Status of satellite observations of high latitude methane and validation needs

J. Tamminen on behalf of MethaneCAMP projet team + collaborators

Ella Kivimäki, Aki Tsuruta, Hannakaisa Lindqvist, Rigel Kivi, Tomi Karppinen, Tuula Aalto, Leif Backman, Alba Lorente, Oliver Schneising, Michael Buchwitz, Hartmut Boesch, Heinrich Bowensmann, Ilse Aben, Sander Howeling, ..

Thank you TCCON sites: Debra Wunch, Kimberly Strong, Matthias Buschmann, Huilin Chen

MethaneCAMP – Methane in the Arctic in support of the Arctic Methane and Permafrost Challenge (AMPAC)

Methane CAMP

esa

Methane observations by satellites

Increasing number of satellites are measuring methane

Global observations:

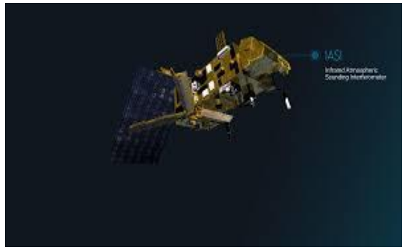
- GOSAT observations since 2009.
- TROPOMI/ Sentinel 5P daily global coverage with 5.5 x 7 km pixels (assuming cloud free sky). 2017 – onwards.
- IASI, CrIS – using TIR. GOSAT-2: SWIR & TIR.

Hot-spots:

- High spatial resolution images with Landsat, PRISMA, GHGSat, Sentinel 2.








Methane CAMP

esa

SWIR instruments and XCH4 retrievals in high latitudes and permafrost region

Known challenges in SWIR retrievals at high latitudes:

- Seasonal coverage limited due to polar night and low solar angles
- Frequent clouds
- Low reflectivity in SWIR over snow, ice and sea.
- Vertical profile of methane is variable due to polar vortex.

