

Author comments for (RC1)

We would like to thank the reviewer for the valuable feedback and efforts in reviewing the manuscript.

Review of Bharathan et al.: Enhancing GOSAT methane observations over the high latitudes using a multi-objective genetic algorithm optimisation approach, submitted to Atmospheric Measurement Techniques

5 May 2026

Review Summary

The study by Bharathan et al. utilises ground-based observations of total column methane from the high-latitude TCCON to optimise the post-processing filtering for satellite-based methane retrievals from GOSAT. The optimization is done using a multi-objective genetic algorithm. As a result, they are able to significantly increase the number of high-latitude observations by a reasonable compromise in the RMSE. The high-latitude-optimised product is also shown to have a good global performance.

In our review, we find this study and the high-latitude-optimised dataset highly useful for applications such as inverse modelling or satellite-data-driven approaches. An increase in the data amounts during the data-poor seasons can be highly significant when optimizing for fluxes in satellite-based inversions, also beyond the Arctic (though not shown in the study). This data product is therefore of high interest for the community. This paper describing the generation and validation of the GOSAT data product is appropriate for AMT, and we are happy to recommend it for publication. However, we have two broader questions, multiple minor comments and questions, and some technical corrections that would need to be addressed before publishing should be considered. We have detailed these below. In addition, we recommend making the postprocessed end product publicly available when publishing the paper.

Major comments

1) We recommend that the authors would more clearly describe the convergence of the optimisation and the end of generations. Currently, there is no description of the stopping criterion for the algorithm used in the study, though it appears to be a predetermined number of generations, i.e., 100. It would be good to add in the paper more discussion on how to ensure convergence has been reached, whether and why subsequent generations result in improvements, and how the limiting 100 generations has been selected. Since the solutions seem to stabilize after 15-20 generations, and the population becomes filled with non-dominated individuals, is there a danger that the solutions are crowded, or is this fast convergence desired behaviour?

Thanks to reviewer for pointing this out. The study uses NSGA-II for the optimisation. It assesses crowding distance and uses it in the selection procedure to minimise solution crowding and fast convergence is a known characteristic of NSGA II due to its elitist N+N parent - offspring selection mechanism (Deb et al., 2002). Thus the rapid improvement in the first few generations (figure 5) can be attributed to natural optimisation rather than to excessive crowding. To further assess the convergence, we analysed the variation of Inverted Generational distance (IGD) over generations. IGD is the average distance from a reference pareto front (final generation's front, used as the reference as a true front) to the nearest solution point in a population. The lower the IGD, the closer the population is to convergence. IGD also evaluates the spread of solutions across the reference pareto front, hence it indicates the diversity of the population as well. Evolution of IGD for two runs with 100 and 200 as generation lengths are shown in figure A2 added in the Appendix. IGD falls sharply in the first 15 to 20 generations and remain stable through ~ 90 generation for both the runs. Since the reference front is taken as the last generation's population, IGD necessarily approached zero independent of the generation length. For this study, a stopping limit of 100 generations was set in advance, with a longer 200-generation run used to

verify convergence behaviour. The stable IGD through 20 to 90 generations indicates convergence and maximum convergence was already attained by generation 100.

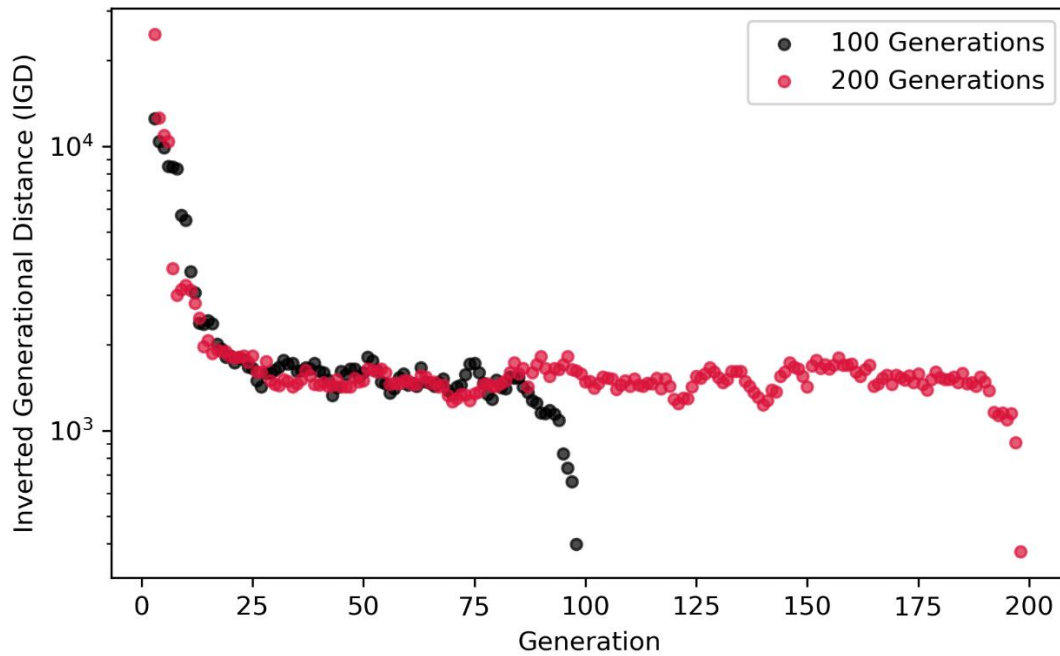


Figure A2: Generational evolution of Inverted Generational distance (IGD) in logarithmic scale for 100 and 200 generation run lengths.

2)a) The optimisation is based on the RMSE between high-latitude TCCON and the GOSAT observations. We recommend adding in a short description on the calculation of this RMSE, including the co-location of GOSAT and TCCON observations. b) Evaluating the optimized filtering using TCCON data (Sect. 4.4) is somewhat circular, considering the role of TCCON data in the optimization process. We recommend adding in a short discussion on how the authors justify their approach, instead of utilizing other available options (such as comparisons against the EM27/SUN instruments).

a) We agree with the reviewer and have added the calculation of RMSE and clarified the spatio-temporal collocation criteria used for GOSAT-TCCON comparison in section 2.4.

