MethaneCAMP: Methane in support of the Arctic Methane and Permafrost Challenge – Overview of the results

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ATMOS 2024, Bologna 1–5.7. 2024

MethaneCAMP (04/2022 – 05/2024)

Focus on satellite retrievals of methane at high latitudes

Objectives of MethaneCAMP:

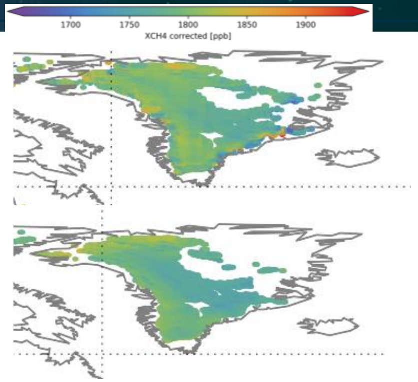
- Assess and validate existing satellite retrievals of methane.
- Optimise and advance satellite retrievals for high latitude conditions; utilise and support high latitude campaigns
- Demonstrate capabilities of satellite data for high latitude CH_4 analysis together with modeling and inverse modeling

Recent TROPOMI algorithm updates

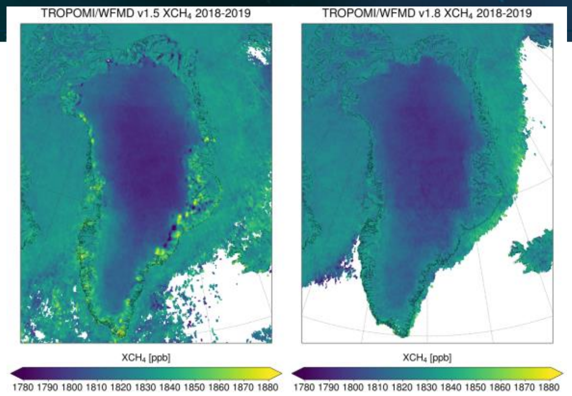
SRON oper. and UoB WFMD TROPOMI

- 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.