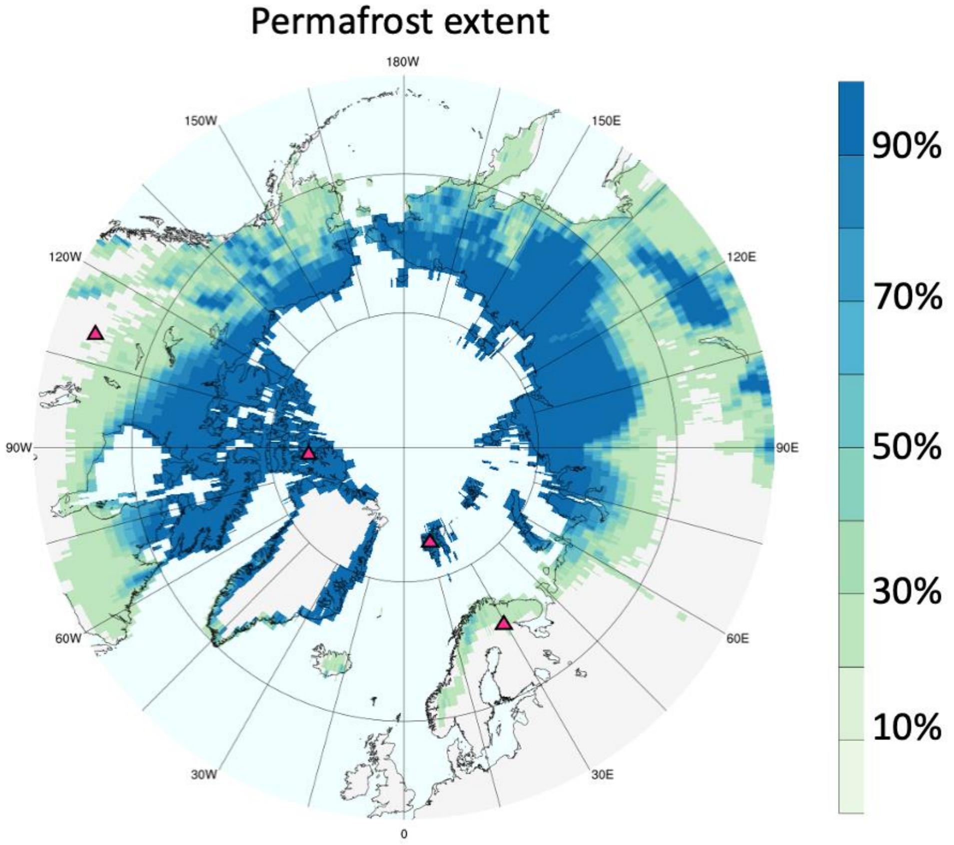
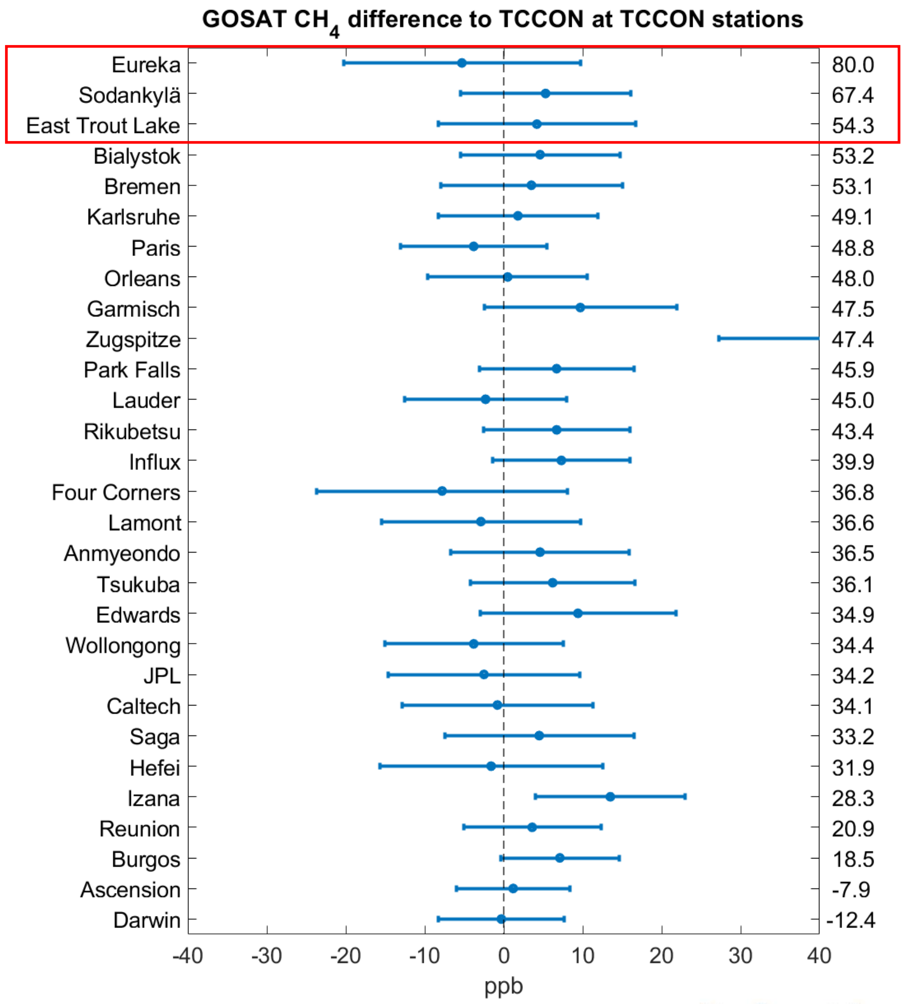


Figure 1. *The extent and fraction of permafrost, based on the ESA CCI-Permafrost L4 product.*

Methane CAMP

esa

GOSAT XCH_4 compared to TCCON



Karppinen et. Al.

- NIES GOSAT product up to 2020.
- Good performance also at high latitudes on average

