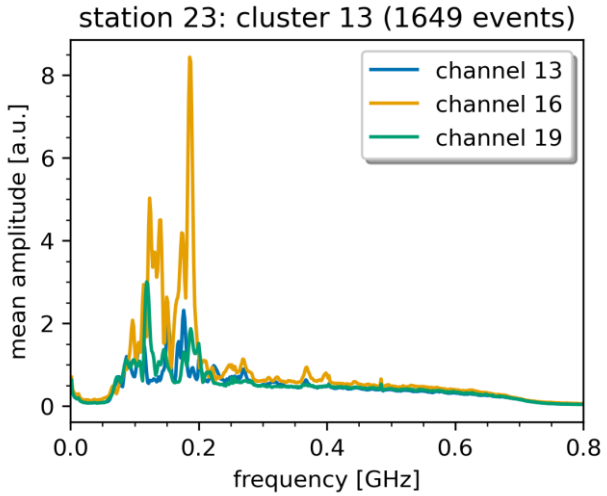
Clustering results

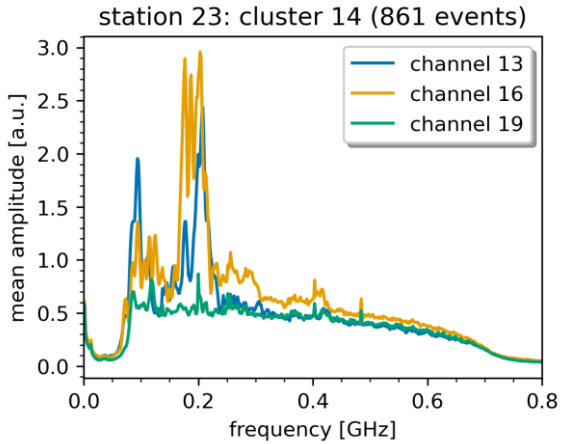
Station 23

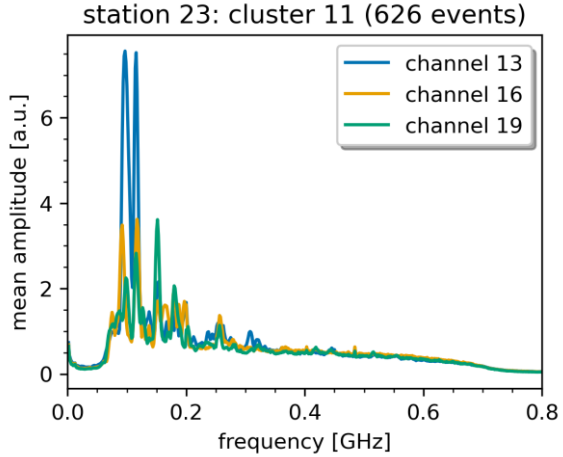
- Mean frequency spectra: different wind event classes → different production mechanisms?











Planned work for LOFAR/SKA-low

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- **Goal**: 4D (space + time) imaging/interferometry of radio emission from cosmic-ray air showers
- Joint project (Erlangen, Karlsruhe, Garching)
- Use LOFAR data and SKA-low simulations
- Use IFT
- Hopefully gain more insights in air shower physics
- Maybe applicable to lightning

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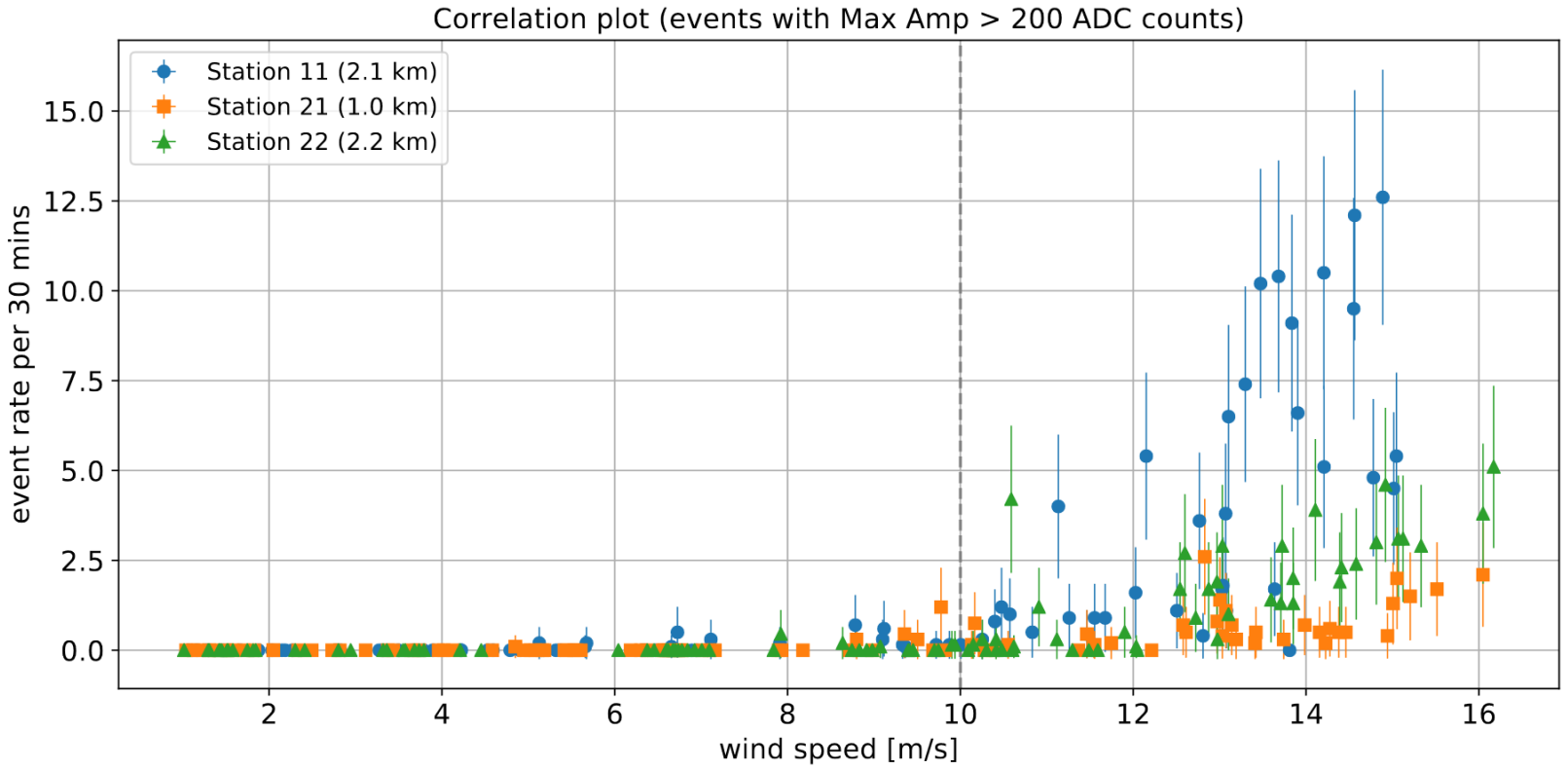
Thank you for your attention!