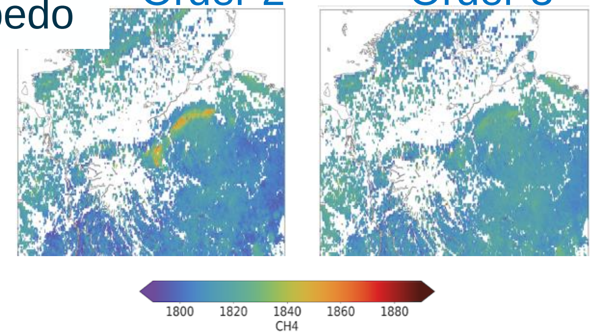
SRON: DEM



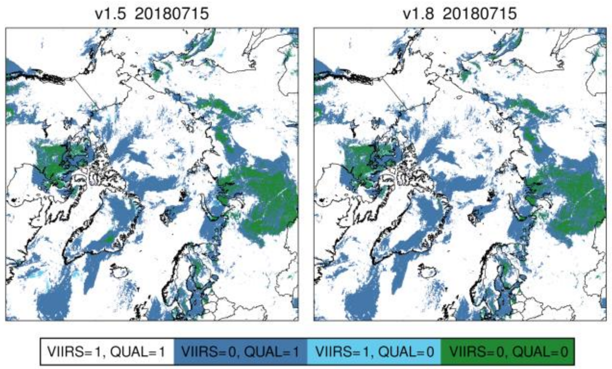
WFMD: DEM



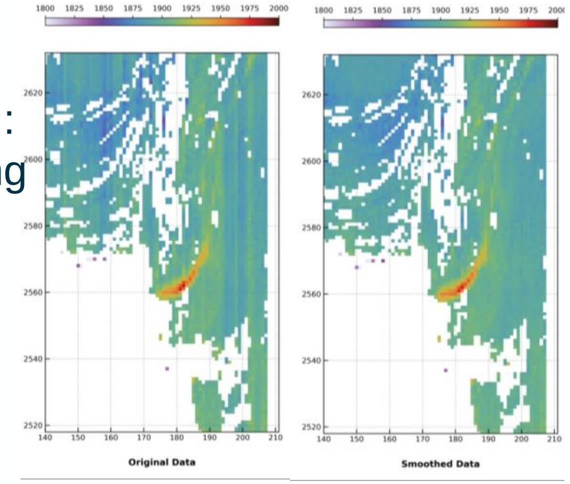
SRON: Albedo



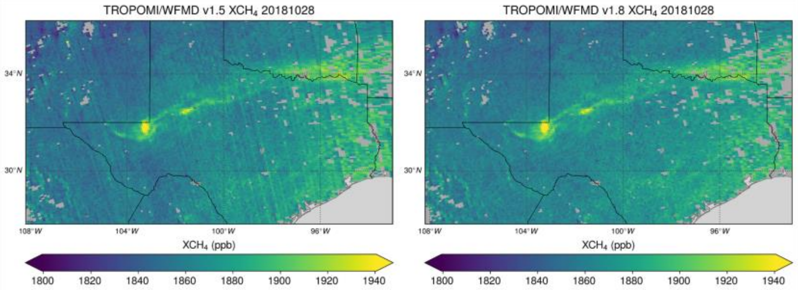
WFMD: Quality filtering, residual clouds