Methane CAMP

esa

TROPOMI XCH4 retrievals

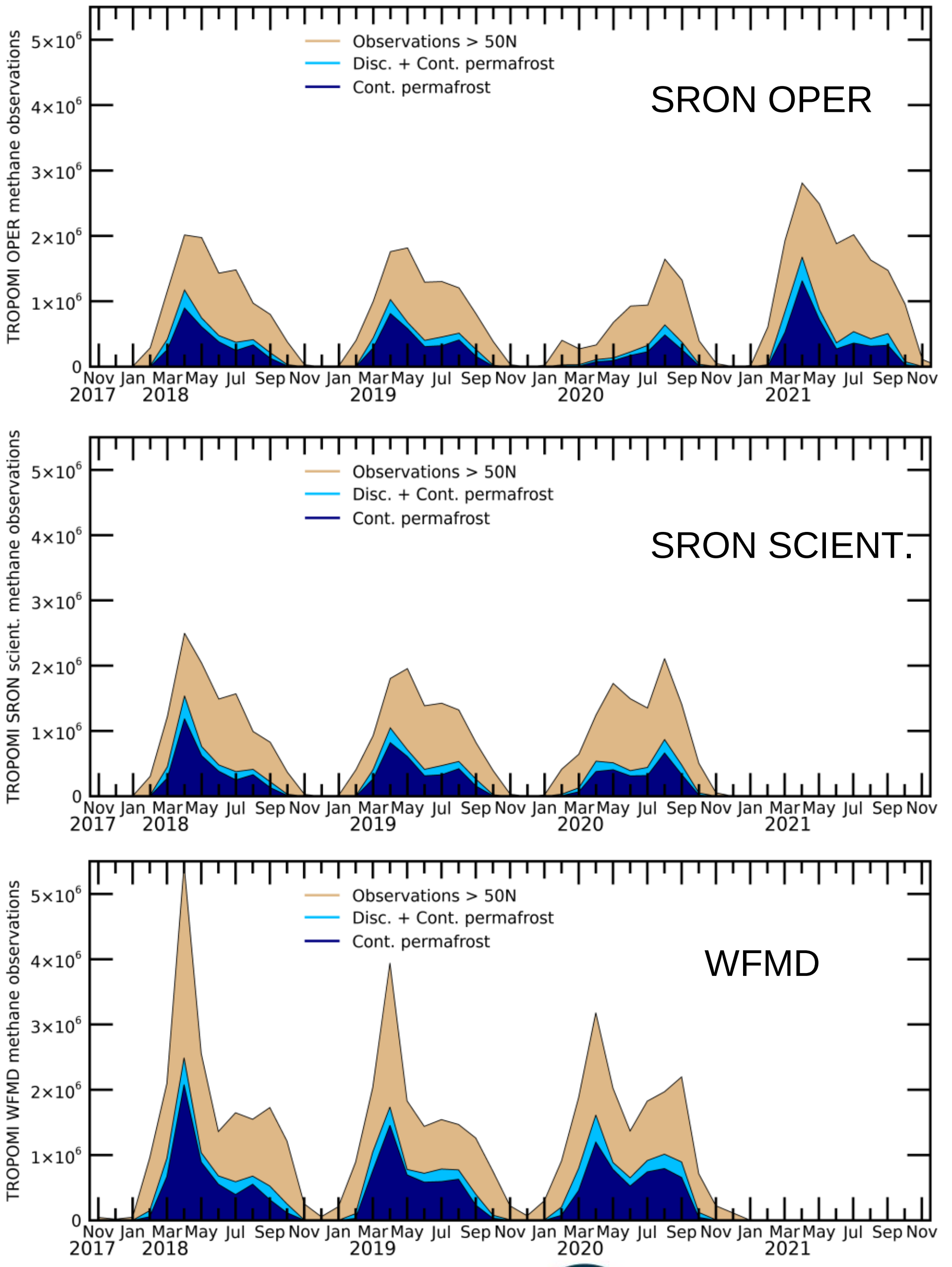
In ESA MethaneCAMP project the methane retrievals are optimized for high Northern latitude conditions.

Comparison on three existing XCH4:

- **SRON operational algorithm**
  (Hu et al., 2016)
- **SRON scientific algorithm**
  (Lorente et al., 2021)
- **Univ. Bremen WFMD algorithm**
  (Schneising et al., 2019, 2020)

Changes in data sets include also changes in:

- Data flagging and coverage (e.g. cloud screening)



Lindqvist et al.