Backup

Backgrounds

Wind events

- Appearance of impulsive signals during periods of high wind speed
- Trigger rates increase with increasing wind speed
- Turn-on at ~10 m/s
- Physics of wind events not yet understood (potentially linked to triboelectric effect)



J.A. Aguilar et al, Astroparticle Physics 145 (Mar. 2023), p. 102790

Backgrounds

Wind events: possible production process

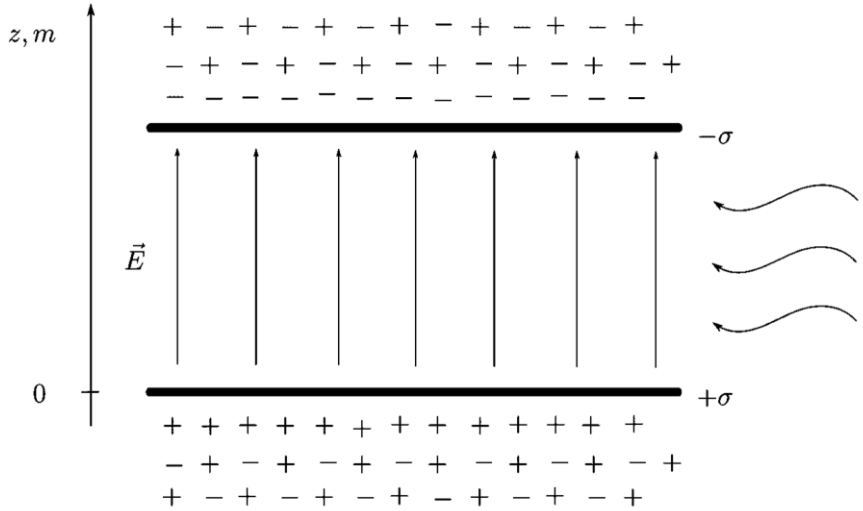
- Wind events potentially linked to triboelectric effect:
  1. Wind-induced charge displacement at surface
  2. Development of electric fields

  } effect measured by multiple experiments

  3. Coronal discharge
  4. Radio emission

  } impulsive radio signals can be measured after spark discharge

- But: production of wind events via triboelectric effect not yet confirmed

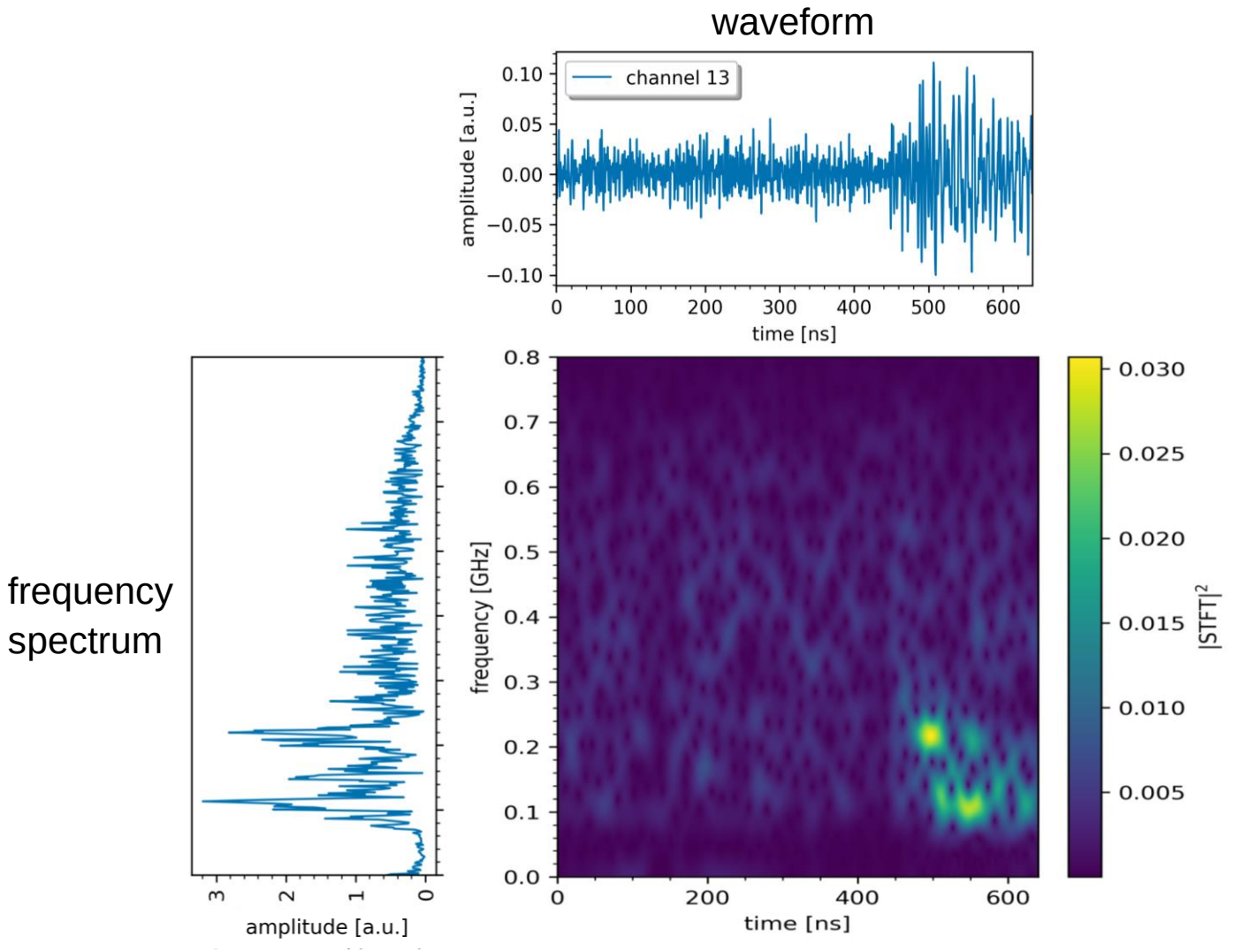


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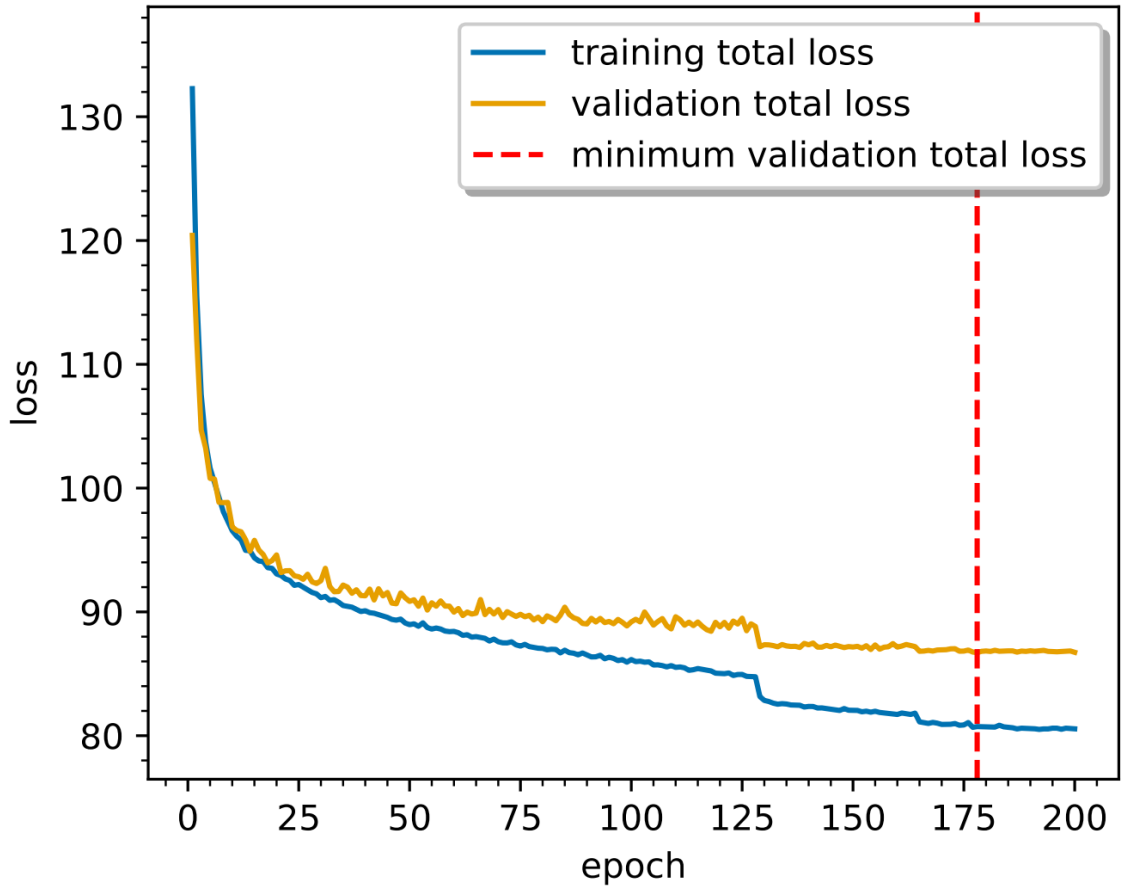
Data preparation