2.4 GOSAT-TCCON matching

Collocated GOSAT-TCCON pairs are estimated following the established validation methodology for the University of Leicester GOSAT Proxy XCH₄ product (Parker et al., 2020). GOSAT soundings located within $\pm 5^\circ$ of a TCCON station are selected, and the TCCON measurements acquired within ± 2 h of the GOSAT overpass were averaged to form a GOSAT-TCCON matching pair. Root Mean Square Error (RMSE_{GOSAT-TCCON}) between GOSAT and TCCON XCH₄ data is estimated as root-mean-square difference between the bias-corrected GOSAT XCH₄ and the corresponding TCCON XCH₄ for all co-located pairs as shown below. RMSE is calculated as a single value from all co-located GOSAT-TCCON observation pairs across the six high-latitude TCCON stations shown in figure 2a. (M) is the total number of matched pairs from the six high-latitude TCCON stations.

$$RMSE = \sqrt{\frac{\sum_{i=1}^N \left(XCH_{4(GOSAT)} - XCH_{4(TCCON)} \right)^2}{M}}$$

b) We agree that evaluating the final filter using the same six high-latitude TCCON data, that is used in the optimisation process (in the objective function) can cause potential circularity and does not make it a fully independent validation. TCCON was selected for validating the optimised dataset because the validity of the University of Leicester GOSAT Proxy XCH₄ product has been established against TCCON (Parker et al., 2020), and, using the same reference dataset for both the original and optimised datasets provides consistency in comparing the effect of optimised filtering in the new data set.

However, the evaluation also includes a global comparison with 15 TCCON sites that were not used in the optimisation. These additional sites provide an independent assessment of the performance of the optimised filter beyond the high-latitude stations used in the objective function. We acknowledge that the evaluation using the six high-latitude stations is not fully independent, but the global comparison provides additional evidence of the filter's performance at sites not involved in the optimisation.

Independent ground-based EM27/SUN observations provides another potential complementary dataset for independent validation of the optimised dataset. These include COCCON observations (Frey et al., 2019), GEMINI-UK network data (Kurganskiy et al., 2025 ; Humpage et al., 2026) and other coordinated EM27/SUN campaigns (Hase et al., 2015), which provide an opportunity for the independent validation of the optimised dataset. Although these datasets were not used in the present optimisation, their use in future work could provide an independent evaluation of the optimised filter, particularly at locations where TCCON observations are unavailable.

We have revised the manuscript by adding the discussion to make this point clear and to avoid implying that the TCCON comparison represents a completely independent validation of the optimisation.

Frey, M., Sha, M. K., Hase, F., Kiel, M., Blumenstock, T., Harig, R., Surawicz, G., Deutscher, N. M., Shiomi, K., Franklin, J. E., Bösch, H., Chen, J., Grutter, M., Ohyama, H., Sun, Y., Butz, A., Mengistu Tsidu, G., Ene, D., Wunch, D., Cao, Z., Garcia, O., Ramonet, M., Vogel, F., and Orphal, J.: Building the COllaborative Carbon Column Observing Network (COCCON): long-term stability and ensemble performance of the EM27/SUN Fourier transform spectrometer, *Atmos. Meas. Tech.*, 12, 1513–1530, <https://doi.org/10.5194/amt-12-1513-2019>, 2019.

Kurganskiy, A., Feng, L., Humpage, N., Palmer, P. I., Woodwark, A. J. P., Doniki, S., and Weidmann, D.: The Greenhouse gas Emission Monitoring network to Inform Net-zero Initiatives UK (GEMINI-UK): network design, theoretical performance, and initial data, *Atmos. Meas. Tech.*, 18, 7525–7563, <https://doi.org/10.5194/amt-18-7525-2025>, 2025.

Humpage, N., Palmer, P., Kurganskiy, A., Feng, L., Woodwark, J., Morrison, W., Doniki, S., Weidmann, D., Parker, R., and Bharathan, L.: GEMINI-UK: Towards improved carbon flux estimates for the UK using a national network of ground-based greenhouse gas observing spectrometers, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-18382, <https://doi.org/10.5194/egusphere-egu26-18382>, 2026.

Hase, F., Frey, M., Blumenstock, T., Groß, J., Kiel, M., Kohlhepp, R., Mengistu Tsidu, G., Schäfer, K., Sha, M. K., and Orphal, J.: Application of portable FTIR spectrometers for detecting greenhouse gas emissions of the major city Berlin, *Atmos. Meas. Tech.*, 8, 3059–3068, <https://doi.org/10.5194/amt-8-3059-2015>, 2015.

Minor comments

1) Lines 20-21: Arctic warming has been shown to be three to four times faster than the global average (Rantanen et al., 2022).

Updated the first sentence to the following .

“Monitoring greenhouse gases (GHG) in northern high-latitude regions is important as Arctic has warmed nearly four times faster than the global average over the period 1979–2021 (Rantanen et al., 2022)”.

2) Line 24: what is meant by the exposure of organic matter? This may be largely focusing on the thawing of permafrost but Arctic methane emissions are also dependent on seasonal frost and snow.

We apologise for lack of clarity in the discussion. Text has been modified as follows to include additional points as well.

Climate change-induced warming over the northern high-latitudes leads to extensive thawing of the permafrost, reduced surface albedo, and makes stored carbon available for microbial decomposition that can release large amounts of methane (CH₄) and carbon dioxide (CO₂) into the atmosphere, potentially leading to positive feedback loops and associated impacts on climate (Miner et al., 2022; Schuur et al., 2015). In addition, seasonal freeze–thaw cycles, snow cover, soil moisture and temperature affect microbial activity, and substantial emissions occur during the cold season and spring thaw (Zona et al., 2016; Rößger et al., 2022).

D. Zona, B. Gioli, R. Commane, J. Lindaas, S.C. Wofsy, C.E. Miller, S.J. Dinardo, S. Dengel, C. Sweeney, A. Karion, R.Y. Chang, J.M. Henderson, P.C. Murphy, J.P. Goodrich, V. Moreaux, A. Liljedahl, J.D. Watts, J.S. Kimball, D.A. Lipson, & W.C. Oechel, Cold season emissions dominate the Arctic tundra methane budget, *Proc. Natl. Acad. Sci. U.S.A.* 113 (1) 40-45, <https://doi.org/10.1073/pnas.1516017113> (2016).