Methane CAMP

esa

Differences in regional XCH_4 patterns at high latitudes

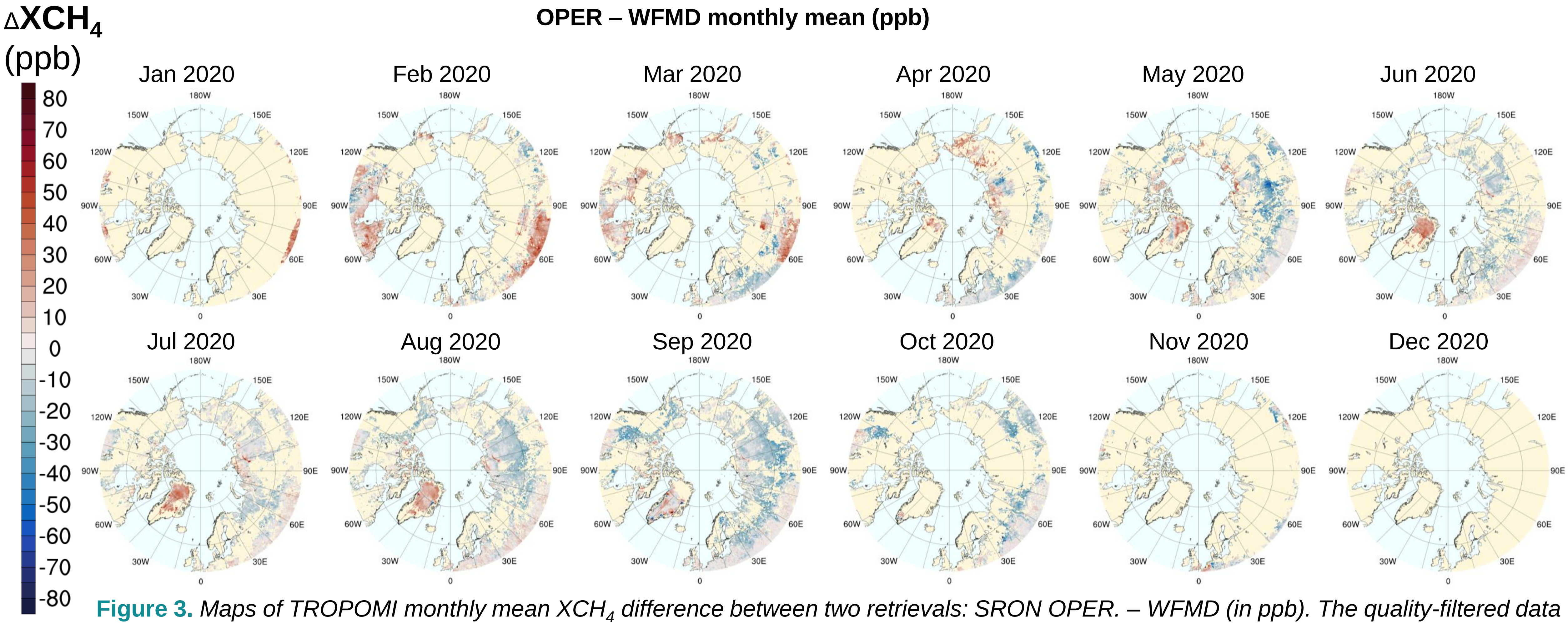


Figure 3. *Maps of TROPOMI monthly mean XCH_4 difference between two retrievals: SRON OPER. – WFMD (in ppb). The quality-filtered data have been gridded into 0.25 deg x 0.2 deg grids. The difference maps are comparable to those for years 2018 – 2019 (not shown).*

