Improvements of S5P methane retrievals by using updated digital elevation models

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Introduction

The Sentinel-5 Precursor (S5P) mission was launched in October 2017 and has since provided data with high spatio-temporal resolution using its remote sensing instrument, the TROPOspheric Monitoring Instrument (TROPOMI). The latter is a nadir viewing passive grating imaging spectrometer. The retrieval of trace gases of TROPOMI spectra yields e.g. column-averaged dry air mole fractions of methane (XCH_4) which is the product of interest to this study. The daily global coverage of the atmospheric methane mole fraction data enables the analysis of the methane distribution and its variation on large scales and also to estimate surface emissions. The spatio-temporal high-resolution satellite data are potentially particularly valuable in remote regions, such as the Arctic, where few ground stations and in-situ measurements are available. In addition to the operational Copernicus S5P total-column averaged dry air mole fraction methane data product developed by SRON and the scientific SRON product, the scientific TROPOMI/WFMD algorithm data product v1.5 (WFMD product) was generated at the Institute of Environmental Physics at the University of Bremen. In a recent study [3] we showed that noticeable features in the maps of retrieved XCH_4 over Greenland can be explained by inaccuracies in the underlying digital elevation model (DEM). In follow-up research we identified further regions with inaccuracies in the Global Multi-resolution Terrain Elevation Data (GMTED2010) and show that the use of the GLO90 Copernicus DEM can solve these issues.

Influence of digital elevation models on S5P methane retrievals

All three S5P methane retrieval algorithms rely on digital elevation models (DEMs) in their retrievals. While the three algorithms vary in their exact use of DEMs, they all use the surface elevation in combination with European Centre for Medium-Range Weather Forecasts (ECMWF) data to calculate dry air columns (through calculation of the surface pressure) which are used to convert the total CH_4 column to XCH_4 values. Inaccurate surface elevation data leads to an error in the surface pressure, which in turn influences the XCH_4. A $\pm 1\%$ error in the surface pressure (about 10 hPa) leads to a 1% error in the retrieved XCH_4 (about 20 ppb).

Greenland case study

In a recent paper [3] we investigated noticeable geophysically unrealistic features in the maps of retrieved XCH_4 over Greenland, which can be seen both in the operational S5P XCH_4 product and the S5P WFMD product. We investigated the DEM used in both retrievals, the Global Multi-resolution Terrain Elevation Data (GMTED2010) and compared it to new elevation data from the ICESat-2 satellite mission. To account for the seasonal variability of methane and the overall increase of methane concentrations we calculated the mean of 7-day XCH_4 anomalies. For this we averaged the XCH_4 over 7 day steps and calculated the anomaly by substracting the mean XCH_4 in a reference area.

