MethaneCAMP: Remote sensing of high-latitude emissions

MethaneCAMP - Methane in the Arctic in support of the Arctic Methane and Permafrost Challenge

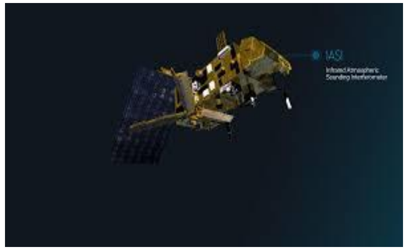
J. Tamminen, H. Lindqvist, H. Bösch, S. Houweling, M. Buchwitz, I. Aben, C. Crevoisier, R. Parker, A. Bartsch, A. Fix, H. Bovensmann, O. Schneising, B. Maasakkers, T. Bordsforff, M. Velarte, X. Zhang, J. van Peet, N. Meilhac, T. Aalto, A. Tsuruta, R. Kivi, I. Ialongo, T. Karppinen, T. Häkkilä, J. Nurmela, E. Kivimäki, M. Tenkainen, A. Erkkilä, and L. Amoros

2024 EU Polar Science Week

3–6.9. 2024 Copenhagen







MethaneCAMP (2022 –2024)

Focus on satellite retrievals of methane at high latitudes

Objectives of MethaneCAMP:

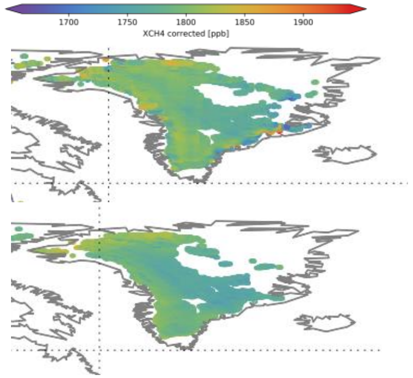
- Assess and validate existing satellite retrievals of methane.
- Optimise and advance satellite retrievals for high latitude conditions; utilise and support high latitude campaigns
- Demonstrate capabilities of satellite data for high latitude CH_4 analysis together with modeling and inverse modeling

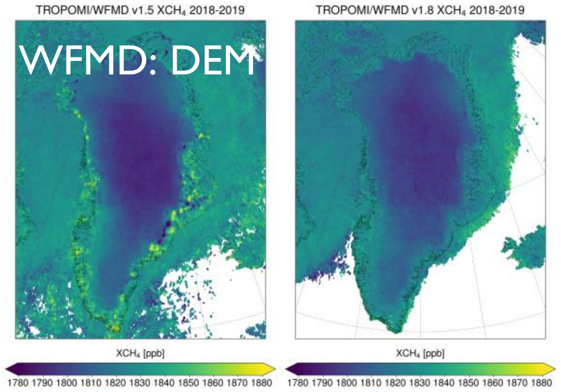
Recent TROPOMI algorithm updates

SRON oper. and UoB WFMD TROPOMI

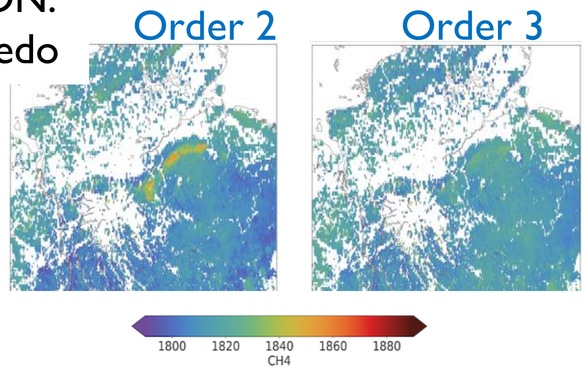
- **Artefacts reduced:**
  - Updated Digital Elevation Map with significant differences for parts of the Arctic and Antarctica
  - Improved characterization of the spectral dependency of albedo.
  - Cloud clearing and quality filter updates
  - Destriping
- **Increased data coverage:**
  - Sun-glint geometry added.
  - Refinement of quality filttering (also for GOSAT UoL product)
- **At high latitudes: improved coverage (more good quality observations) and better agreement with reference observations.**

SRON: DEM

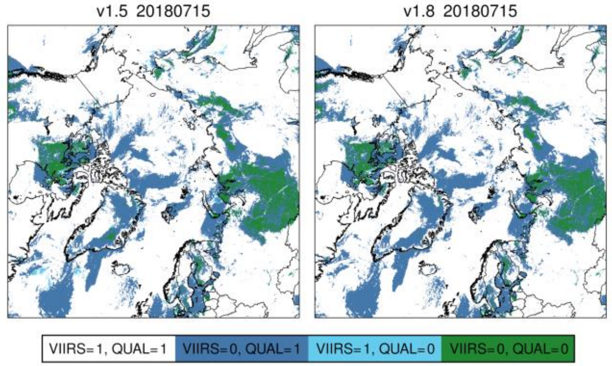




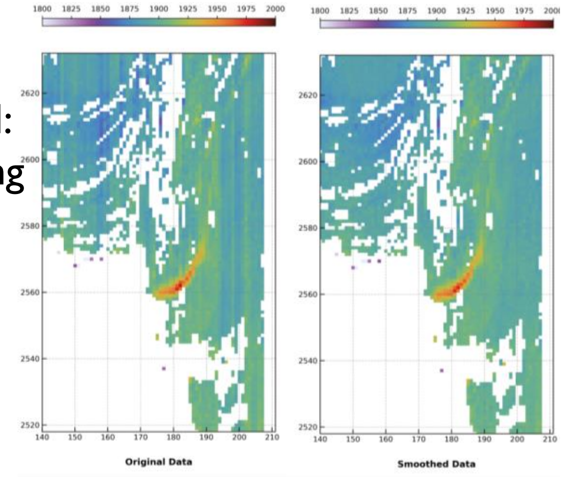
SRON: Albedo



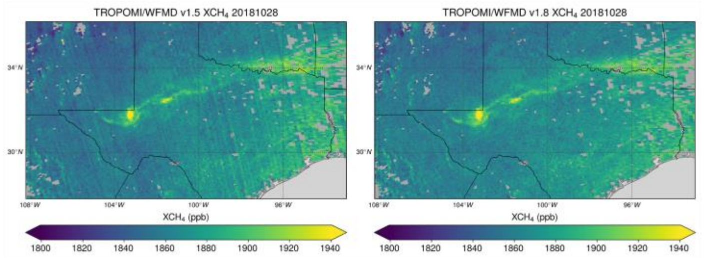
WFMD: Quality filtering, residual clouds