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

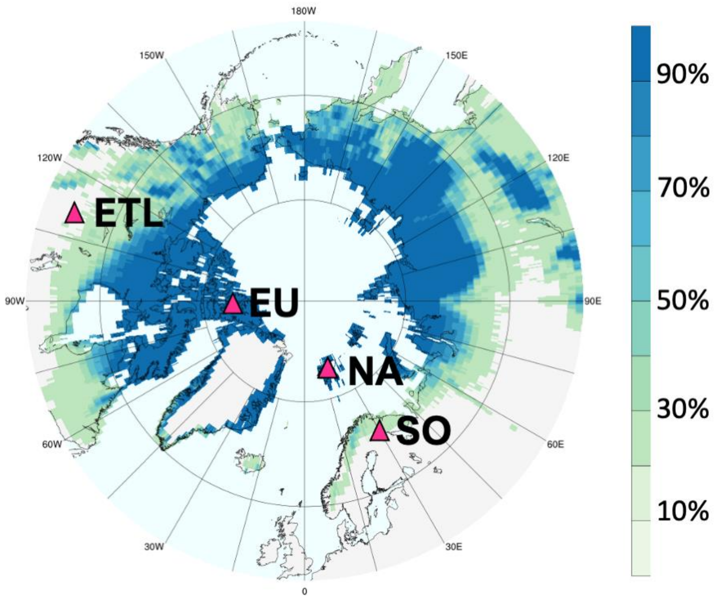
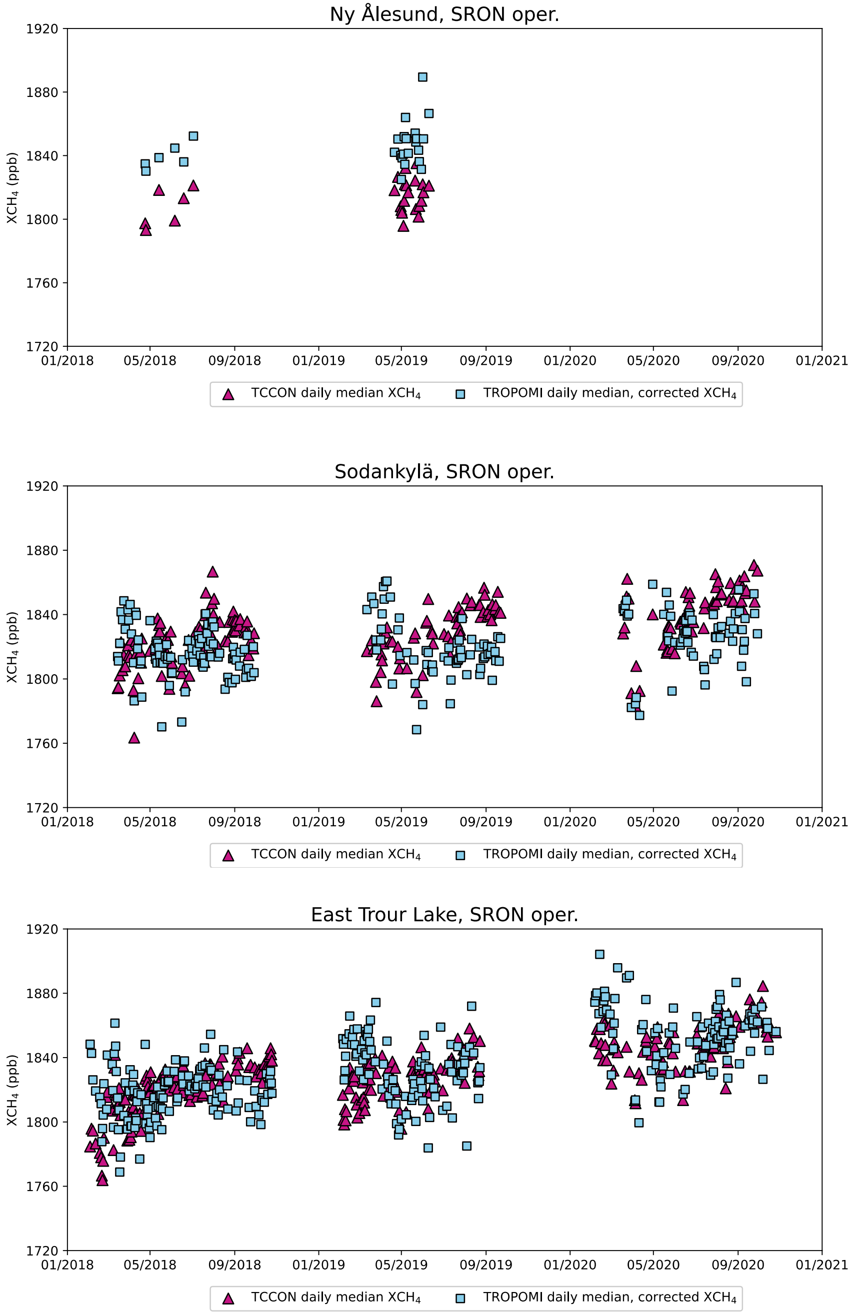


Figure 4. *Four high-latitude TCCON site locations are shown.*

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



Methane CAMP

Kivimäki et al.

Ground-based evaluation at high-latitude TCCON

- There is a clear seasonality in the biases at all sites and all retrievals.
- 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.