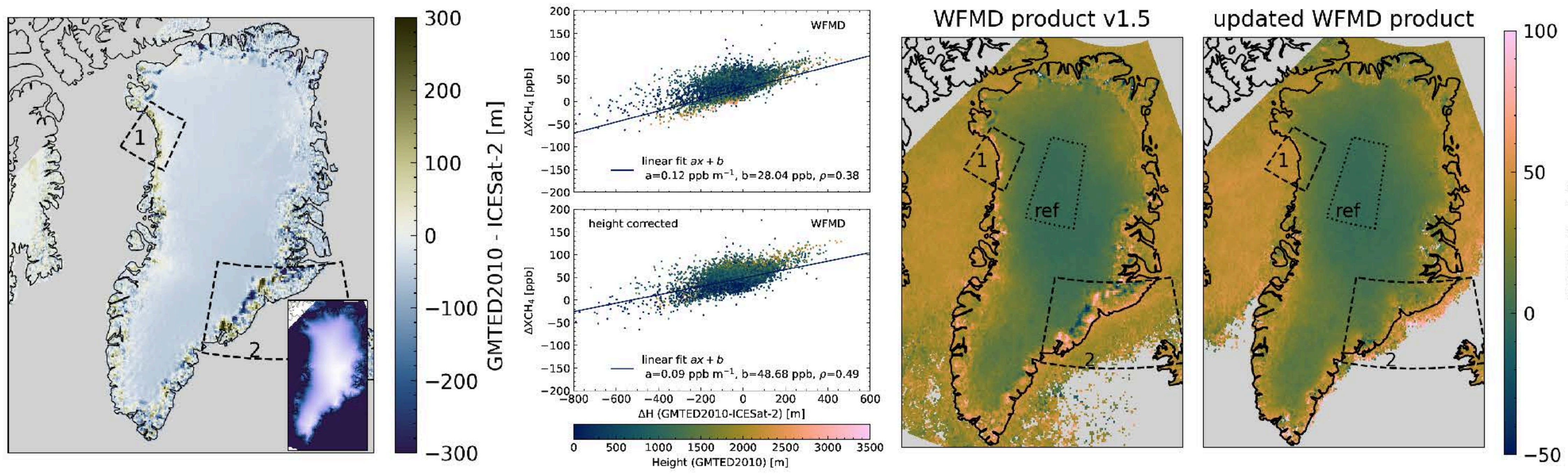

Figure 1. Difference between GMTED2010 and ICESat-2 elevation data, ΔH (left). Correlation between 7-day methane anomaly and ΔH; the height correction accounts for the actual influence of the elevation on XCH_4 caused by elevation-dependent weighting of tropospheric and stratospheric air (middle). Maps of the 7-day methane anomaly for the WFMD product v1.5. and an updated version using a DEM based on ICESat-2 data (right).

Our investigations showed a clear correlation between the height anomaly $\Delta H = H_{GMTED2010} - H_{ICESat-2}$ and the 7-day methane anomaly, which can be seen in the above figure. Correlations for the operational S5P product are less clear due to the lower coverage and further effects of higher magnitude (see [4]). An updated WFMD product using a DEM based on ICESat-2 data was prepared for which the noticeable XCH_4 features disappear.

Source of inaccuracies

The GMTED2010 DEM is a suite of global terrain elevation data available at three different resolutions (approximately 250, 500 and 1000m). While the GMTED2010 datasets provide global coverage of almost all land areas there are some exceptions. Most importantly the data for Greenland is only available in the lowest resolution. The source data for Greenland is based on a publication from Bamber et al. (2001) [1], which reports vertical errors of 20-200m over bare rock regions. Thus three contributions to inaccuracies can be named: the DEM resolution, the vertical errors in the elevation data and the potential change of the terrain (e.g. glaciers melting).

Relevance for other satellite data products

Depending on the retrieval strategy of the target gas in question, inaccurate DEM data will impact the retrieved column of other products as well. We recommend the usage of up-to-date and precise DEMs in all algorithms which rely on elevation data. While the magnitude of the errors may vary or not be significant at all, depending on the retrieval algorithm design, we advise the use of the most accurate data available to ensure the highest possible quality of the resulting data products.

Global replacement DEM – Copernicus GLO-90

As the case study of Greenland showed, use of accurate elevation data is key to ensure high quality S5P methane products. The global Copernicus 90m (GLO-90) digital elevation model is based on radar satellite data acquired between 2011–2015 during the TanDEM-X Mission and is freely available [2]. Below we show comparisons between GLO-90 and GMTED2010, various regions show significant differences between both DEMs. In Figure 2 we show strong regional differences in the Arctic region. Figure 4 shows global differences.

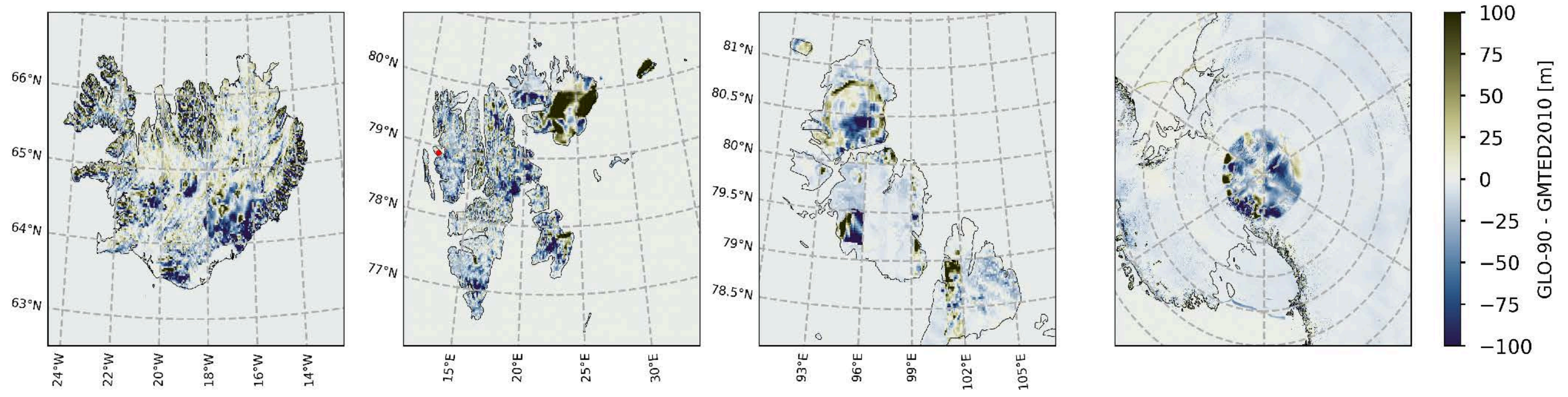

Figure 2. Difference between GLO-90 and GMTED2010 elevation data, ΔH for Iceland , Spitsbergen (Ny-Ålesund marked with red dot), Severnaya Zemlya and Antarctica.

