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Operational radar-based mesocyclone detection in Alpine regions

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1. Introduction

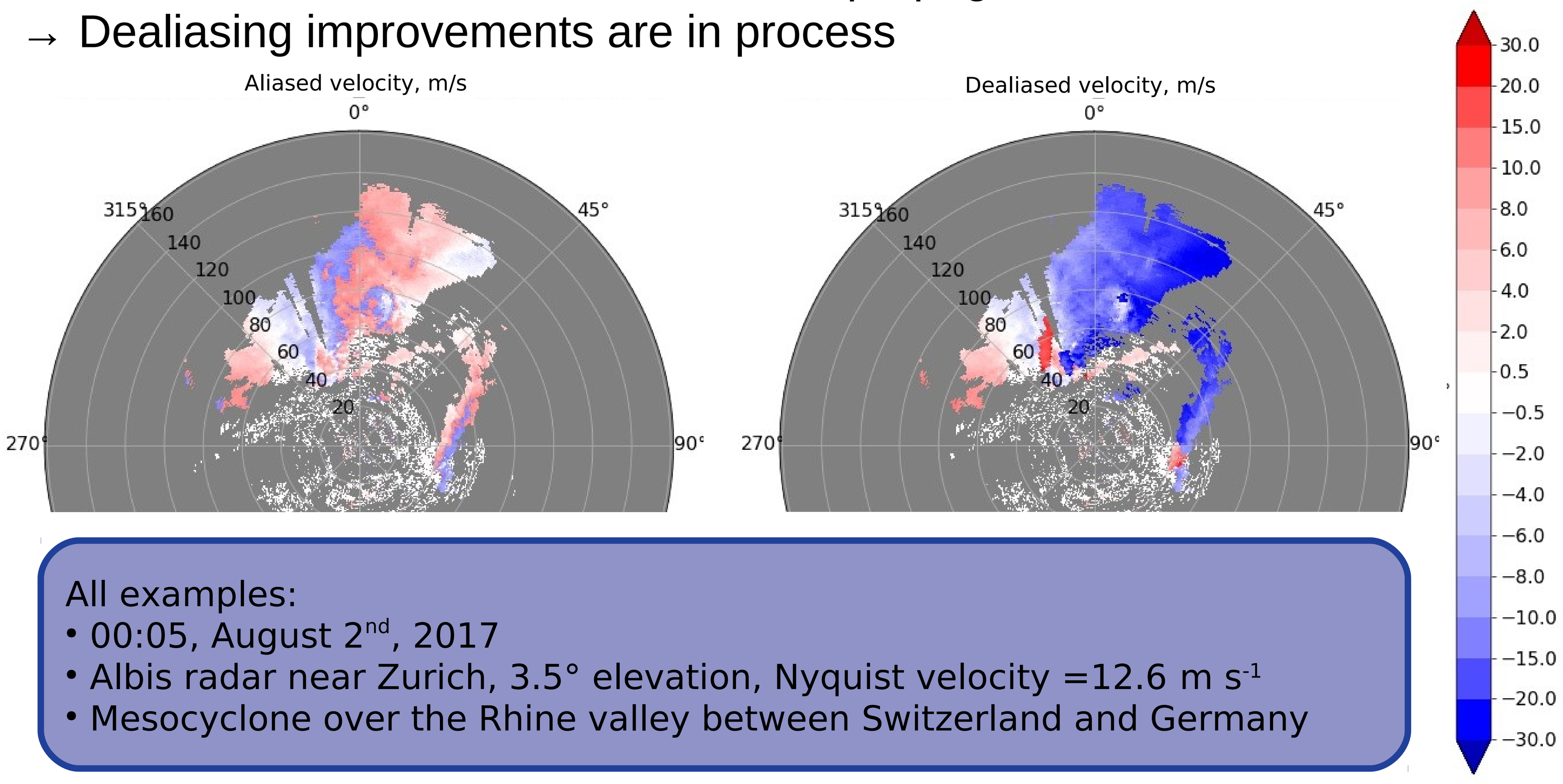
- Mesocyclone:
  - Rotation core of severe thunderstorm
  - Indicator of severe weather
  - Potential for hail, wind gusts, intense precipitation and tornadoes [2]
- Motivation:
  - Hailstorms prominent in Switzerland [2]
  - Source of damage in agriculture and property
- Objective:
  - Identification and tracking of mesocyclones as improvement of severe weather nowcasting