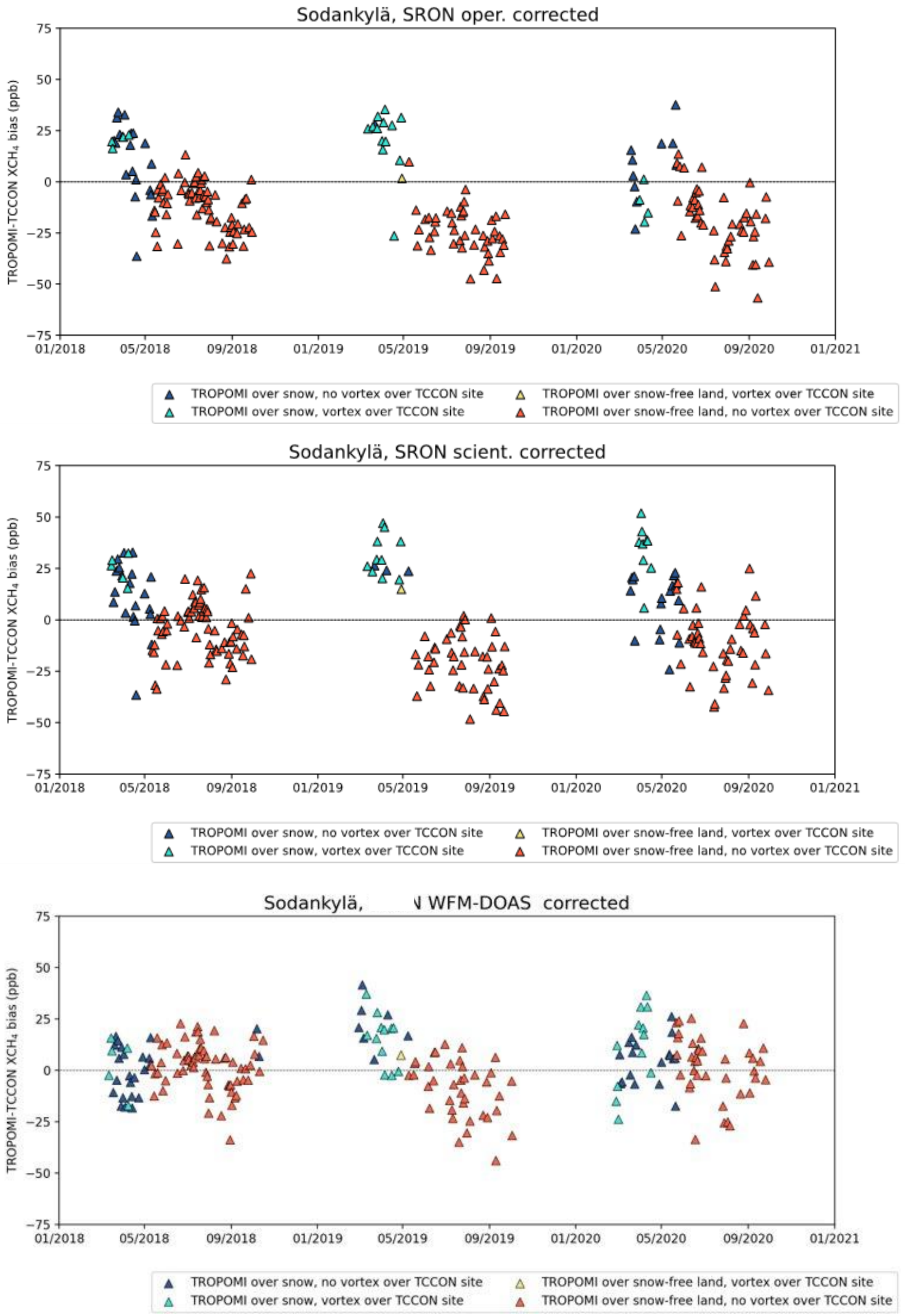


Figure 6. *TROPOMI daily median XCH_4 – TCCON/GGG2020 daily median XCH_4 with co-located snow cover and polar vorticity information at Sodankylä TCCON site for all three TROPOMI retrieval.*

Kivimäki et al.

