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USING A 3D WIND RETRIEVAL ALGORITHM TO IMPROVE THE UNDERSTANDING OF DYNAMICS OF HAIL CELLS IN GERMANY AS PART OF THE LIFT PROJECT

ESTIMATION OF SUITABLE WEIGHTING PARAMETERS

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Motivation

- The overall goal of the LIFT (Understanding Large HaIl Formation and Trajectories) project is the comprehensive understanding of hailstorm processes and the processes involved in hail growth and their correlation with dual polarized radar signatures (hail growth indicators).
- Ultimately, a new radar-based nowcasting technique for large hail growth will be generated -> appropriate hail growth indicators (e.g. Z_{DR} columns) will be inserted in the hail nowcasting technique from our project partners from Australia (HailTrack, Brook et al. 2021).
- HailTrack also utillizes windfields from 3D wind retrievals (Brook et al. 2023), which offer many opportunities about dynamics of e.g. tornaedos or hailstorms (Shapiro et al. 2009).
- Parameters for different hail growth models can be provided, which e.g. improve insurance loss models and parametrization schemes in NWP models.

Methodology

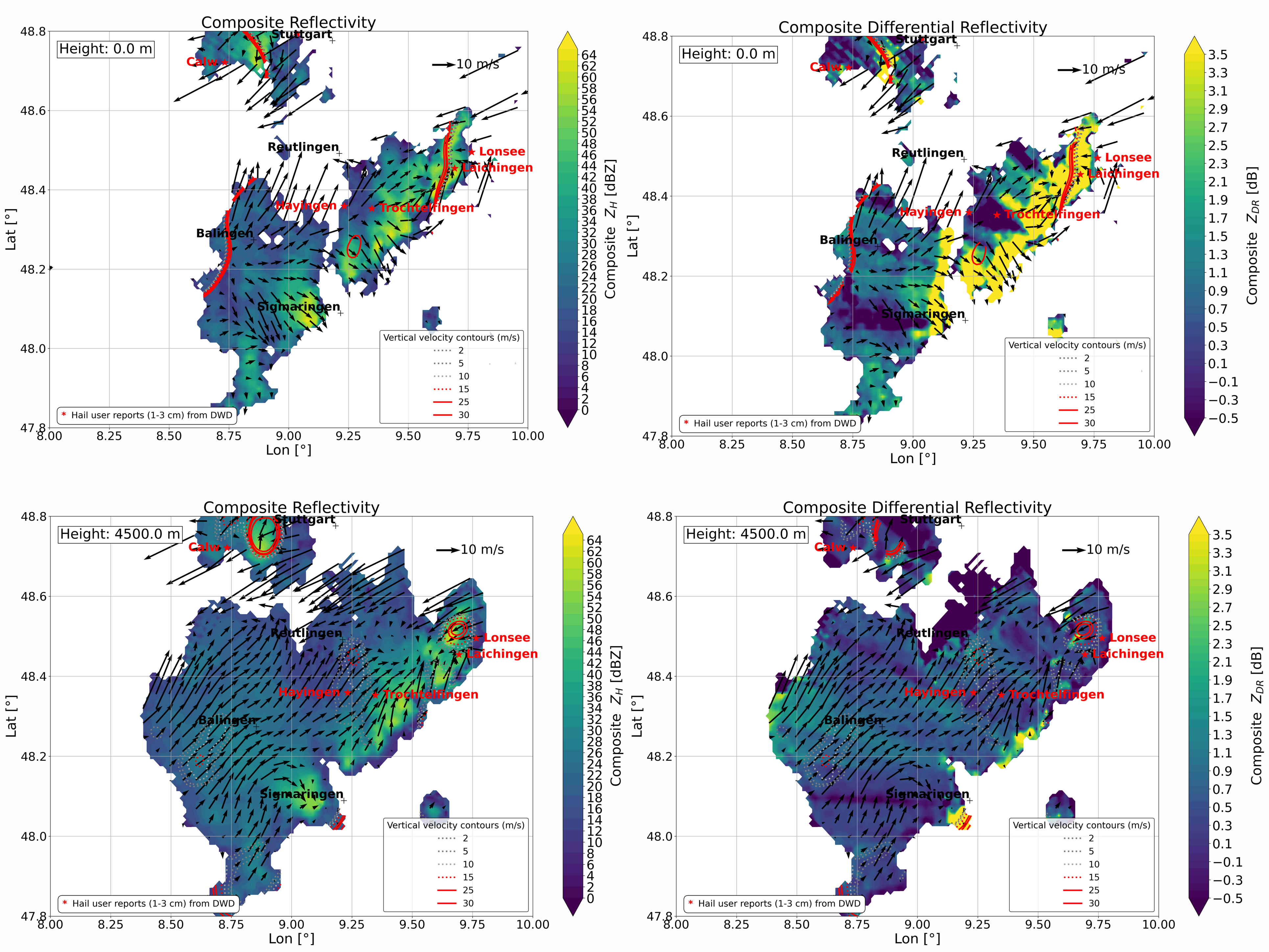
In the LIFT project, the Pythonic Direct Data Assimilation (PyDDA; Jackson et al. 2020) is applied to retrieve 3D wind fields from DWD C-band radar network:

- PyDDA is an open-source algorithm using a 3D variational (3DVAR) framework applied on radar Doppler velocities on a cartesian grid.
- The windfield is estimated via minimization of various cost functions (see also https://openradarscience.org/PyDDA/):

Cost Function	Symbol	Equation
Total	$\nabla J(\mathbf{v})$	$c_m \nabla J_{\text{mass}} + c_o \nabla J_o + c_r \nabla J_r + c_s \nabla J_s + \ldots$
Radar observations	∇J_o	$J_o = \sum_{\text{radar}} \left[V_{\text{obs}} - \mathbf{V}_{\text{proj}}\right]^2$
Mass continuity	∇J_{mass}	$J_m = \nabla \cdot \mathbf{V}_{\text{proj}} + w_{\text{proj}} \frac{d\rho}{dz}$
Vertical vorticity	∇J_v	see e.g. equation 10. in Potvin et al. (2012)
Radiosonde	∇J_r	$J_b = \sum_{\text{background}} \left[V_{\text{sounding}} - \mathbf{V}_{\text{proj}}\right]^2$
Smoothness	∇J_s	$J_s = \nabla^2 \mathbf{V}_{\text{proj}}$
Model (e.g. ERA5)	∇J_{model}	$J_o = \sum_{\text{domain}} \left[V_{\text{model}} - \mathbf{V}_{\text{proj}}\right]^2$
Point obs. (from stations)	∇J_{point}	$J_{\text{point}} = \sum_{\text{region}} \left((u_{\text{proj}} - u_{\text{point}})^2 + (v_{\text{proj}} - v_{\text{point}})^2\right)$

Hail cells on the 17th August 2023 in southern Germany

- Utilization of three C-band radars: Feldberg, Türkheim and Memmingen.
- Accurate preprocessing of polarimetric variables (e.g. calibration, attenuation correction and excluding data > 3 m/s of the velocity texture).
- Hail cells (> 60 dBZ) visible with accompanied larger Z_{DR} values at retrieved updraft and convergence regions.
- Used parameters for the wind retrieval presented in the figures below: continuity equation: 100; Radar observations: 10; ERA5 model: 0.01; Smoothing of x,y,z: 10; with maximum iterations limited to 100 and a tolerance of 0.05 m/s.