2. Available data

- 5 operational C-band radars (Rad4Alp) of MeteoSwiss at 1000 m – 3000 m above sea level
- 5 minute scan frequency, 20 elevations, 500 m x 1° resolution
- High range (up to 246 km) to ensure coverage of Alps from different directions
- Low pulse repetition frequency → extremely low Nyquist velocity down to 8.2 m s^{-1}
- Velocity data heavily folded, especially in high-wind and turbulent situations → dealiasing often fails [3]

→ Use of raw, folded data to avoid error propagation

→ Dealiasing improvements are in process



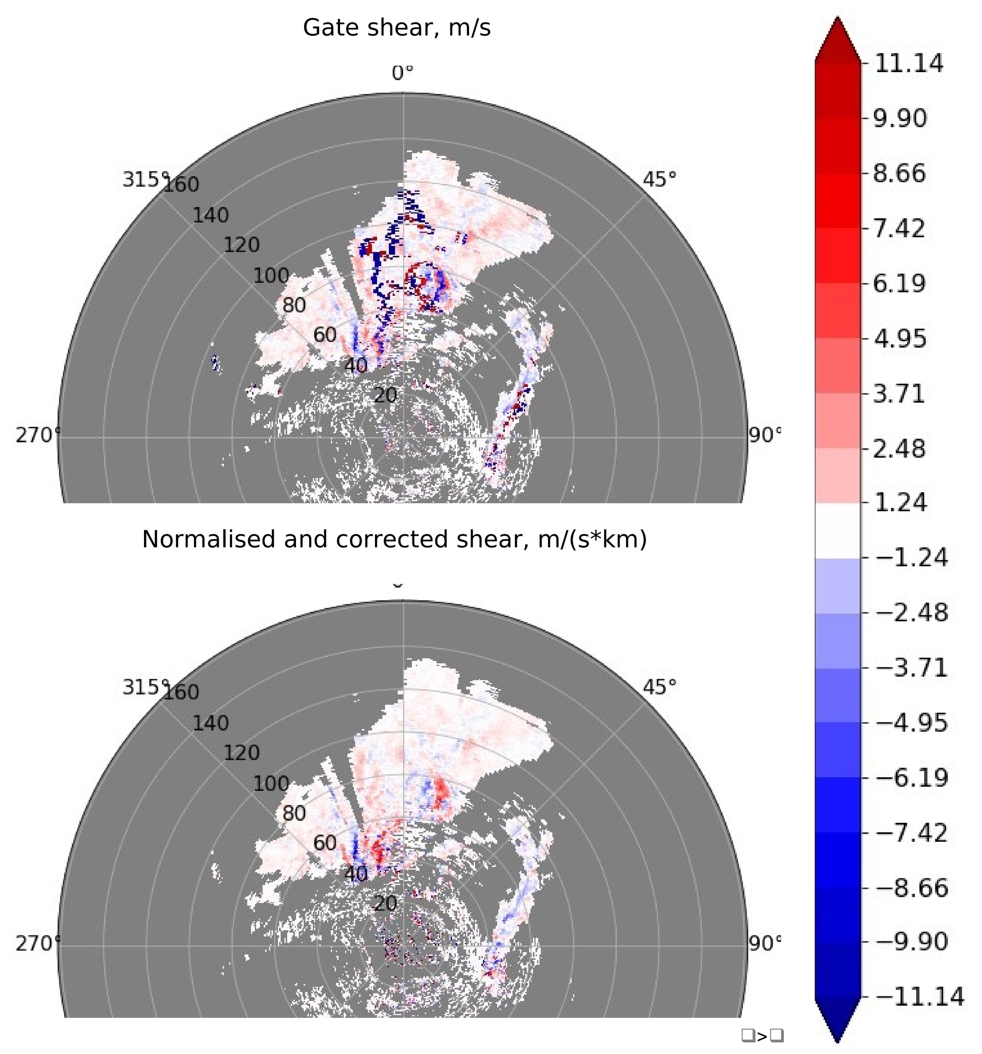
All examples:
- 00:05, August 2nd, 2017
- Albis radar near Zurich, 3.5° elevation, Nyquist velocity =12.6 m s^{-1}
- Mesocyclone over the Rhine valley between Switzerland and Germany