Improvements to TROPOMI/TCCON comparison

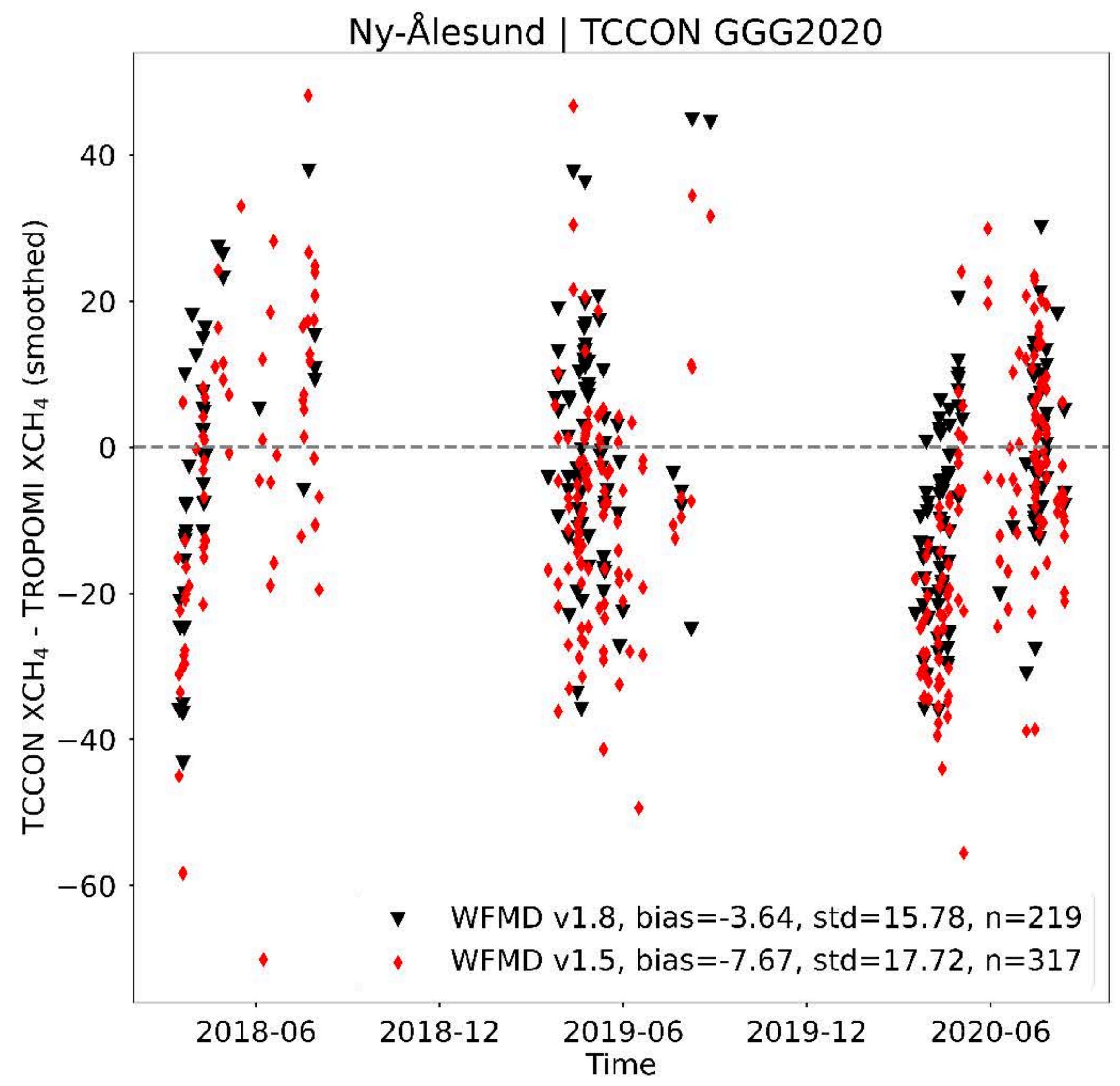

Figure 3. Difference between TCCON GGG2020 measurements and TROPOMI/WFMD data (r=100km, Δt=1h).

The updated WFMDv1.8 product which uses GLO-90 as a DEM shows a lower bias and spread compared to the WFMD v1.5 product based on GMTED2010 data. We note that the WFMD v1.8 product also contains other improvements (e.g. stricter cloud filter) that contribute at least as much to the better validation results at Ny-Alesund as the DEM update. However, we don't observe similar improvements for other TCCON stations, where both the DEM differences and the impacts of the other changes are smaller.