Rößger, N., Sachs, T., Wille, C. et al. Seasonal increase of methane emissions linked to warming in Siberian tundra. *Nat. Clim. Chang.* 12, 1031–1036 (2022). <https://doi.org/10.1038/s41558-022-01512-4>

3) Lines 34-36: challenging weather conditions are only part of the explanation for the lack of Arctic measurements. Large regions of the Arctic are not accessible due to geopolitics and/or lacking infrastructure, such as roads or permanently manned stations.

We agree with the reviewer and modified the sentence by adding additional constraints, as follows.

Station based atmospheric methane measurements are sparse over the Arctic due to challenging adverse weather conditions especially during winter, limited infrastructure and the logistical difficulties of accessing remote regions, and geopolitical constraints further restrict the establishment and maintenance of long-term observing stations

4) Line 45: Low solar angle → Either write “low solar elevation angle” or “large solar zenith angle” to avoid confusion.

Changed to ‘low solar elevation angle’

5) Line 49: “Ice” → “snow and ice” because the same applies to snow. Although snow is in practice ice, this makes the message more clear.

Corrected in the revised manuscript.

6) Line 71 (also elsewhere): There are multiple terminologies in the paper to describe XCH₄. Please choose one and use it systematically. Also, 4 should be in subscript, and the X should not be italicized (e.g. line 179).

Italics and subscripts have been corrected in the revised manuscript.

7) Paragraph starting on line 73: this is interesting and relevant background, and directly ties to the motivation of this paper. We recommend to extend this part with a description of the current work and how it is related to the previous work (perhaps move the last sentence from the previous paragraph here).

As per reviewer’s suggestion the paragraph has been rearranged and modified as follows.

Mendonca et al., 2021 utilised a neural network approach to filter the OCO-2 XCO₂ data based on binary classification criteria that require training the algorithm with multiple, labelled proxy parameters measured at a reference ground site. More recently, Keely et al. (2025) explored a machine-learning-based approach to satellite retrieval quality filtering using multi-objective Bayesian optimisation, demonstrating the potential of optimisation methods to balance data quality and data availability. Our study explores the application of the non-dominated sorting genetic algorithm II (NSGA-II), to optimise the GOSAT methane total column dry-air mole fraction (XCH₄) data retrieved by the University of Leicester GOSAT Proxy methane algorithm (Parker et al., 2011, 2020) with a focus on high-latitude regions north of 50°N.

8) Figure 1: What is the motivation for showing this figure? For a high-latitude-focused paper we would recommend considering a polar projection, or at least drawing a 50 N line on the global map for pointing out the focus region. In addition, the caption reads that gridded data are shown; however, the data seem to be Level 2 retrievals (please check). The text says “mean GOSAT UoL Proxy XCH₄” – please check and harmonise with what is shown in Fig. 1 (mean gridded values or L2 observations?).

As reviewer suggested, we have replaced figure 1 with Gridded UoL Proxy GOSAT XCH₄ data over high-latitude in polar projection at 1° x 1° grid resolution.

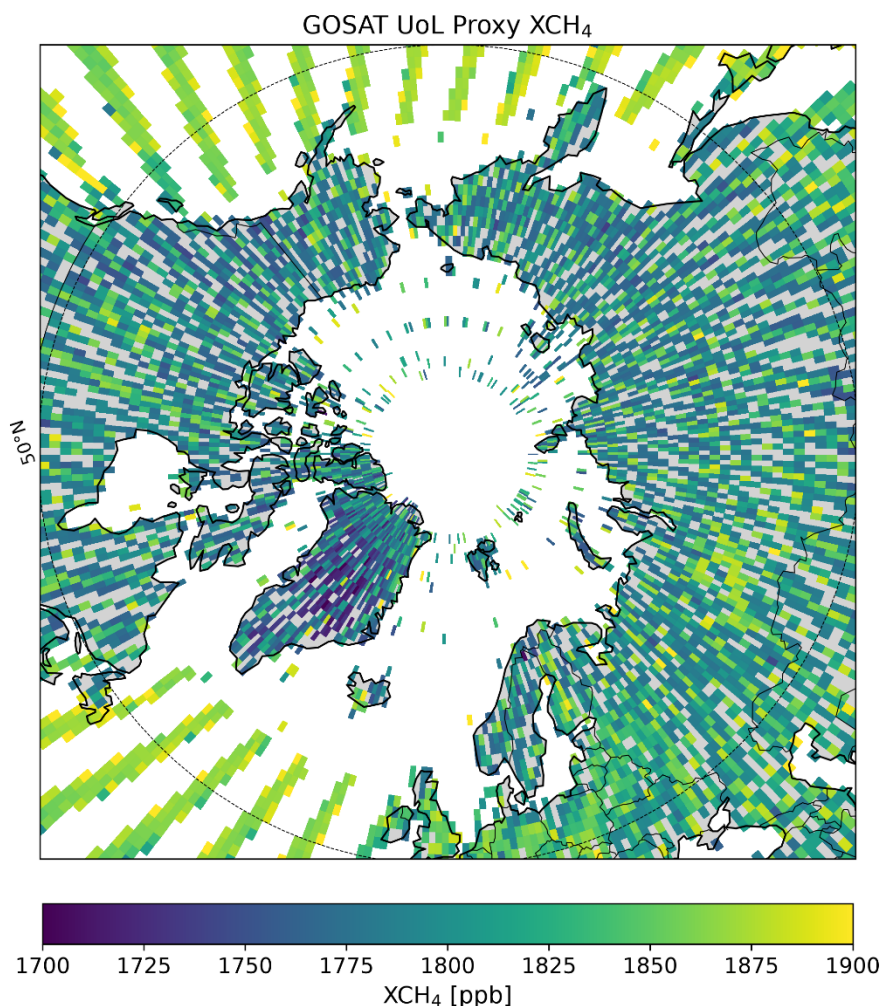


Figure 1 - High-latitude distribution (>50 °N) of mean gridded column-averaged methane dry-air mole fraction [XCH₄] from GOSAT at 1° x 1° grid resolution, retrieved using the University of Leicester GOSAT Proxy XCH₄ algorithm for the period 2009 to 2023.