- Raw data: waveform (voltage trace) per channel (antenna)
- Short time Fourier transform (STFT):
  - Time and frequency information
  - 2D matrix
- Use $|STFT|^2$

  → Thermal noise suppressed



VAE clustering training history

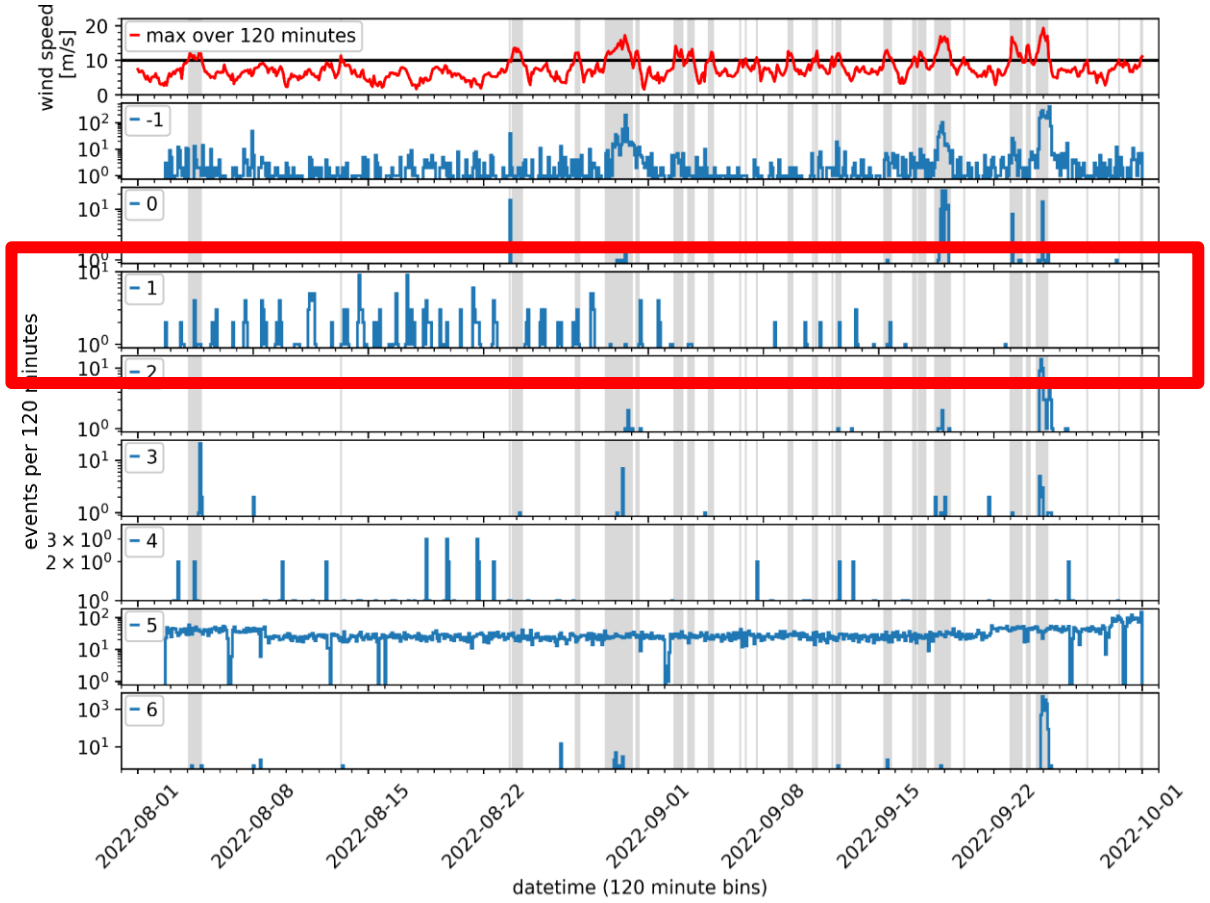


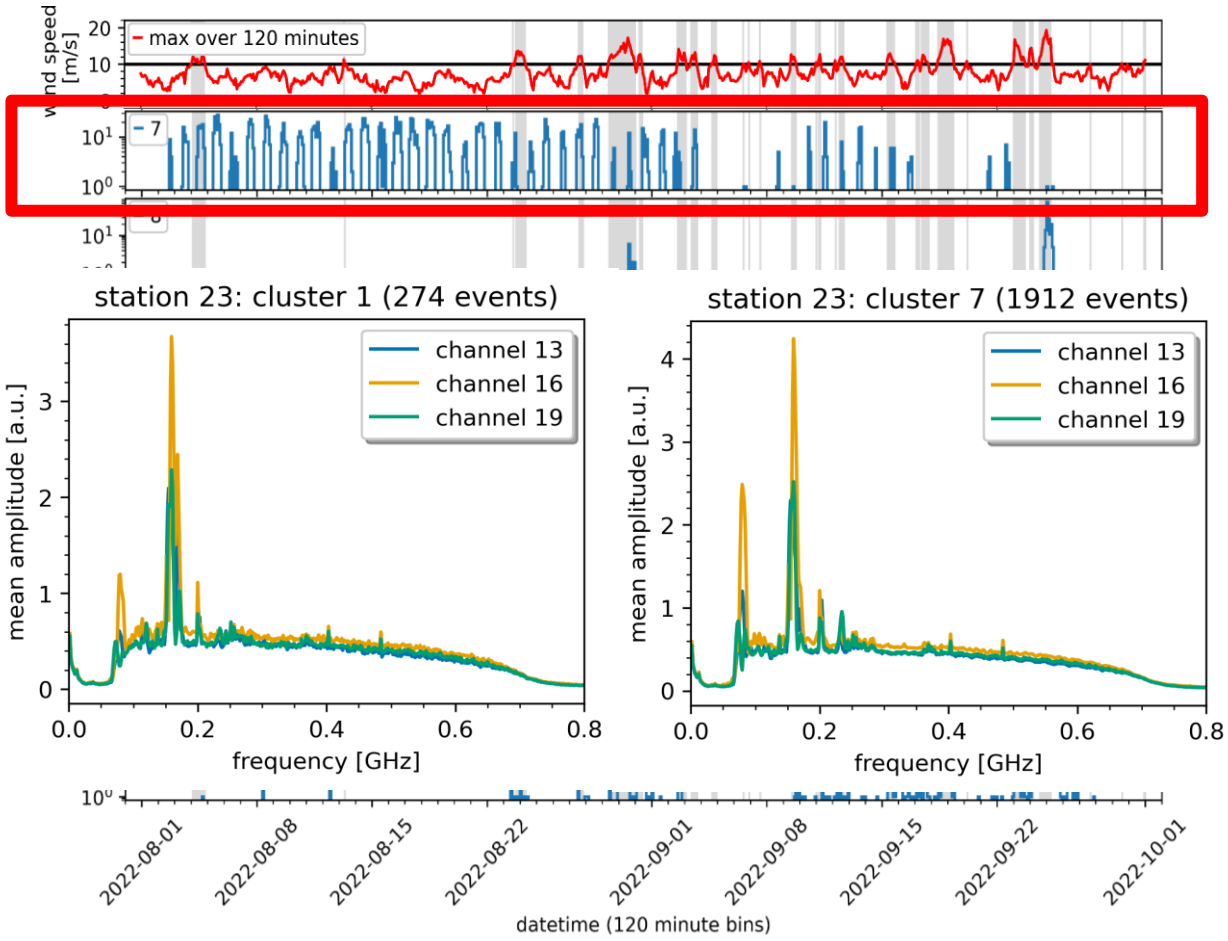
Clustering results

