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## Reply on CC1

Gunter Stober et al.

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Author comment on "Atmospheric tomography using the Nordic Meteor Radar Cluster and Chilean Observation Network De Meteor Radars: network details and 3D-Var retrieval" by Gunter Stober et al., Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2021-124-AC1>, 2021

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We thank Jorge L. Chau for his public comment on the 3DVAR retrieval.

Vertical velocities are an important physical quantity to measure and often part of scientific disputes. In the case of meteor radar observations, it was known since the first systems were deployed that the wide field of view and least square fitting techniques won't provide reliable results for various reasons. For the analysis of reliable vertical winds, there is nothing unimportant e.g., phase calibration, antenna positions, surface motions (frost), mutual antenna coupling, etc. they all play a role and are nearly impossible to handle. Retrievals that offer a mathematically elegant way involving a priori knowledge to reduce the impact of all these quantities by giving preference to solutions that are physical more likely, which also provides an opportunity to reduce biases that are intrinsic to the least square fitting for certain mathematical problems.

The results presented herein are obtained by applying advanced mathematics with non-linear error propagation, a spatio-temporal Laplace filter, and WGS84 geometry. All three elements provide key contributions to the presented results. The geometry is important for the non-linear error propagation, which defines weights for the spatio-temporal filter between the iterations (max 8). Thus, we use complicated cost functions with several different weights and only the WGS84 geometry is always the same. Removing the WGS84 geometry certainly degrades the solutions, which is demonstrated in Figure 2 (Stober et al., 2018, AMT). Due to the radial nature of the observations any change of the horizontal winds also impacts the vertical wind solution (eq. 1, this paper). However, we did not explicitly evaluate how much each part contributes to the final solution for the meteor radar, but we did perform such a comparison for the Middle Atmosphere Alomar System in Gudadze et al., 2019 and there it turned out that the vertical velocities become even smaller when considering a WGS84 geometry compared to the case without.

There is no doubt that the WGS84 geometry is important in retrievals to obtain the results, but it is certainly not the only factor. However, we are confused about the statement in the public comment that Chau et al. 2021, and Conte et al, 2021 include the WGS84 geometry. We carefully read the papers and found no statement or reference or citation that suggests that such an important aspect is included. Neither is a WGS84 geometry presented in Chau et al., 2017, which uses spherical coordinates for the volume velocity processing (VVP, Waldteufel and Corbin, 1979). We also found no statement in Egito et al., 2016 about the implemented geometry for the fitting. Due to the missing

information about the geometry, we assumed that this is the likely cause for the substantial deviations.

The second aspect in regards to the comment “without including additional damping terms or regularization constraints” which presumably refers to previous retrievals (Stober et al., 2017, Wilhelm et al., 2017), which included a strong damping of the solution towards  $w=0$  m/s, which is comparable to a damped least square. However, this part was removed from the retrievals in this work. There is also no regularization included to cure a potential rank deficiency for the monostatic case. Nevertheless, it is true that our cost function tends to have a preference to smaller norms (giving preference to smaller errors for the vertical velocity), which appears to be related to small values of  $w$ , although a small value of  $w$  is not required and large values that are statistically significant should be still retrievable. The Sodankyla meteor radar indicates a certain skewness towards larger positive values, which are 3 times larger compared to Kiruna. This approach is also described for the 3DVAR retrieval, but with a different implementation. Currently, we are working on new retrievals with even more complicated cost functions to further improve this aspect and to perform certain benchmark tests.

Furthermore, we have to note that we were not able to retrieve vertical velocities with a smaller statistical uncertainty compared to its absolute value, which suggests that the effective measurement response for an instantaneous vertical measurement is negligible and no statistically significant values can be obtained. This led us to the conclusion to refer to these values as residual bias.

More importantly, we tested whether the retrievals are meaningful concerning existing model physics. Therefore, we performed an initial comparison of the meteor radar data using the UA-ICON model and simulated a meteor radar beam to extract vertical velocities. A comparison of the horizontal winds is presented in Stober et al., 2021 (<https://acp.copernicus.org/preprints/acp-2021-142/>). The UA-ICON run is published in Borchert et al., 2019 (<https://gmd.copernicus.org/articles/12/3541/2019/>). The histograms presented in the supplement Figure below are obtained using all available data from the meteor radars at Sodankylä and Kiruna and the complete UA-ICON run to ensure a sufficient statistics.

Although the agreement is impressively good, we don't want to claim that our retrievals are representing 'true' vertical velocities. Our retrievals appear to provide statistically sound solutions to the meteor radar data, but certainly if one of the mathematical aspects turns out to be not applicable or not generally true, this might change. However, we are glad that our paper triggered such a good discussion and brought that much attention to the topic.

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Please also note the supplement to this comment:

<https://amt.copernicus.org/preprints/amt-2021-124/amt-2021-124-AC1-supplement.pdf>