9) Line 113. GOSAT XCH₄ → please specify the product name

Product name has been specified in the revised manuscript.

“Figure 2 shows the a) spatial, b) latitudinal and c) monthly distribution of the observation count (N) of the University of Leicester GOSAT Proxy XCH₄ v9.0 data (quality-checked).”

10) Line 115. “Low solar zenith angles” should be low solar elevation angles or large solar zenith angles, please correct.

Thank you for pointing that out. We have corrected it as low solar elevation angles.

11) Line 116. What are the extreme atmospheric conditions, please specify.

Sentence is modified as given below.

In addition, surface albedo effects, rapid water vapour fluctuations, strong temperature inversions, boundary-layer light scattering by wind-blown snow, affect the retrieval quality over high latitudes (Bradley et al., 1992; Lesins et al., 2009; Tjernstr et al., 2012).

Bradley, R. S., F. T. Keimig, and H. F. Diaz (1992), Climatology of surface-based inversions in the North American Arctic, *J. Geophys. Res.*, 97(D14), 15699–15712, doi:[10.1029/92JD01451](https://doi.org/10.1029/92JD01451).

Lesins, G., Bourdages, L., Duck, T. J., Drummond, J. R., Eloranta, E. W., and Walden, V. P.: Large surface radiative forcing from topographic blowing snow residuals measured in the High Arctic at Eureka, *Atmos. Chem. Phys.*, 9, 1847–1862, <https://doi.org/10.5194/acp-9-1847-2009>, 2009.

Tjernström, M., Birch, C. E., Brooks, I. M., Shupe, M. D., Persson, P. O. G., Sedlar, J., Mauritsen, T., Leck, C., Paatero, J., Szczodrak, M., and Wheeler, C. R.: Meteorological conditions in the central Arctic summer during the Arctic Summer Cloud Ocean Study (ASCOS), *Atmos. Chem. Phys.*, 12, 6863–6889, <https://doi.org/10.5194/acp-12-6863-2012>, 2012.

12) Line 117. It is interesting that about a third of cloud-cleared observations are lost during the quality filtering process. Is this a global mean value? Is it about the same for high latitudes – we’d assume larger? Is there seasonal variability? This could be described with a couple additional sentences since it partly motivates the actual work.

About a third of total global cloud-cleared-successful retrievals are lost during the quality filtering process. This data loss is greater at high latitudes (>50°N), where around half of the retrievals are rejected (53%). The rejection rate also varies seasonally. Globally, around half of the retrievals are rejected in winter (52%), compared with about one-fifth in summer (18%). At high latitudes, the data loss increases to more than 80% in winter. These results highlight the need to optimise quality filtering to retain more observations at high latitudes, particularly during winter, while maintaining data quality.

13) Figure 2. We suggest removing Figure 2b which does not provide additional information considering Fig. 2a. A few latitude lines might be a useful addition in Fig. 2a. Figure 2b could potentially be replaced by a polar view of the data count; we leave this up to the authors’ consideration.

We thank the reviewer for this helpful suggestion. We would prefer to keep Figure 2b as well, because it gives complementary information to Figure 2a, highlighting the deficit in data volume at high latitudes. Since the study aims to increase the availability of reliable observations in the high-latitude region, this illustration would be relevant. We have added latitude lines to Figure 2a to improve figure.

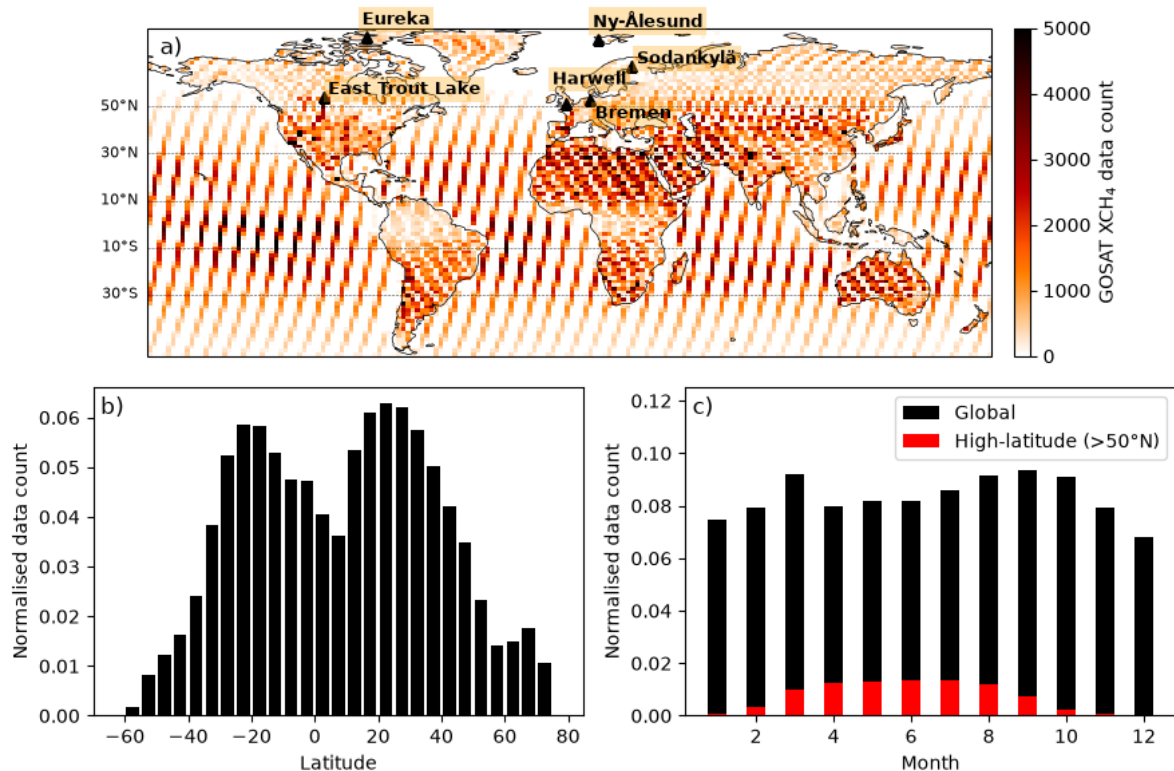


Figure 2. a) Global distribution of GOSAT XCH₄ data count from 2009 to 2023, at 2° x 2° grid resolution, with high-latitude TCCON stations used in the present study b) latitudinal variation of normalised data count, and c) monthly normalised observation counts during the period 2009 and 2023.

