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Towards Arctic and boreal methane flux estimates: systematic evaluation of TROPOMI XCH4 observations at high latitudes

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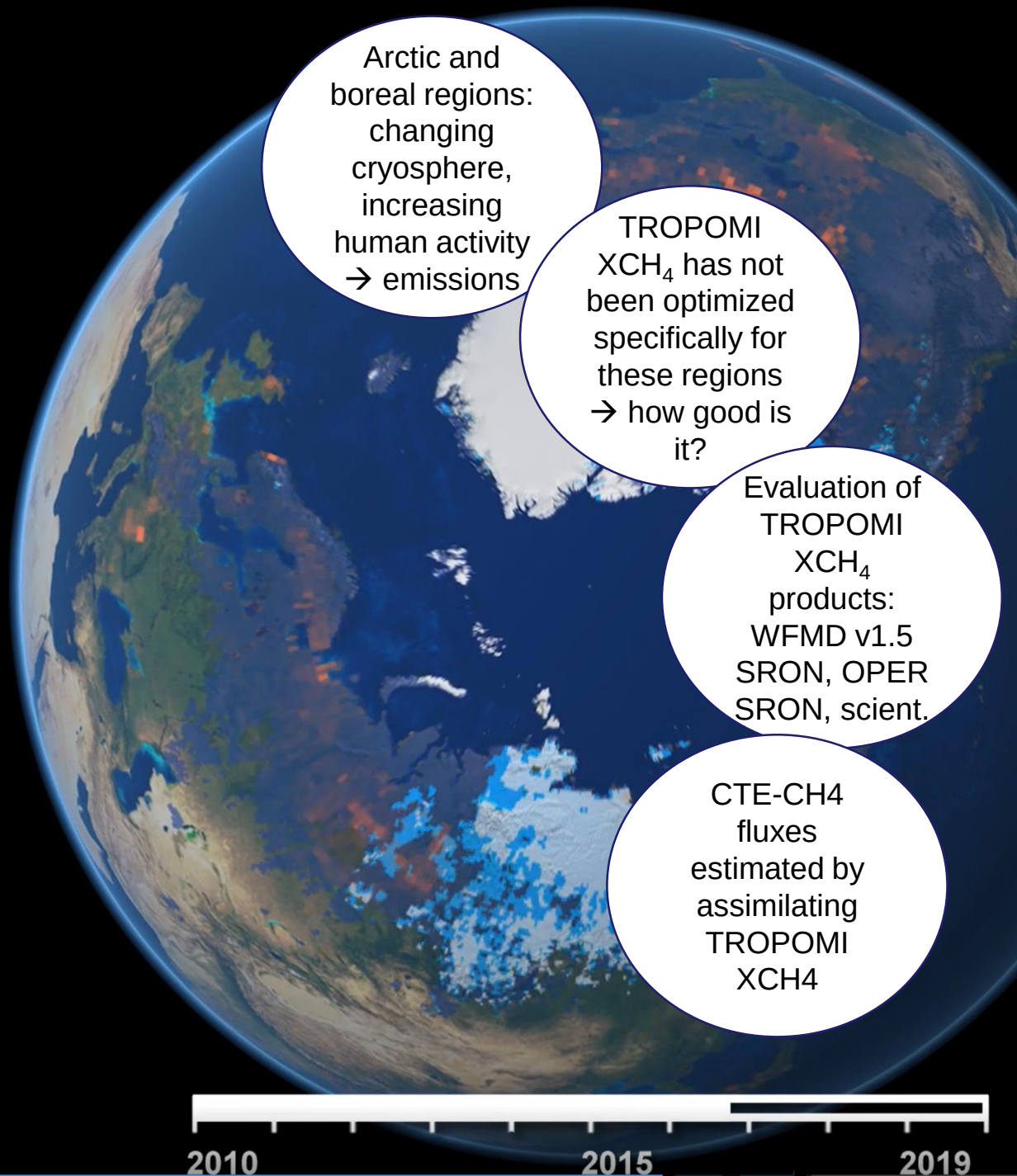
Sentinel-5P Mission:5 years anniversary