Available at: *July 12, 11:00 – 13:00 CEST & July 13, 16:00 – 18:00 CEST*

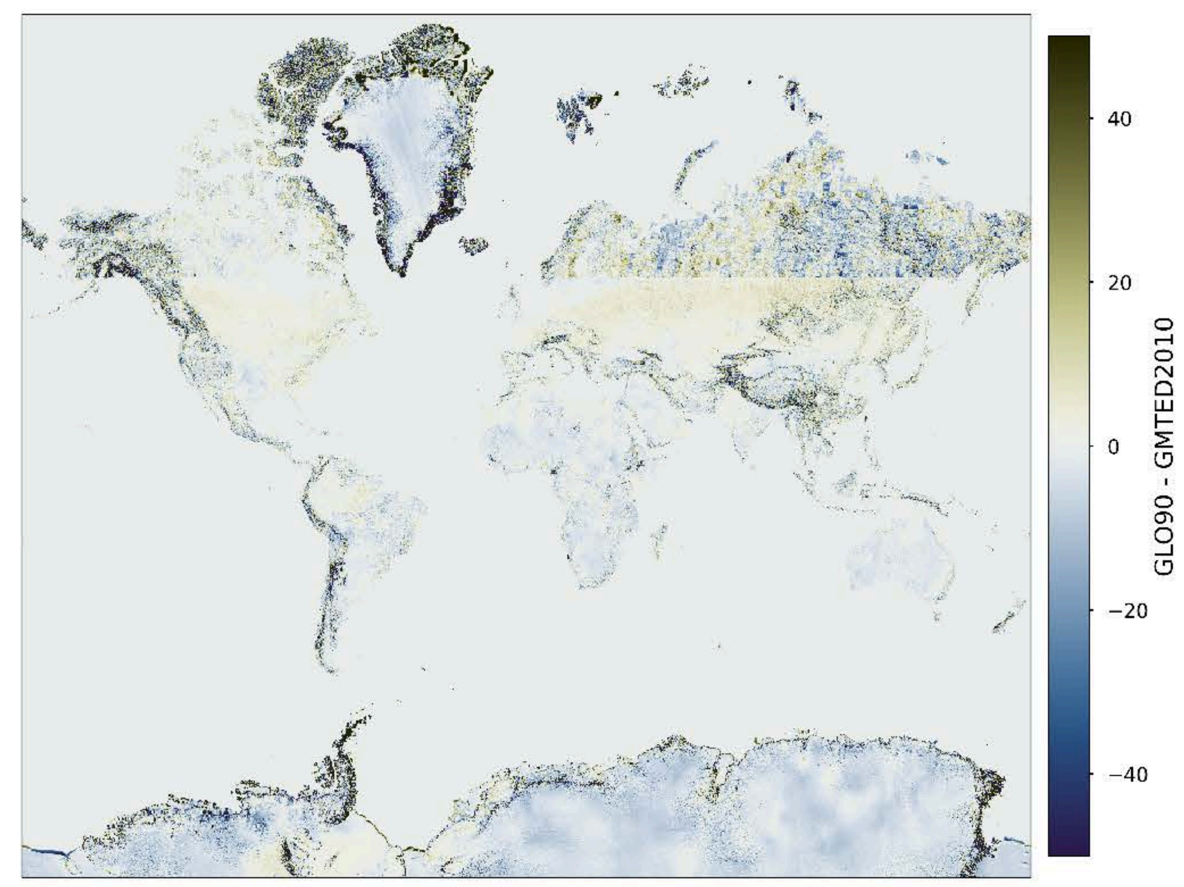

Figure 4. Difference between GLO-90 and GMTED2010 elevation data, ΔH for the whole globe.

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References

[1] J. L. Bamber et al. A new, high-resolution digital elevation model of greenland fully validated with airborne laser altimeter data. *Journal of Geophysical Research: Solid Earth*, 106(B4):6733–6745, 2001.

[2] European Space Agency. Copernicus global digital elevation model. distributed by opentopography, 2021.

[3] J. Hachmeister, O. Schneising, M. Buchwitz, A. Lorente, T. Borsdorff, J. P. Burrows, J. Notholt, and M. Buschmann. On the influence of underlying elevation data on sentinel-5 precursor satellite methane retrievals over greenland. *Atmospheric Measurement Techniques Discussions*, 2022:1–29, 2022.

[4] A. Lorente, T. Borsdorff, et al. Methane retrieved from tropomi: improvement of the data product and validation of the first 2 years of measurements. *Atmospheric Measurement Techniques*, 14(1):665–684, 2021.

[5] O. Schneising et al. A scientific algorithm to simultaneously retrieve carbon monoxide and methane from tropomi onboard sentinel-5 precursor. *Atmospheric Measurement Techniques*, 12(12):6771–6802, 2019.

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