Author's Response to Reviewer 1

Jonas Hachmeister

July 14, 2025

We thank Frank Hase for reviewing the paper and providing valuable feedback.

Reply to specific comments

I agree one would expect the variations of the CH4 a-priori profile to be a profound disturbance of CH4 retrievals under vortex conditions. However, the disappointingly low Pearson correlation of the results shown in Fig. 4 and the huge scatter of airmass dependence as fct of XGF shown in Figs. 10, 11, 12, 13, and 14 seem to indicate further mechanisms of action being involved. There is only a very short discussion on this problem (lines 145 ff). I think this aspect would deserve a more systematic investigation. Specifically, I would find it interesting to show the typical scatter of XCH4 airmass dependence for a midlatitude background site. This would provide a benchmark and help to decide whether this large scatter is related to some additional mechanism affecting polar sites. We added a new appendix showing the airmass dependence as a function of XHF for two mid-latitude sites: Bremen and Orleans. This shows that (a) scatter in AMD is similar in the Arctic compared to mid-latitude sites and (b) that increased AMDs for larger XHF can also be observed at mid-latitude sites. (a) is expected as numerous effects can cause AMDs separate from problems with the prior profile. (b) indicates that prior related problems can also occur outside the Arctic.

Overall, it would preferrable to perform a more consistent investigation across all TCCON sites (the model prior is investigated for Ny-Alesund only, why?). The model prior was first tested for Ny-Ålesund and showed no improvement compared to the dynamic prior modification. Because the number of possible retrievals was limited by available resources and time, the model prior was not tested for the other sites. For Eureka, only the dynamic prior is provided due to technical problems. Modified retrievals were only possible after the manuscript was first submitted. This only allowed the inclusion of the dynamic prior modification during the first technical corrections.

On several occurences (section on detection of polar vortex, use of model prior, relation between observation and vortex edge, ...) the reader wonders whether the slanted line-of-sight of the FTIR measurement is taken into account. Given the low SZA angles during relevant periods, the lateral displacement of LOS coordinates as function of altitude can be quite pronounced. Please detail on this aspect. The TCCON retrieval assumes that the prior profiles derived for a given site is applicable to the slant column that the instrument really measures. If this assumption sufficiently violated this can lead to problems at all sites. In the Arctic, assuming a SZA of 75° the lateral displacement of the line of sight is about 37km/75km at a height of 10km/20km. Since the Arctic sites look southward this could lead to situations where the line of sight does not or only partially crosses the polar vortex even if the site is located within the vortex according to a mask. As of now this is not considered in the GINPUT software. Mention of this lateral displacement was added to the section "Polar vortex as based on Nash criterion" and "Detection of polar vortex air using a chemical tracer". Mention of the assumption that the prior is applicable to the slant column was added to the section "TCCON prior". Mention that the line of sight was not regarded was also added to the "Model prior" section. We added mention of the importance of the line of sight to the conclusions.

My main critics of the current manuscript is related to section 7.4, the AirCore comparison. In my impression, the study falls short at this point. A single AirCore is used for illustrating the effects on a TCCON observation. I would expect a systematic investigation in this section which makes use of all available in-vortex AirCore launches and compares these profiles with standard TCCON a-prioris for estimating the expected disturbance on TCCON XCH4 results. Note that this only requires TCCON sensitivities, not actual colocated TCCON observations. Next, the static prior (using the option of a vortex mask) and the model prior could undergo the same kind of investigation. In the manuscript we use AirCore data for Sodankylä between 2017–2021. Unfortunately, only two AirCores (both shown in the manuscript) with a clearly depleted stratospheric CH_4 profile are available from this dataset. The available measurement data of CH_4 profiles (known to us) is hence really sparse. We agree however that it is possible to estimate the expected effect on the TCCON retrieval by "simulating" a TCCON retrieval using a TCCON prior and averaging kernel and an arbitrary profile inside the vortex to perform a sensitivity study. However, we do not expect this to provide any additional insights compared to comparison of retrievals using different priors presented in the paper (see Fig. 22, which shows the magnitude of the XCH4 difference between different priors).

Reply to minor/technical comments

Abstract: "In the Arctic .. polar nights .. prevent solar absorption measurements for half of the year". This is not true. Correct, this was unclear as data coverage depends on the site latitude (and surrounding topography). This was changed to "...which prevent solar absorption measurements during large parts of the year".

Abstract: "These effects can be explained by the fact that TCCON uses a profile scaling retrieval". This would indicate that application of a profile retrieval would altogether cure the problem. This is not true, as a constrained profile retrieval still has imperfect column sensitivity (although improved over a scaling retrieval). That is correct, similar problems are expected for profile retrievals with imperfect vertical sensitivity. We changed this sentence accordingly: "These effects can be explained by the imperfect vertical sensitivity, especially to the stratosphere"

Appendix B and C: Why are these rather ad-hoc profile correction schemes used? A correction describing a downwelling of the original undisturbed profile would better correspond to the underlying processes? The intention of this paper was to identify, quantify and explain airmass-dependent biases in XCH_4 during polar vortex conditions. For this the ad-hoc profile correction scheme was sufficient to show that improvements to the XCH_4 retrieval are possible by modifying the prior. Ideally, we would have provided a complete solution to the problem (i.e., a new/updated prior generation scheme). This was not possible due to multiple reasons. First, the TCCON prior profiles are uniformly generated using the GINPUT software. Changes to the TCCON prior profiles can thus only be made by modifying the GINPUT software. This needs to be done in close collaboration with the TCCON. This manuscript could provide a starting point for such a discussion. Furthermore, it is not clear whether problems with the TCCON prior stem directly from the GINPUT software or from problems with the underlying used GEOS-FPIT model data.