1) Seasonal coverage at high latitudes and permafrost regions

- We evaluated the seasonal coverage for SRON oper., SRON scient., and WFMD:
  - North from 50ºN
  - Over discontinuous and continuous permafrost
  - Over continuous permafrost

- WFMD product has a higher number of observations at all regions in spring and fall, and about 1-2 months longer seasonal coverage

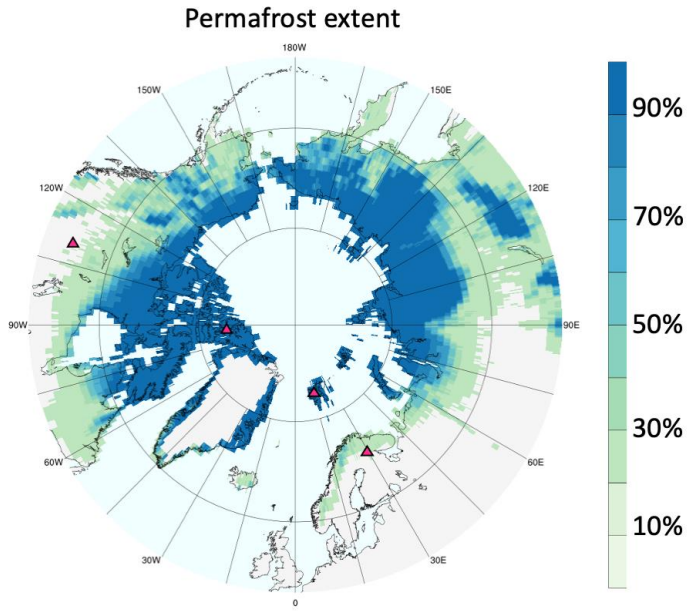


Figure 1. *The extent and fraction of permafrost, based on the ESA CCI-Permafrost L4 product.*