SRON: Destriping

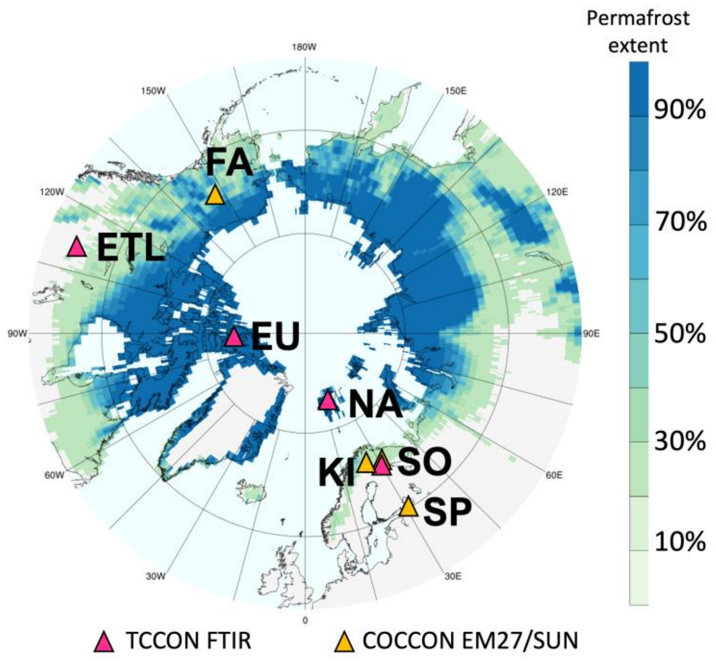


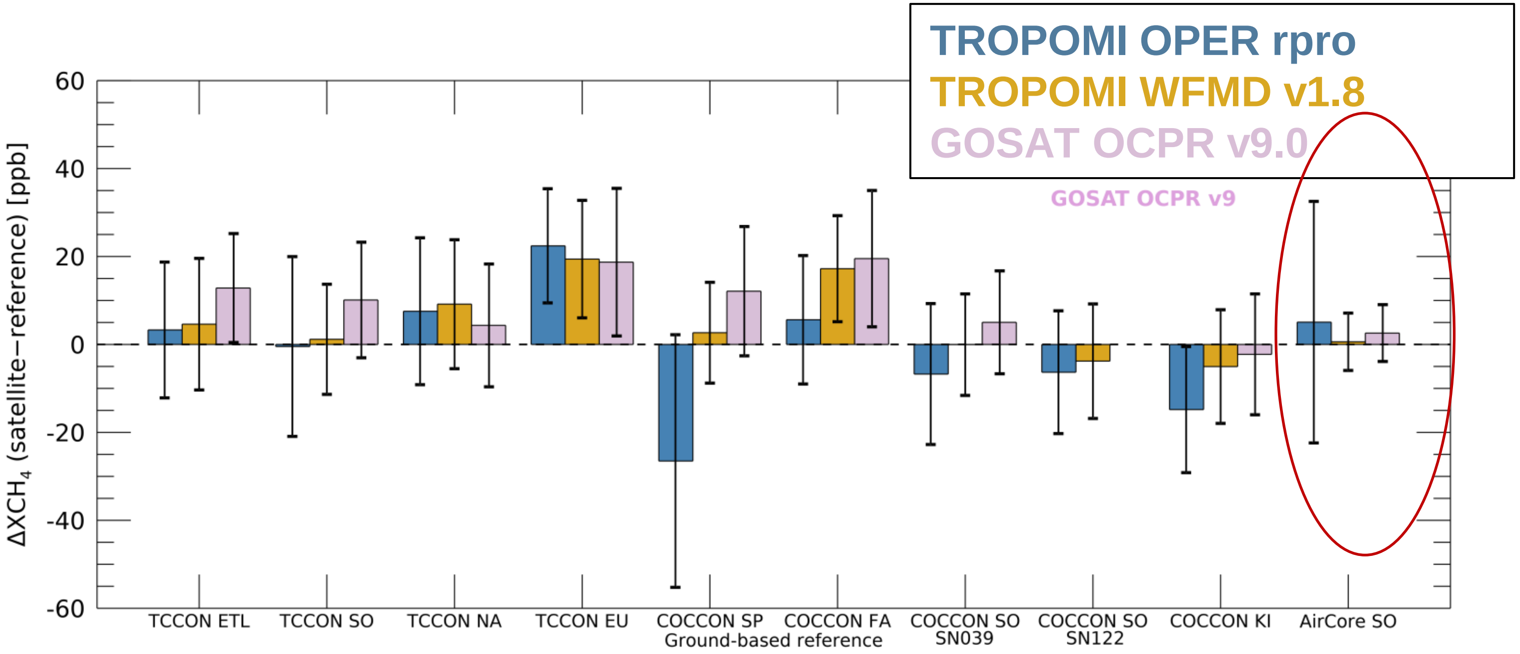
WFMD: Destriping



Figs. SRON and UoB/IUP

TROPOMI and GOSAT XCH4 validation at N. High Latitudes





H. Lindqvist et al., 2024

- Overall agreement between satellite and TCCON/COCCON instruments is good, daily median difference between –13 ppb and +22 ppb, std 11-20 ppb, depending on the site.
- The updated TCCON retrievals are systematically about 7 ppb lower than in previous veresion. Could be linked to systematic difference seen in comparision with satellites.
- In addition to TCCON and COCCON networks, AirCore profiles provide valuable independent validation.