14) Line 171. Are these fit individuals passed on to the next generation as-is, or are these used as parents to generate the next generation?

A set of non-dominated solutions in a population provides the optimal trade-off between the objectives. At each generation, a population (n) of parents is created by the best non-dominated solutions which undergo crossover and mutation to produce an offspring population (n). Parents and offspring are then merged and sorted into non-dominated fronts, and the next generation is filled from the best fronts. In addition to non-dominated sorting, selection of fit individuals is also based on crowding distance, which is a measure of how close a solution is to its neighbours in the objective space. A higher crowding distance is generally preferred, as it keeps solutions from crowding in the objective space, and thereby preserves the diversity of the solutions and avoids premature convergence.

We have modified the discussion in the revised manuscript to clarify this point.

15) Section 3.1: How were the eight filter values selected? Some are obvious (e.g. high chi-square) but why a lower limit of chi-square is needed, and why low thresholds of XCH₄ and XCO₂ but not high? Are the “uncertainty values” the statistical uncertainties from the retrieval process? Did the authors experiment with any other filter values?

The eight filter parameters were selected from the existing quality-filtering procedure for the well-validated University of Leicester GOSAT Proxy XCH₄ product, which are selected based on empirical thresholding based on validation against ground-based TCCON (Parker et al., 2020). Lower χ^2 threshold does not actively filter out data within our current high-latitude dataset, as distribution of the filter shows no valid retrievals below around 0.4 for both gases. Therefore, this threshold does not affect the current dataset, although it remains part of the predefined filter parameterisation.

Low threshold for target gases, however, is used for filtering because unusually, very low retrieved columns typically indicate light-path changes from cloud or scattering from the atmosphere. High values were left unfiltered because they can be real, for example over emission regions. The uncertainty thresholds refer to the posterior uncertainties for XCH_4 and XCO_2 from the retrieval process (Parker et al., 2015). We preserved the existing filter values of the original dataset so that consistent comparison is possible between the optimised and original data and assessment of data gain. We have kept all other parameters in the standard processing, including signal to noise ratio, surface pressure, fixed and chose conventional filters for the optimisation. Extending the optimisation to these parameters would be future work.

Parker, R. J., Boesch, H., Byckling, K., Webb, A. J., Palmer, P. I., Feng, L., Bergamaschi, P., Chevallier, F., Notholt, J., Deutscher, N., Warneke, T., Hase, F., Sussmann, R., Kawakami, S., Kivi, R., Griffith, D. W. T., and Velazco, V.: Assessing 5 years of GOSAT Proxy XCH_4 data and associated uncertainties, *Atmos. Meas. Tech.*, 8, 4785–4801, <https://doi.org/10.5194/amt-8-4785-2015>, 2015.

Parker, R. J., Webb, A., Boesch, H., Somkuti, P., Barrio Guillo, R., Di Noia, A., Kalaitzi, N., Anand, J. S., Bergamaschi, P., Chevallier, F., Palmer, P. I., Feng, L., Deutscher, N. M., Feist, D. G., Griffith, D. W. T., Hase, F., Kivi, R., Morino, I., Notholt, J., Oh, Y.-S., Ohyama, H., Petri, C., Pollard, D. F., Roehl, C., Sha, M. K., Shiomi, K., Strong, K., Sussmann, R., Té, Y., Velazco, V. A., Warneke, T., Wennberg, P. O., and Wunch, D.: A decade of GOSAT Proxy satellite CH_4 observations, *Earth Syst. Sci. Data*, 12, 3383–3412, <https://doi.org/10.5194/essd-12-3383-2020>, 2020.

16) Table 1: We suggest to remove this table entirely as it does not bring any added information with respect to the text.

We thank the reviewer for the suggestion. We have kept Table 1 because it shows how a candidate filter set is encoded as a chromosome of eight genes, which is central to how the genetic algorithm works and can be unfamiliar to many readers of this journal. To make it more informative, we have added the search range of each gene with units, so the table now shows both the structure of the chromosome and the bounds within which the algorithm searches.

Table 1. Structure of a GA chromosome - each of the eight genes is one quality-filter threshold, with the range searched by the algorithm.

Gene	$\chi^2_{low}[CH_4]$	$\chi^2_{high}[CH_4]$	$\chi^2_{low}[CO_2]$	$\chi^2_{high}[CO_2]$	$XCH_{4,low}$	$XCO_{2,low}$	$XCH_{4,error}$	$XCO_{2,error}$
Range	0–1	1–3	0–1	1–3	1400–2100	250–450	0–30	0–4
Unit	–	–	–	–	ppb	ppm	ppb	ppm

17) Figure 3: Since the focus of this study is on the high latitudes, we would suggest only showing the region of interest in this figure. Also, both the caption and text describe the figure as showing averages of the filter parameters, but there is no mention of how the data have been averaged (spatio-temporally?); the data also seem to correspond to Level 2 retrievals rather than averages, as in Fig. 1, please check.

We apologise for the error in the caption and text. We have modified the caption as given below, to specify that they are L2 data rather averages. The figure shows individual Level-2 GOSAT retrievals rather than spatio-temporal averages. We have corrected the caption and accompanying text to clarify this. We would prefer to retain the global distribution because it provides a useful comparative overview of variability of the filter parameters across the globe.

Figure 3. Global distribution of UoL GOSAT proxy Level 2 QA filters - a) and b) indicate goodness-of-fit χ^2 parameter between measured and simulated spectra for CH_4 and CO_2 respectively, c), d), e) and f) indicate raw retrieved XCH_4 and XCO_2 values and their associated error estimates respectively.