Station 23

- Clusters 1 and 7 appear periodically during daytime, but unknown origin (solar panels?)

→ Presumably wind-independent





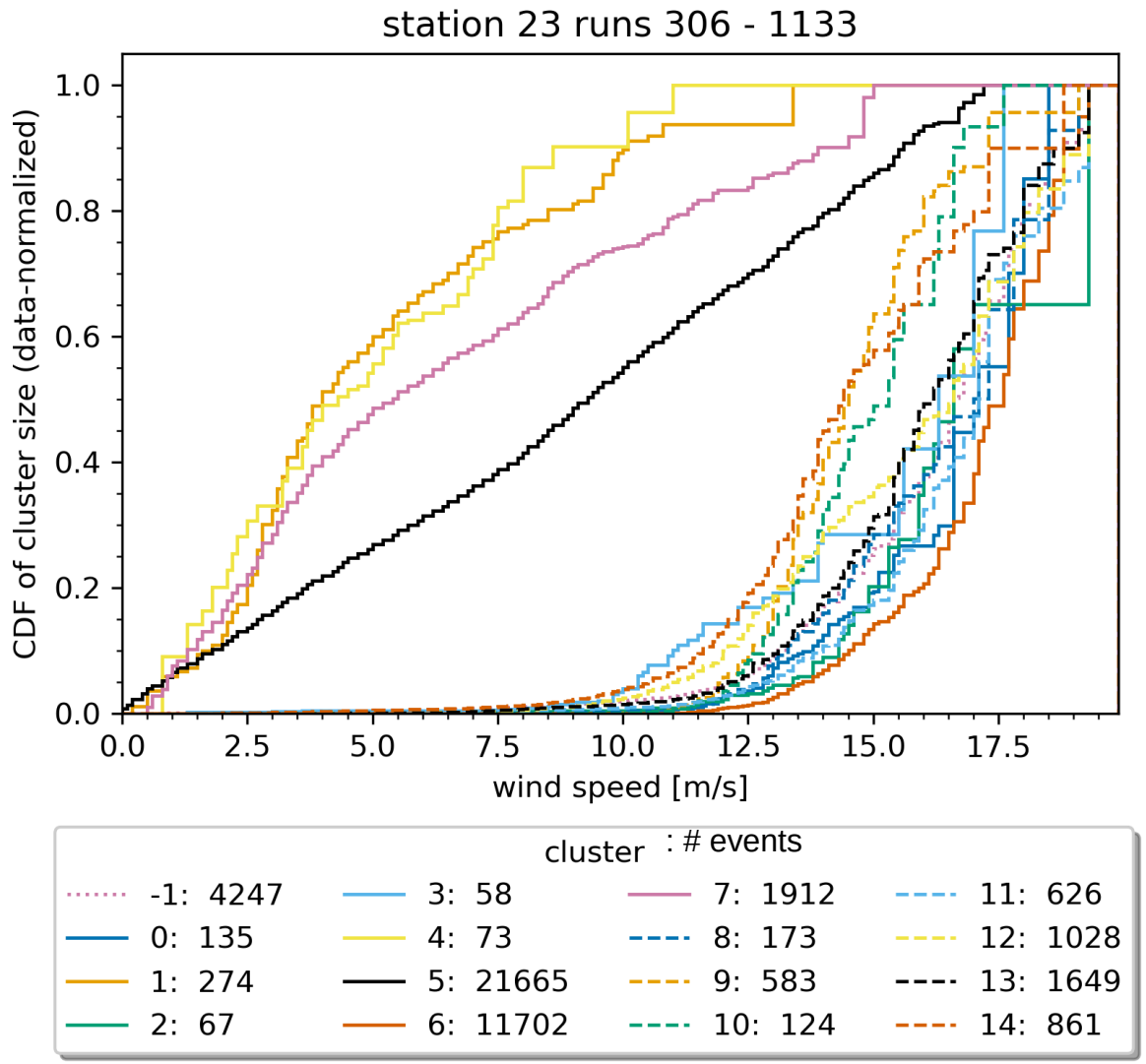
Clustering results

Station 23

- Investigate cluster size as function of wind speed
- Data-normalization: account for over- and underrepresentation of wind speeds