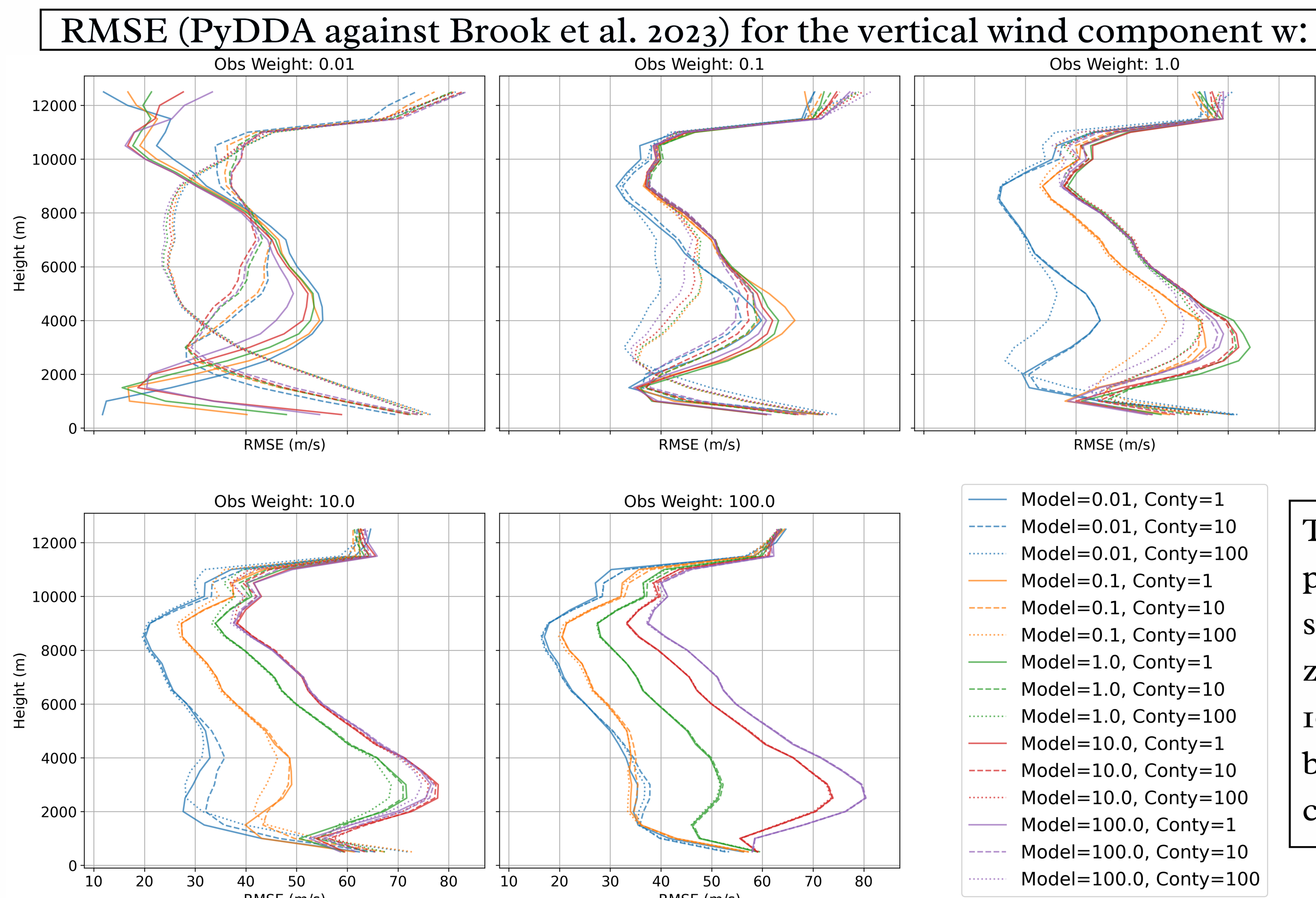


Estimating suitable weighting parameters

- Every single cost function has different weighting coefficients, which have to be proper estimated before using PyDDA to retrieve wind profiles.
- It is unclear to what extent these parameters (individual cost functions) should be weighted in order to reflect reality as accurately as possible.
- To identify the best configuration of the weighting parameters, a comparative analysis is performed based on the wind field obtained from another recently published 3D wind retrieval (Brook et al. 2023).