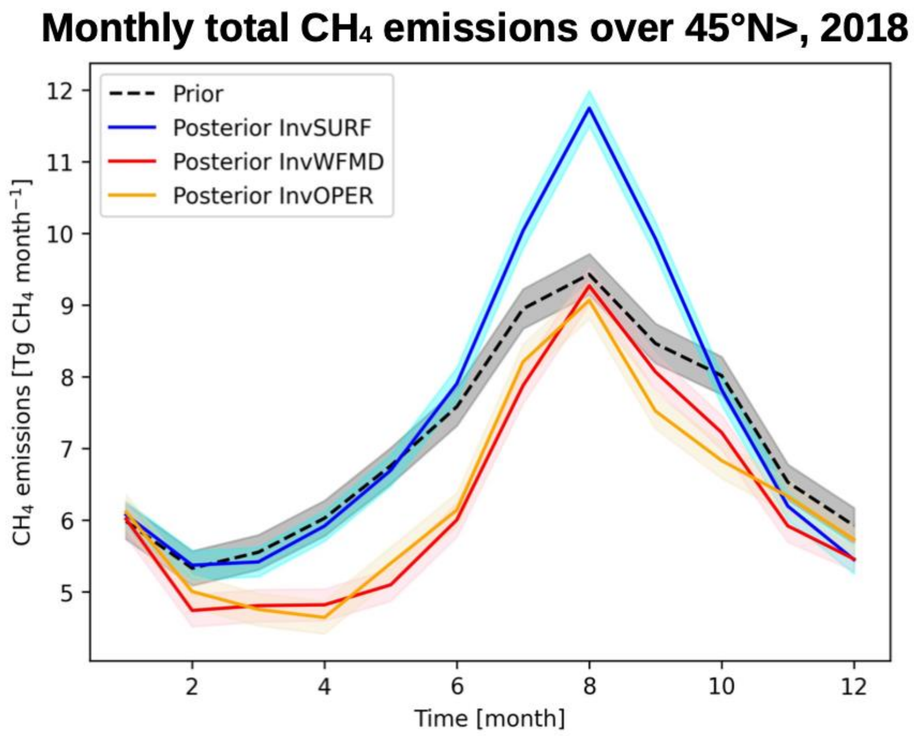
Methane CAMP

TROPOMI observations assimilated in CarbonTracker - Europe CH_4 atmospheric inverse model

The CTE-CH4 fluxes are estimated for 2018 by assimilating

- TROPOMI operational SRON observations
- TROPOMI WFMD observations
- ground-based observations of surface CH4 from global and regional networks, e.g. ICOS and NOAA

- 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.



Monthly total CH4 emissions from CTE-CH4

Methane CAMP

Tsuruta, Aalto et al.