SRON: Destriping

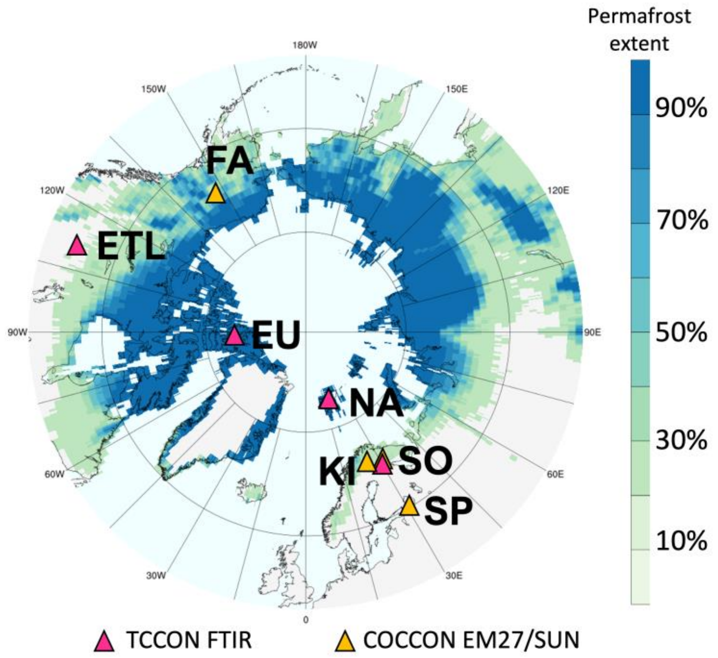


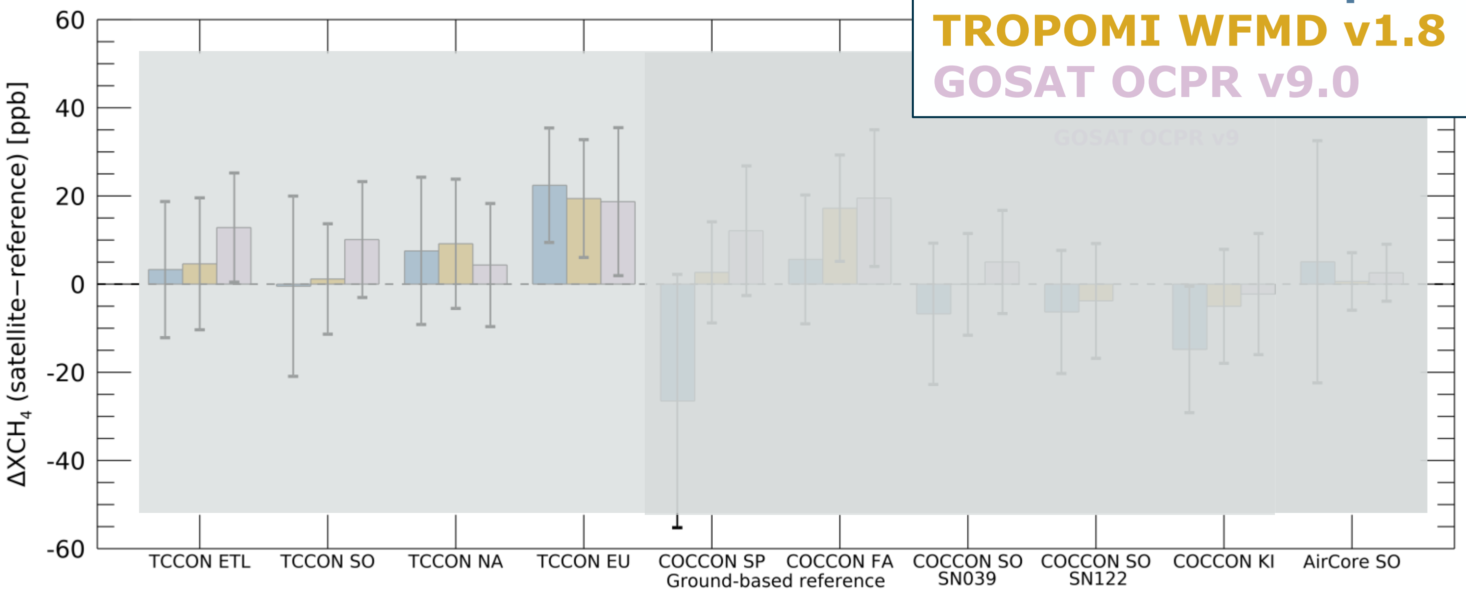
WFMD: Destriping



Figs. SRON and UoB/IUP

TROPOMI and GOSAT XCH4 validation at N. High Latitudes





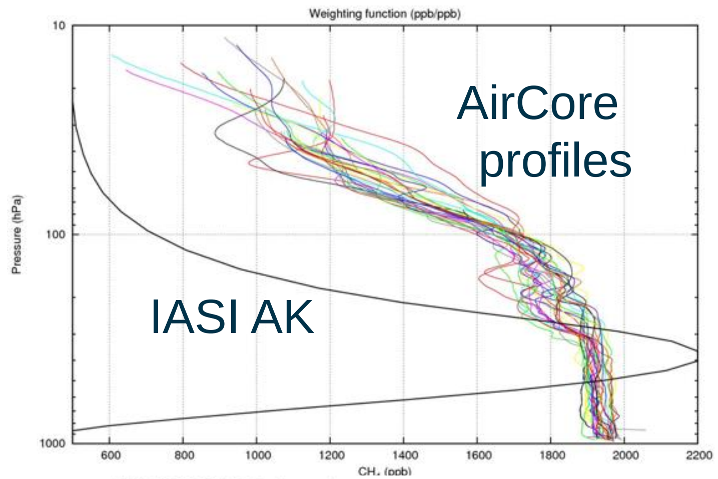
H. Lindqvist et al., submitted

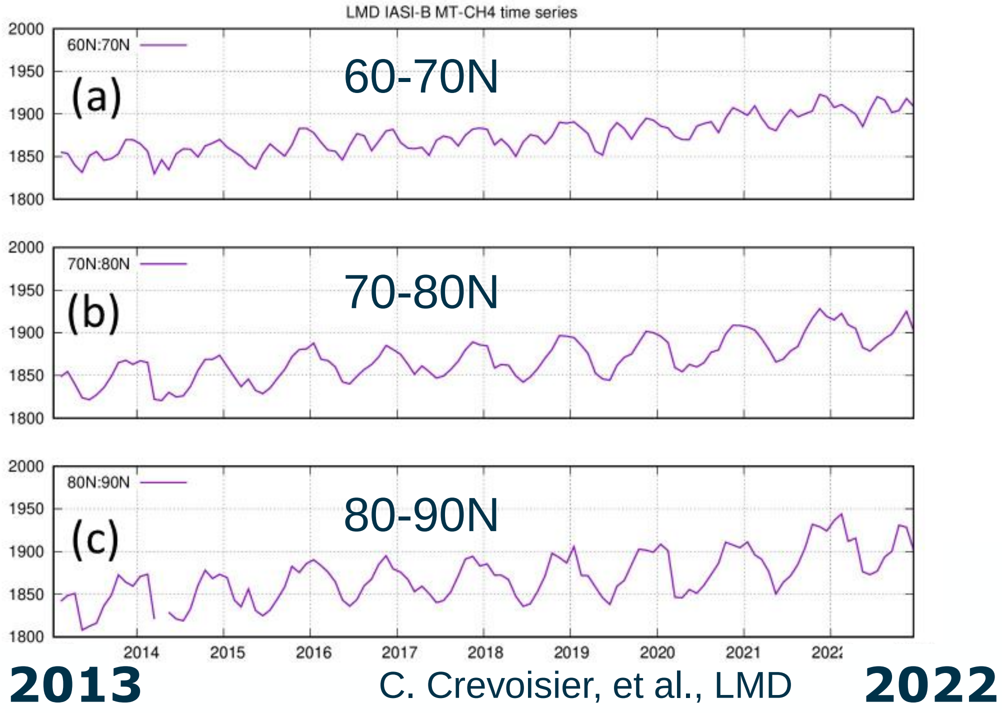
- Overall agreement between satellite and TCCON/COCCON instruments is good, daily median difference between –13 ppb and +22 ppb, std 11-20 ppb, depending on the site.
- The updated TCCON retrievals are systematically about 7 ppb lower than in previous veresion. Could be linked to systematic difference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

Methane CAMP

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.
- IASI mid-tropospheric product includes also winter months during polar night and covers 2013 – 2022.