18) Line 192-195 (and elsewhere). Here, within a few lines, the word “solution” appears in three different contexts as equal to individual, chromosome, and offspring. We would suggest sticking to a limited set of words throughout most of the manuscript, instead of giving multiple options each time.

We have revised the manuscript to maintain consistent terminology.

19) Line 210. The sentence here starts with “similarly”, but it’s unclear what the mutation process described is similar to. Perhaps “additionally” would work better, if mutation takes place after crossover. Are the mutation performed on solutions created through crossover, or are these completely separate processes, as might be interpreted from Table 2. Please clarify.

Mutation is applied to the offspring produced by crossover. Sentence modified as below.

Subsequently, mutation is applied to the offspring produced by crossover using a polynomial mutation operator that introduces small, random changes to the gene values.

20) Line 215. What is the difference between ranks and (pareto) fronts? Please clarify. If they are essentially the same thing, consider using only one of these terms.

Rank is the label for individual’s level of non-domination, and set of all Individuals with the same rank is termed as pareto fronts. We would drop description on rank to eliminate ambiguity. Text has been revised as follows.

Solutions are grouped into sequential Pareto fronts using non-dominated sorting. The first Pareto front contains all non-dominated solutions across the entire population. The second Pareto front is formed by removing the first-front solutions and identifying the non-dominated individuals among the remaining population. This process is repeated iteratively to classify the entire population into successive Pareto fronts.

21) Figure 5, caption. C: 15 generations; should this be 20? Please check.

Corrected. We thank reviewer for pointing this out.

22) Figure 6: Since all the panels have the same colour scale, please use a single colour bar for the figure.

Figure 6 is modified with a single colour bar.

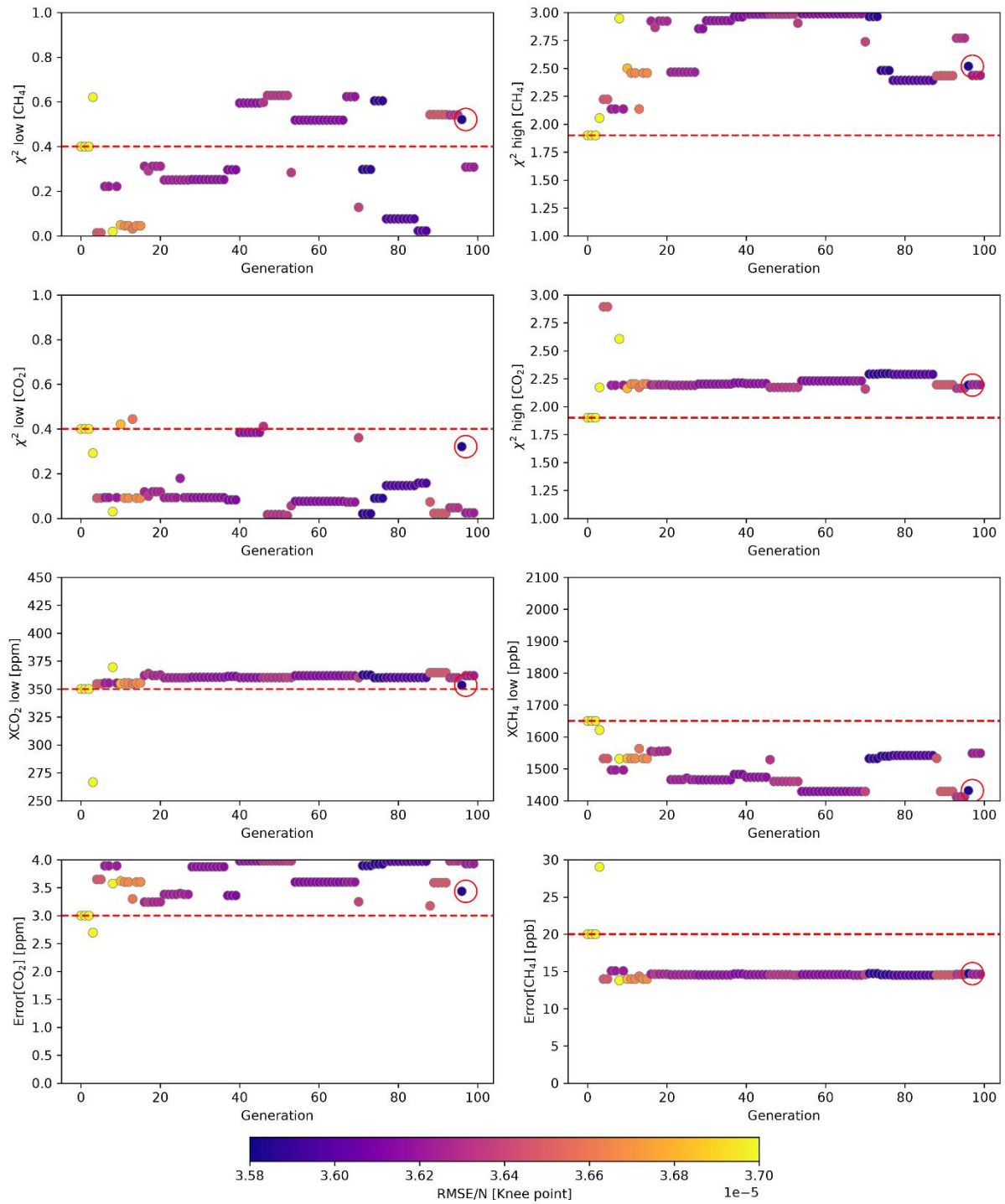


Figure 6. Evaluation of decision variables (filter values as given in Table 1) with generations. Red dotted line shows the initial standard filters. The red circle shows the selected optimised filter values correspond to the generation of minimum of the ratio of RMSE to N.

23) Figure 7c: are there any negative values? It is not obvious from the figure. If there are, should the color scale be reconsidered or saturated to better show these values?

We checked for this thoroughly. Only 7 of 8,359 populated $1^\circ \times 1^\circ$ cells show a decrease in sounding count, with a maximum loss of 9 soundings per cell (15 in total), compared with a net gain of 311,309 soundings. These cells were not visible in the original figure because the linear colour scale (± 700) made changes of this size indistinguishable from zero. We have therefore redrawn Fig. 7c with a symmetric logarithmic colour scale (linear

within ± 1 sounding, range -450 to $+450$), so that small losses appear clearly in blue. Cells with no data in either run are shown in grey.