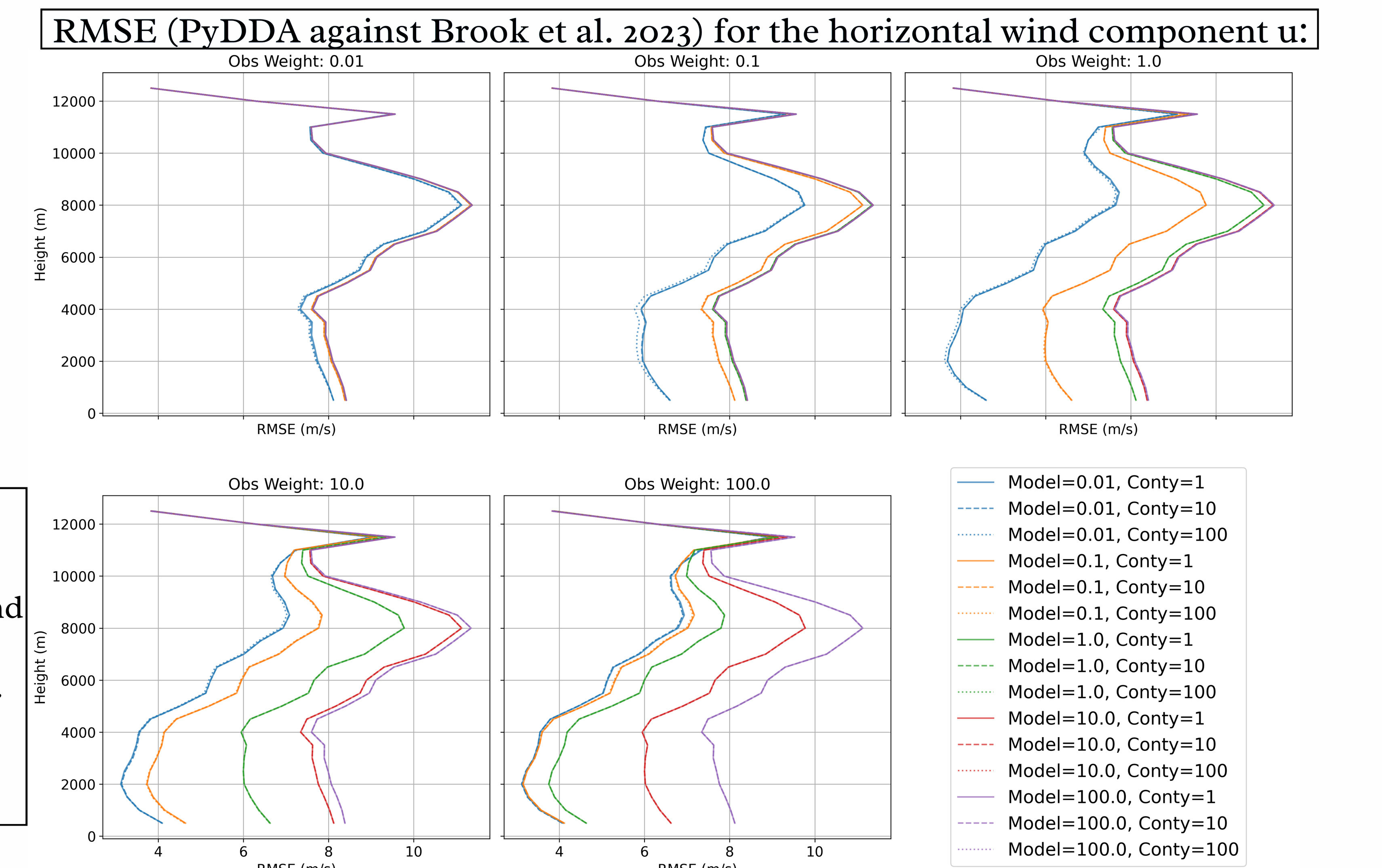
Weight Obs	Weight Conty	Weight Model	Weight Smooth x, y	Weight Smooth z
0.01	1	0.01	1	1
0.1	10	0.1	10	10
1.0	100	1.0	100	100
10.0		10.0		
100.0		100.0		

RMSE (PyDDA against Brook et al. 2023) for the vertical wind component w:



The weighting parameter for the smoothing of x, y and z in PyDDA is set to 10 (best suitable) for both wind components.

RMSE (PyDDA against Brook et al. 2023) for the horizontal wind component u:



References:

Potvin et al.: Impact of a vertical vorticity constraint in variational dual-Doppler wind analysis: Tests with real and simulated supercell data, 2012
Brook et al.: HailTrack—Improving radar-based hailfall estimates by modeling hail trajectories, 2021
Shapiro et al.: Use of a vertical vorticity equation in variational dual-Doppler wind analysis, 2009
Jackson et al.: PyDDA: A Pythonic direct data assimilation framework for wind retrievals, 2020
Jackson et al.: Improving PyDDA's atmospheric wind retrievals using automatic differentiation and Augmented Lagrangian methods, 2022
Brook et al.: The effects of spatial interpolation on a novel, dual-Doppler 3D wind retrieval technique , 2023

Conclusions and Outlook:

- Polarimetric variables showing typical signatures of a Hail cell -> Horizontal wind patterns reliable.
- Comparative analysis reveals large differences between the two wind retrieval algorithms especially in the vertical component. The updraft regions are not well detected by PyDDA -> some are missing.
- The most suitable weighting parameters for Germany will be determined using synthetic radar observation from ICON RUC simulations coupled with the forward operator EMVORADO from DWD.
- Updrafts and downdrafts will be compared with trajectories of Hailsondes.
- Utilizing of the Augmented Lagrangian method implemented in PyDDA (Jackson et al. 2022).