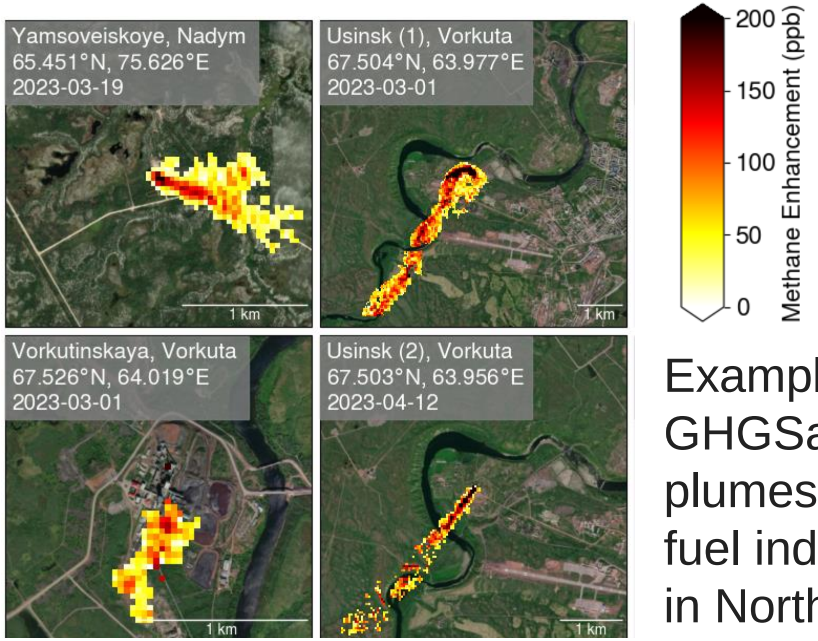


C. Crevoisier, et al., LMD

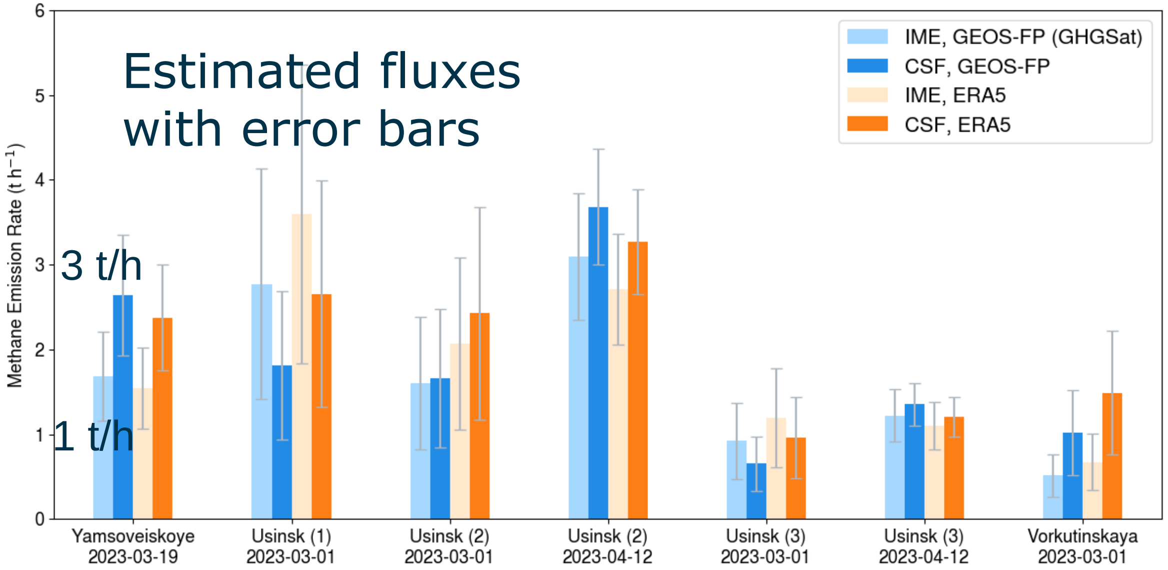
Methane CAMP

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

Is the methane trend in the Arctic different than elsewhere?