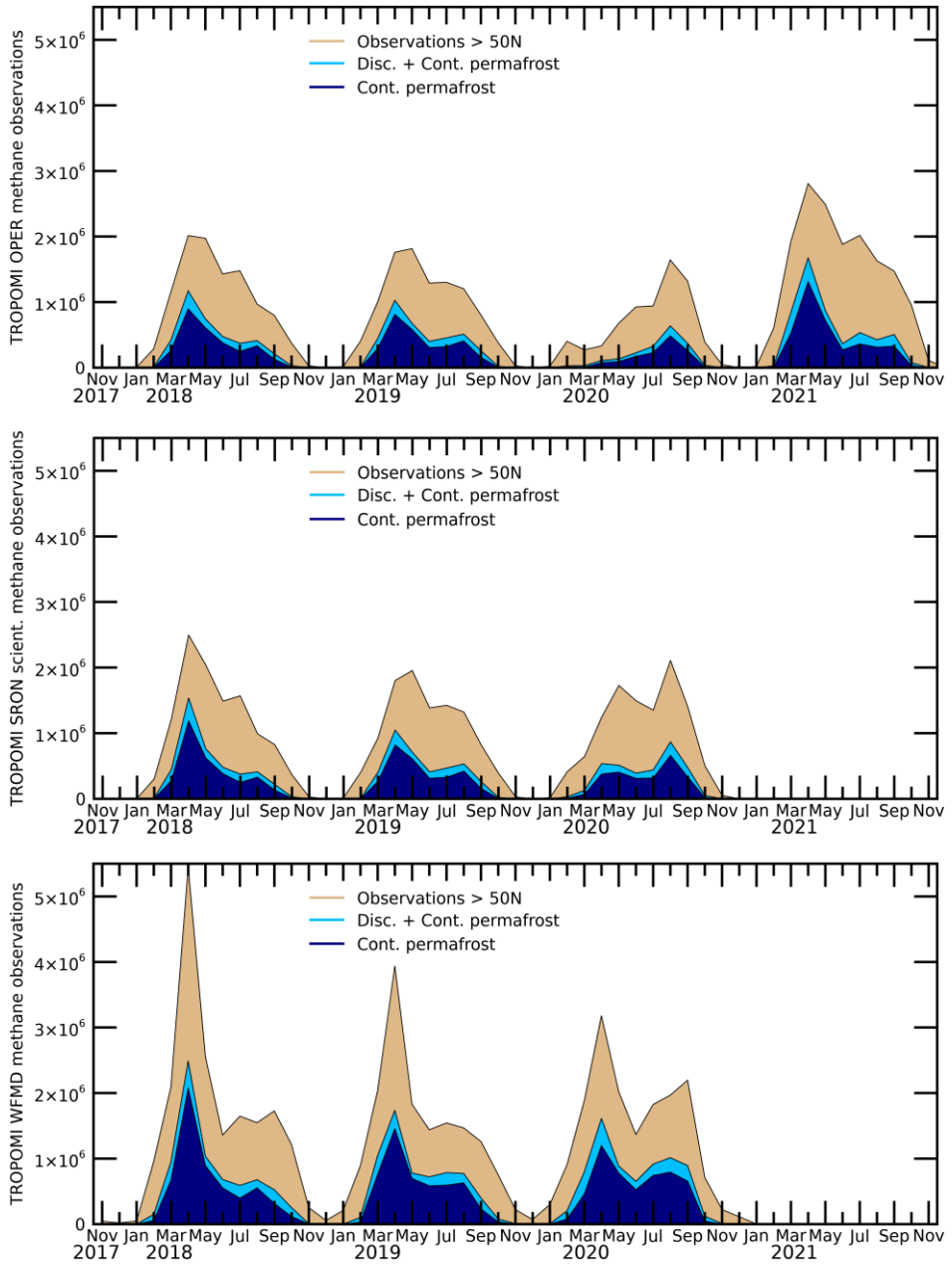


Figure 2. *The number of TROPOMI XCH_4 observations over permafrost regions for SRON oper. (top), SRON scient. (middle), and WFMD (bottom) retrievals.*

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2) Differences in regional XCH_4 patterns at high latitudes