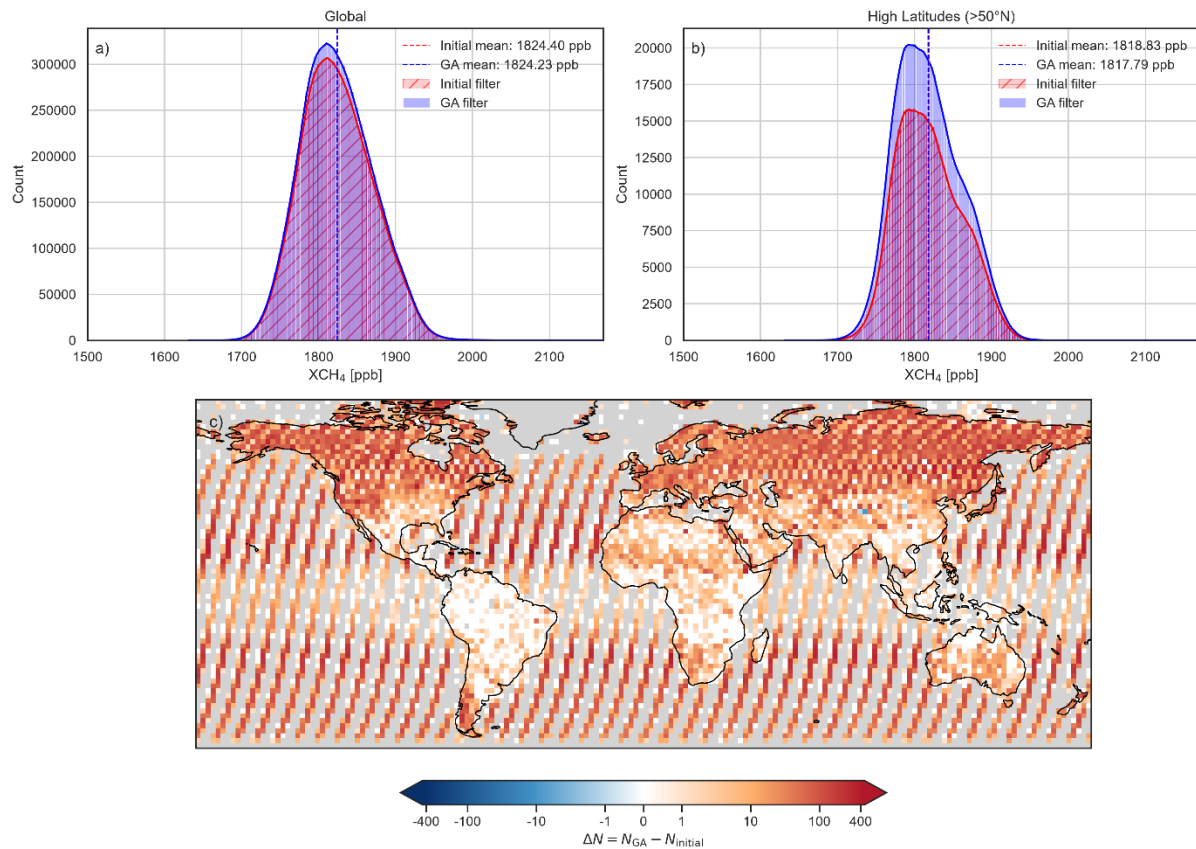


Figure 7. Frequency distribution of GOSAT Proxy XCH₄ [2009 - 2023] on applying initial filters and GA optimised filters a) globally, b) over high latitudes ($> 50^{\circ}\text{N}$) and c) global distribution of change in observation count (ΔN) upon optimisation at $2^{\circ} \times 2^{\circ}$ grid resolution, with a symmetric logarithmic colour scale, so that small losses appear clearly in blue.

We have modified manuscript text as follows.

GA optimisation has enhanced data density globally except in the equatorial tropics where data density remained the same, with no major regional/localised data loss (Fig. 7c). Only 7 of 8,359 populated $1^{\circ} \times 1^{\circ}$ cells show a decrease in sounding count, with a maximum loss of 9 soundings per cell (15 in total) which is negligible compared with a net gain of 311,309 soundings.

24) Figure 7: There seem to be quite a lot more observations also over the tropical / subtropical oceans. We recommend to point this out in the text and discuss why this is the case.

There is a notable increase in observations over tropical and subtropical oceans, which is due to the addition of ocean glint soundings whose chi-squared values fall near the previous 1.9 cut-off threshold. With the new GA filters, the higher threshold for χ^2 has increased the data yield over oceans.

25) Figure 8b: the y scale reads fractional increase and the caption says total; please harmonise.

Corrected the figure caption as b) fractional increase in total observations above 50°N during different months.

26) Line 267: emission flux sounds redundant; we suggest to use emissions

Replaced with 'emissions'

27) Line 268: not only permafrost; we suggest to also include wetlands

Modified the sentence and added reference as given below.

‘Altogether these factors contribute to severe reduction in atmospheric methane data density during high-latitude winter and make it much harder to quantify the methane emissions from the seasonal freeze-thaw processes of highly heterogeneous permafrost landscapes and wetlands (Bartsch et al., 2023; Saunio et al., 2020)’

Bartsch, A., Strozzi, T., and Nitze, I.: Permafrost Monitoring from Space, <https://doi.org/10.1007/s10712-023-09770-3>, 2023.