OBS4MIPS merged data set growth rate

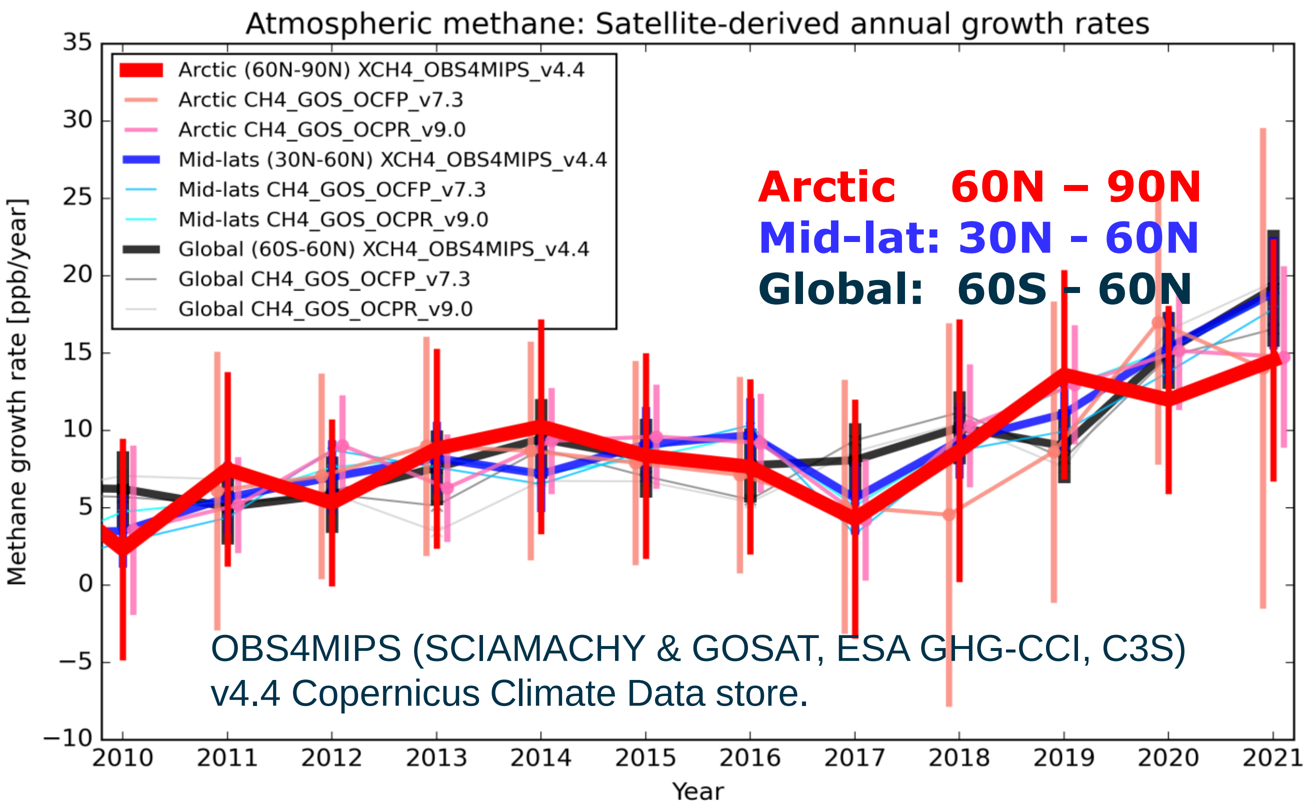
- Methane growth rate over Arctic region in 2010 – 2021 around 5 – 15 ppb /yr.
- During record year 2021 the growth rate in the Arctic is lower than global growth rate.
- Overall, the growth rate is similar to other latitude bands, agreement within 1-sigma uncertainty range (of approx. 5 ppb for arctic latitudes).