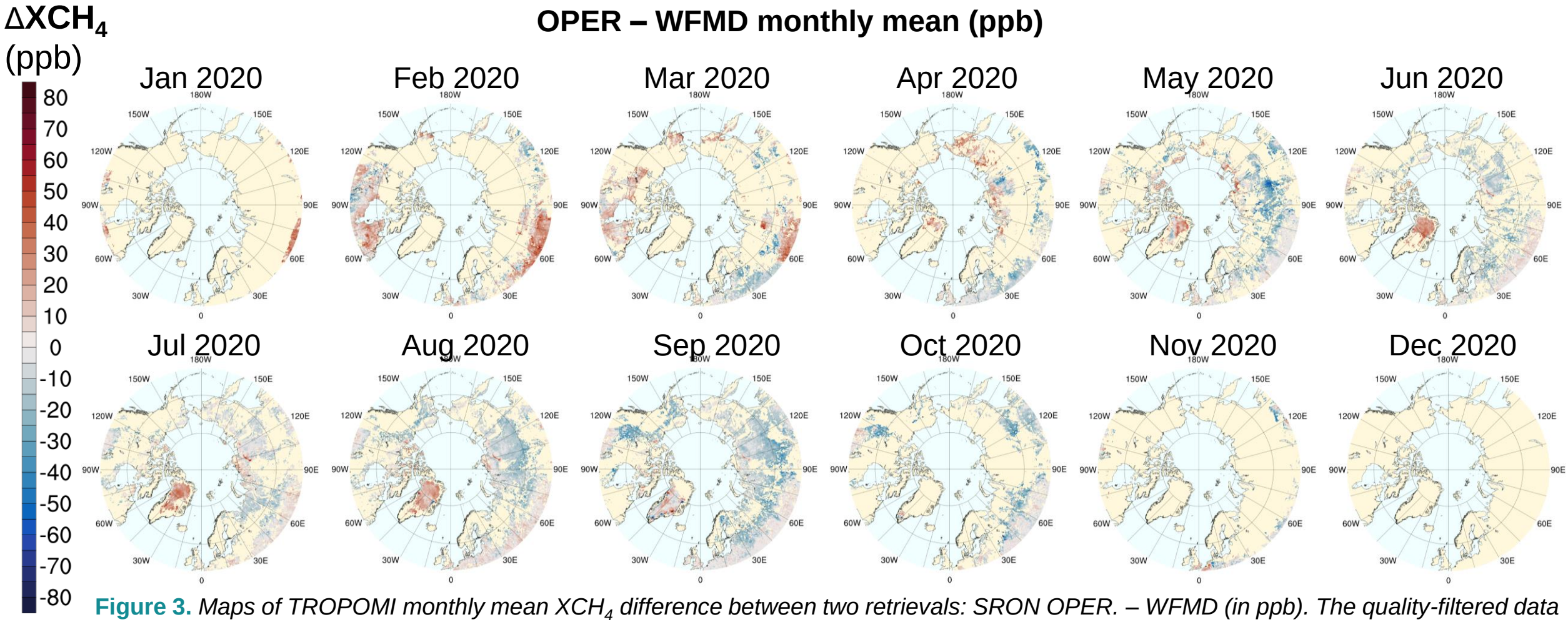


Figure 3. *Maps of TROPOMI monthly mean XCH_4 difference between two retrievals: SRON OPER. – WFMD (in ppb). The quality-filtered data have been gridded into 0.25 deg x 0.2 deg grids. The difference maps are comparable to those for years 2018 – 2019 (not shown).*

3) Ground-based evaluation at high-latitude TCCON

- We evaluated the three TROPOMI retrievals against **TCCON/GGG2020** at three high-latitude sites: East Trout Lake (ETL, CA), Sodankylä (SO, FI), and Ny Ålesund (NA, NO)
- Spatial co-location criterion is ±2° from the TCCON site
- Temporal co-location criterion is same-day medians
- TROPOMI observations are averaging kernel corrected by using the TCCON prior profiles as a common prior

- **Snow data:**
  NSIDC IMS Daily Northern Hemisphere Snow and Ice Analysis
- **Polar vortex flag:**
  Calculated from potential vorticity fields from ERA5 reanalysis data