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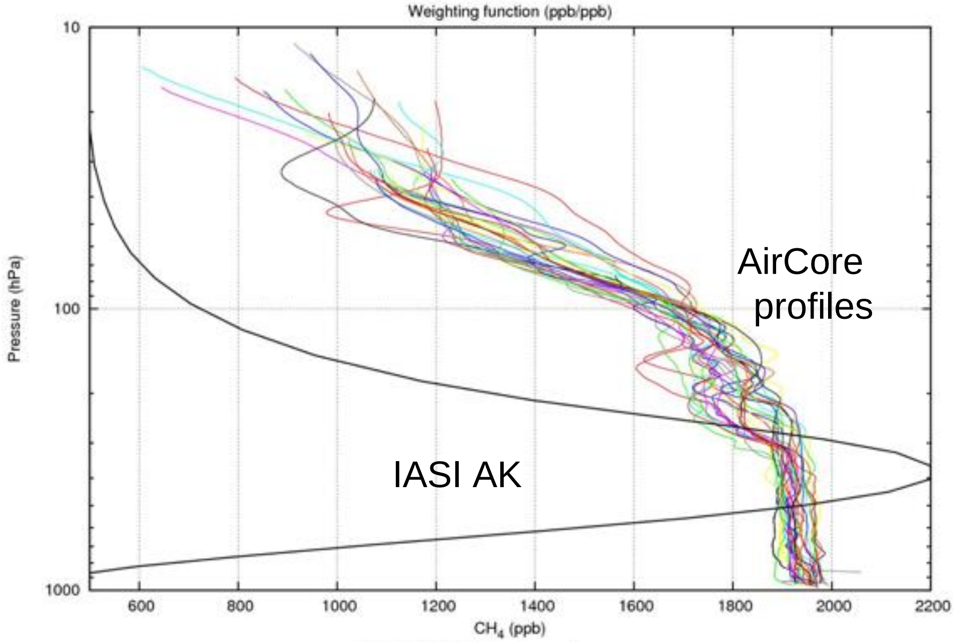
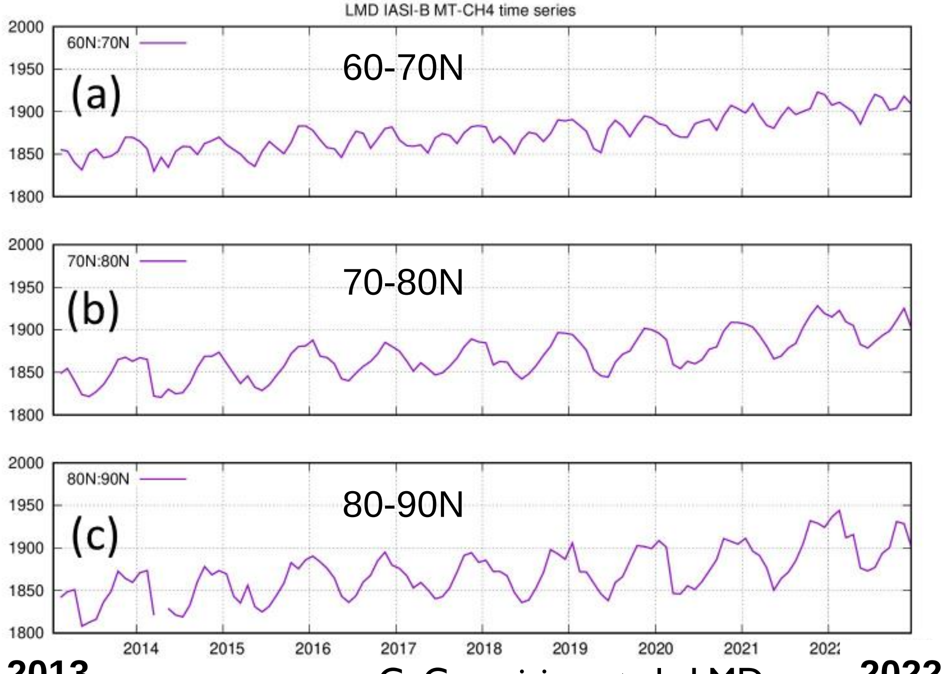
Advances in IASI retrievals

- IASI uses TIR wavelengths to detect mid-tropospheric columns of methane.
- In MethaneCAMP the IASI LMD neural network retrieval of IASI-B data set has been extended to latitudes >60°N
- Changes in wavelength windows to compensate surface sensitivity. Larger wavelength windows to compensate the noise. Dedicated high latitude training data.
- Limited validation with AirCore show good agreement, and similar as at other latitudes.
- **New IASI mid-tropospheric methane product 2013 – 2022 has good seasonal coverage and includes also winter months during polar night.**