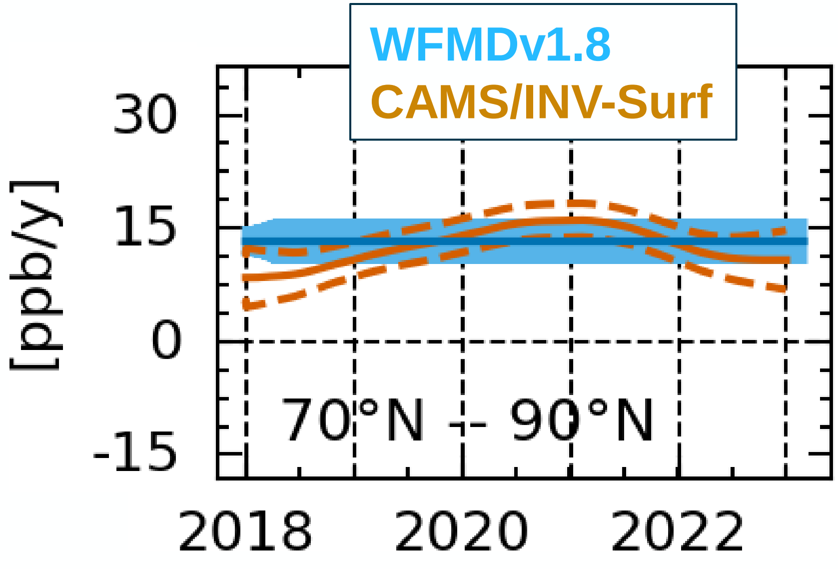
TROPOMI growth rate

- No trend observed in latitude band 70-90N. (Hachmeister et al., 2024)

M. Buchwich et al (Univ. Bemen)
Hachmeister et al., ACP, 2024

Methane CAMP





Trends in biospheric emissions in summer

Two inverse modeling systems, CTE-CH4 and TM5-4DVAR (CAMS), and different setups were studied.

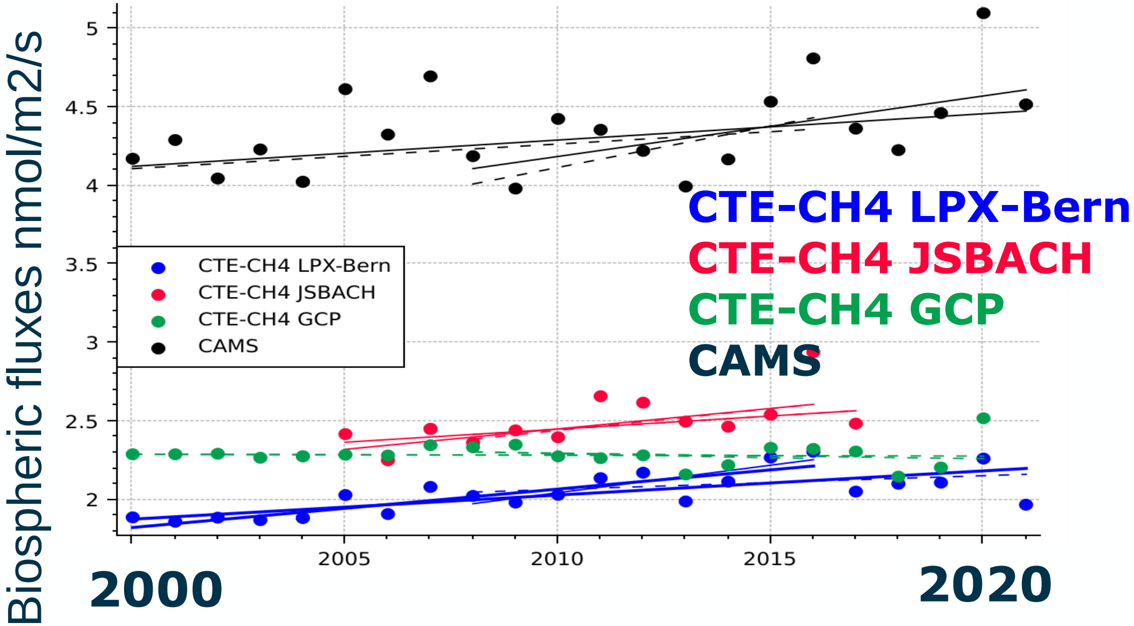
Inverse modeling with in-situ data (2000 – 2020):

- 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.