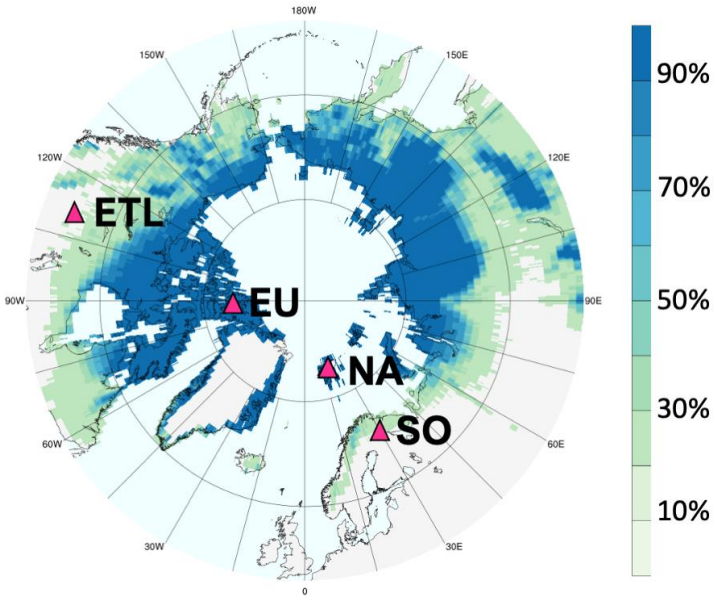
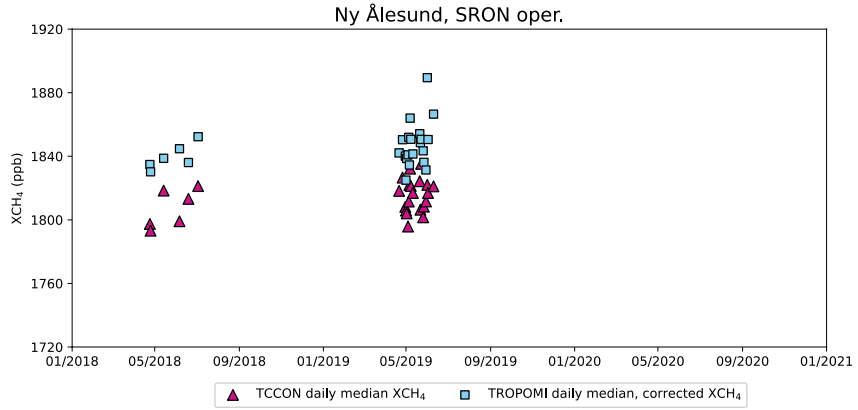
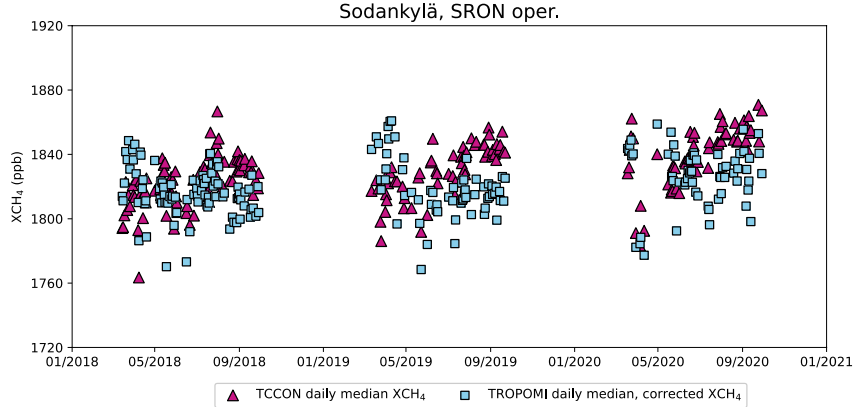
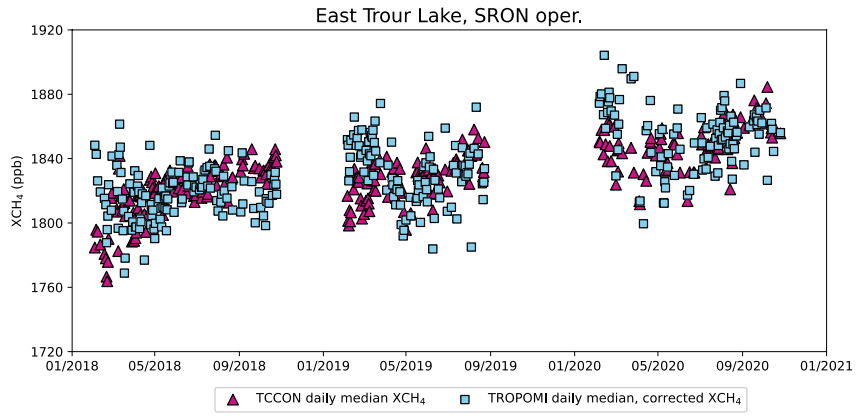


Figure 4. *Four high-latitude TCCON site locations are shown.*

Figure 5. *TROPOMI/OPER and TCCON/GGG2020 daily medians at three high-latitude TCCON sites.*







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3) Ground-based evaluation at high-latitude TCCON

- There is a clear seasonality in the biases at all sites and all retrievals.
  - At Ny Ålesund this is not as clear as at Sodankylä and East Trout lake due to the lower number of observations and limited seasonal coverage.
- We have studied the effect of snow cover and polar vorticity to the seasonal bias.
  - These do not explain the seasonality entirely.
- These figures are done with the averaging kernel corrected TROPOMI XCH4 values, the effect of the correction is on average only 1-3 ppbs and we are still investigating that in more details.