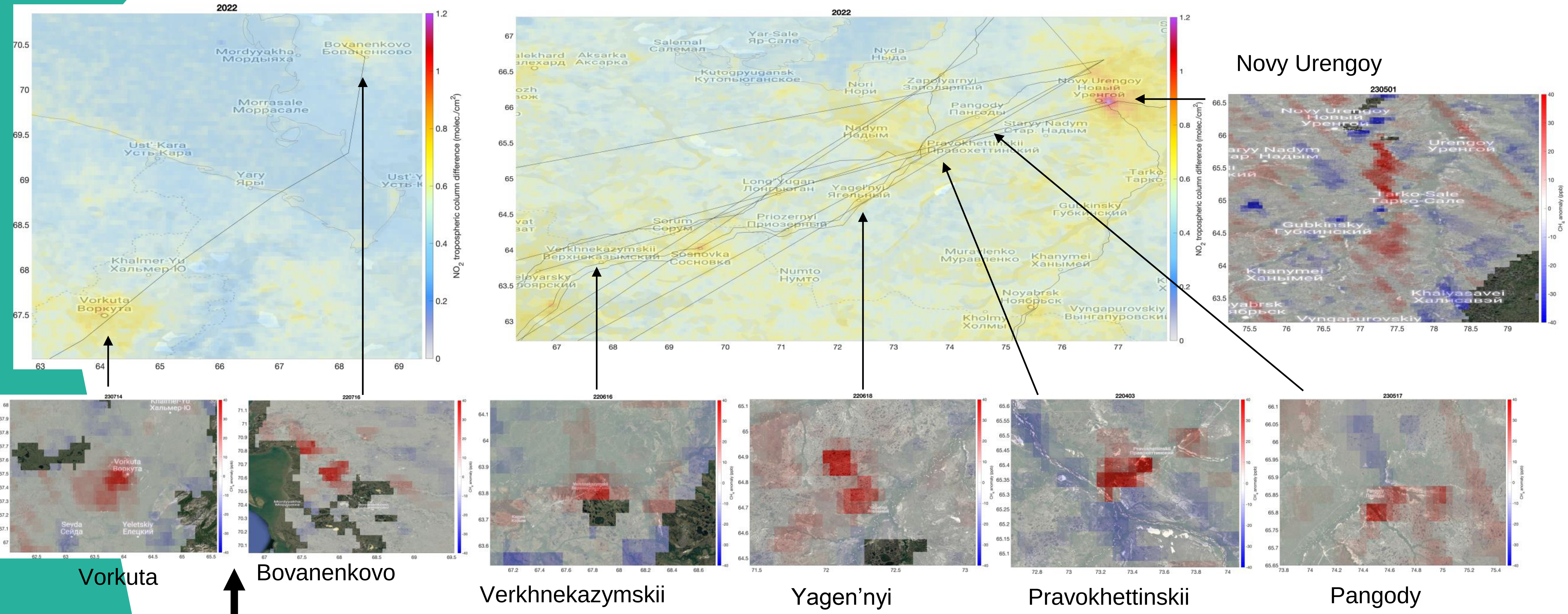




C. Crevoisier, et al., LMD

Joint NO_2 and CH_4 analysis

NO_2 annual averages over Yamalo-Europe and West-Siberian Gas Pipelines



CH_4 high pass filter anomalies along the pipelines and compressors

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@Ialongo I. (FMI)

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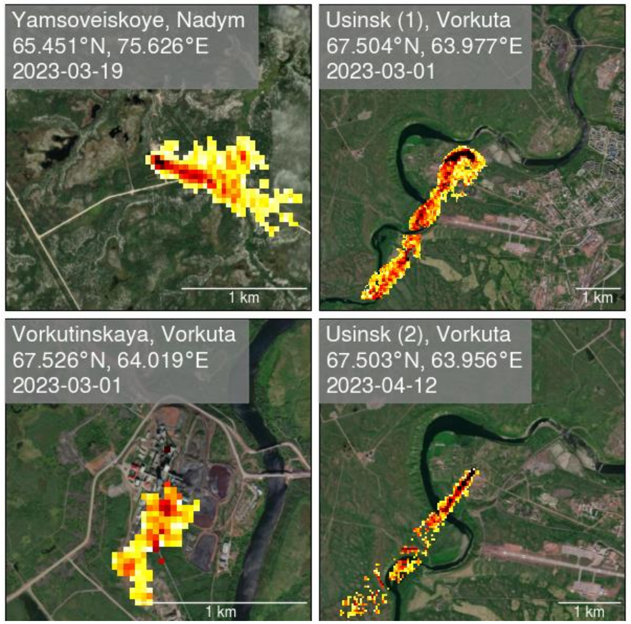
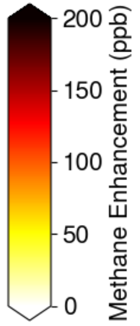
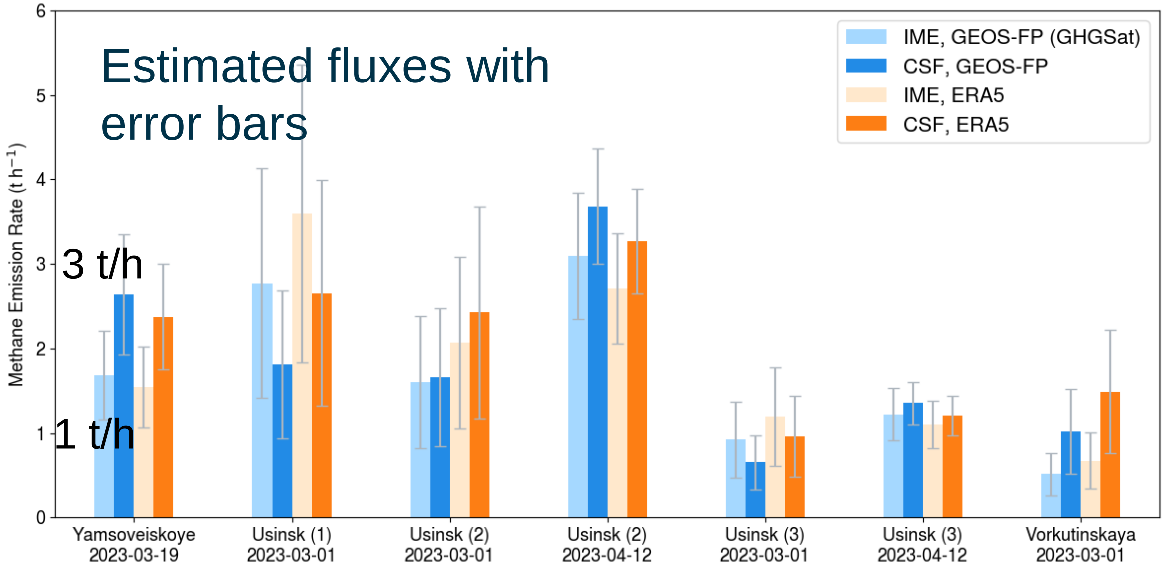
Detecting local emission hotspots with high spatial resolution SWIR spectrometers

- **High spatial resolution (~10 - 300m) multi-channel and hyperspectral observations can potentially improve the point source detection.**
- **Sentinel-2:** At high latitudes non-homogenous surfaces hampers Sentinel-2 methane detection.
- **PRISMA**: despite successful data request we were not successful in identifying methane emissions.
- **GHGSat** is more suitable for point source detection also in high latitudes.
  - Five industry sites (coal mine, oil and gas) in North-West Siberia studied: comparison of alternative techniques for plume masks, emission quantification techniques (IME, CSF) and winds: emissions agree within the error bars. CSF can be more robust in case partially observed plume.
  - **Validation of emissions remains still a challenge**.