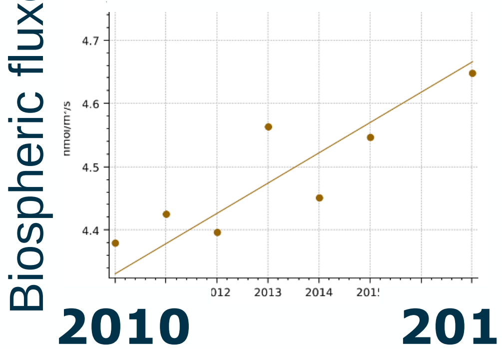
Inverse modeling with GOSAT data (2010 – 2017):

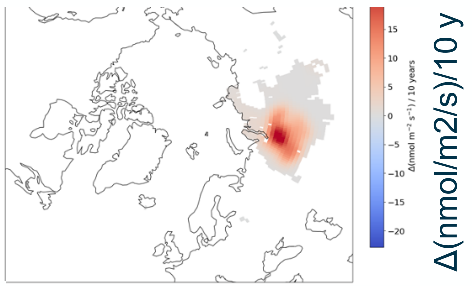
- Significant increasing trend seen in CTE-CH4 inversion in summer while in CAMS the trend was not significant.

Inverse modeling with in-situ data.



Inverse modeling with GOSAT data CTE-CH4 JSBACH





Significant trends

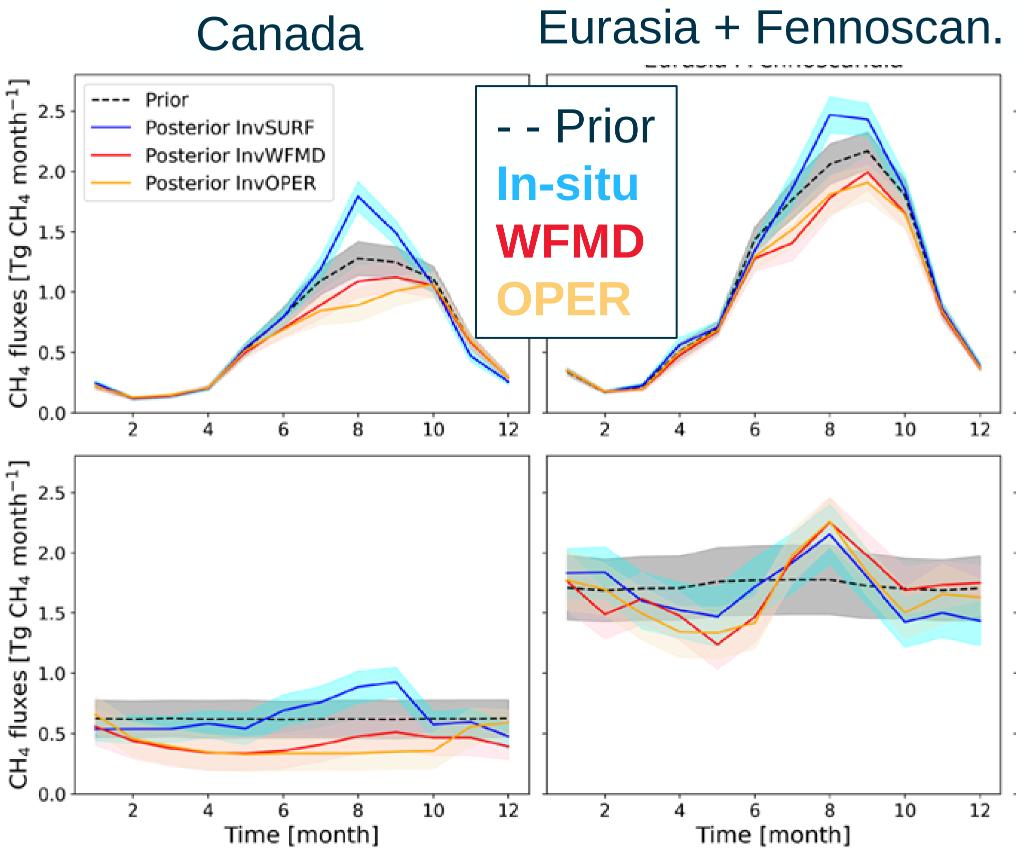
T. Aalto (FMI), S. Houweling (VuA) et al.,

Methane CAMP

Inverse modeling using TROPOMI data

Inverse modelling with TROPOMI data

- Better coverage of observations is expected to improve separating anthropogenic and biospheric fluxes.
- CTE-CH4 inverse modelling:
  - Wetland emissions do not correlate with the anthropogenic emissions as strongly as those in the surface inversion indicating potential for better separation.
  - Two different TROPOMI datasets show similarities but also clear differences, e.g. in timing of the emission maximum in Canada.
- Differences between CTE-CH4 and TM5-4DVAR require further analysis.