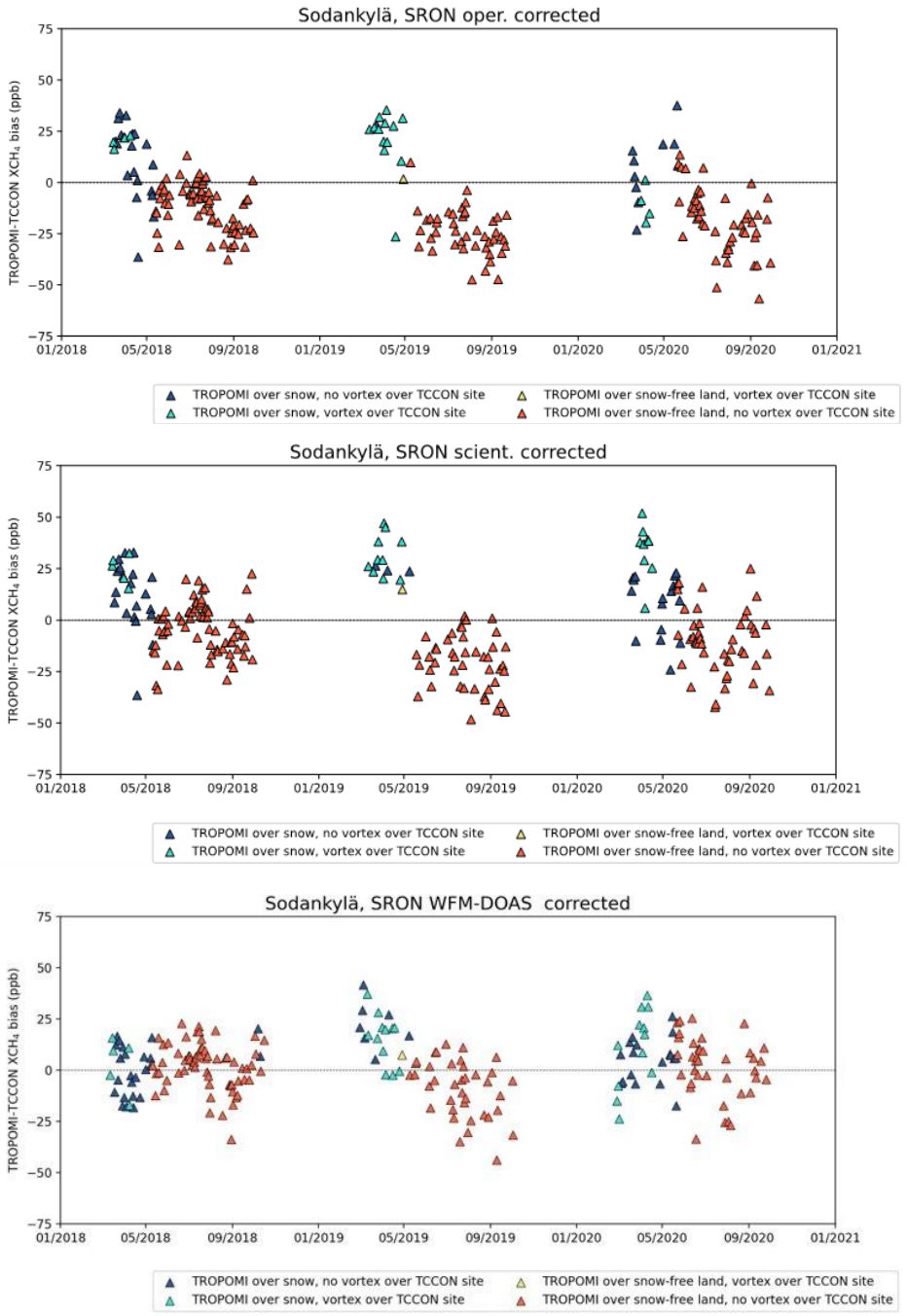

Figure 6. *TROPOMI daily median XCH_4 – TCCON/GGG2020 daily median XCH_4 with co-located snow cover and polar vorticity information at Sodankylä TCCON site for all three TROPOMI retrieval.*

3) Ground-based evaluation at high-latitude TCCON: GGG2014 vs. GGG2020

- As there are some differences in the time series, we did these comparisons including only the exact same dates from GGG2014 and GGG2020
- The new TCCON/GGG2020 does not systematically improve the agreement:
  - The differences between TROPOMI retrievals remain relatively the same at all sites.
  - At all three sites the absolute value of mean bias over snow is smaller for GGG2014 than for GGG2020, but over snow-free landscape the bias is usually smaller for the new retrieval.
  - The absolute value of mean bias is at Sodankylä smaller for GGG2020 but at East Trout Lake and Ny Ålesund the mean bias is generally smaller for GGG2014.