Examples of GHGSat methane plumes over fossil fuel industry sites in Northern Russia



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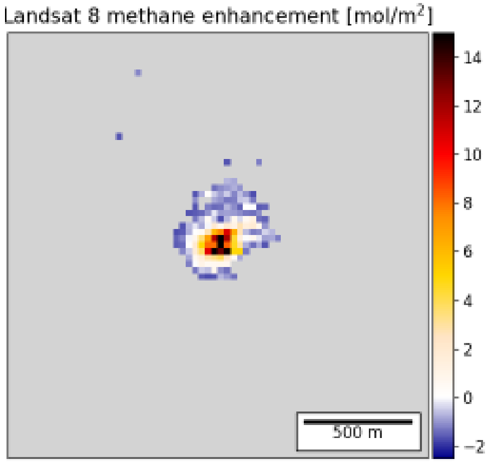
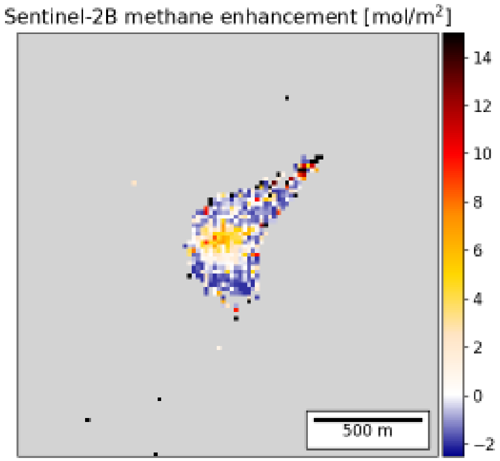
Nord Stream methane leak in Sep 2022

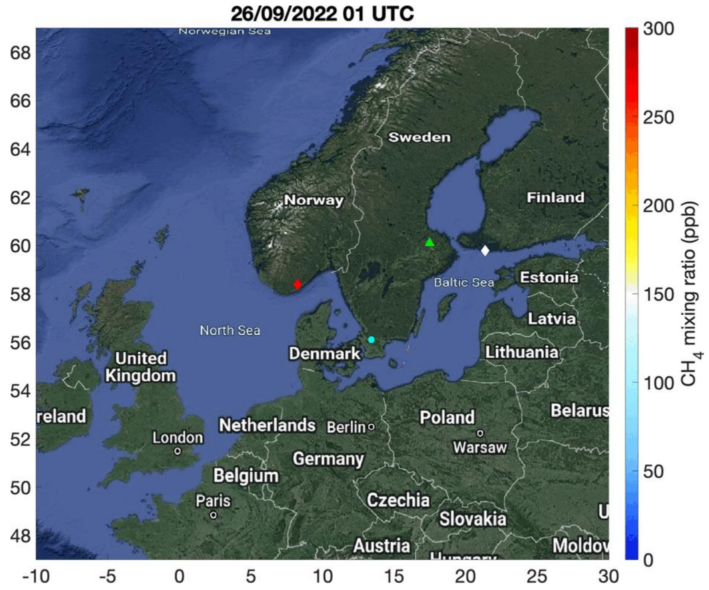
- Nord Stream leakage Sep-Oct 2022 highlighted the importance of careful interpretation of the satellite data.
  - Custom calibration needed for Landsat 8 and Sentinel-2B methane retrievals.
  - Assuming independence of satellites, 502±464 t/hr emisison was estimated for Nord Stream 2 leak.

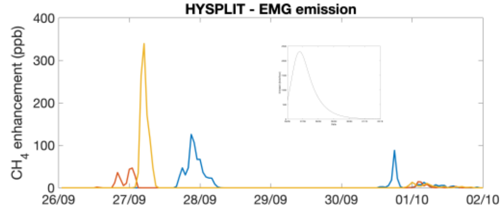


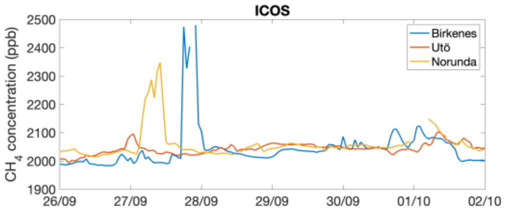


"**Report on Landsat 8 and Sentinel-2B observations of the Nord Stream 2 pipeline methane leak**" : doi.org/10.31223/X53M42 ,
M. Dogniaux, I. Aben et al. (SRON)

- Hysplit & EMG modeling of Nord Stream leak with ground based observations at Utö, Birkenes and Norunda used to scale emission.
- Assuming 90 kton of methane emissions at both leaks were found to correspond the ground based observations.







Ialongo et al., FMI

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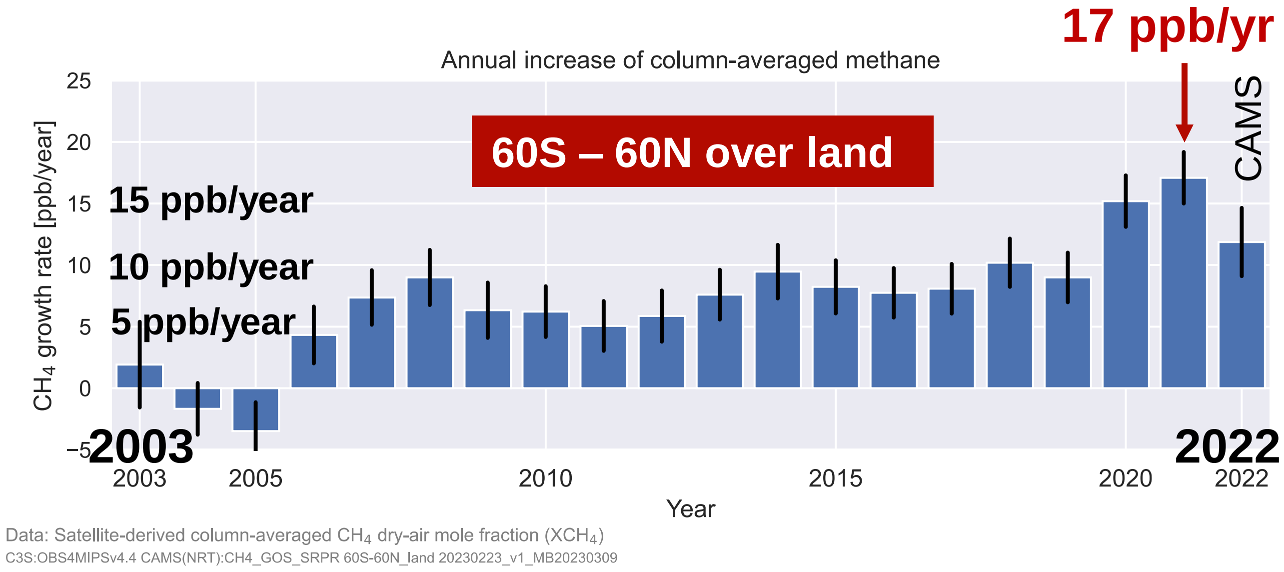
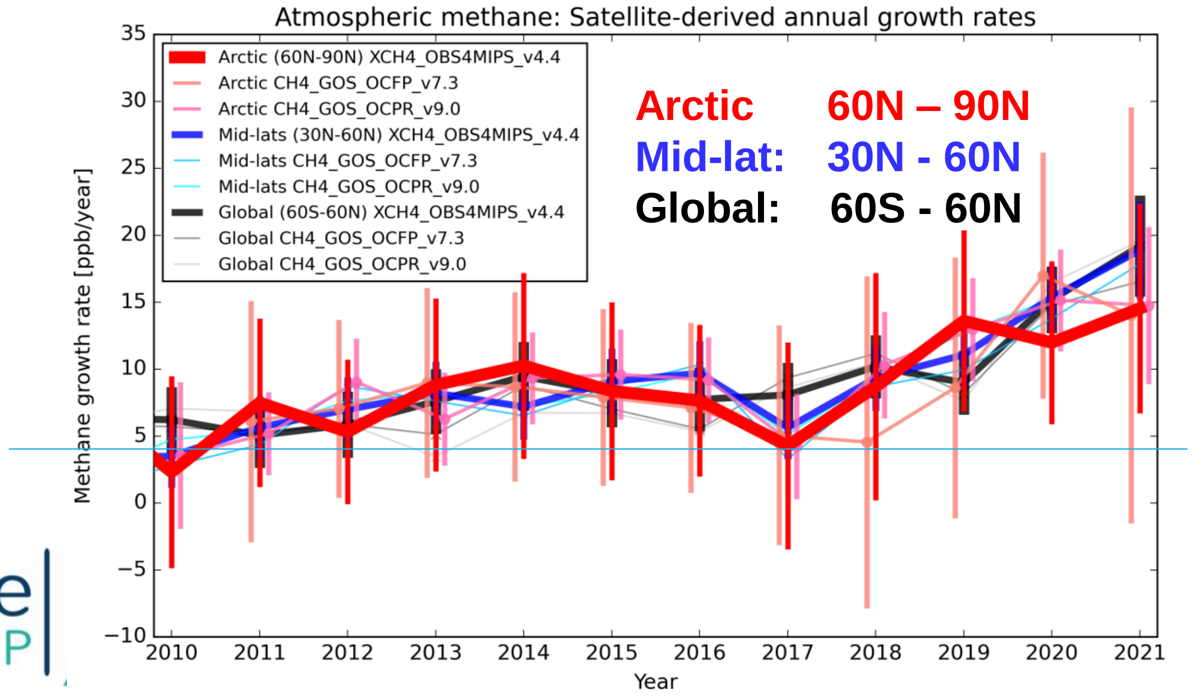
Methane trends: Arctic (60N-90N) growth rates