esa

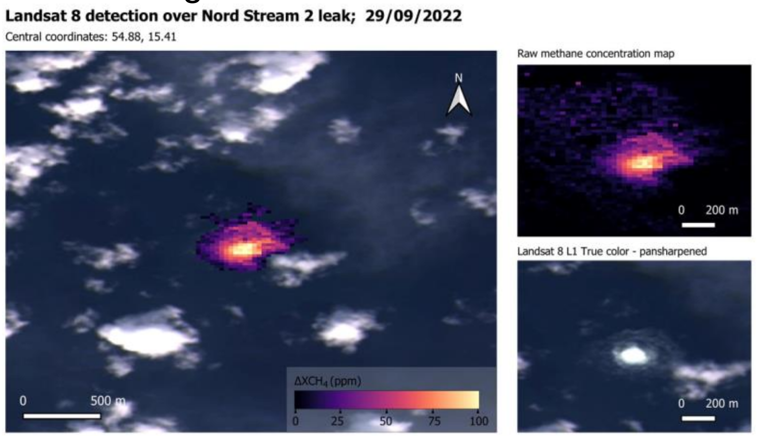
Nord Stream leakage

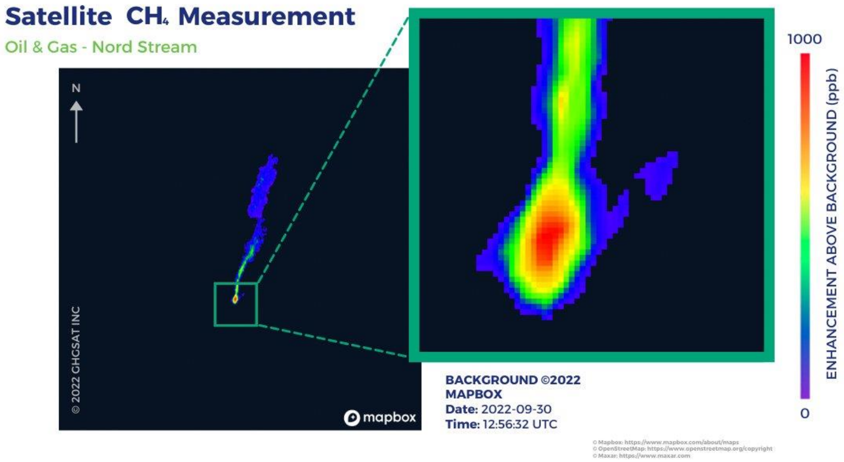
Large gas leakage detected in Baltic sea close to Bornholm island after series of explosions that broke Nord Stream 1 and 2 natural gas pipelines on 26th September 2022.

Satellite observations of CH4:

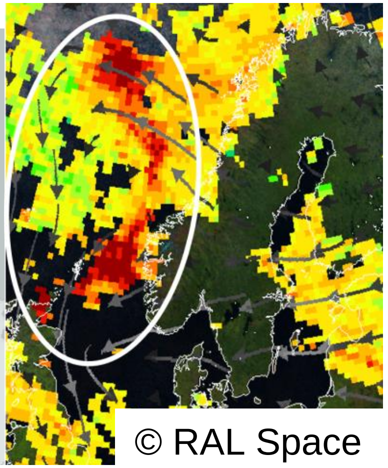
- Cloudy conditions were challenging for global view instruments using SWIR
- Landsat-8 and GHGSat detected CH4
- IASI TIR observations were useful.

Images from Twitter:





© ESA



© RAL Space

Methane CAMP

Summary

- 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.
- In MethaneCAMP project it is expected to optimize retrievals at high latitudes.
- 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:

- **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

Satellite validation needs

Improved coverage:

- Validation over permafrost regions is limited to only few TCCON and COCCON sites.
- Validation of observations over water (globally) needed
- Validation of observations over sea ice (high latitudes) needed

Hot-spots:

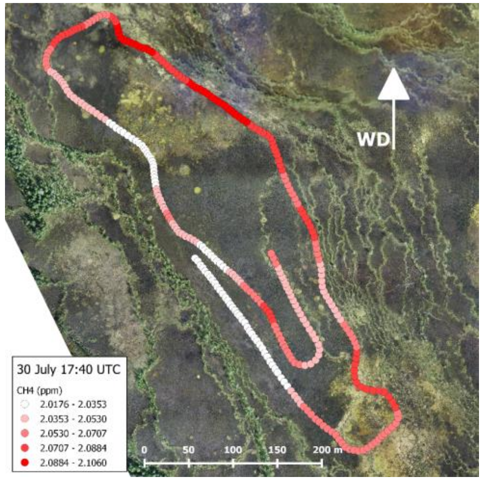
- Validation of anthropogenic hot spots and high spatial resolution observations needed.

Challenging conditions:

- Validation of observations over mixed pixels at land-water boundaries (e.g. lakes, sea shores)
- Surface reflectance in the near-infrared wavelengths at large SZA and various viewing angles (particularly relevant: snow, ice)

Continuity

- Campaigns that cover current gaps in validation but also established, well-known reference sites to validate longer-term temporal changes
- Regular vertical profile observations at several sites to support retrieving also partial columns and profiles



Methane CAMP

Fiducial Reference Measurements for Greenhouse Gases (ESA FRM4GHG)

Phase 1:

- Characterization of various portable low-resolution spectrometers for GHG measurements (Sha et al., AMT 2020).

Phase 2:

- Improve further the quality of GHG measurements and implementing new methods, Intercomparison of instruments (EM27/SUN, Vertex70, IRCube, Laser Heterodyne Spectroradiometer with TCCON and reference in-situ profiles from AirCore),
- Improve GHG data retrieval algorithms including (amongst others) latest development in spectroscopy, optimization of retrievals of partial columns of new species (HCHO, N_2O, CH_4) from lower resolution FTSs in the mid-infrared spectral region
- Improve further links between TCCON and COCCON.
- Develop AirCore observation of additional species (N_2O, OCS).