3. Data pre-processing

Azimuthal shear

Fold removal

Shear normalisation



- Centered difference azimuthal shear: $\frac{dv_{centered}}{d\theta} = \frac{v_{r,\theta-1} - v_{r,\theta+1}}{2 \cdot d\theta}$
- Fold removal: If $dv = |v_{r,\theta-1} - v_{r,\theta}|$ or $dv = |v_{r,\theta} - v_{r,\theta+1}| > v_{Nyquist}$, $dv = min(dv \pm 2 \cdot v_{Nyquist})$
- Shear is normalised by arc length dθ between gates
- Shear physically exceeding Nyquist velocity is unresolved

4. Mesocyclone identification

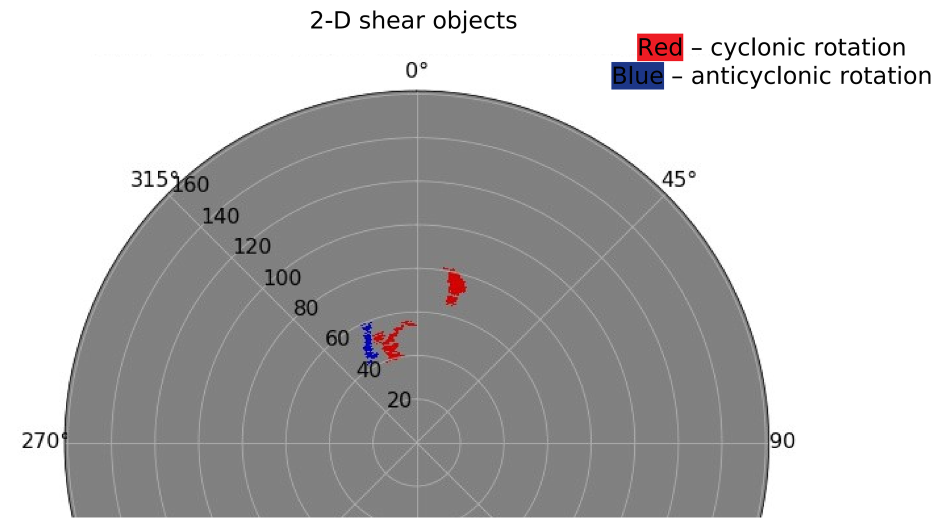
1-D pattern vectors [1]