Data: OBS4MIPS merged data set (ESA GHG-CCI, C3S), v4.4 Copernicus Climate Data store.



Copernicus Climate Change Service Climate Indicators | 2022 — PROGRAMME OF THE EUROPEAN UNION — Copernicus Europe's eyes on Earth — IMPLEMENTED BY ECMWF

- Methane growth rate over Arctic region in 2010 – 2021 around 5 – 15 ppb /yr.
- During record year 2021 the growth rate in the Arctic is lower than global growth rate.
- Overall, the growth rate is similar to other latitude bands, agreement within 1-sigma uncertainty range (of approx. 5 ppb for arctic latitudes).
- Similar conclusion by analysing TROPOMI WFMD 2018-2022 data (50N-70N) (Hachmeister et al., 2023)



M. Buchwich et al (Univ. Bemen)

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Inverse modeling: Trends in biospheric emissions in summer

Inverse modeling: CTE-CH4 and TM5-4DVAR(CAMS) using in-situ data (2000 – 2020):

- Significant increasing trends where generally found in summer time in northern high latitudes, especilly in Northern Scandinavia, Western Siberian lowlands and Alaska.
- Winter-time trend was also seen in some inversions, but it was less clear with more variability.

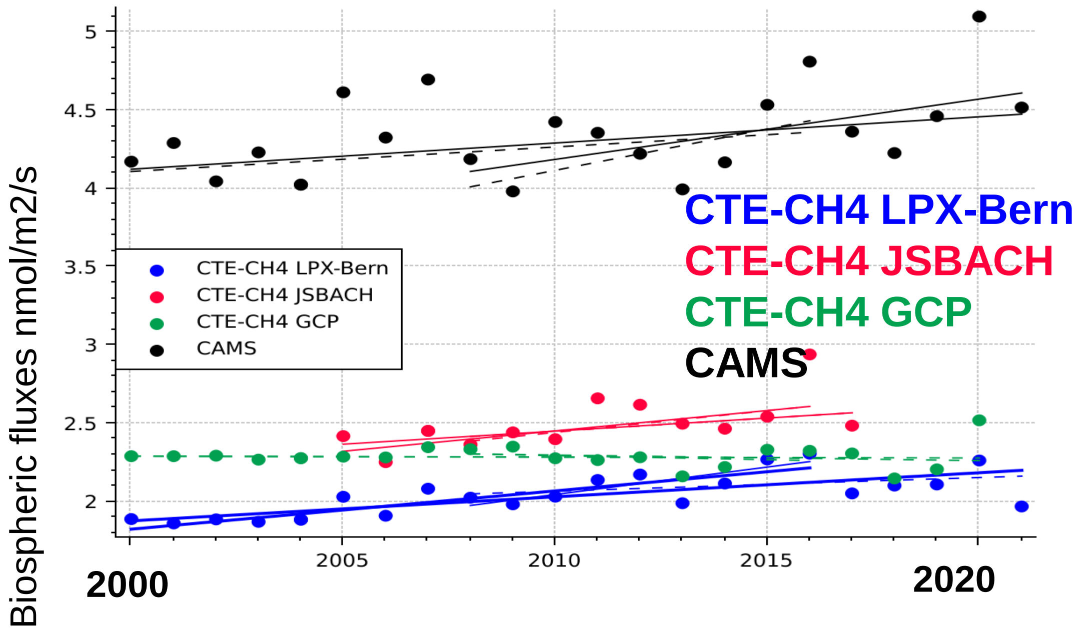
Inverse modeling with GOSAT data (2010 – 2017):

- Significant increasing trend seen in CTE-CH4 inversion in summer while in CAMS the trend was not significant.