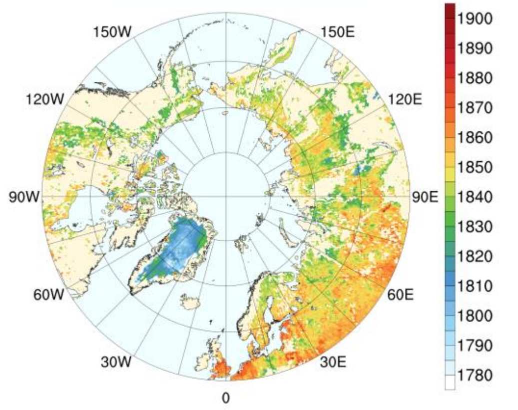
CTE-CH4 Monthly fluxes biospheric (top) and anthropogenic (bottom)

Tsuruta et al., Remote Sensing, 2023

Summary

- **MethaneCAMP project has been major contribution to AMPAC studies in Europe by advancing, assessing and demonstrating the potential of satellite retrievals of methane at high latitudes.**
- **Resent advances in satellite retrievals have improved the data availability and data quality and reduced seasonal bias.**
  - SWIR satellite observations of XCH4 are in general high quality, with systematic differences less than ~22 ppb.
  - IASI mid-tropospheric NN-retrieval method has been extended successfully to cover high latitudes.
  - High resolution instruments like Sentinel 2, PRISMA have not been found very useful for analysing local hotspots at high latitudes while GHGSat is more suitable.
- Reference observations (TCCON, COCCON) are also sensitive to retrieval updates. AirCore **profile observations were found valuable** in provide alternative independent validation data.
- **Recent satellite observations of methane have potential to improve flux estimation also at high latitudes.**
  - Inverse modelling of methane fluxes suggest increasing trend for biospheric emissions at northern high latitudes, especially in summer.
  - Full seasonal coverage of data is needed to constrain further the separation of biospheric and anthropogenic emissions.
- New instruments CO2M and Merlin are expected to improve greatly the observation capabilities.

06 / 2020



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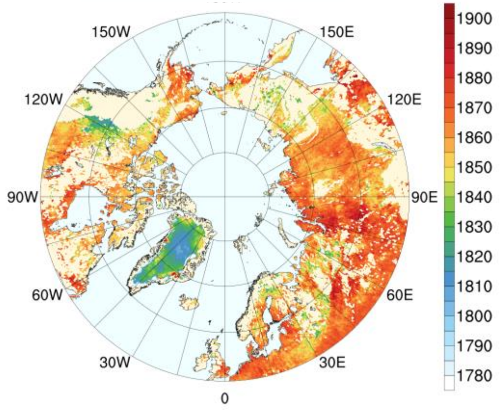

Fig. TROPOMI XCH4 (SRON oper.)

Recommendations

- In MethaneCAMP we have experienced that synergies and complementarities of instruments, retrievals, reference observations and inverse modelling setups are very valuable in advancing the potential of satellite observation and in reducing the uncertainties of data and models. **It would be beneficial to continue such collaboration to enhance the utilisation of satellite observations of methane for monitoring and studying changes in the warming Arctic.** In the present geopolitical situation, satellite observations are basically the only way of getting reliable information from large permafrost and high-latitude areas in Russian Siberia.

- It is important to continue the **support to the few high-latitude reference sites** to ensure the continuation of high-quality data. High-latitude **profile analyses** are recommended to be developed further to support validation of satellite and ground-based products. It is advised to continue **advancing satellite retrievals** of high latitude satellite products (TROPOMI, IASI, GOSAT). Improved retrieval **uncertainty quantification** is needed in terms of spatially correlated uncertainties and in analysing non-linearities in the retrievals.

- Efforts should be made for future instruments (e.g. Sentinel-2NG, CHIME) to **optimise channels and and develop retrievals** for methane observations. **Tailored high latitude methane products** should be developed for upcoming missions including CO2M, and tropospheric column retrievals using SWIR-TIR synergy of IASI-NG and S5 (on MetOp-SG). The developments should be supported by sufficient **validation campaigns and activities.**

- Analysis of the **flux trends should be continued** including sensitivity studies to improve robustness of the results. To use of satellite data in global inversions should rely less on bias corrections, for which a **continued effort is needed to reduce retrieval and transport model uncertainties**.

- To separate natural and anthropogenic emissions, **year-around measurements** are needed with adequate sensitivity to the surface (**Merlin** will be important). The potential of using co-emitted gases like NO_2 to improve the separation should be studied.