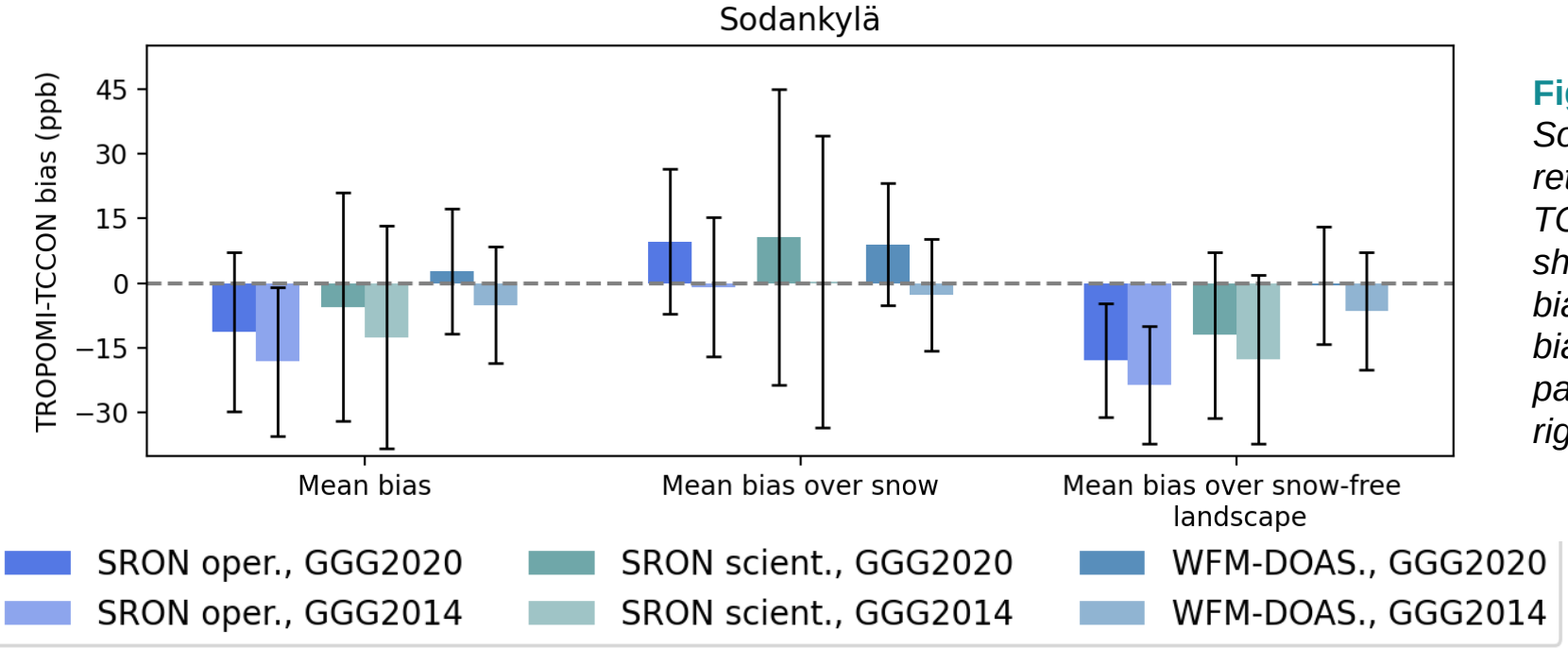

Figure 7. *TROPOMI-TCCON biases at Sodankylä TCCON site for all three TROPOMI retrievals and for both TCCON/GGG2014 and TCCON/GGG2020 retrievals. The leftmost bars shows the mean biases, middle bars the mean biases over snow and rightmost bars the mean biases over snow free landscapes. For each pair of bars, the left one is for GGG2020 and right one for GGG2014.*

4) TROPOMI observations assimilated in CarbonTracker-Europe CH4 (CTE-CH4) atmospheric inverse model

The CTE-CH4 fluxes are estimated for 2018 by assimilating

1) TROPOMI operational SRON observations **(InvOPER)**
2) TROPOMI WFMD observations **(InvWFMD)**
3) ground-based observations of surface CH4 from global and regional networks, e.g. ICOS and NOAA **(InvSURF)**

- The difference between OPER and WFMD-informed high-latitude fluxes can be up to 0.5 Tg CH_4 / month (September)
- The results from TCCON site comparison show that the seasonality of TROPOMI bias may have a significant impact on the fluxes from TROPOMI inversions.