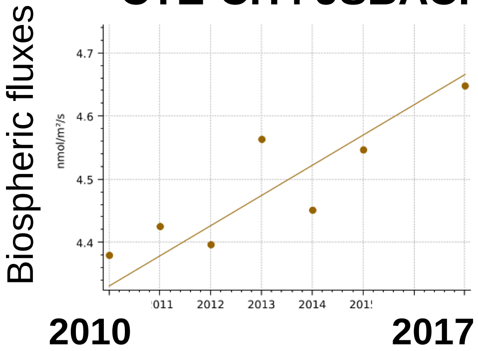
Inverse modeling with TROPOMI data:

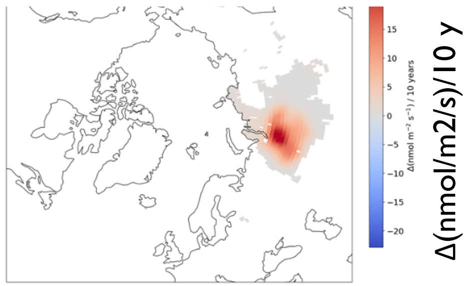
- Potentially improved separation of biospheric and anthropogenic emissions.
- Differences between CTE-CH4 and TM4-4DVAR require further analysis.

Inverse modeling with in-situ data.



Inverse modeling with GOSAT data
CTE-CH4 JSBACH



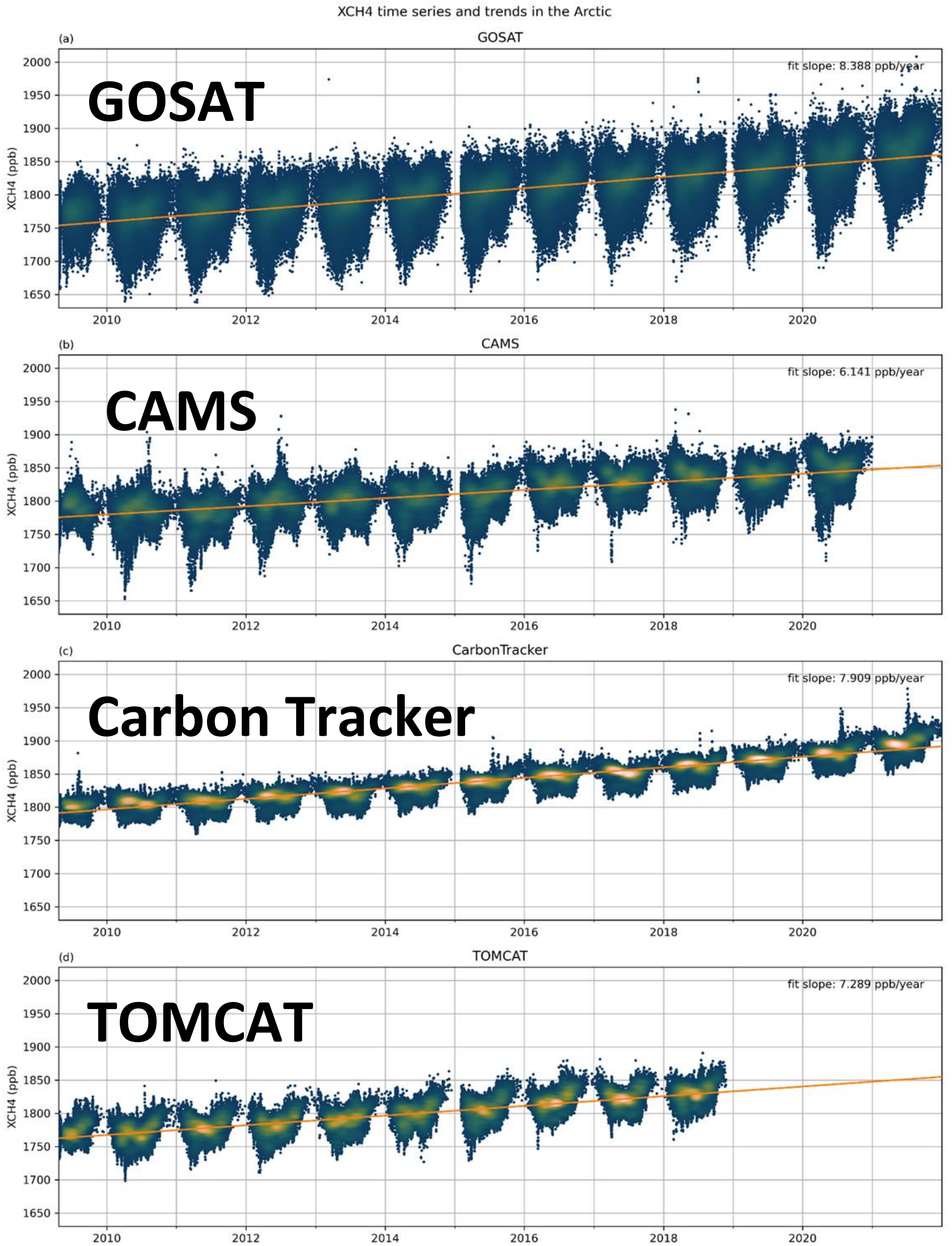


Significant trends

T. Aalto (FMI), S. Houweling (VuA) et al.,

Satellite data vs. models

- **Improved satellite data can be used to analyse model performance, e.g., spatial and temporal variability of methane concentrations.**
- Resampled models (in-situ data assimilated) show higher-level XCH_4 than GOSAT.
- GOSAT observations have a higher growth rate by 0.5-2.3 ppb/year
- Large model-to-model differences in the seasonal cycle of methane; GOSAT shows the largest seasonal variability.
- Large regional variability in growth rate also observed.