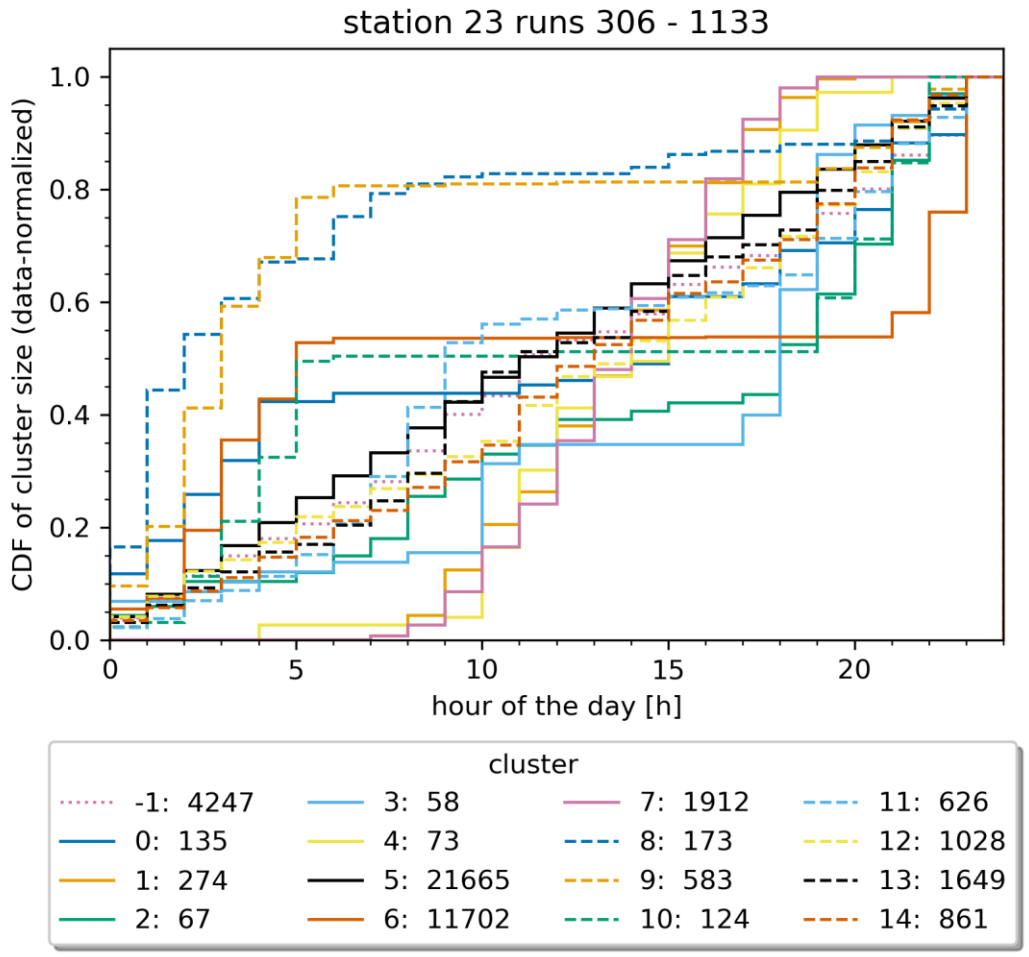
  → Linear CDF: independent of wind speed
- Only CDF of cluster 5 linear: thermal noise
- Some clusters with concave or convex CDF

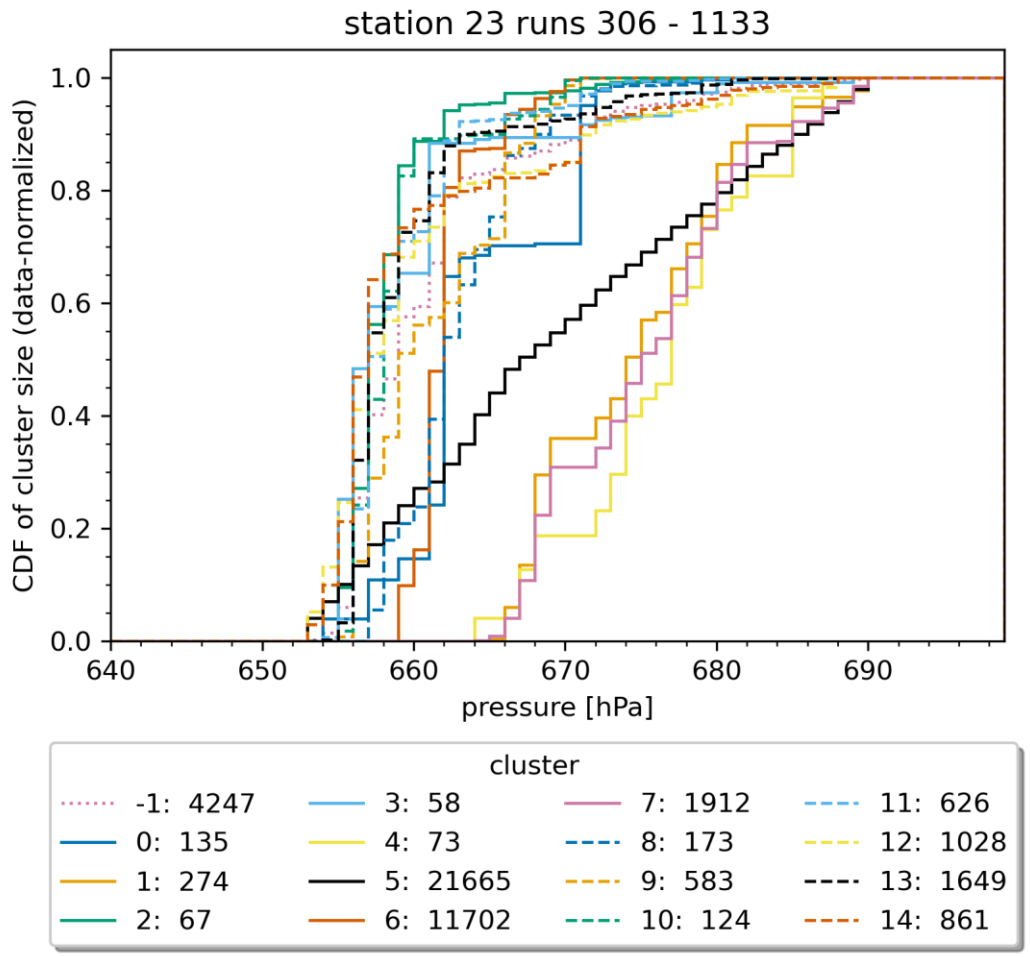
→ Investigate event rate per cluster vs. time and compare to wind speed