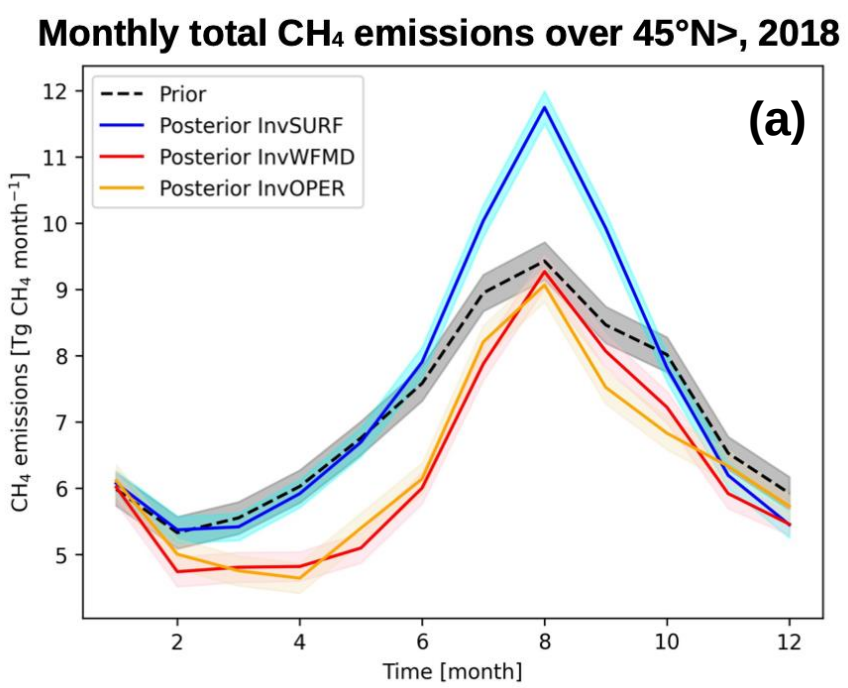

Figure 8.
(a) Monthly total CH4 emissions from CTE-CH4
(b) CTE-CH4 XCH4 anomaly (= the annual means are subtracted) against TCCON/GGG2020 anomaly
(c) CTE-CH4 profiles against AirCore profile measurements

Summary and Conclusions

- Based on our evaluation, TROPOMI observations enable seasonal analyses of methane at high latitudes, even over permafrost.
- The operational and WFMD products show a generally good agreement but also systematic seasonal and latitudinal differences.
  - Seasonal differences are shown to have a significant impact of up to 0.5 $TgCH_4$/month on the high-latitude total fluxes solved using inverse modelling
- All products have biases smaller than 27 ppb against the TCCON. TCCON/GGG2020 does not systematically improve the agreement → can help in identifying improvements.
- Lack of validation data especially at permafrost regions severely limits the evaluation.

We acknowledge ESA projects MethEO, MethaneCamp, and SNOWITE for funding this high-latitude work.

We acknowledge all colleagues providing the data for high-latitude validation:

- **TROPOMI XCH_4:** operational XCH_4 product (Hu et al., 2016), Bremen WFMD XCH_4 product (Schneising et al., 2019, 2020) and SRON scientific product (Lorente et al., 2021)
- **TCCON retrievals:** Sodankylä (https://doi.org/10.14291/tccon.ggg2014.sodankyla01.R0/1149280), East Trout Lake (https://doi.org/10.14291/tccon.ggg2014.easttroutlake01.R0/1348207), Ny Ålesund (https://doi.org/10.14291/TCCON.GGG2014.NYALESUND01.R1), and Eureka (http://doi.org/10.14291/tccon.ggg2014.eureka01.R2).
- **Auxiliary data:** NSIDC 4x4 km snow extent, ERA5 reanalysis data, ESA CCI-Permafrost Level 4