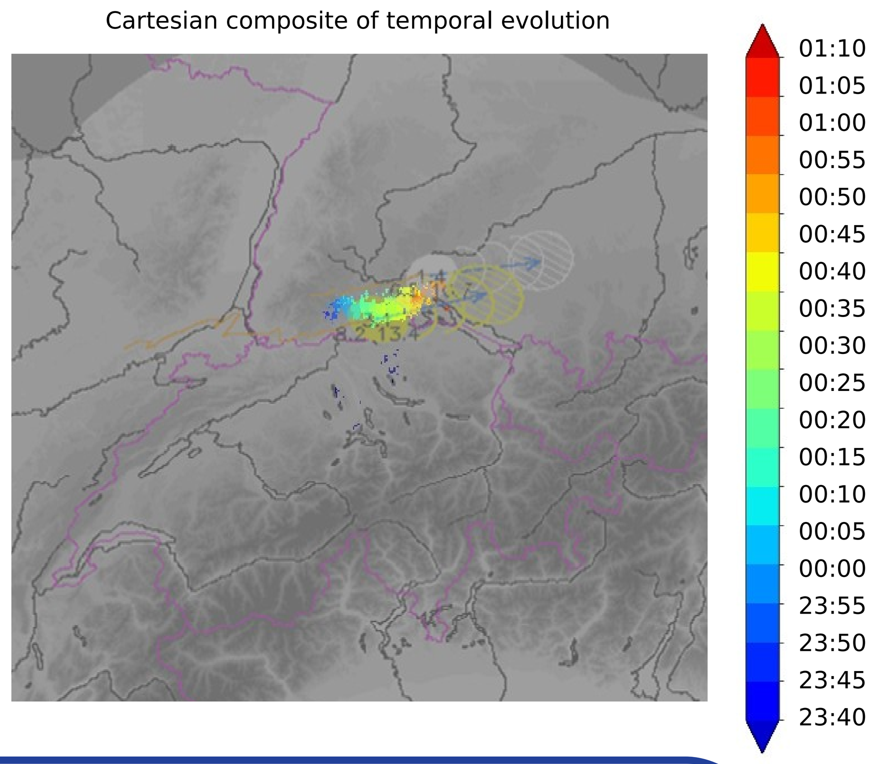
2-D shear objects [1]