Clustering results

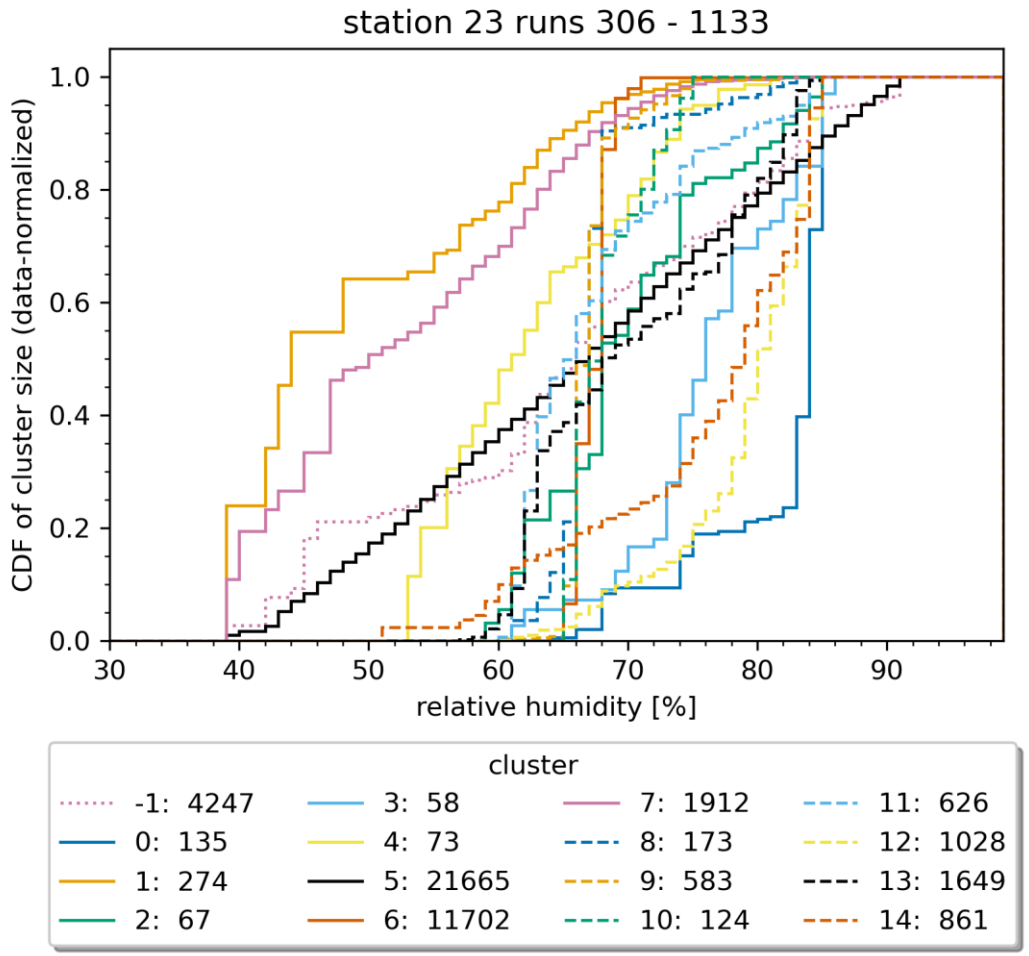
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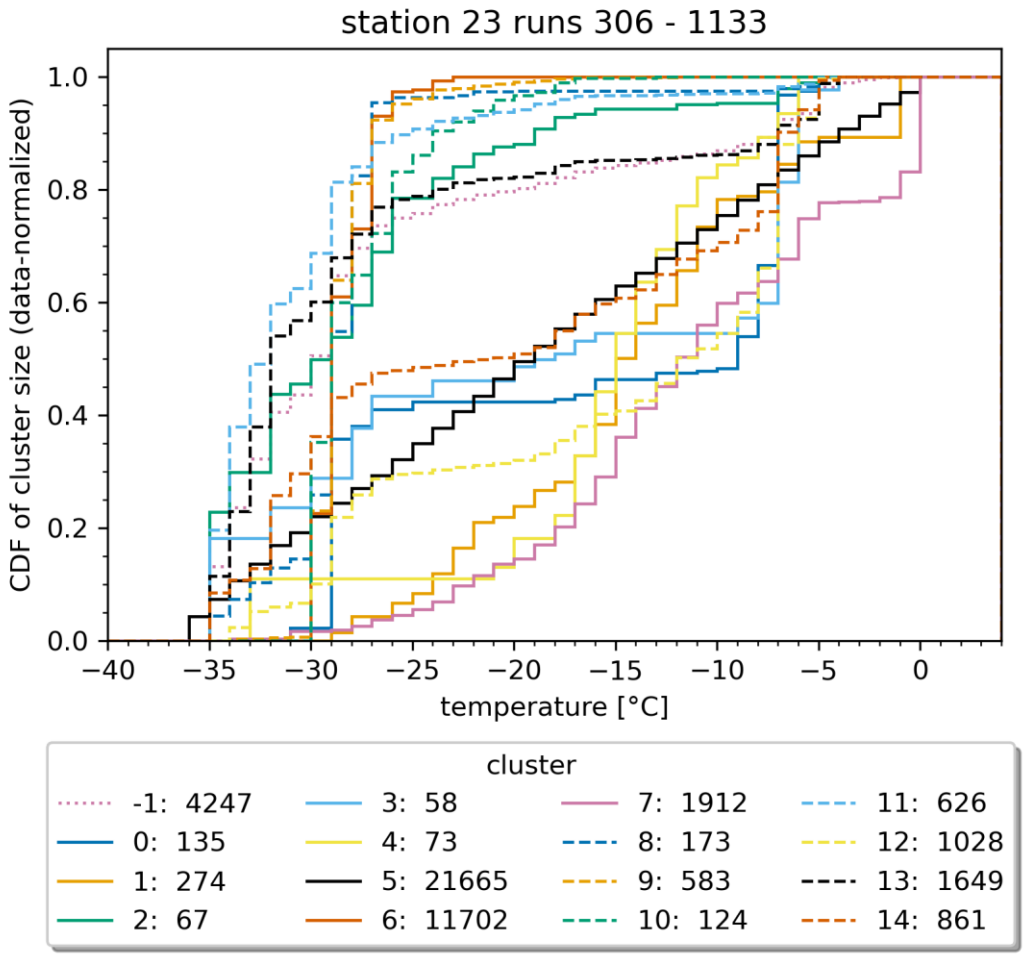