Saunio, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., Houweling, S., Patra, P. K., Ciais, P., Arora, V. K., Bastviken, D., Bergamaschi, P., Blake, D. R., Brailsford, G., Bruhwiler, L., Carlson, K. M., Carrol, M., Castaldi, S., Chandra, N., Crevoisier, C., Crill, P. M., Covey, K., Curry, C. L., Etiope, G., Frankenberg, C., Gedney, N., Hegglin, M. I., Höglund-Isaksson, L., Hugelius, G., Ishizawa, M., Ito, A., Janssens-Maenhout, G., Jensen, K. M., Joos, F., Kleinen, T., Krummel, P. B., Langenfelds, R. L., Laruelle, G. G., Liu, L., Machida, T., Maksyutov, S., McDonald, K. C., McNorton, J., Miller, P. A., Melton, J. R., Morino, I., Müller, J., Murguía-Flores, F., Naik, V., Niwa, Y., Noce, S., O'Doherty, S., Parker, R. J., Peng, C., Peng, S., Peters, G. P., Prigent, C., Prinn, R., Ramonet, M., Regnier, P., Riley, W. J., Rosentreter, J. A., Segers, A., Simpson, I. J., Shi, H., Smith, S. J., Steele, L. P., Thornton, B. F., Tian, H., Tohjima, Y., Tubiello, F. N., Tsuruta, A., Viovy, N., Voulgarakis, A., Weber, T. S., van Weele, M., van der Werf, G. R., Weiss, R. F., Worthy, D., Wunch, D., Yin, Y., Yoshida, Y., Zhang, W., Zhang, Z., Zhao, Y., Zheng, B., Zhu, Q., Zhu, Q., and Zhuang, Q.: The Global Methane Budget 2000–2017, *Earth Syst. Sci. Data*, 12, 1561–1623, <https://doi.org/10.5194/essd-12-1561-2020>, 2020.

28) Section 4.4: it would be helpful to the readers if the authors added one representative example of a high-latitude time series with the TCCON data, “default” GOSAT Proxy XCH₄ data, and added data with the new postprocessing.

We thank the reviewer for this helpful suggestion. We believe that Fig. 9 and Table 4 already provide a quantitative assessment of the performance of the optimised dataset relative to the default GOSAT Proxy XCH₄ dataset using TCCON observations. To avoid redundancy in the main text, we would prefer not to add another time-series figure. However, we agree that a representative example could be useful to readers and would be happy to include it as supplementary material if the reviewer considers this necessary.

29) Line 308: The citation given here is to a GHG-CCI data set, not the ESA GHG-CCI User Requirements Document. Please check and correct.

We thank reviewer for pointing that out. We have checked the reference and corrected the citation to refer to the ESA GHG-CCI User Requirements Document.

GHG-CCI: User Requirements Document for the GHG-CCI+ project of ESA’s Climate Change Initiative, ESA Climate Change Initiative (CCI) Technical Report, Version 3.0, 17 February 2020, 42 pp., 2020.

30) Lines 295-296 and references. Please correct the citations featuring non-standard English characters. Please check and correct the entire reference list for similar or any other issues (e.g. no authors on the first listed reference, the editors of the IPCC 2023 report (line 417)).

We apologise for the mistakes in references. We have checked and corrected them in the revised document.

31) Data availability: We highly recommend to make the postprocessed data version publicly available (or adding a new filtering flag to the existing data product) to facilitate its use.

We are preparing a separate data file containing the optimised filtering flag, which is to be released alongside the latest version of GOSAT Proxy XCH₄ data product. This will allow users to select the optimised QA filtering, if preferred, along with the original dataset.

32) Appendix A: Few sentences of text could be added in the Appendix.

Following description has been added for figure A1 in the Appendix.

Figure A1 shows grid cells at 2° × 2° resolution where the original dataset contained no observations, but the GA-optimised dataset contains observations. These cells represent newly sampled areas resulting from the relaxation of the quality-filtering criteria. As the fractional increase in observation count cannot be calculated when the initial count is zero, these cells are excluded from the fractional enhancement shown in Fig. 8a. Figure A1 therefore complements Fig. 8 by illustrating areas where the optimisation introduces observations into previously unsampled grid cells.

Technical corrections

Line 1. "Gases" missing from GOSAT

Corrected

Line 7. Unclear sentence; perhaps remove "disproportionately affects"

Sentence corrected

Line 18. Expand abbreviations (CO₂M etc.)

Abbreviations expanded.

Line 36. its → it is

Corrected

Line 40 (and also elsewhere). Parentheses should be written like this when using LaTeX: \citep[GOSAT][{}]{Kuze et al. 2009} to avoid subsequent parentheses.

Correction applied

Line 42. Long-periods → can be removed

Corrected

Line 42. Add space after records

Corrected

Line 70. Remove comma after of

Corrected

Line 83. Reference (Kuz, 2014) is missing

Citation is removed from the text.

Line 107. Add space after observations

Space added.

Line 115. Nights → night

Corrected.

Line 118. Missing the before complete omission

Corrected.

Line 125-127 (and elsewhere). The N should not be italicized when denoting latitude

Corrections applied

Line 133. time-periods → time periods

Corrected

Line 133. carry should be carries

Corrected

Line 174. crowded → “getting crowded” or “crowding”

Corrected

Line 175 (and elsewhere). The abbreviation “NSGA II” was used on line 70, but here it is written as “NSGA-II”. Please use one form consistently.

Corrections applied.

Line 187. You start two consecutive sentences with so here. Maybe remove the first to avoid repetition.

Corrected.

Line 209. 200-members; please remove the dash

Corrected.

Line 213. Remove comma after mentioned

Corrected.

Line 224. carry → carries

Corrected.

Line 226. forms → form

Corrected.

Line 240. 6. should be 6

Corrected.

Line 248. Missing of after number

Corrected.

Line 251. Correct reference to Table 3, not Table 2.

Corrected.

Figure 7 caption. standard → standard. Also remove comma before c) and correct Delta to the Greek letter.

Corrected.

Line 266. Missing a before severe

Corrected

Line 287. Capitalise Appendix

Corrected

Figure 9 caption. High → high

Corrected

Line 309. Remove such as, since you go on to list all the metrics in Table 4 (or rephrase the sentence)

Sentence rephrased as “ Table 4 shows the changes in the optimised GOSAT XCH₄ data metrics, specifically total data count, RMSE between GOSAT and TCCON collocated observations, and single-measurement precision compared to initial values.”

Line 323. Quality-filters → quality filters

Corrected

References

Rantanen, M., Karpechko, A.Y., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., Vihma, T. and Laaksonen, A., 2022. The Arctic has warmed nearly four times faster than the globe since 1979. *Communications earth & environment*, 3(1), p.168.