3-D Cartesian composite

3-D mesocyclone object

4-D mesocyclone tracking



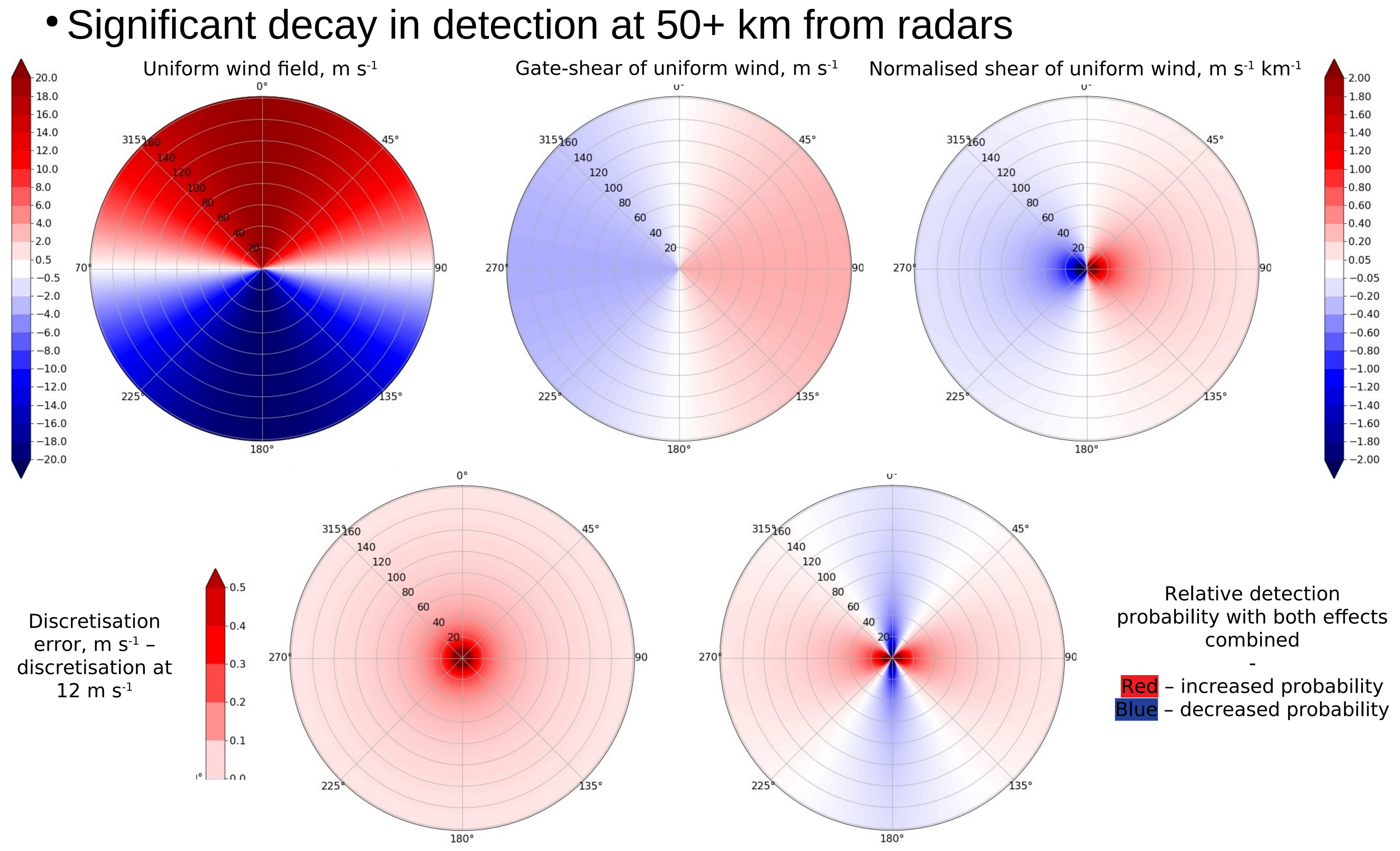


Thresholds:
- Minimum shear: 1 m s^{-1} km^{-1}
- Secondary threshold: 5 m s^{-1} km^{-1}
- Minimum arc length: 3 gates or 1.5 km
- Minimum range length: 3 range gates, allowance for gap of one gate
- Aspect ratio of radial vs. azimuth length: max. 1:3

3-D Cartesian composite:
- Maximum rotation from all 5 radars
- Vertical constraint: min. 3 layers
- Column maximum rotation for 2-D composite

5. Challenges

- Detection maximum around radars due to geometry of azimuthal shear in polar coordinates
- No detection within ~10 km of radars due to noise resulting from discretisation
- Significant decay in detection at 50+ km from radars



6. Outlook

- Range-dependent thresholds on shear
- Linear least squares derivative instead of centered difference [4]
- Wavelet smoothing / despeckling at close ranges, where discretisation error exceeds 0.5 m s^{-1}
- 4-D mesocyclone tracking

[1]
Hengstebeck, T., Wapler, K., Heizenreder, D., & Joe, P. (2018). Radar Network – Based Detection of Mesocyclones at the German Weather Service. Journal of Atmospheric and Oceanic Technology, 35, 299–321. https://doi.org/10.1175/JTECH-D-16-0230.1

[2]
Houze, R. A., Schmid, W., Fovell, R. G., & Schiesser, H.-H. (1993). Hailstorms in Switzerland: Left Movers, Right Movers, and False Hooks. Monthly Weather Review, Vol. 121, pp. 3345–3370. https://doi.org/10.1175/1520-0493(1993)121<3345:hislmr>2.0.co;2

[3]
James, C. N., & Houze, R. A. J. (2001). A Real-Time Four-Dimensional Doppler Dealiasing Scheme. Journal of Atmospheric and Oceanic Technology, 18(10), 1674–1683. https://doi.org/10.1175/1520-0426(2001)018<1674:ARTFDD>2.0.CO;2

[4]
Mahalik, M. C., Smith, B. R., Elmore, K. L., Kingfield, D. M., Ortega, K. L., & Smith, T. M. (2019). Estimates of Gradients in Radar Moments Using a Linear Least Squares Derivative Technique. Weather and Forecasting, 34(2), 415–434. https://doi.org/10.1175/waf-d-18-0095.1

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