Clustering results

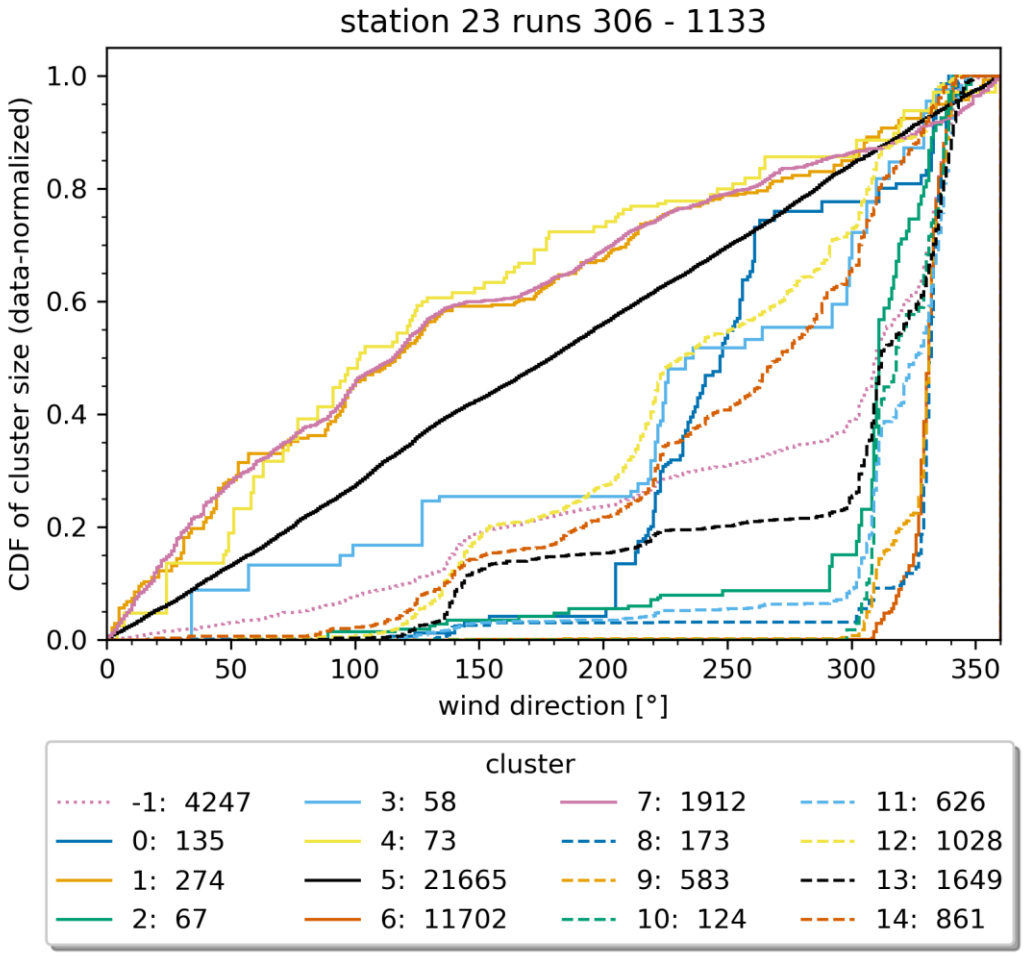
Station 23





Clustering results

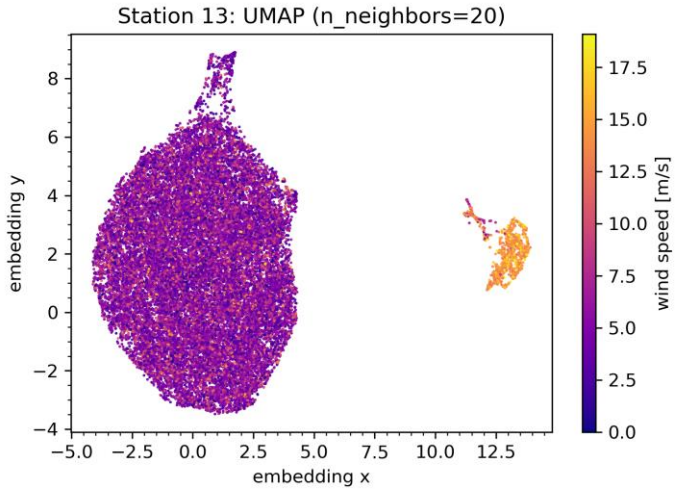
Station 23

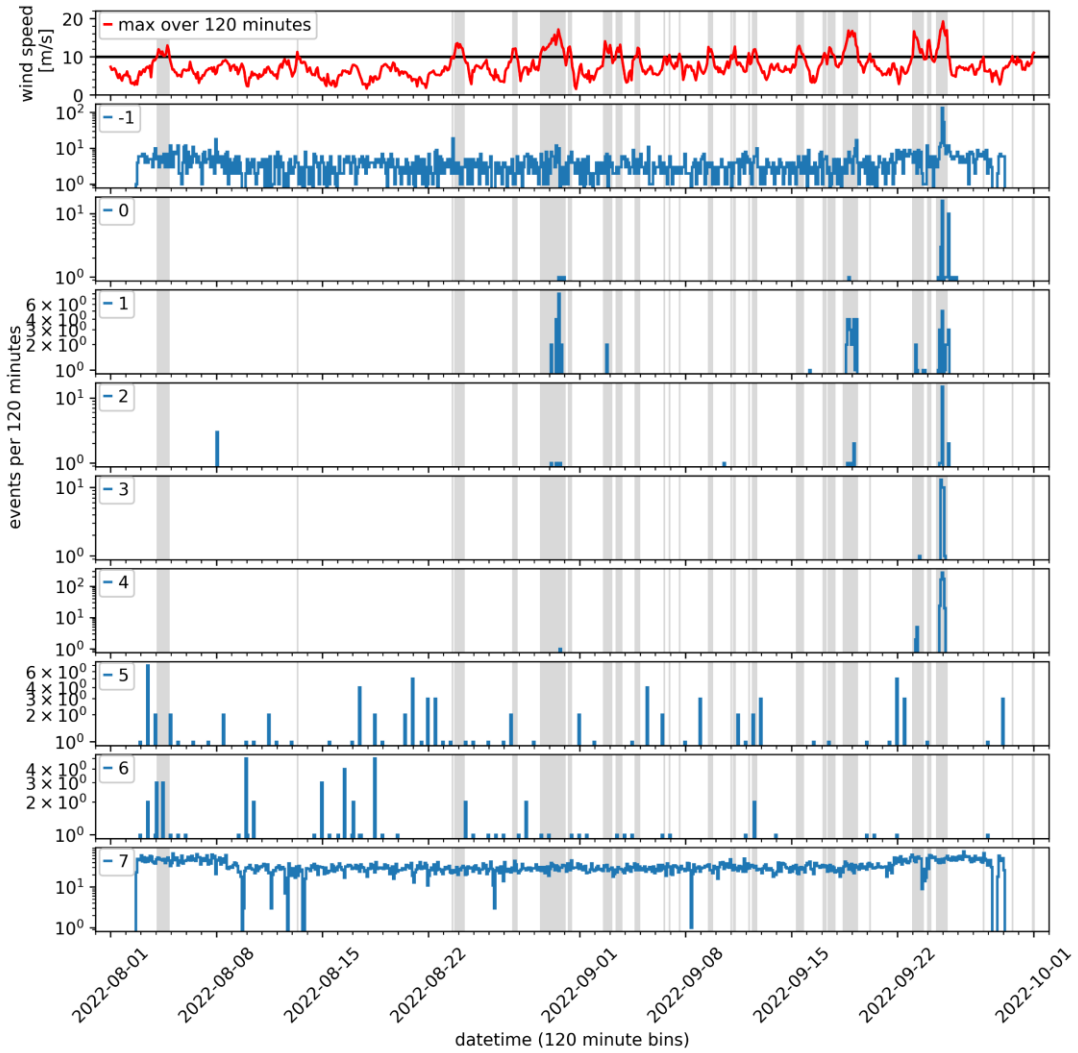


Clustering results

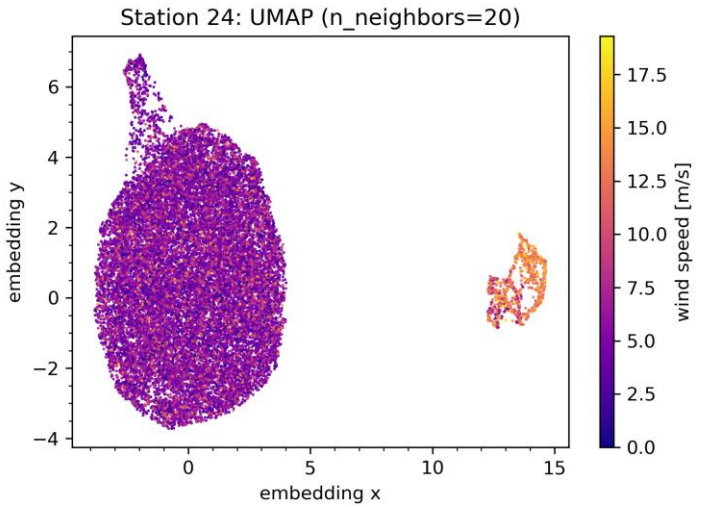
Station 13

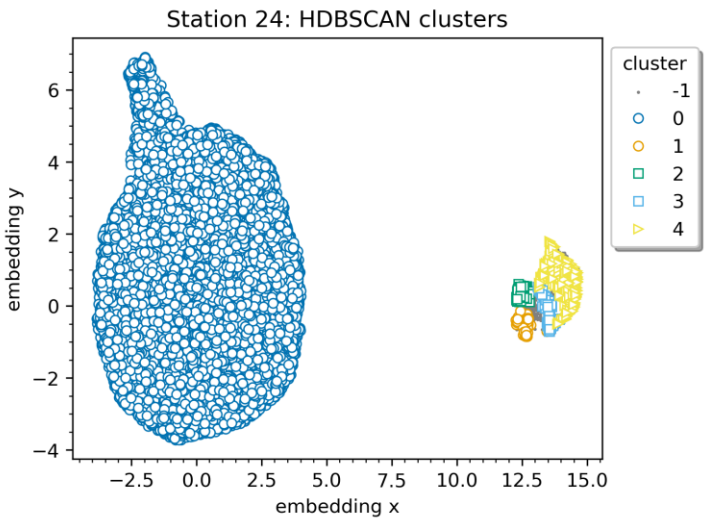
Station 13

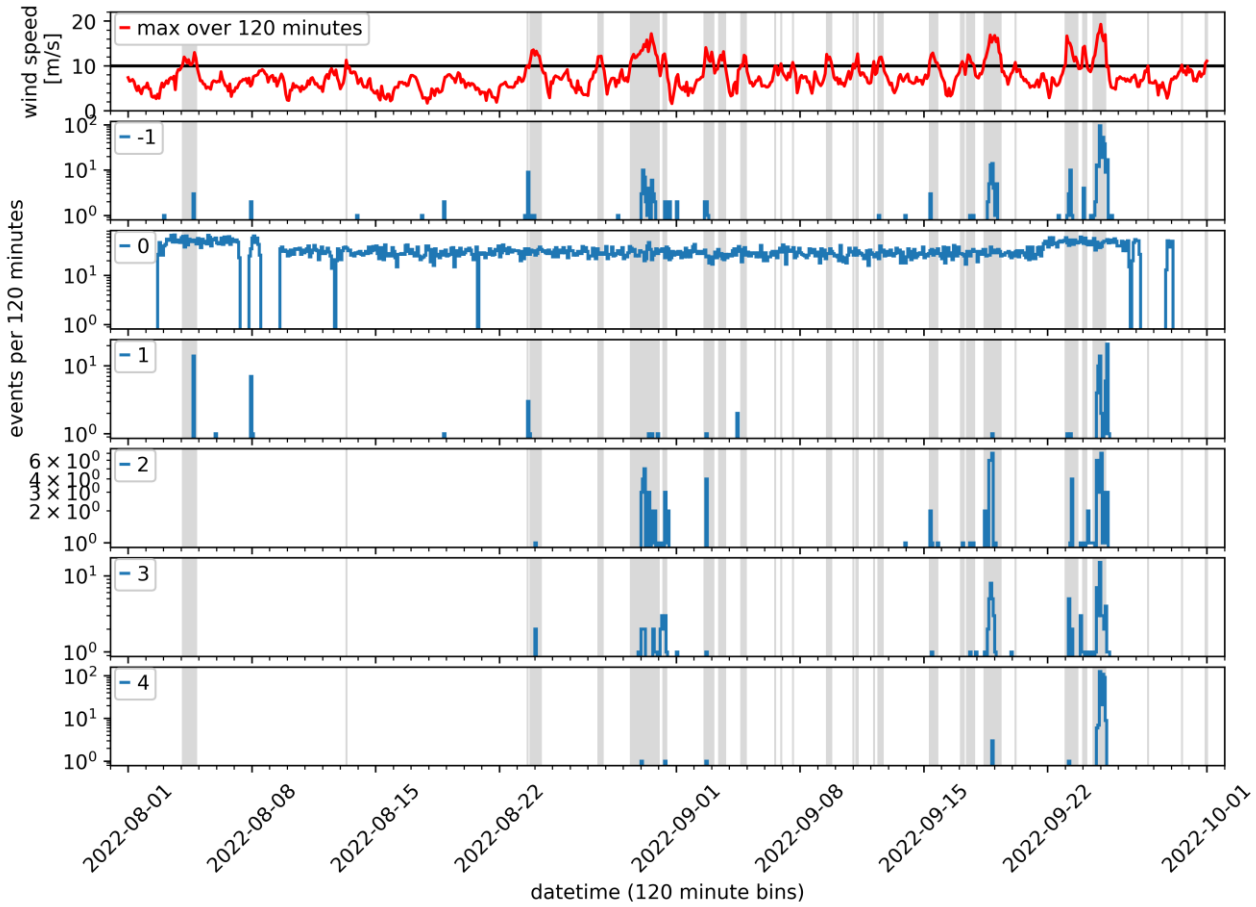




Station 24


Station 24: UMAP (n_neighbors=20)
embedding y
embedding x
wind speed [m/s]
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0

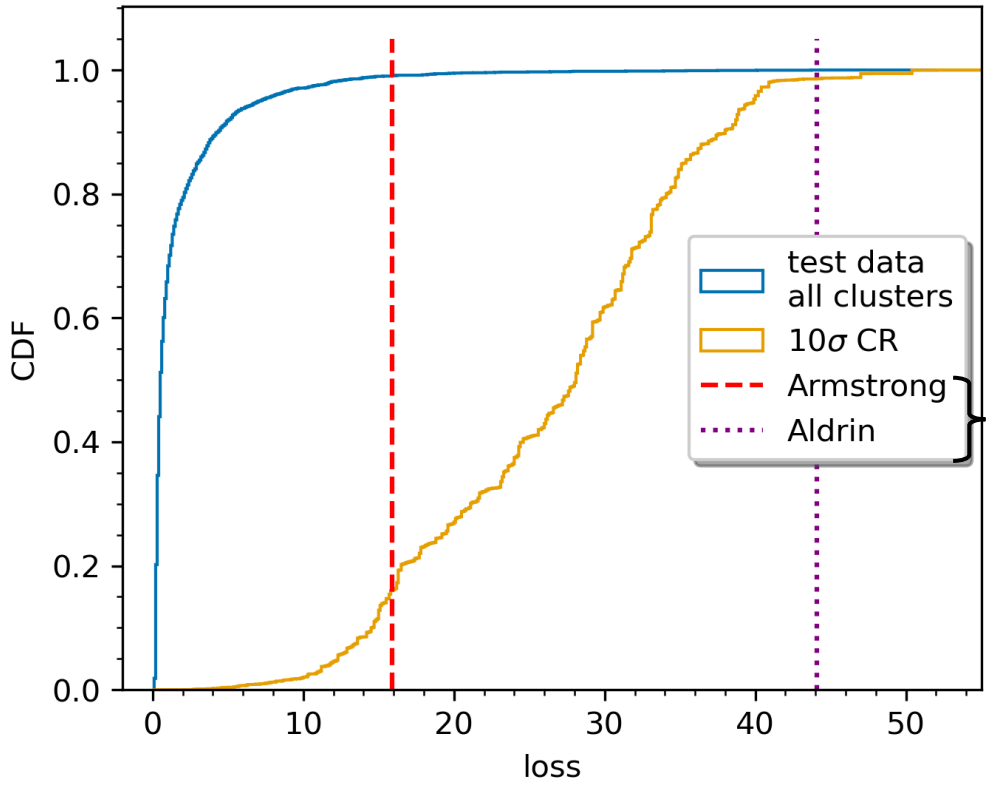

Station 24: HDBSCAN clusters
embedding y
embedding x
cluster
-1
0
1
2
3
4


wind speed [m/s]
max over 120 minutes
events per 120 minutes
-1
0
1
2
3
4
2022-08-01
2022-08-08
2022-08-15
2022-08-22
2022-09-01
2022-09-08
2022-09-15
2022-09-22
2022-10-01
datetime (120 minute bins)

Wind event discrimination

Cosmic ray simulations

- Reconstruction loss of station 23 test wind data and cosmic ray air shower simulations:



cosmic ray candidate events

loss threshold L	% test data $\leq L$	% 10σ CR $\leq L$
2.16	80.1	0.008
4.37	90.0	0.265
7.15	95.0	0.906
7.48	95.3	1.00
15.3	99.0	13.9

→ Promising for cosmic ray searches