Lindqvist et al, in preparation

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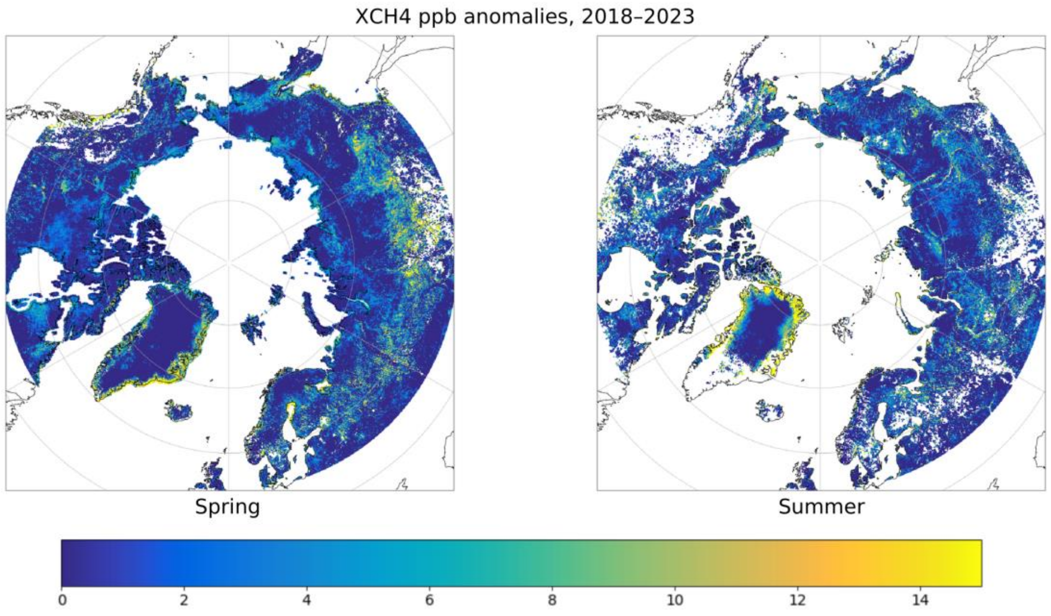
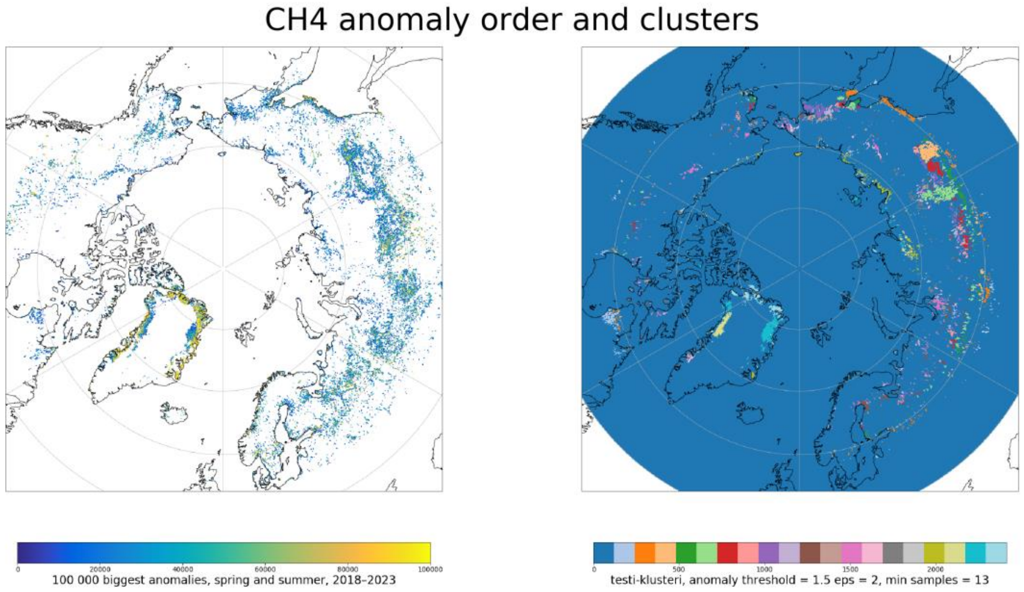
Analysing anomalies

- Improved TROPOMI data can be used to analyse anomalies.
  - Detection of anomalies eg. by comparing to neighbourhood (1000 x 1000 km)
  - Identifying significant anomalies

- Work on-going to analyse anomalies with respect to the surface parameters (land cover, soil moisture, …) and permafrost regions





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Figs. E. Nevalainen et al. (FMI)

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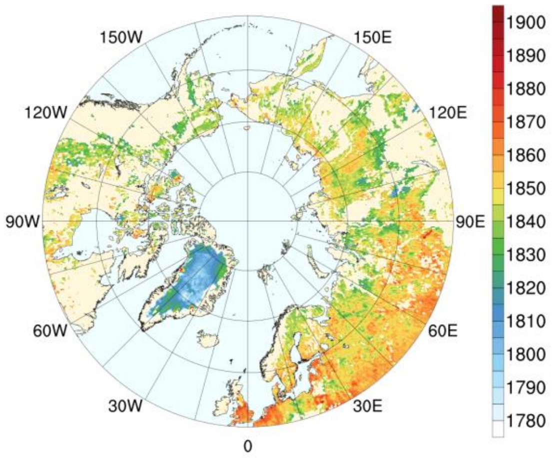
Summary

- Resent advances in SWIR and TIR satellite retrievals have improved the data quality and coverage. Satellite observations of XCH4 are in general high quality.
- Local hot-spots can be detected by GHGSat – Joint use of TROPOMI improves source detection. Validation of emissions still a challenge.
- **Improved TROPOMI, GOSAT and IASI methane products are now useful for analysing methane anomalies and trends in the Arctic in support of AMPAC goals.**
- Inverse modelling of methane fluxes suggest increasing trend for biospheric emissions at northern high latitudes, especially in summer. Further work is needed to reduce the need for bias correction in inverse modelling setups.
- **New satellite data sets can now be used to assess, benchmark and improve model performance at high latitudes.**
- Ground-based observations crucially needed for satellite validation:
  - **Vertical profiles of methane**, AirCore profiles only in few places.
  - Reference observations **over ocean are** missing in high latitudes.

06 / 2020



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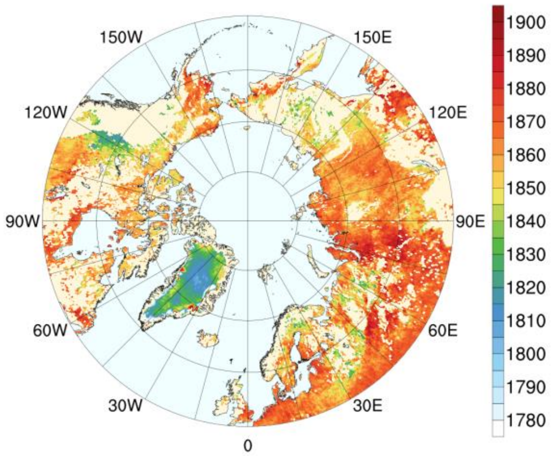

Fig. TROPOMI XCH4 (SRON oper.)

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